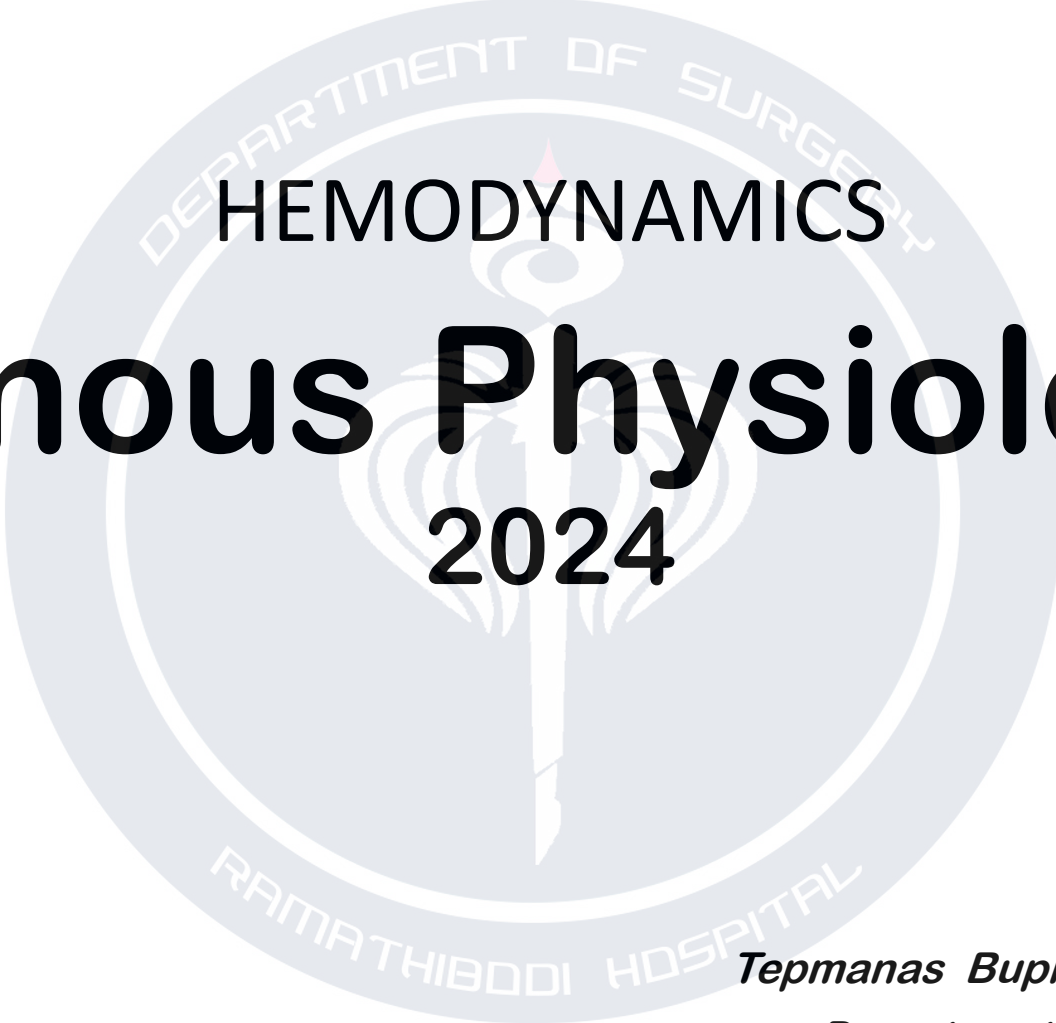




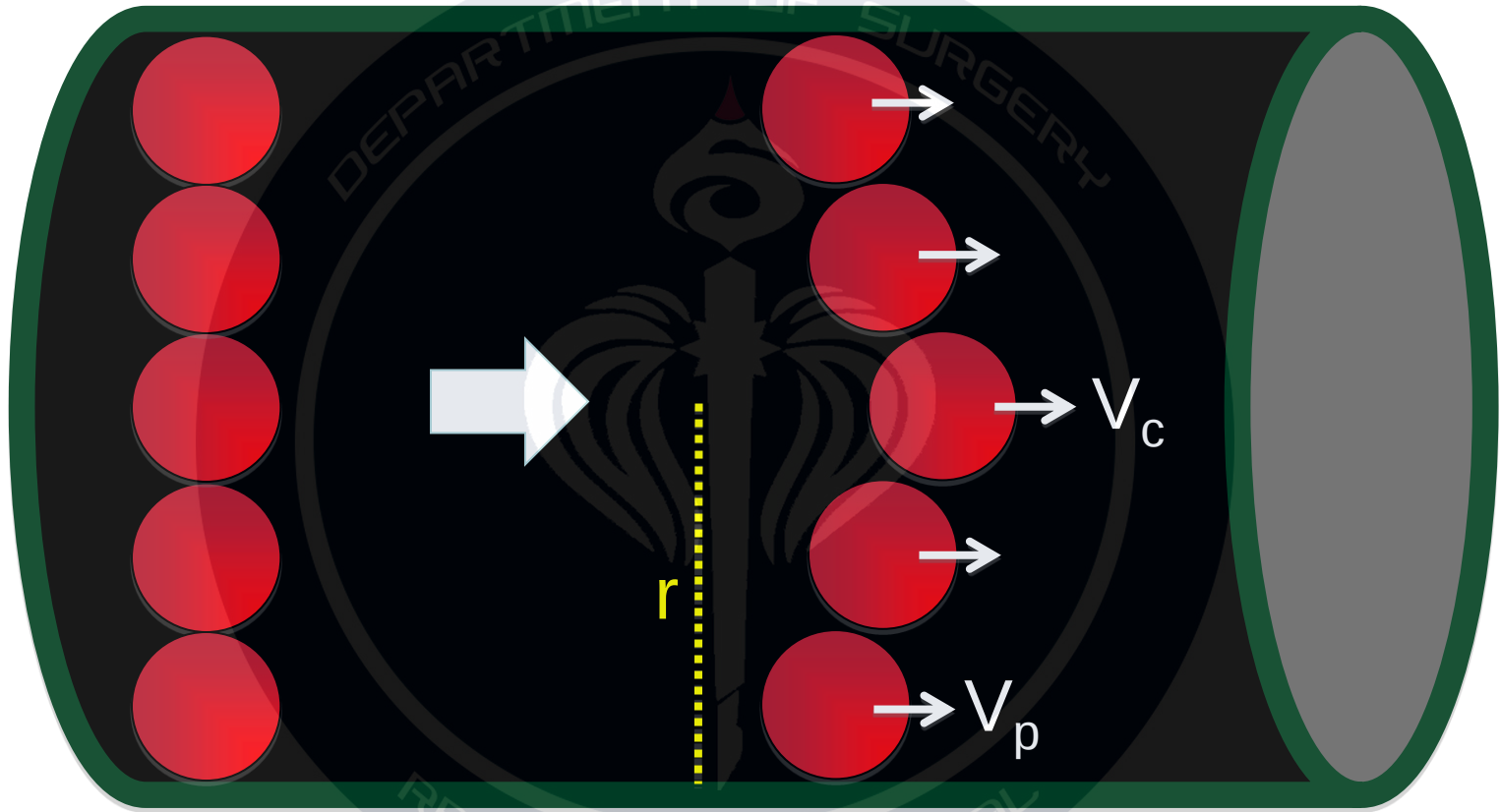
HEMODYNAMICS

Venous Physiology

2024

Tepmanas Bupha-Intr, DVM, PhD
Department of Physiology
Faculty of Science, Mahidol University

