Arterial Physiology

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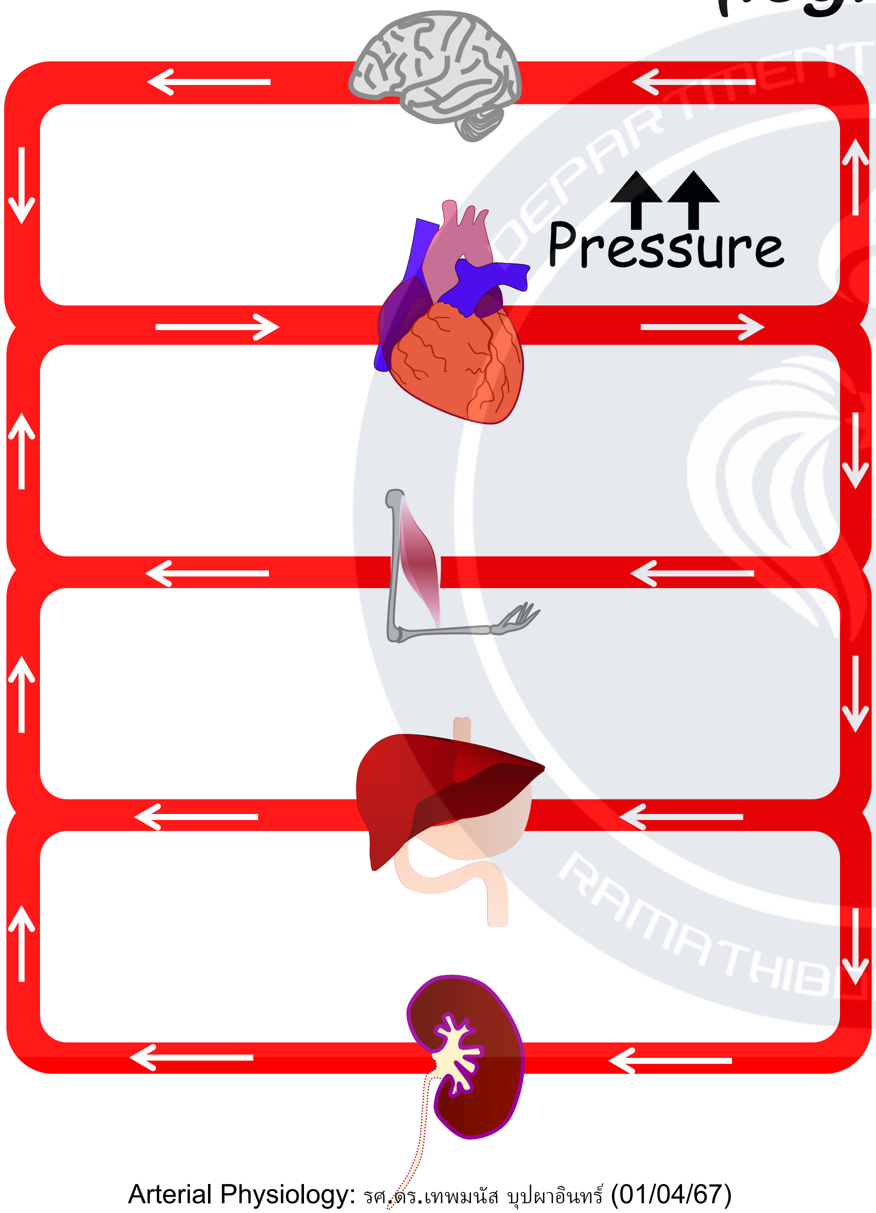
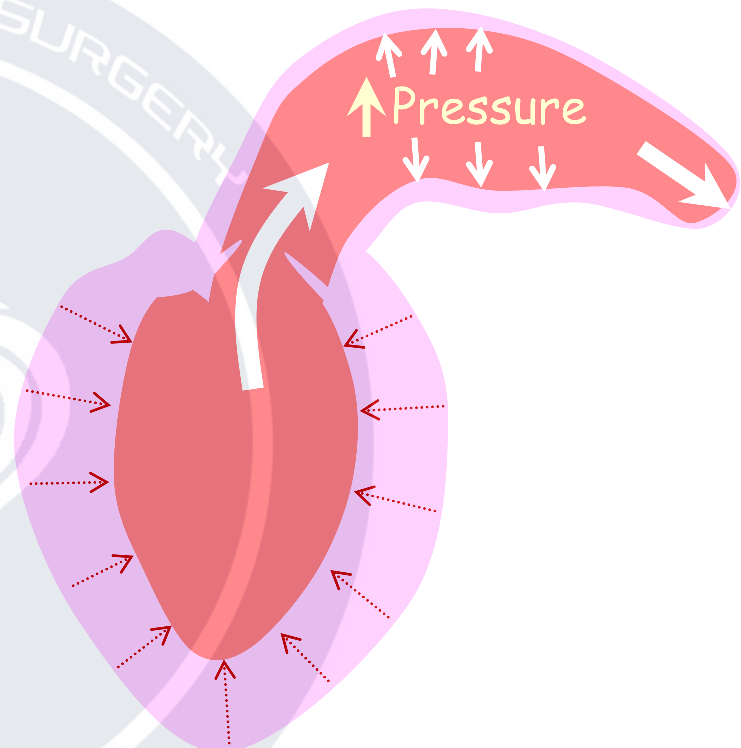
Outline

- Arterial Structure
- Relationship between pressure gradient, fluid flow, and resistance to flow (Poiseuille's equation)
- Flow Pattern & Shear stress
- Arterial Stenosis
- Aneurysm
- Graft-Arterial Anastomosis

CVS is a food supplying system (logistic !)





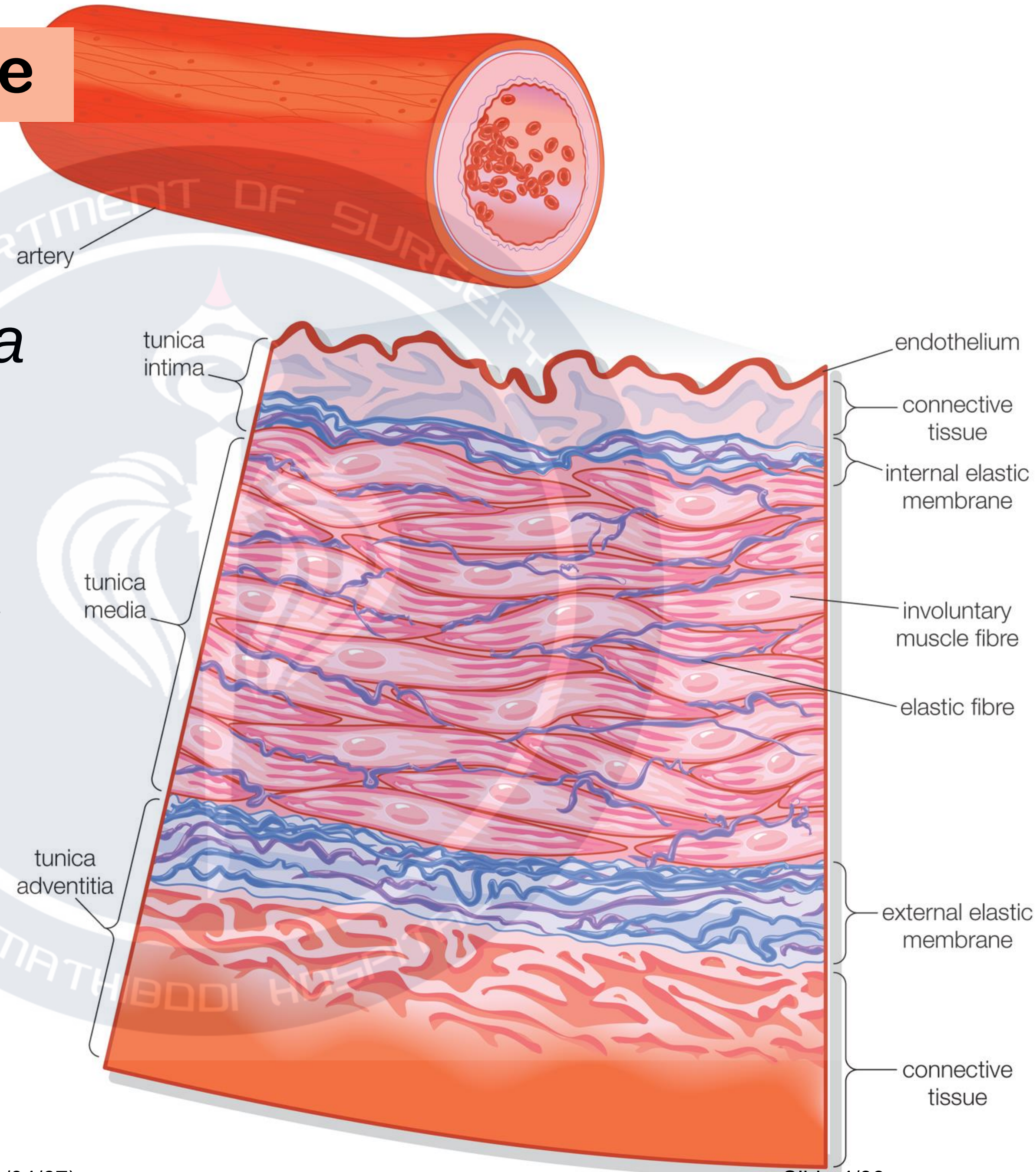
Heart is a pump of life.

Arterial Structure

Tunica intima

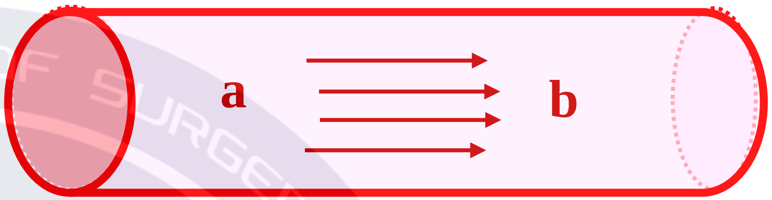
Tunica media

Tunica adventitia



FLOW

Flow ($\dot{Q}$) $\propto$ $P_a - P_b$



$$\dot{Q} \propto \frac{\Delta P}{R}$$

Poiseuille's Law

$$R \propto \frac{8\eta L}{\pi r^4}$$

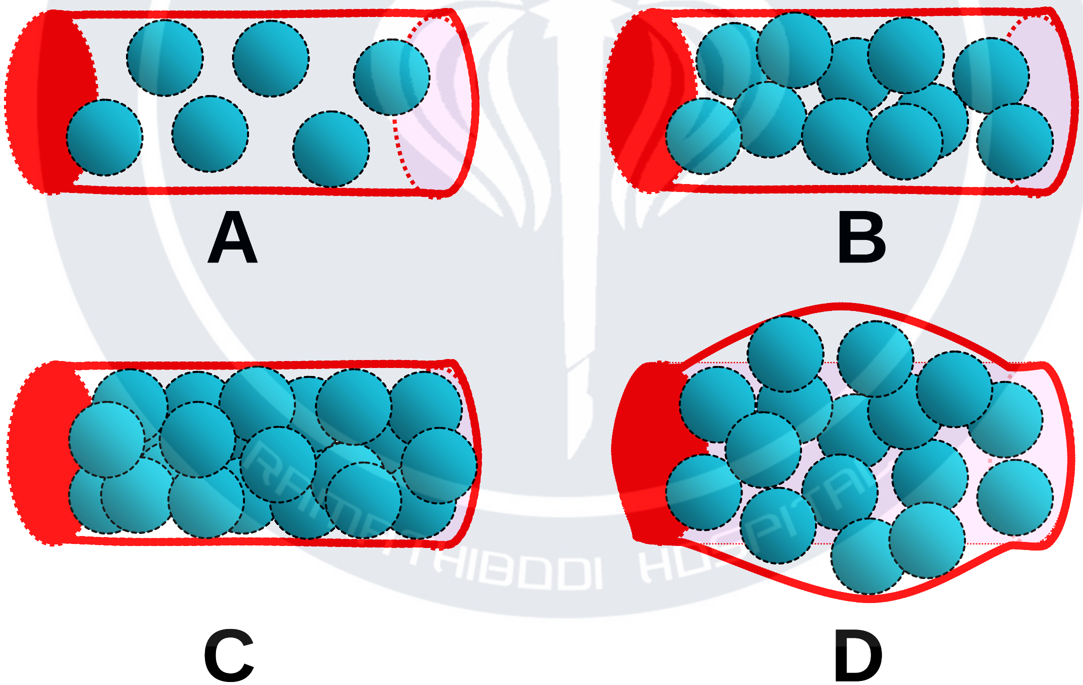
- r = radius of tube
- L = length of tube
- η = blood viscosity ($\propto$ Hct)