Laminar Flow

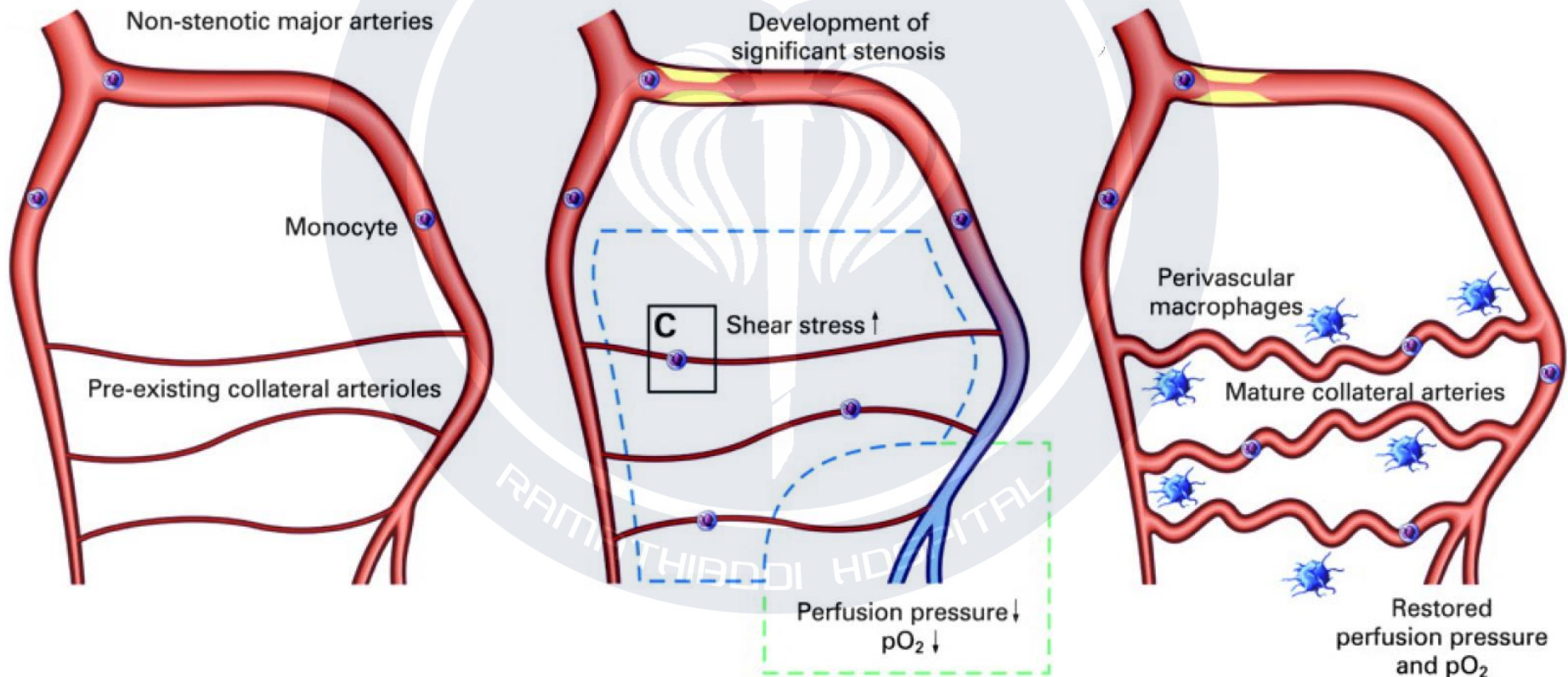


$$\text{Shear Rate (D)} = \frac{V_c - V_p}{r} = \frac{\Delta V}{\Delta r}$$

Collateral Artery: Effect of Shear Stress

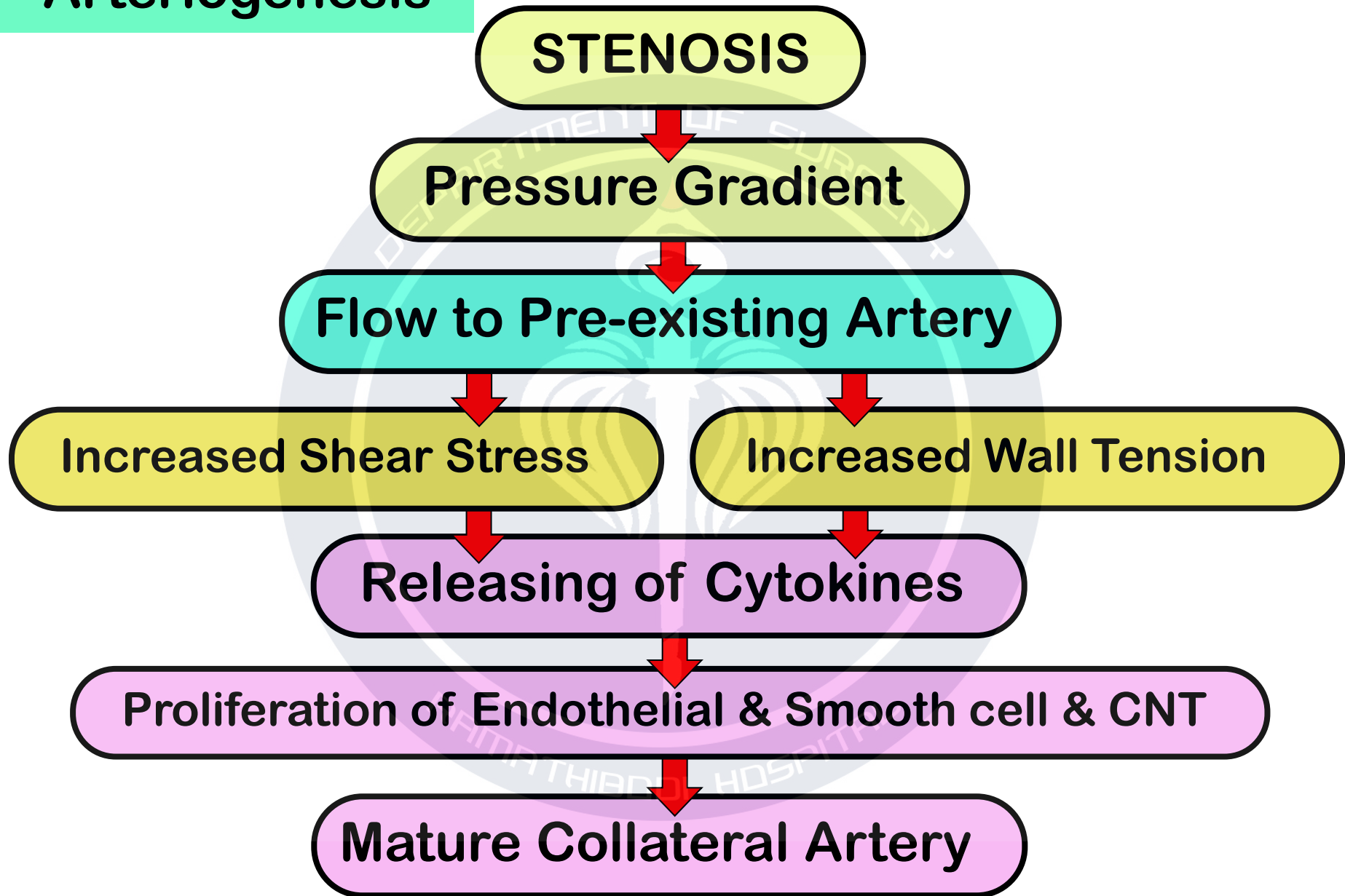
Process: “Arteriogenesis” & “Angiogenesis”

Arteriogenesis occurs by “*Pre-existing artery*”.