$$\dot{Q} \propto \frac{\Delta P \pi r^4}{8\eta L}$$

Pressure Energy

$$\text{Pressure} = \frac{\text{Force}}{\text{Surface Area (Space)}}$$

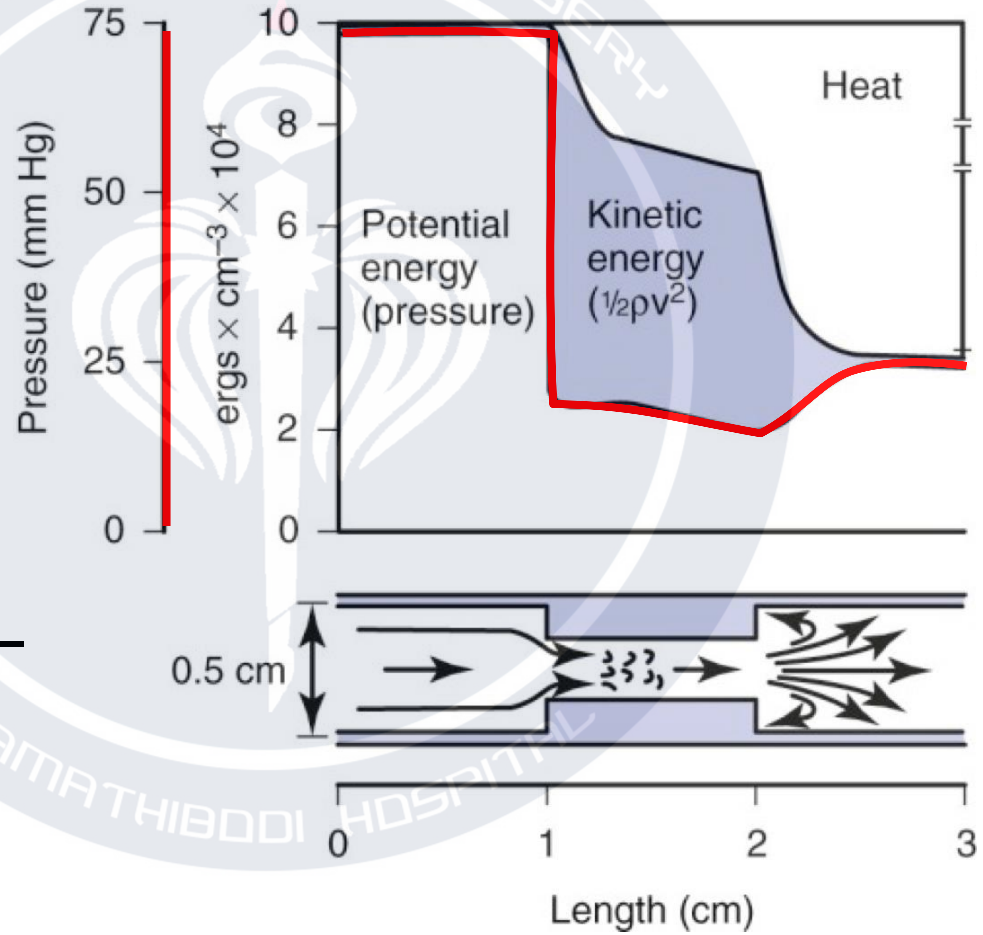
Force = molecule – molecule interaction



Arterial Stenosis

Stenosis induces viscous (inertia) energy losses (ΔP).

$$\Delta P = \dot{Q}\,\frac{8\eta L}{\pi r^4}$$



K.E. = 1/2 mv²

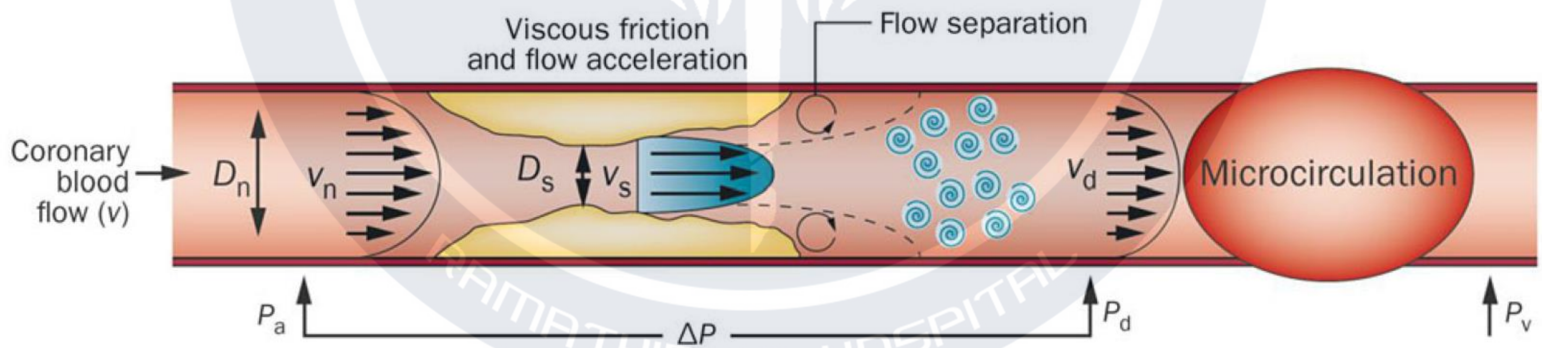
[ρ = momentum]

R. Eugene Zierler, and David S. Sumner

Fractional Flow Reserve

The intra-arterial pressure before and after a specific lesion

- Performed by catheterization
- Normal value is 1.0.
- FFR < 0.75-0.80 =MI (European Society of Cardiology)
- FFR < 0.8 needs revascularization



Van de Hoef et. al. 2013.

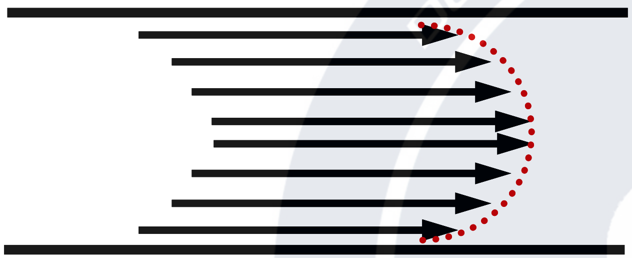
Arterial Stenosis

Factors affecting energy loss (ΔP) :

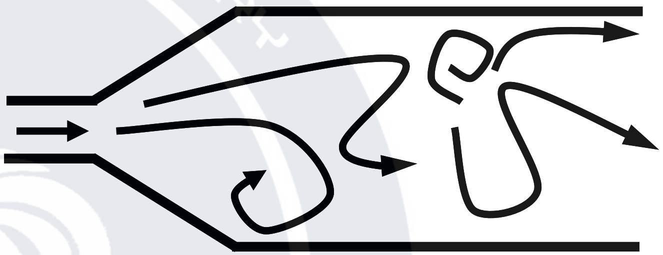
- Radius of stenosis ($\Delta P \propto \mathbf{1}/r^4$)
- Length of stenosis ($\Delta P \propto L$)
- Shape of fluid entrance & exit (turbulence)
- Asymmetrical or axisymmetrical stenosis
- Peripheral resistance (Runoff Diameter)