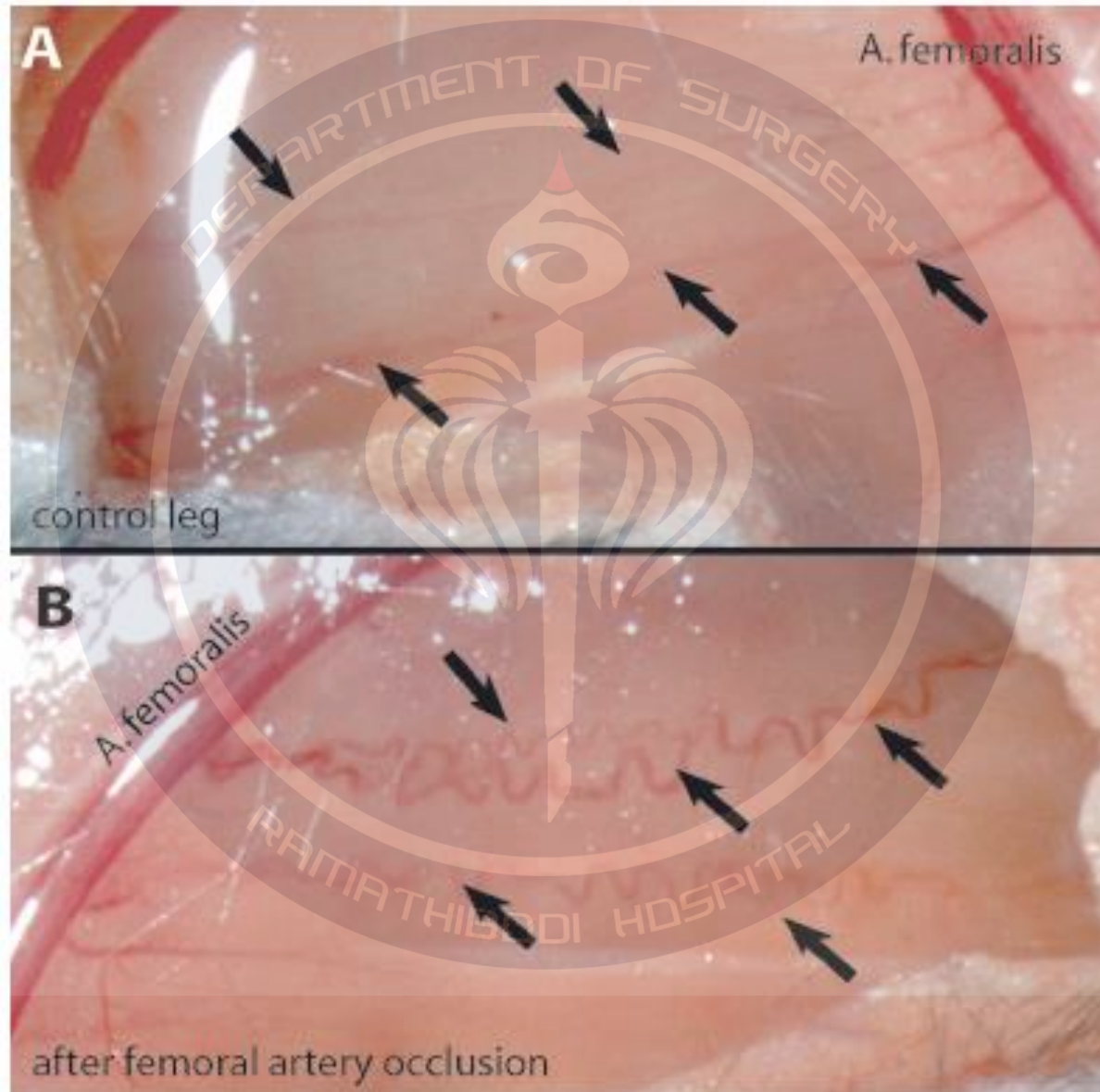
Hakimzadeh et. al. Current Cardiology Review 2014 a

Arteriogenesis



Arteriogenesis

Heil et. al. J cell Mol Med, 2006



Arteriogenesis

Differences Between Angiogenesis and Arteriogenesis

	Angiogenesis	Arteriogenesis
Definition	Formation of new capillaries by sprouting	Growth of collateral arteries
Source	Pre-existing capillaries	Pre-existing arterioles
Location	Lower leg	Upper leg
Oxygen status	Hypoxia	Normoxia
Trigger	Ischemia	Shear stress
Cellular mechanism	Inflammation because of ischemic focal tissue damage	Inflammation because of increased shear stress
Increases blood flow maximally	1.5- to 1.7-fold	10- to 20-fold
Compensation for an occluded artery	Unable	Able

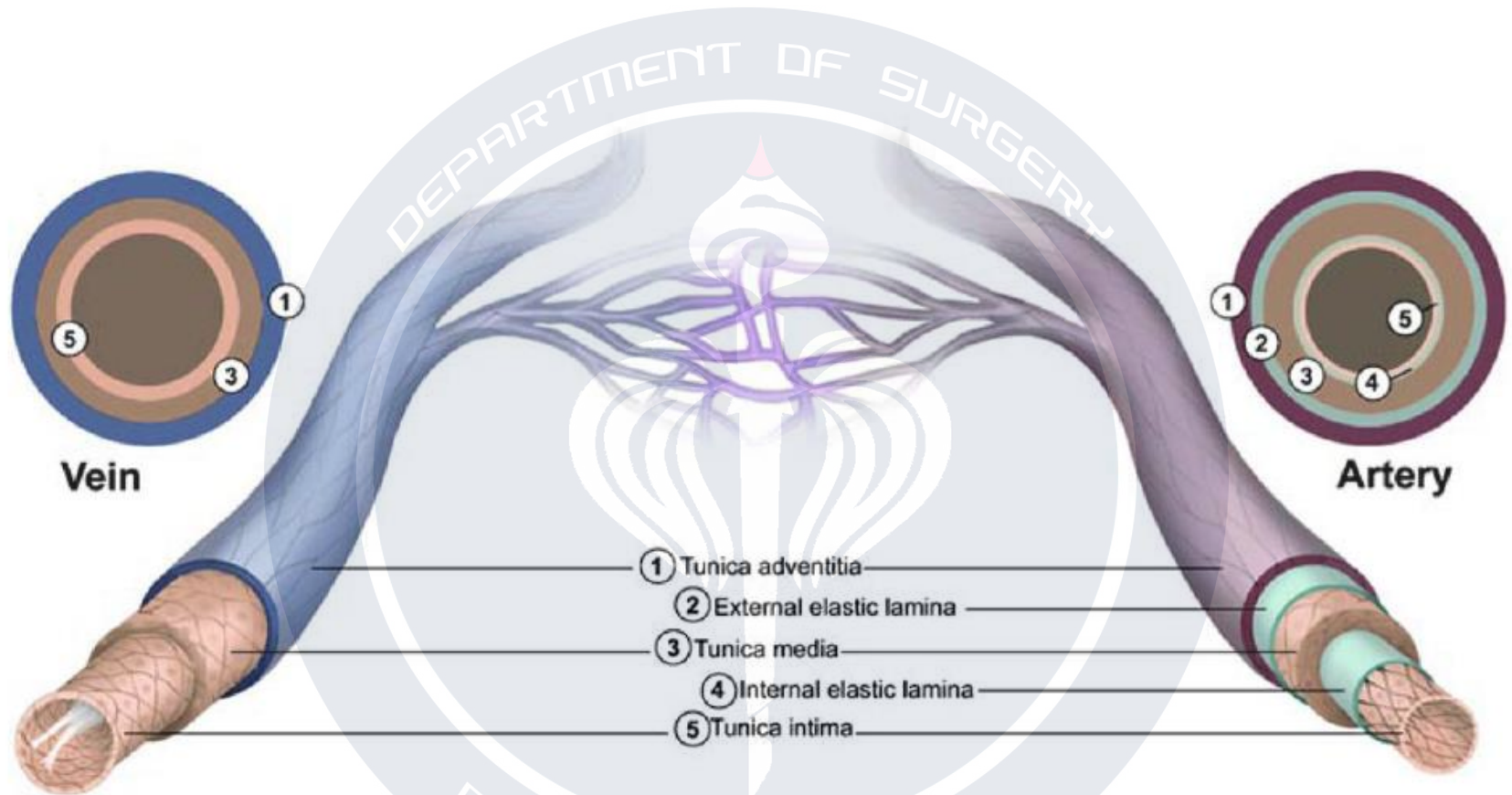
Schaper & Scholz, Arterioscler Thromb Vas Biol, 2003.