Hemodynamics

Flow: Two patterns

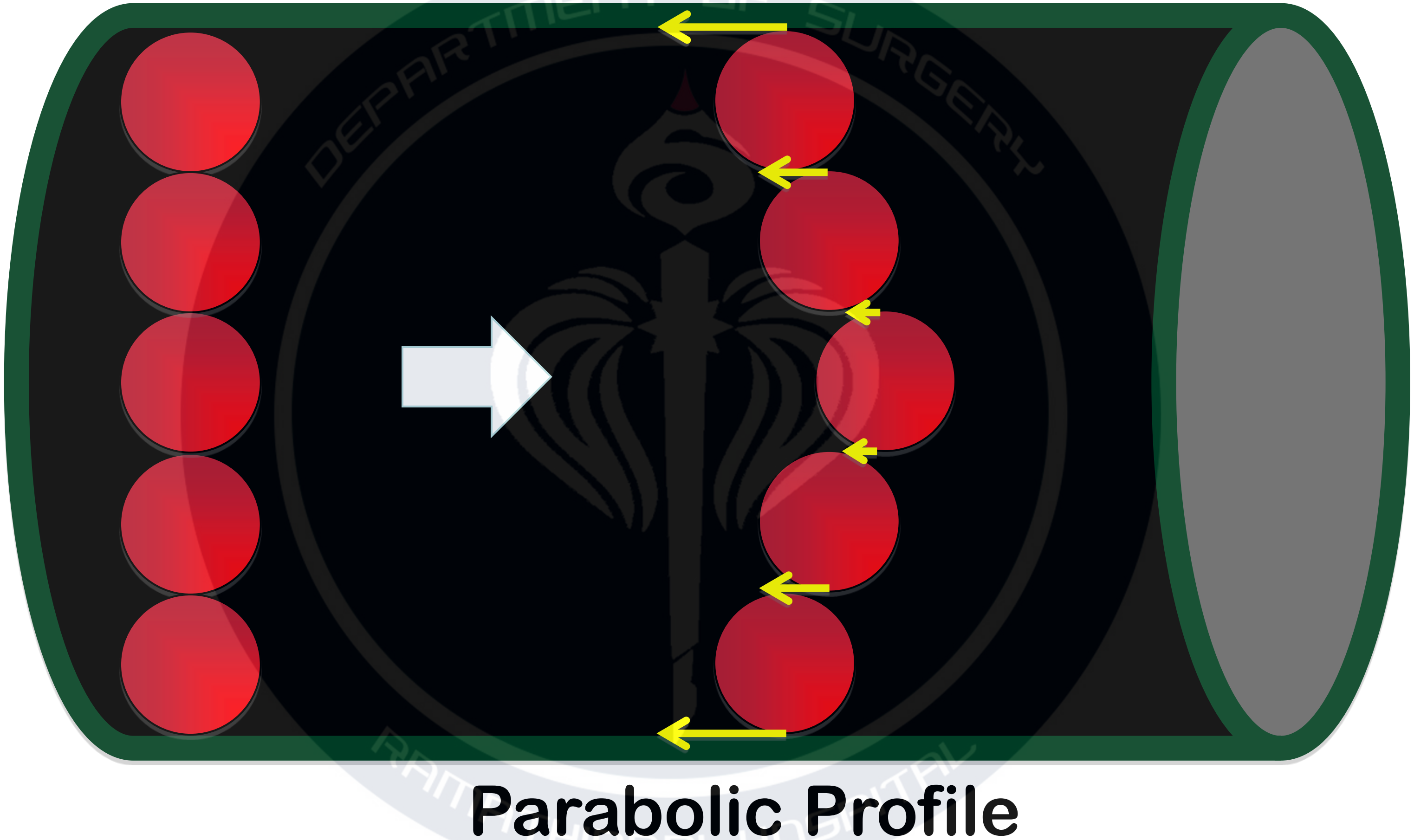


Laminar flow

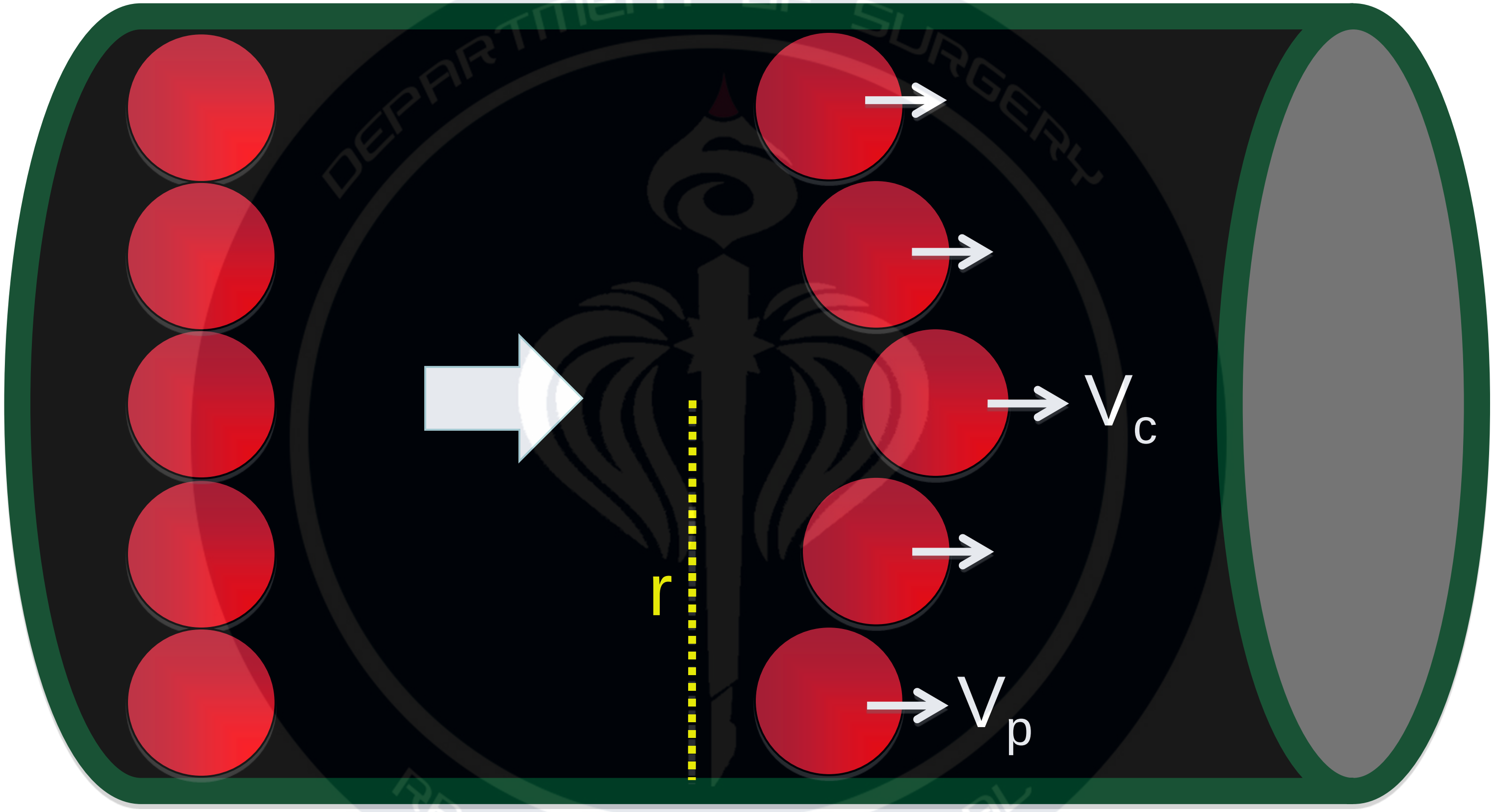


Turbulent flow

Laminar Flow

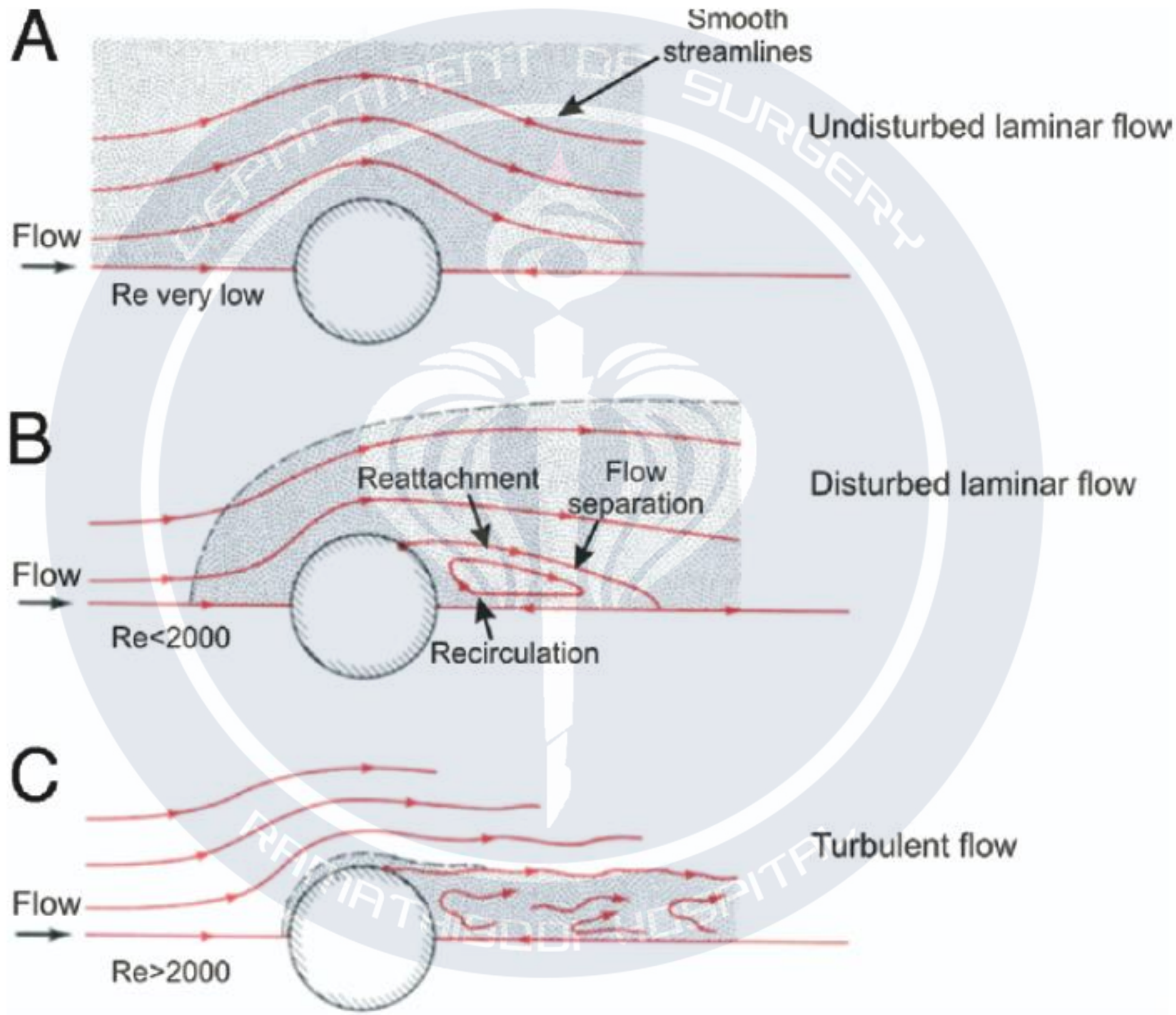


Laminar Flow

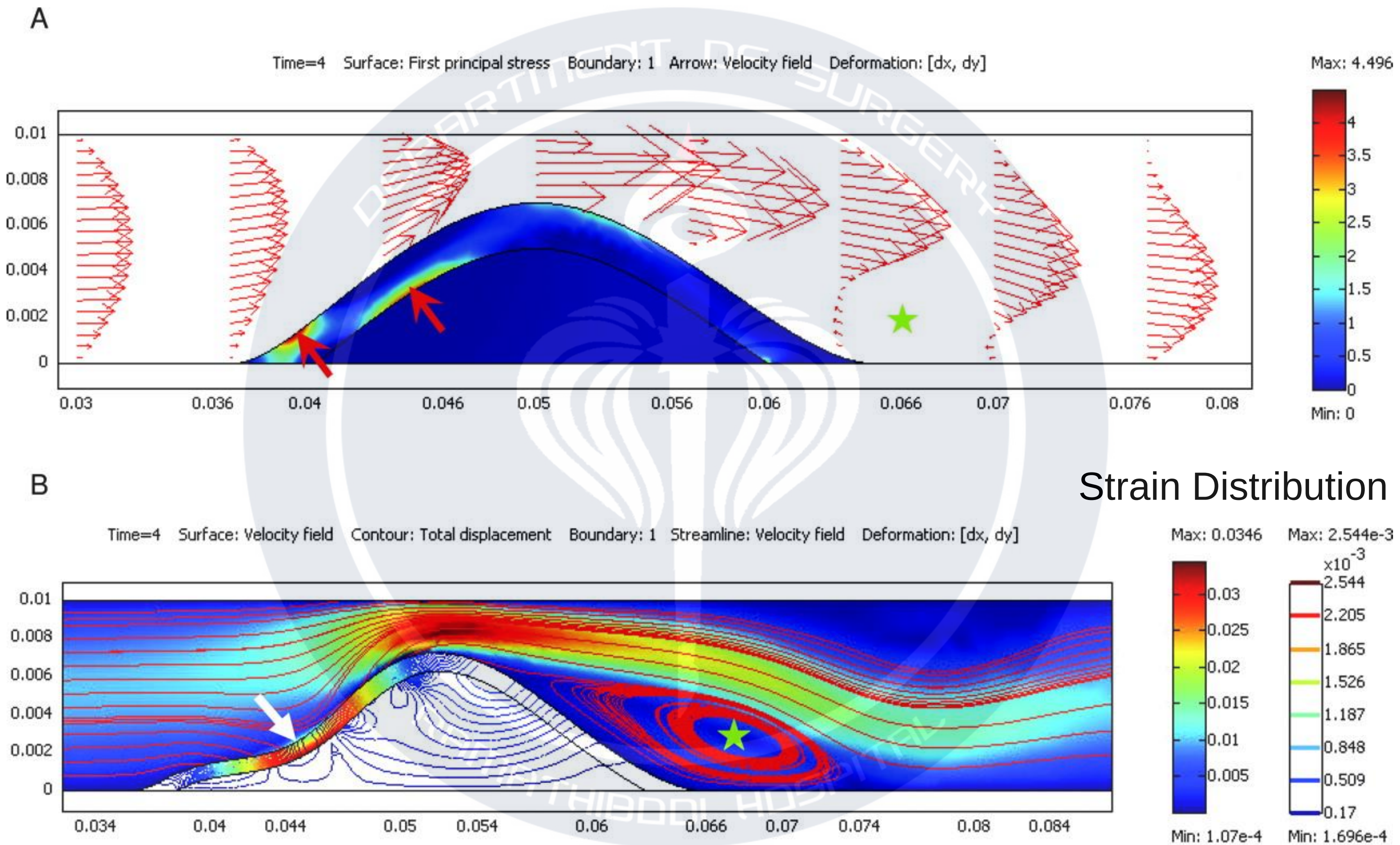


$$\text{Shear Rate (D)} = \frac{V_c - V_p}{r} = \frac{\Delta V}{\Delta r}$$

Flow Patterns



J Am Coll Cardiol 2007;49:2379–93.



Strain Distribution

Plague deformation

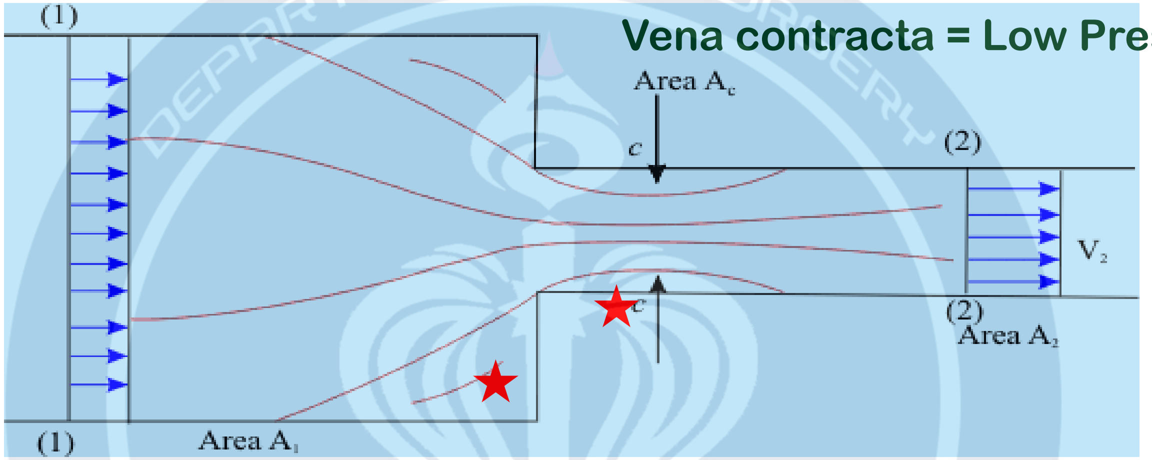
Flow Recirculation

***Stroke*. 2006;37:1195-1199.**

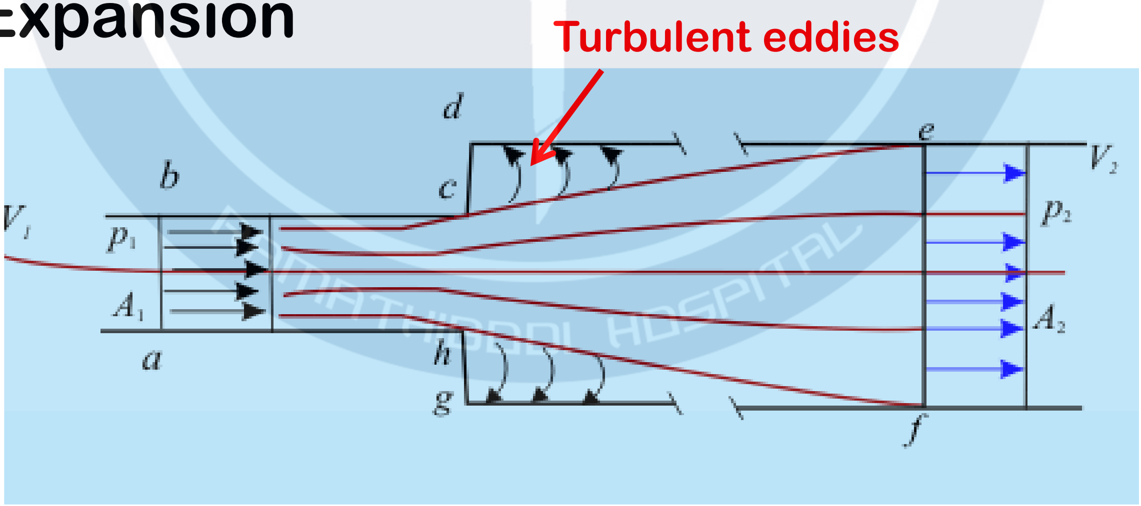
Arterial Stenosis

★ Flow Recirculation

Flow to Contraction



Flow to Expansion



Shear Stress (ความเค้นเฉือน)

Shear = เฉือน

Stress = เค้น

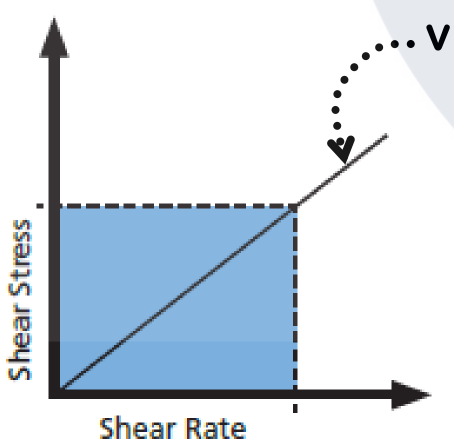
Shear Stress (ความเค้นเฉือน)

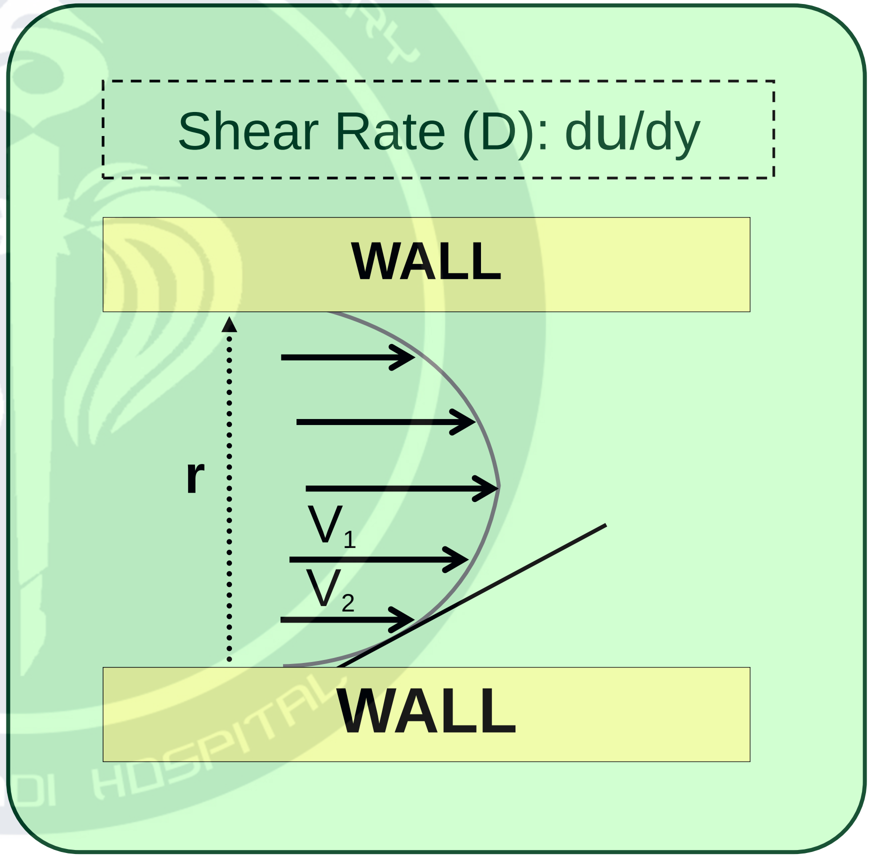
Shear force: *Force Interaction between molecules in parallel that moving at different vector velocities. (one velocity can also be zero.)*

Shear Stress = $\frac{\text{Shear Force}}{\text{Surface Area}}$

Shear Force ∝ Shear Rate

Shear Stress ∝ Shear Rate





Shear Stress

The force exerted to shear the fluid (τ). (η= fluid viscosity)