Venous Physiology

Outline

- Hemodynamics of venous circulation
- Regulation of venous return
- Ambulatory venous pressure
- Venous Abnormality
- Clinical (venous) syndromes

Venous Structure



Tunica adventitia is thickest.

Cell Tissue Res. 2009 January ; 335(1): 5–16.

Tunica media is quite thin.

Venous Structure

Venous Valves

- Bicuspid valve
- Unidirectional flow

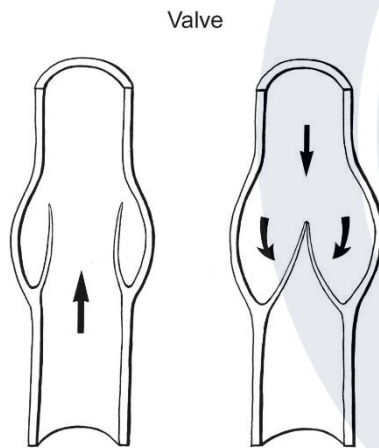
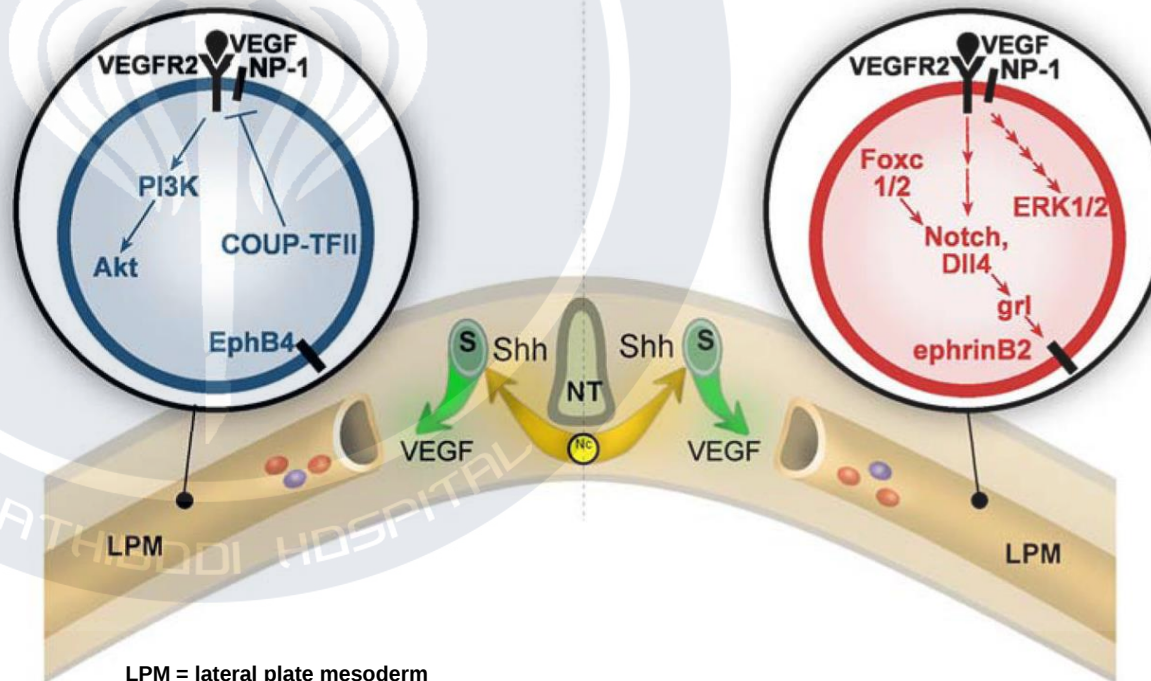


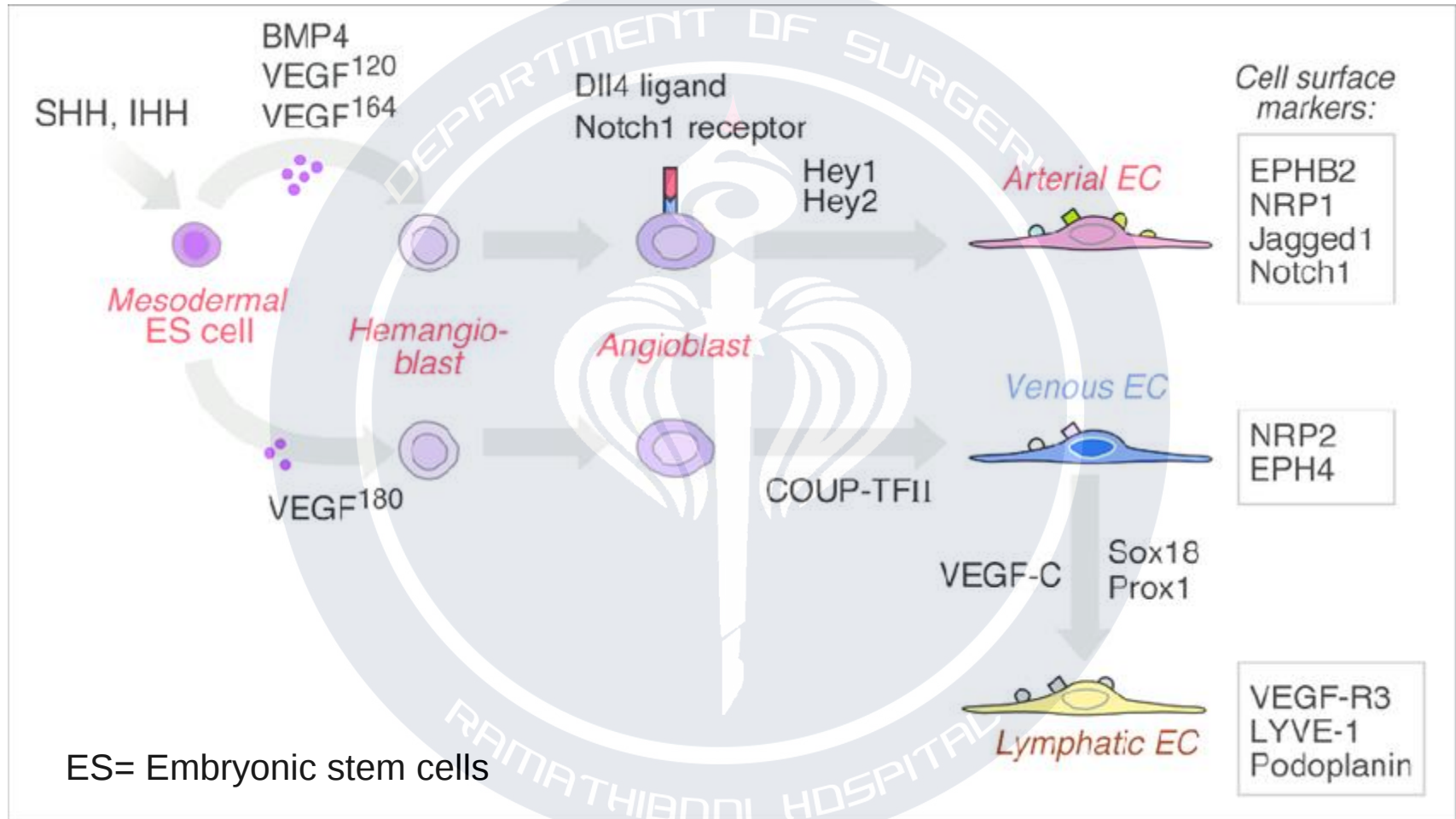
Diagram 1

Endothelial Cells

- Arterial ECs are long and narrow or ellipsoidal.
- Venous ECs are short and wide.