$$\text{Shear Stress } (\tau) = \frac{\Delta V}{\Delta r} \times \eta$$

Shear Stress & Arterial Remodeling

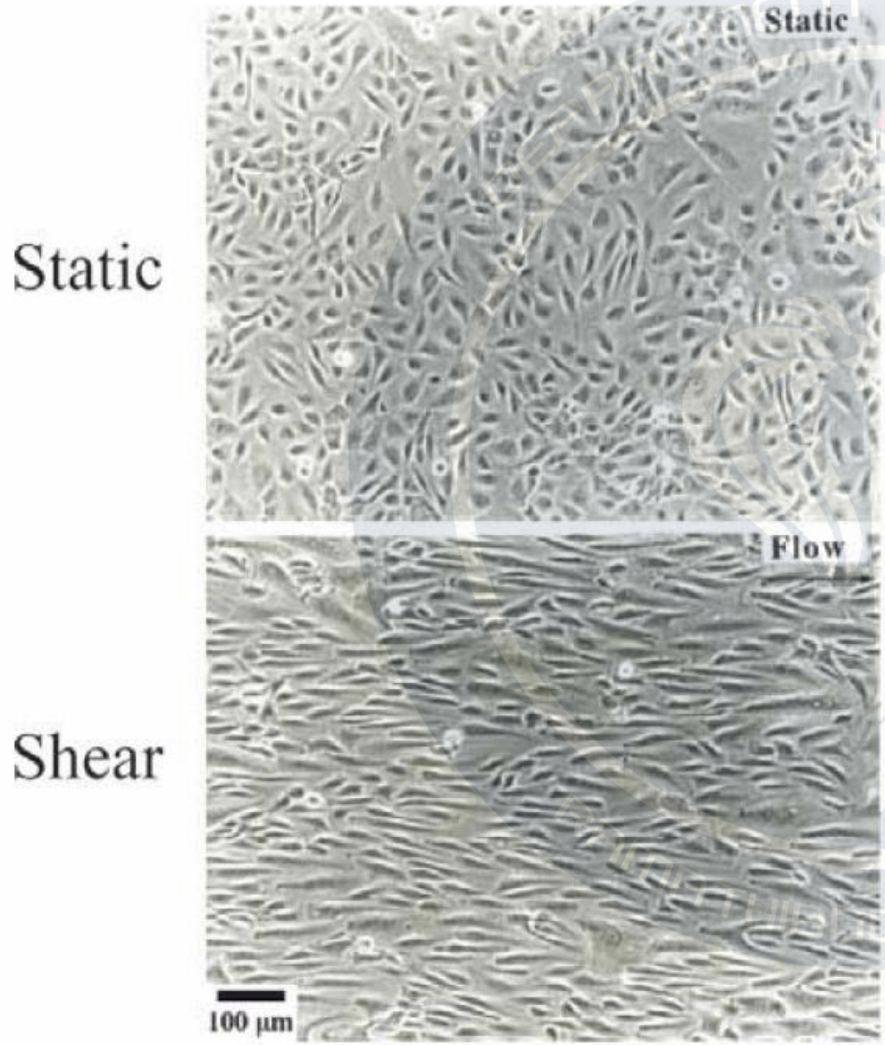
Maintains a state of vascular health

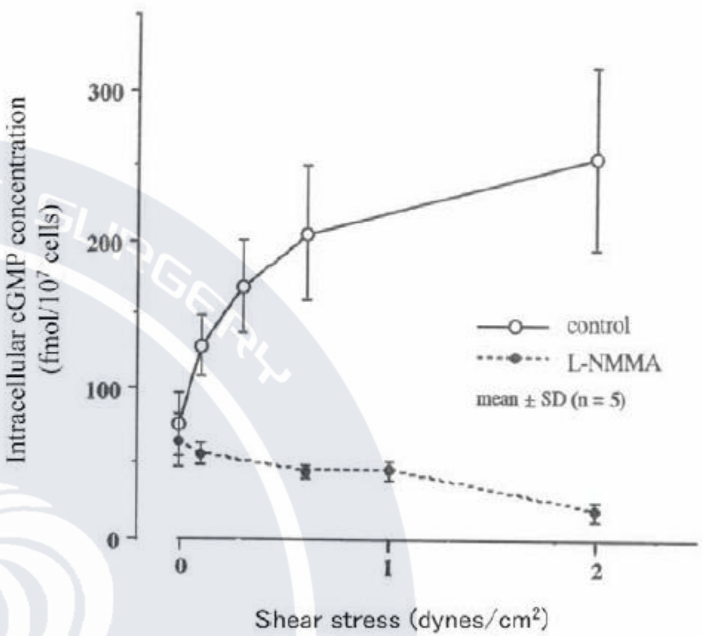
- Activates endothelial arrangement
- Promotes expression of vasodilator and antithrombotic factors
- Suppresses growth and proinflammatory factors

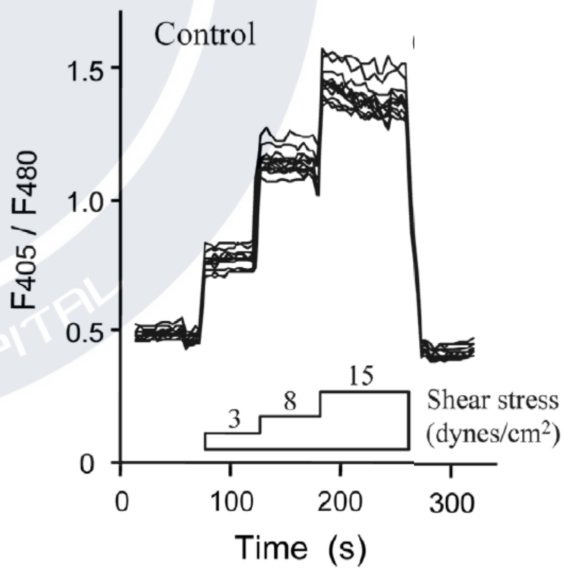
Low, oscillating, and disordered shear stress

- Promotes the development of atherosclerosis

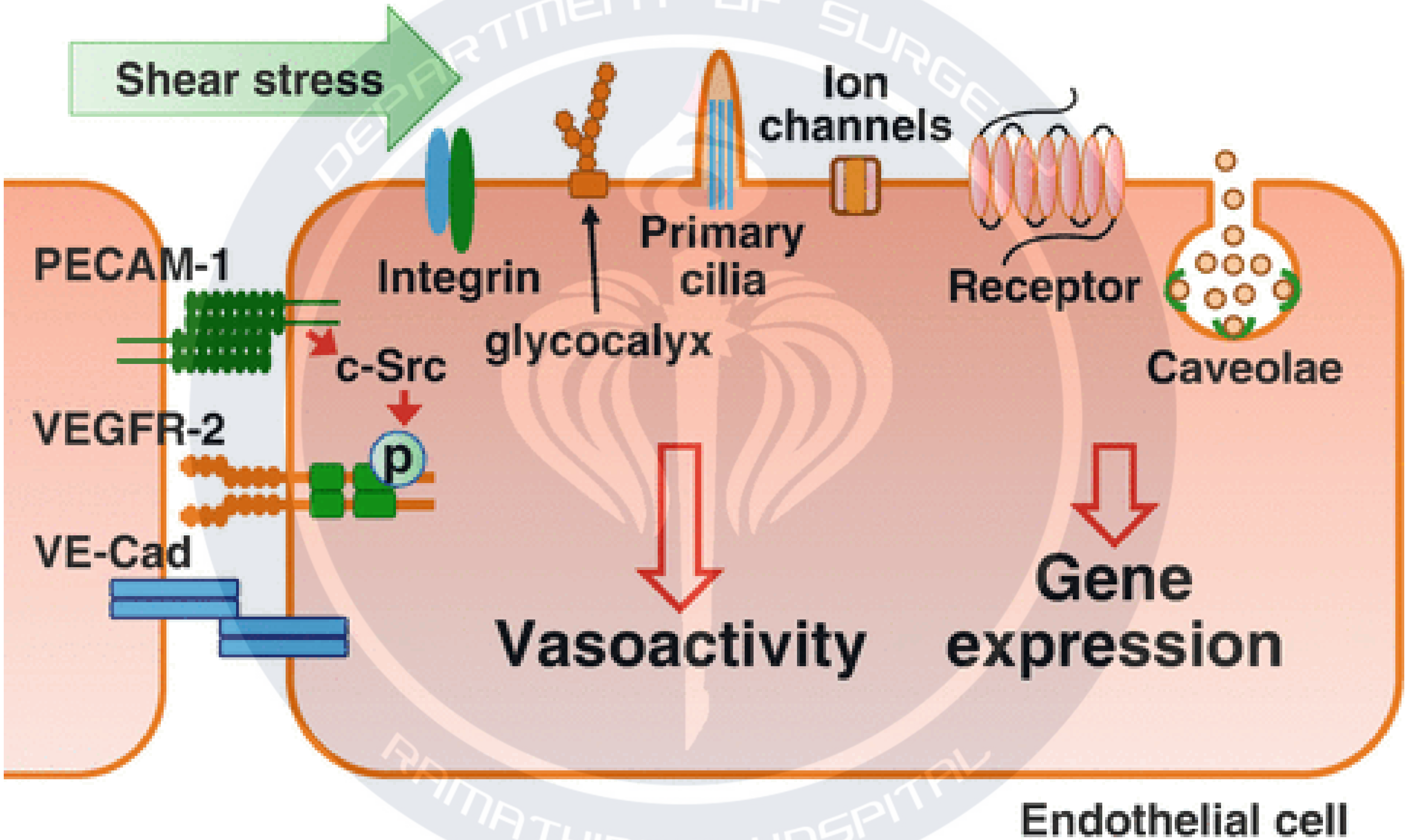
SHEAR STRESS







Shear stress & Mechanotransduction

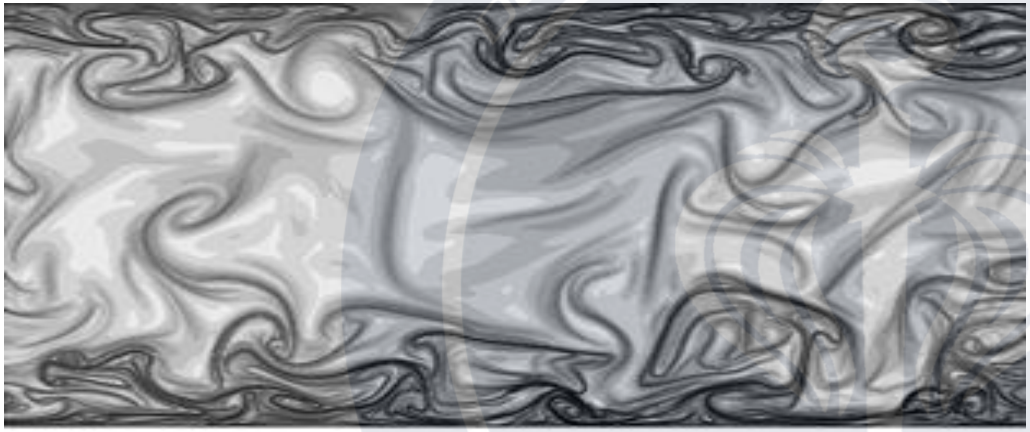


Biology of Vascular Smooth Muscle: Vasoconstriction and Dilatation pp 127-136

Turbulence Flow

- Fluid undergoes irregular fluctuations.
- The speed of the fluid is continuously undergoing changes in both magnitude and direction.

BioMedical Engineering OnLine 2013, 12:129



Credit: Melissa Green

Reynold's number (NR) = $\frac{\rho DV}{\eta}$

ρ = Density

D = Diameter

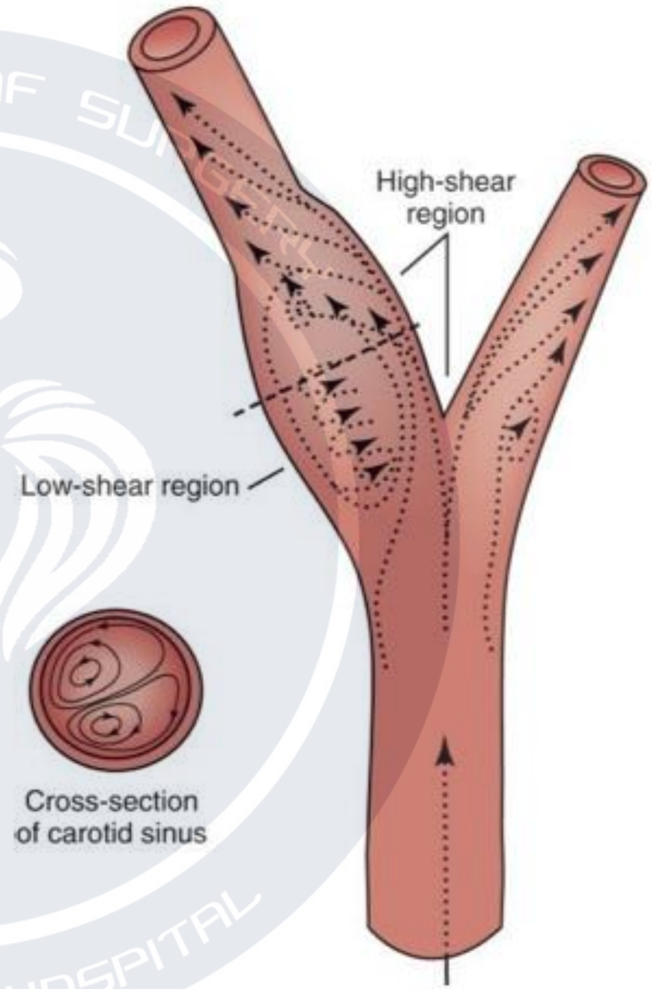
V = Mean Velocity

η = Viscosity

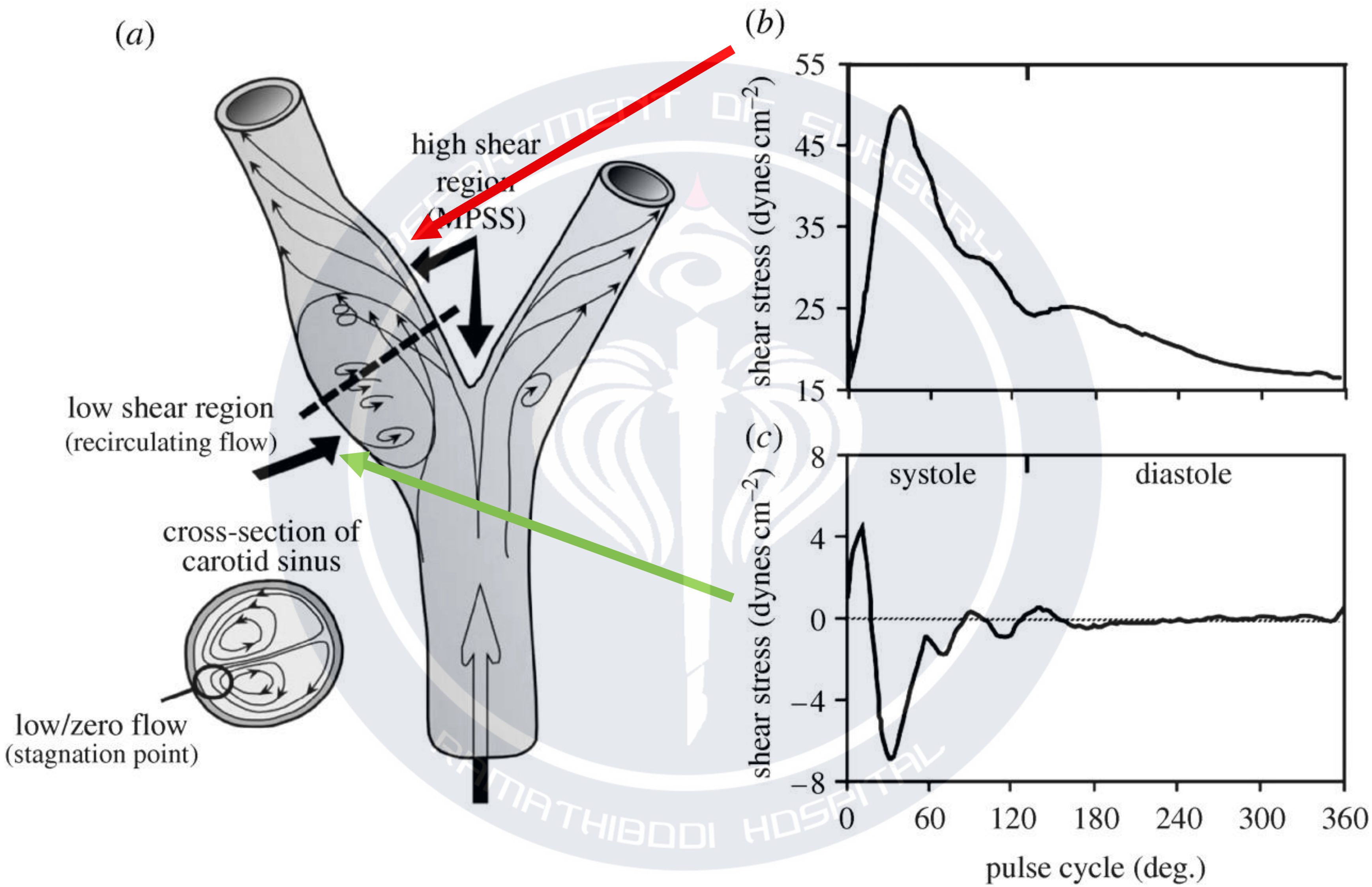
NR > 3,000 → Turbulent

Flow Separation

- occurs in bifurcations & anastomoses
- Boundary layer stops or reverse direction
- Generates high & low shear stress regions



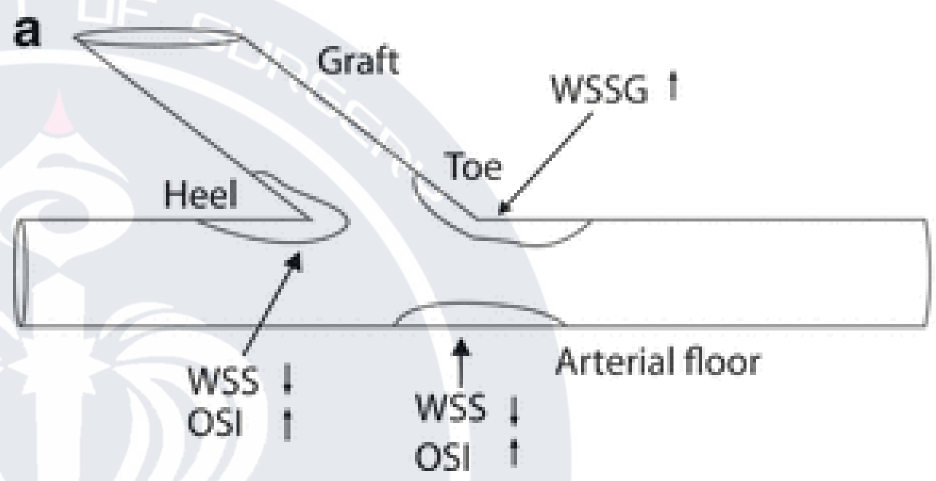
Arteriosclerosis 1985:5, 293–302.



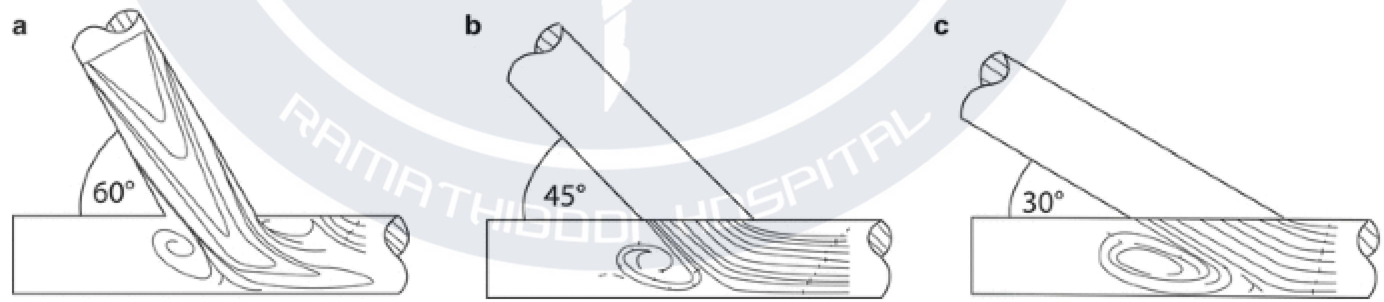
Charles R White, John A Frangos 2007

Graft-Arterial Anastomosis

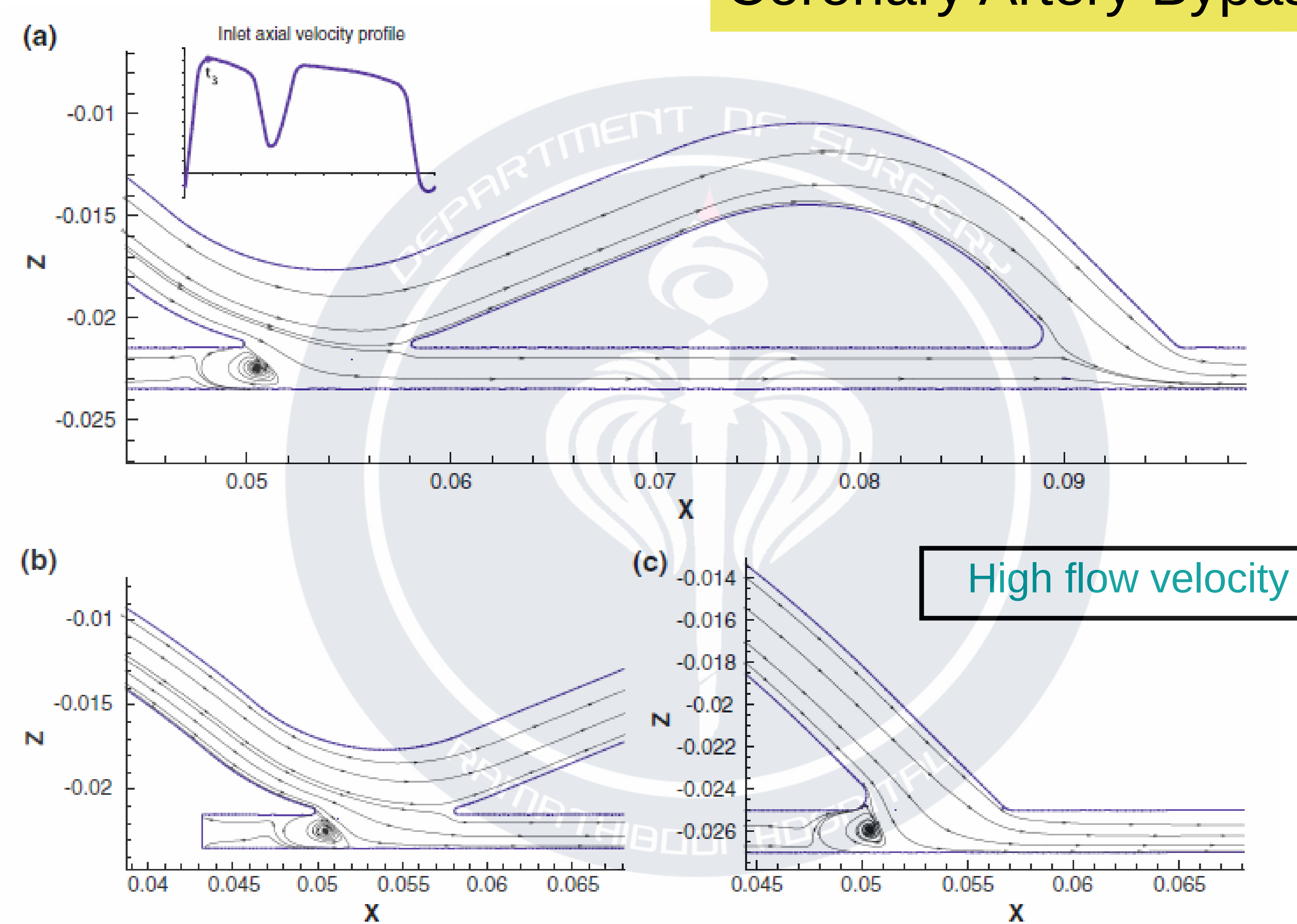
- Flow separation
- Low shear stress
- Platelet adhesion
- Intimal hyperplasia
- Atherosclerosis