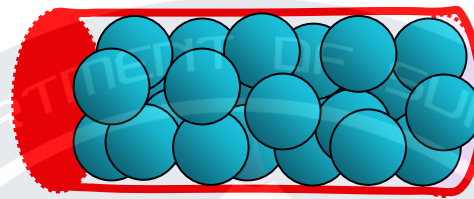
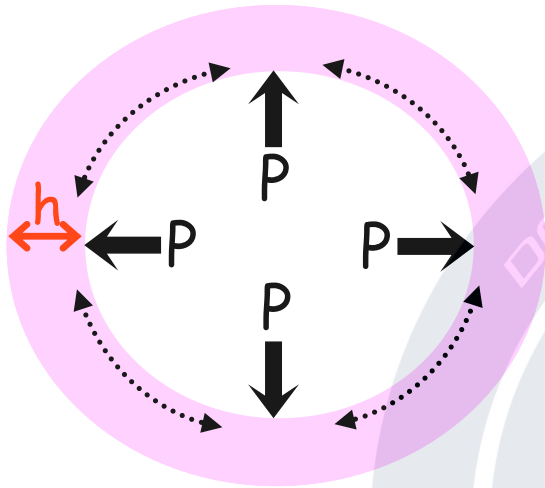


Endothelial cells

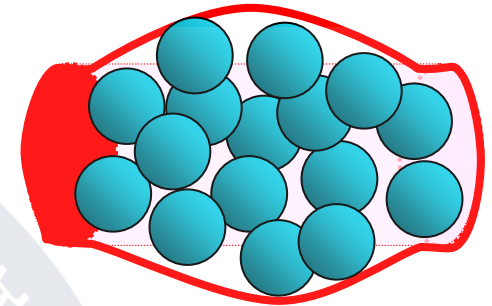


Le Bras A et. al. Vasc Med 2010 15: 321

Venous Compliance



Rigid



Distend able

$$\frac{\text{Volume}}{\text{Pressure}} = \text{Capacitance}$$

$$\frac{\Delta \text{Volume}}{\Delta \text{Pressure}} = \text{Compliance}$$

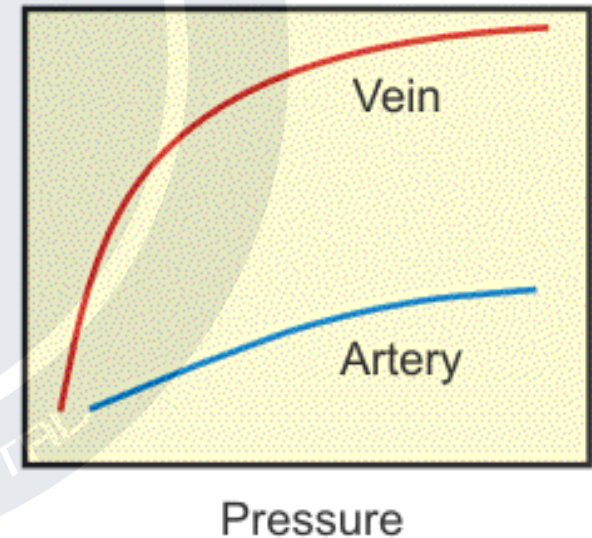
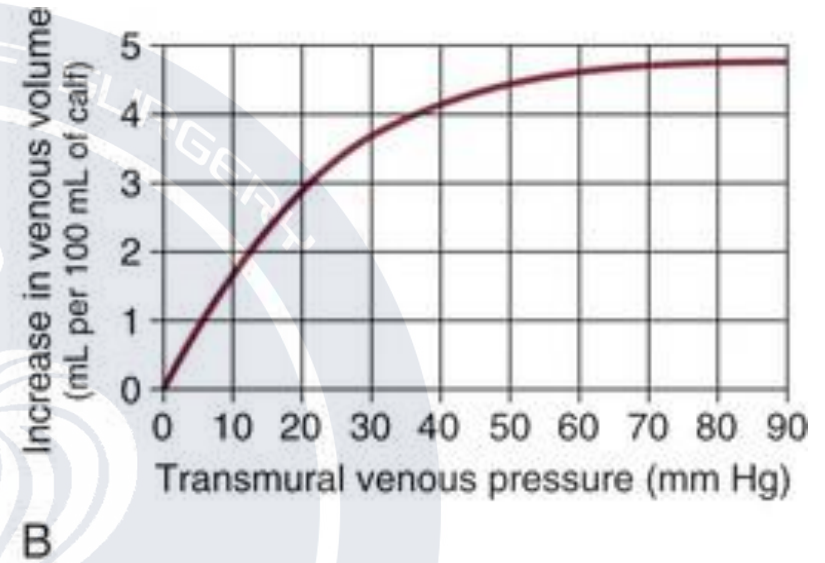
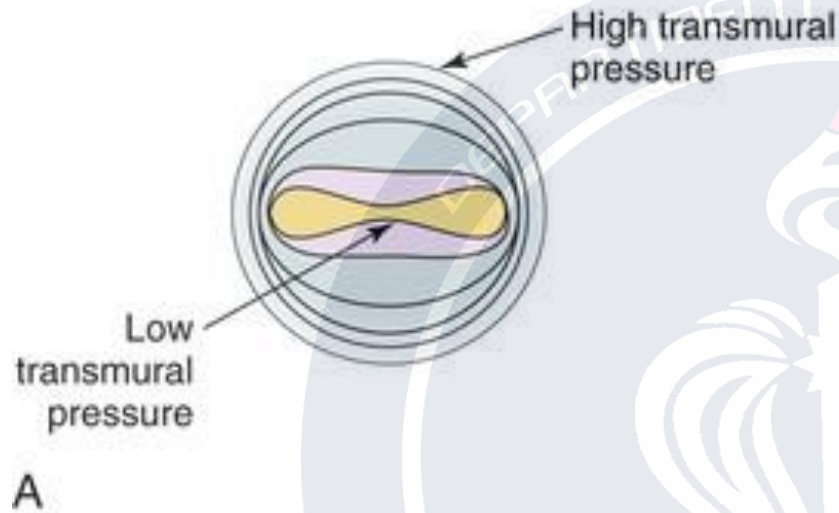


Figure 1. Compliance curve for an artery and vein. The slope of the curve is the compliance. At low pressures, venous compliance is 10 to 20-times greater than arterial compliance, but arterial and venous compliance are similar at high pressures.

Venous Compliance

Circ Res 27:1069, 1970.



FLOW

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

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

Physiological condition

Arterial blood flow velocities range = 4.9-19 cm/sec

Venous blood flow = 1.5-7.1 cm/sec. (higher in Vena cava)

Shear Stress

Physiological condition

Venous shear stress levels are typically 1–5 dynes/cm².

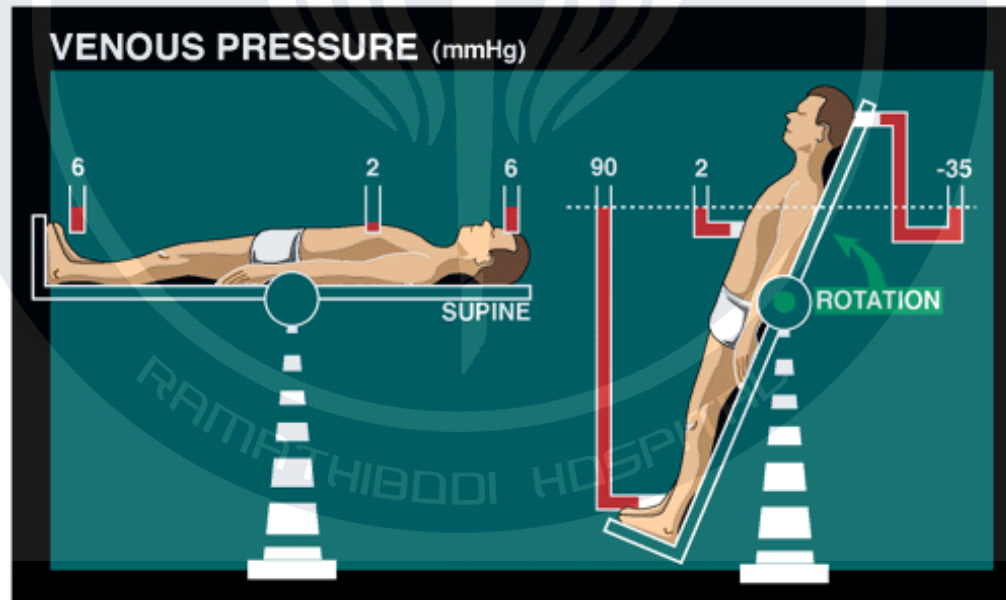
(Arterial = 10–40 dynes/cm²)