Dhanjoo N Ghista and Foad Kabinejadian
Coronary Graft Failure pp 419–436



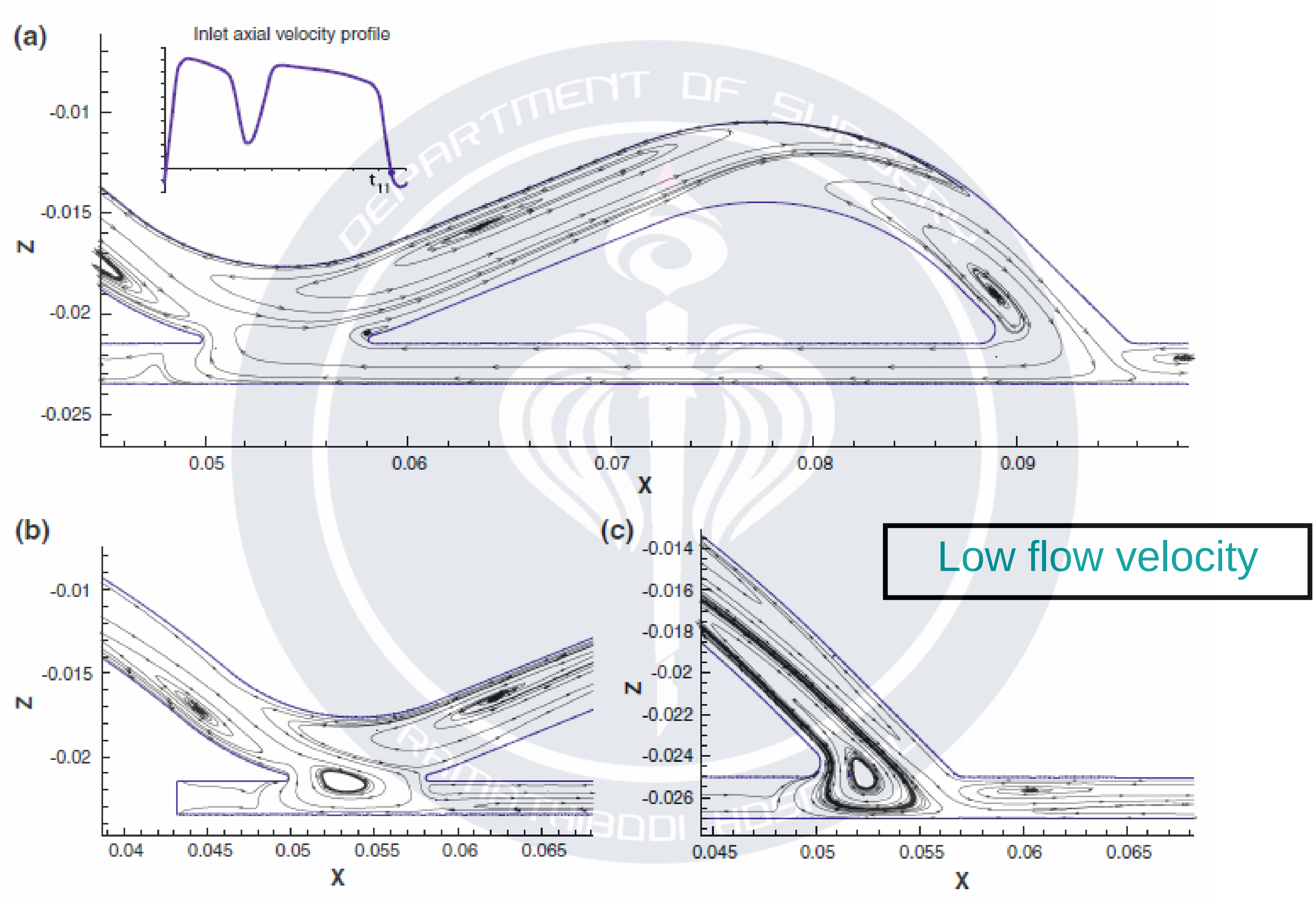
Coronary Artery Bypass



High flow velocity

Kabinejadian et. al. *Annal. Bio. Engin. 38, 2010.*

Coronary Artery Bypass

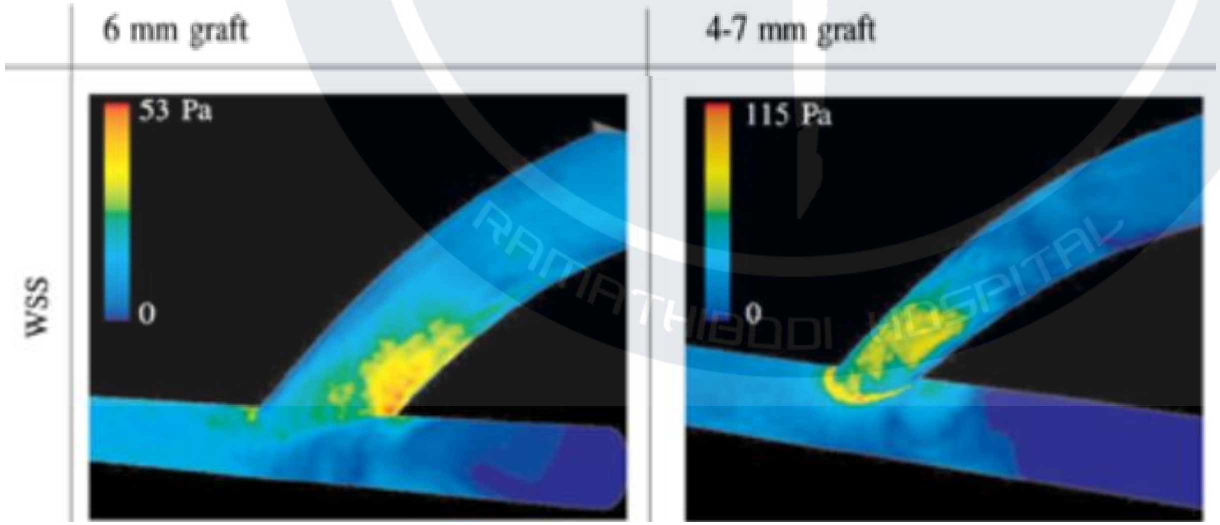


Kabinejadian et. al. *Annal. Bio. Engin. 38, 2010.*

Graft-Arterial Anastomosis

Success of arterial graft is depended on:

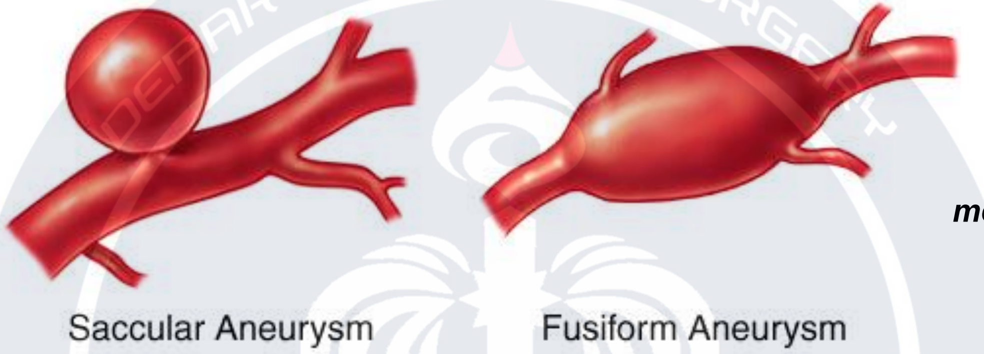
- Graft material: compliance of graft versus of artery
- Graft diameter: affect energy loss; consider length of graft and intimal hyperplasia
- Anastomic configuration: anastomical angle; smaller angle is better



Ilse van tricht et. al. Annals of Biomedical Engineering, Vol. 33, No. 9, 2005 pp. 1142–1157

Aneurysm

a localized, blood-filled balloon-like bulge in the wall of a blood vessel.



memphisvascular.com

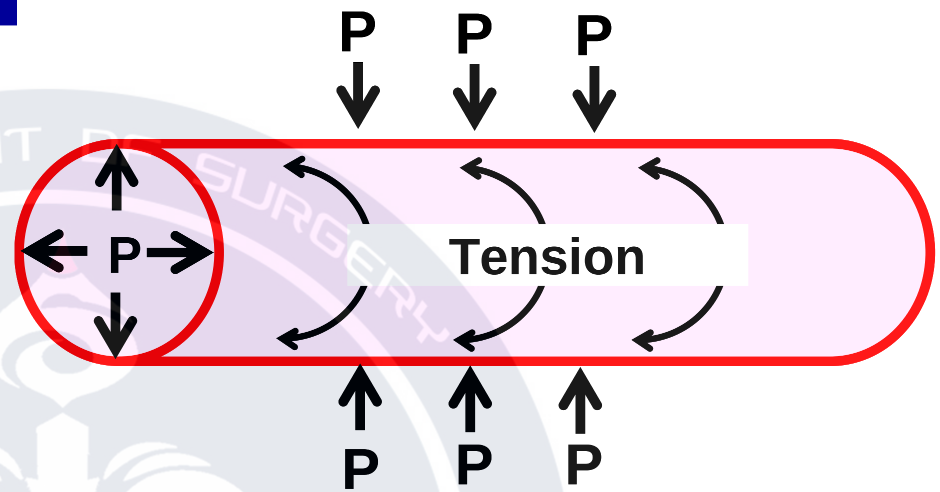
It occurs when the blood vessel is damaged or there is a weakness in the wall of the blood vessel.

Aneurysm rupture when "circumference tension > wall tensile strength".

Decrease in collagen content and fragmentation in aneurysm wall.