$$E = P + \rho gh + \frac{1}{2} \rho V^2$$

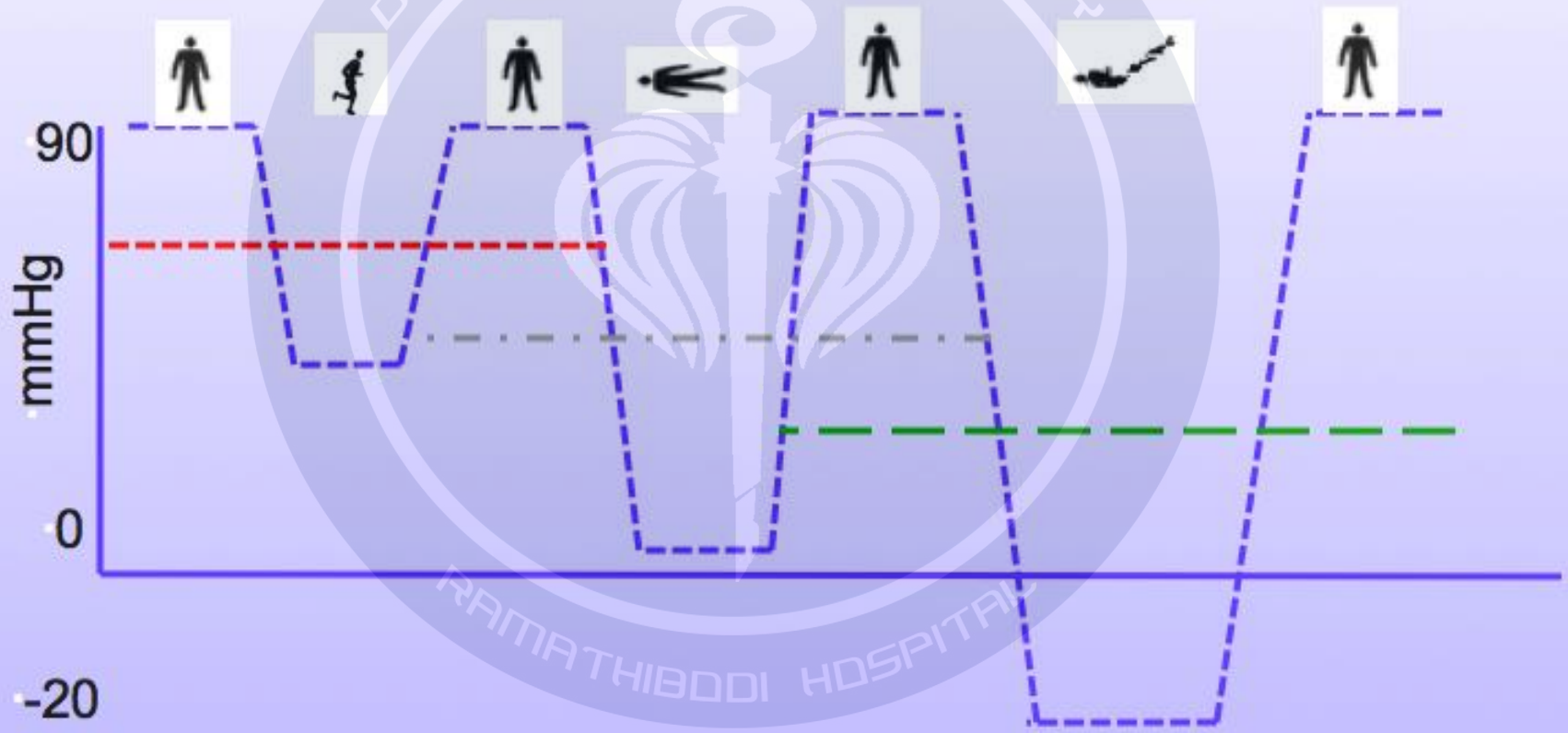
P: Pressure energy

ρgh : Gravitational energy

$\frac{1}{2} \rho V^2$: Kinetic Energy



Position & Venous Pressures



Regulation of Venous Return

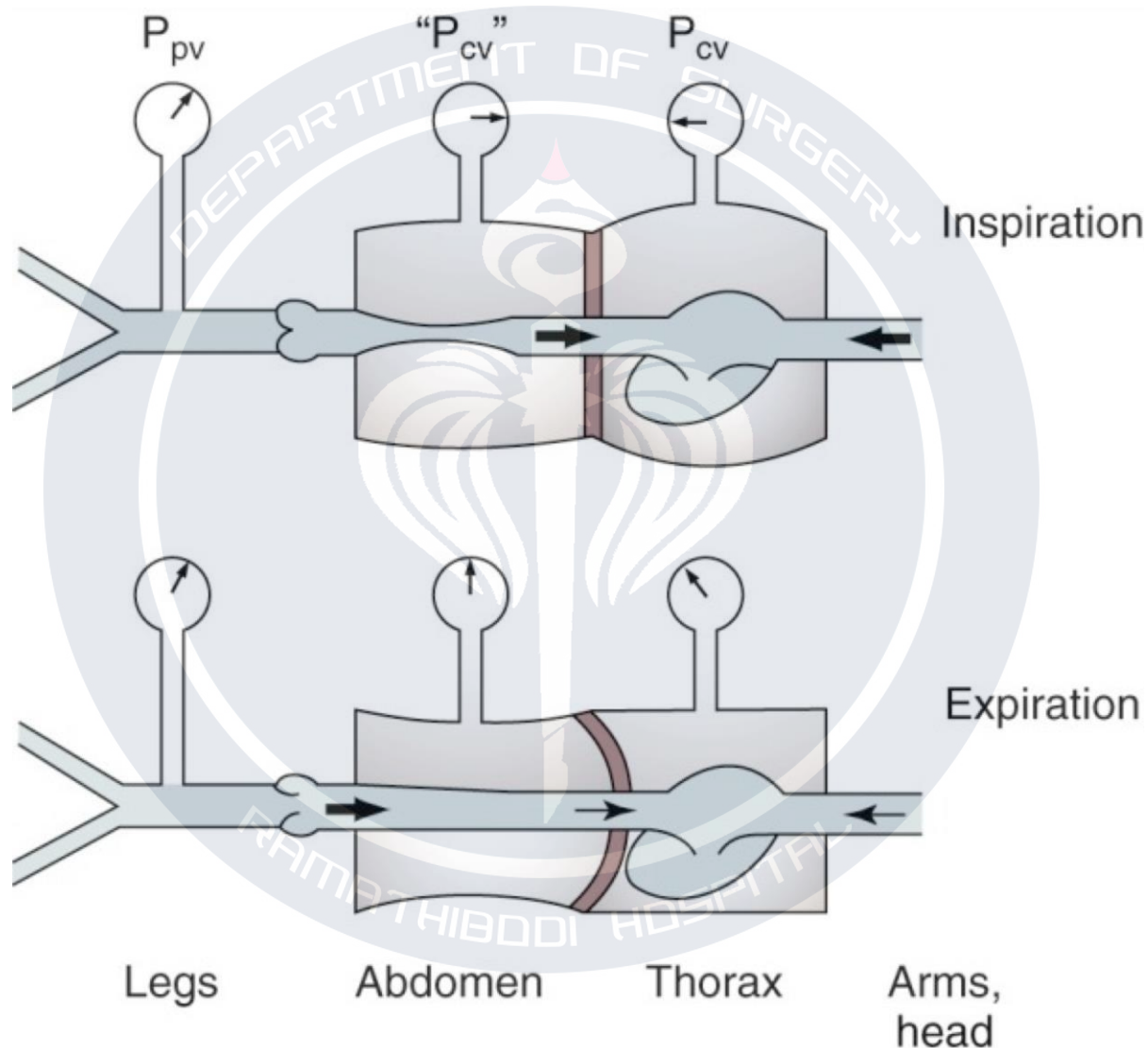
Effective venous return requires:

- Central pump
- Pressure gradient
- Peripheral venous pump
- Competent venous valves

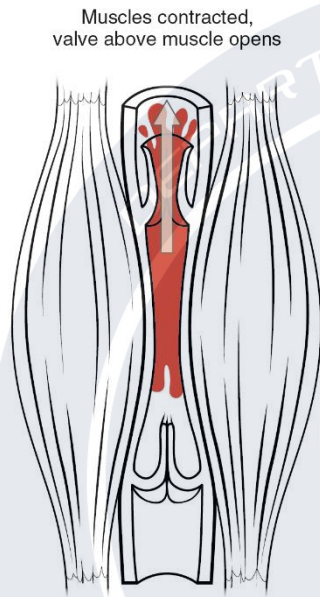
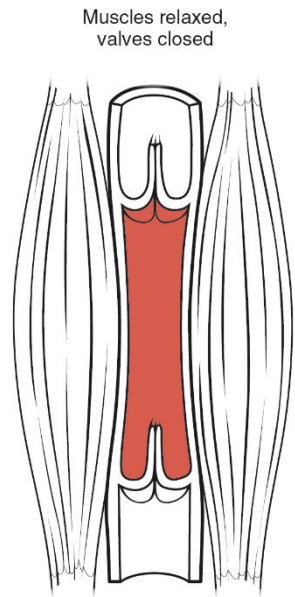
Regulatory Mechanisms

- Sympathetic tone (Splanchnic & Cutaneous)
- Thoracoabdominal pump
- Muscular pump