Circulatory Pressure

- Internal pressure
- External pressure
- Circumference tension

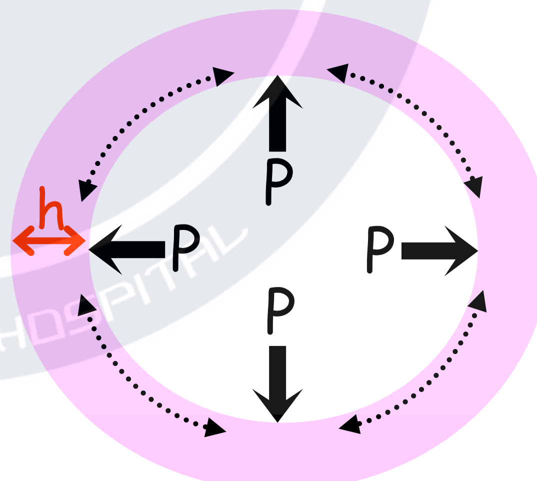


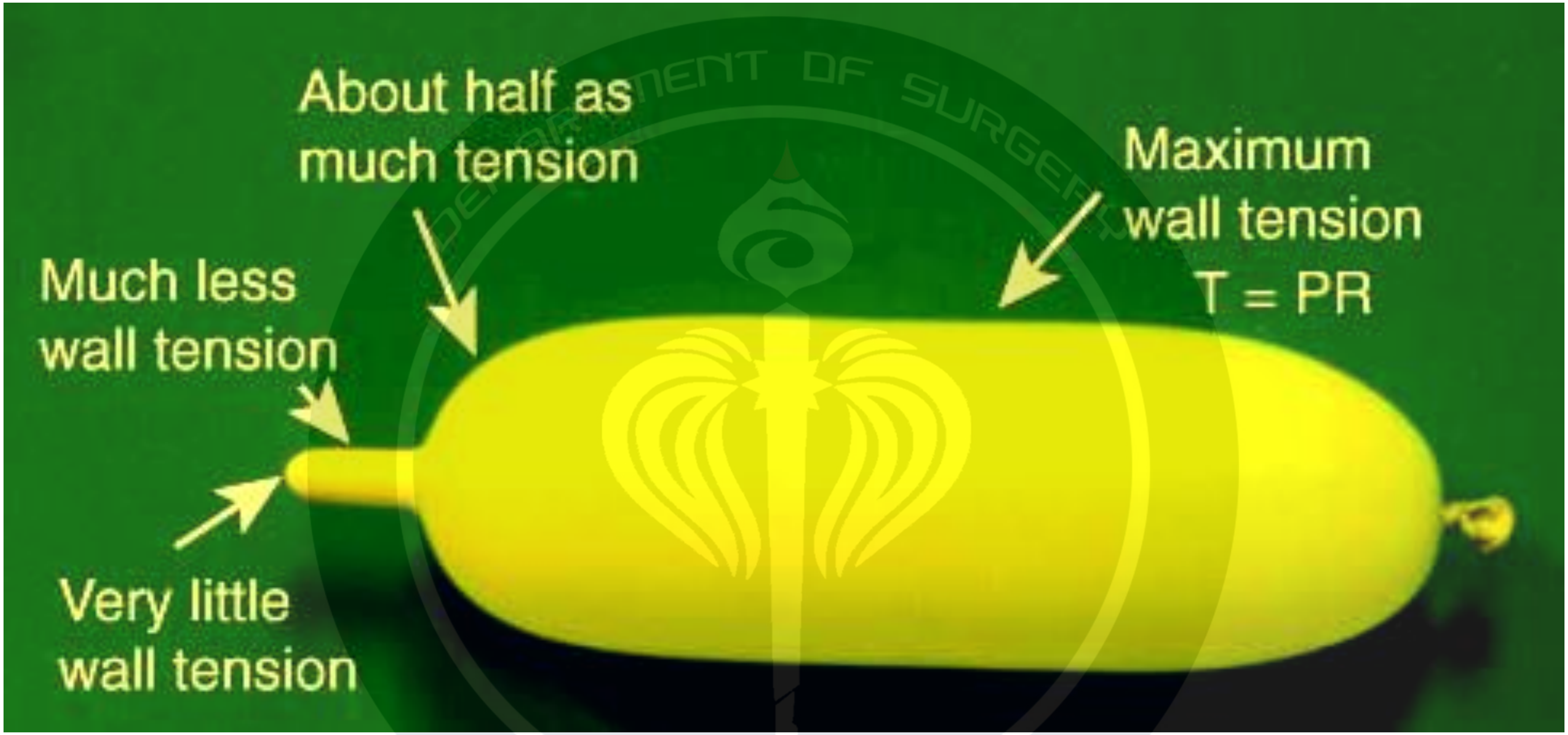
Circumferential tension is the force that counteracts the different between internal and external pressure.

Laplace's law:

$$T = (P_i - P_o) \bullet r$$

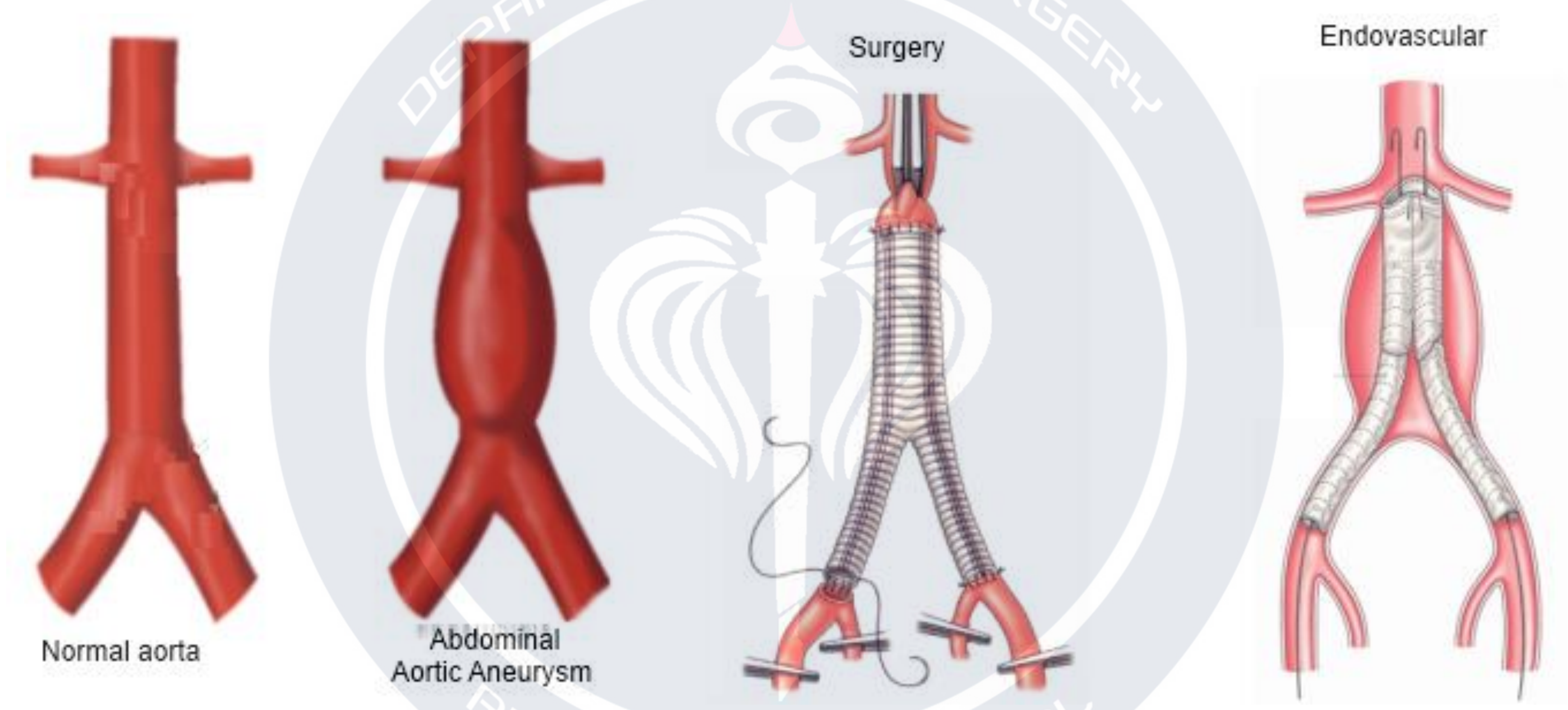
$$T = \frac{\Delta Pr}{h}$$





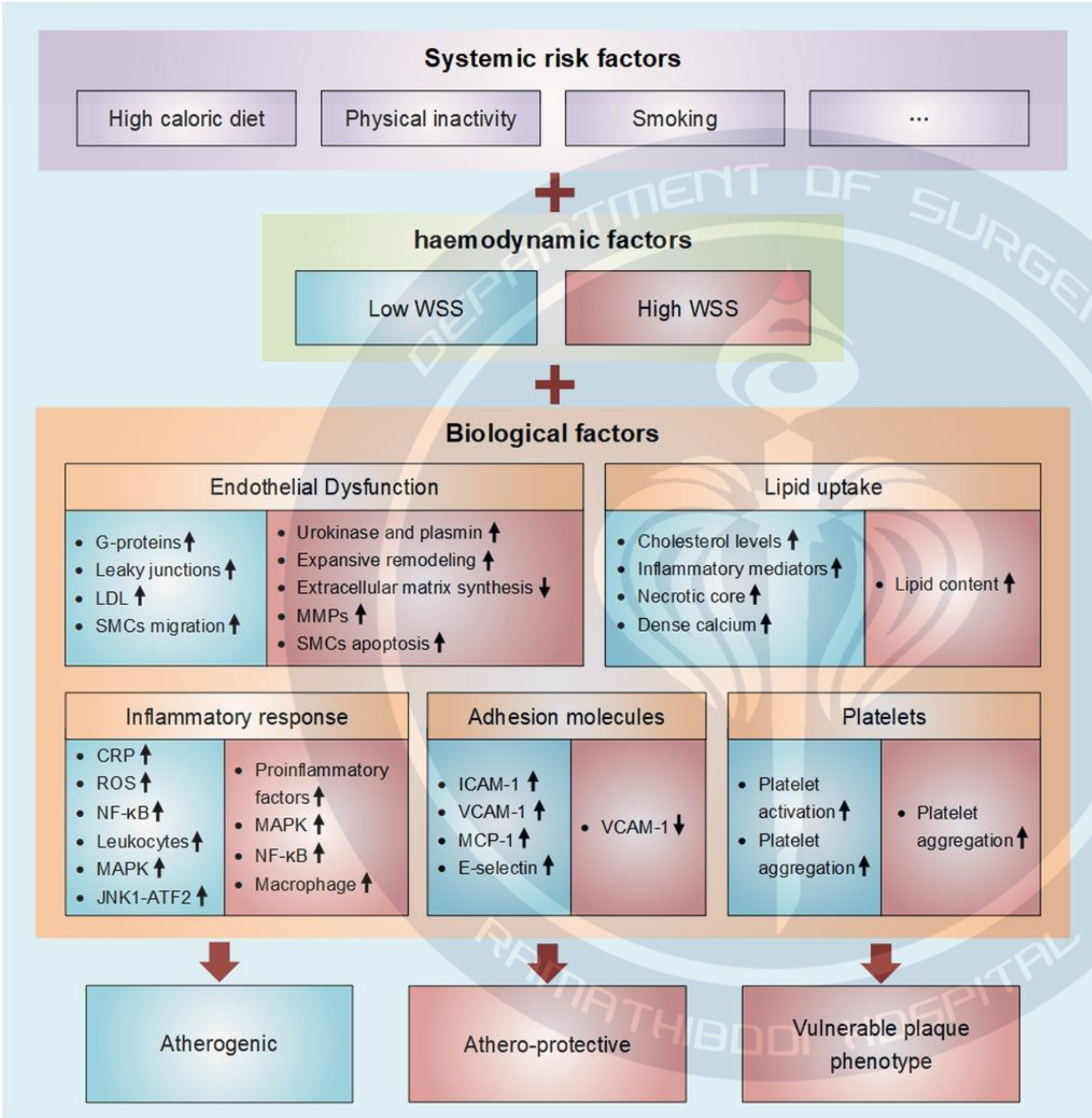
hyperphysics.phy-astr.gsu.edu

$$T = \frac{\Delta P r}{h}$$ **& Wall tensile strength**



https://www.honorhealth.com/

Thank You



Front. Cardiovasc. Med., 03 April 2023
Sec. Atherosclerosis and Vascular Medicine
Volume 10 - 2023 | https://doi.org/10.3389/fcvm.2023.1083547