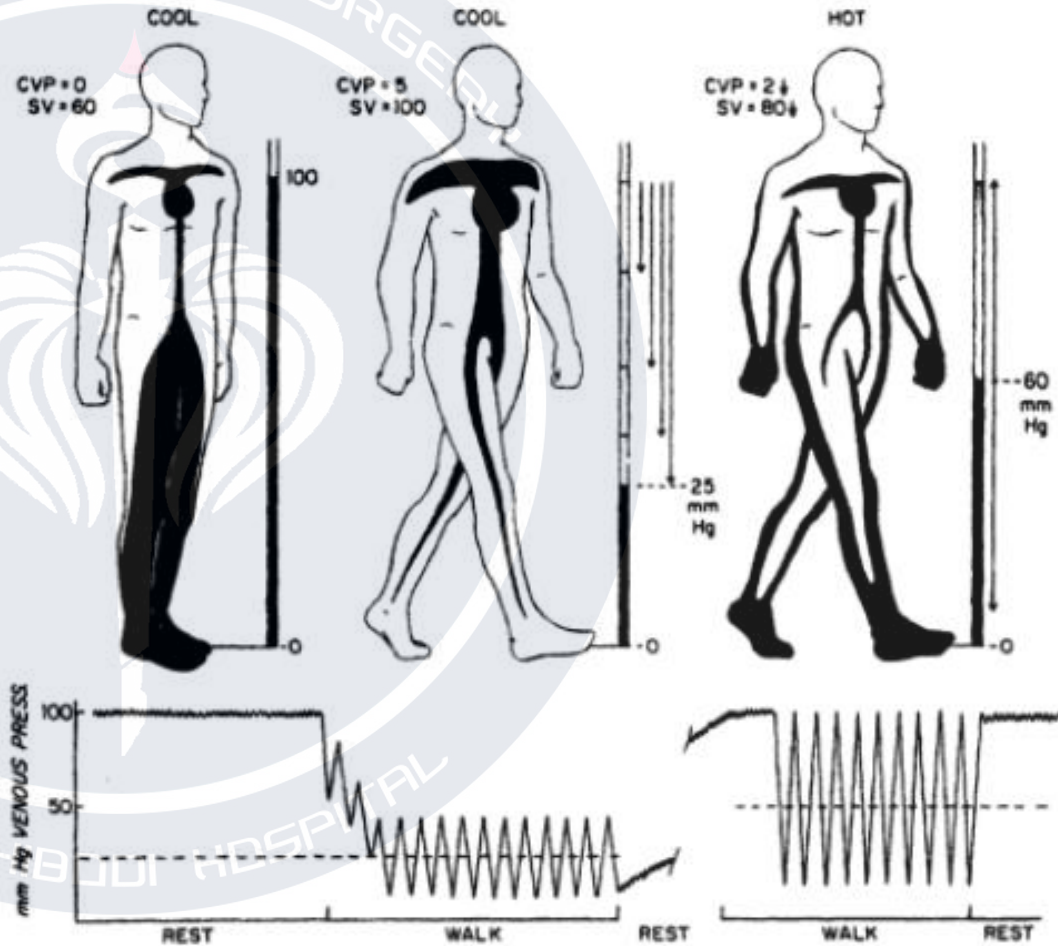
Thoracoabdominal pump



Muscular pump

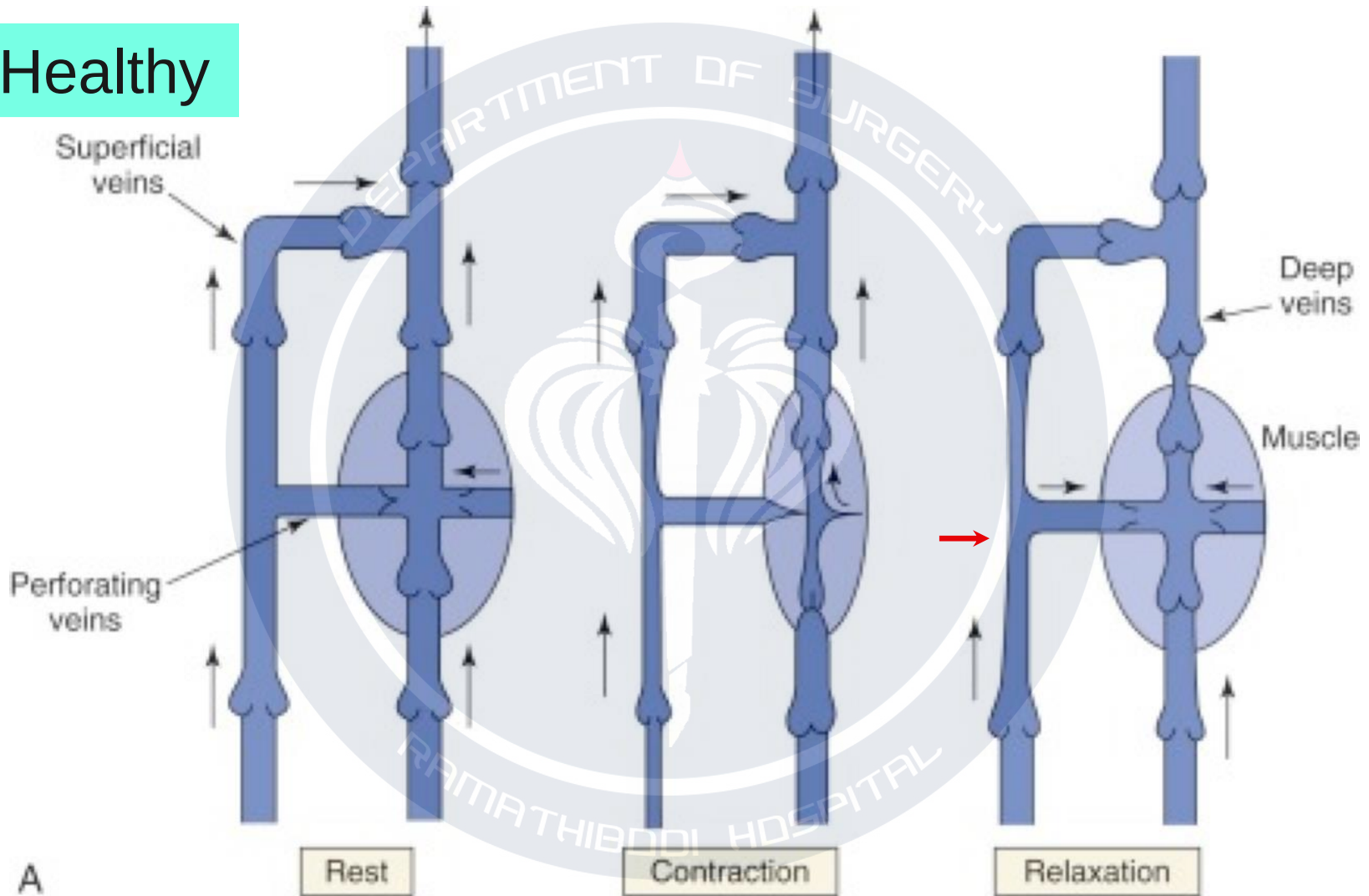


teachmephysiology.com

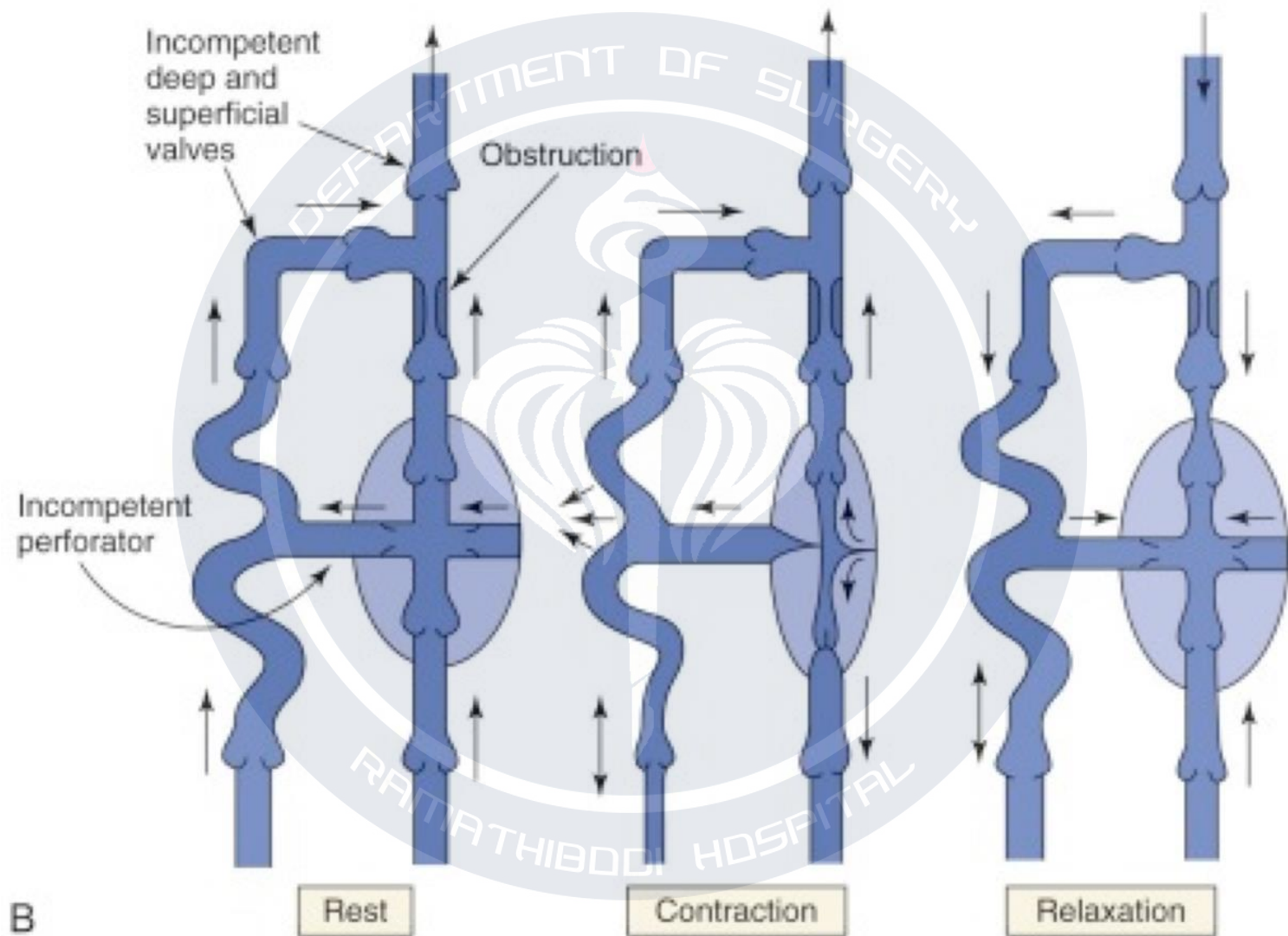


Calf muscle Pump

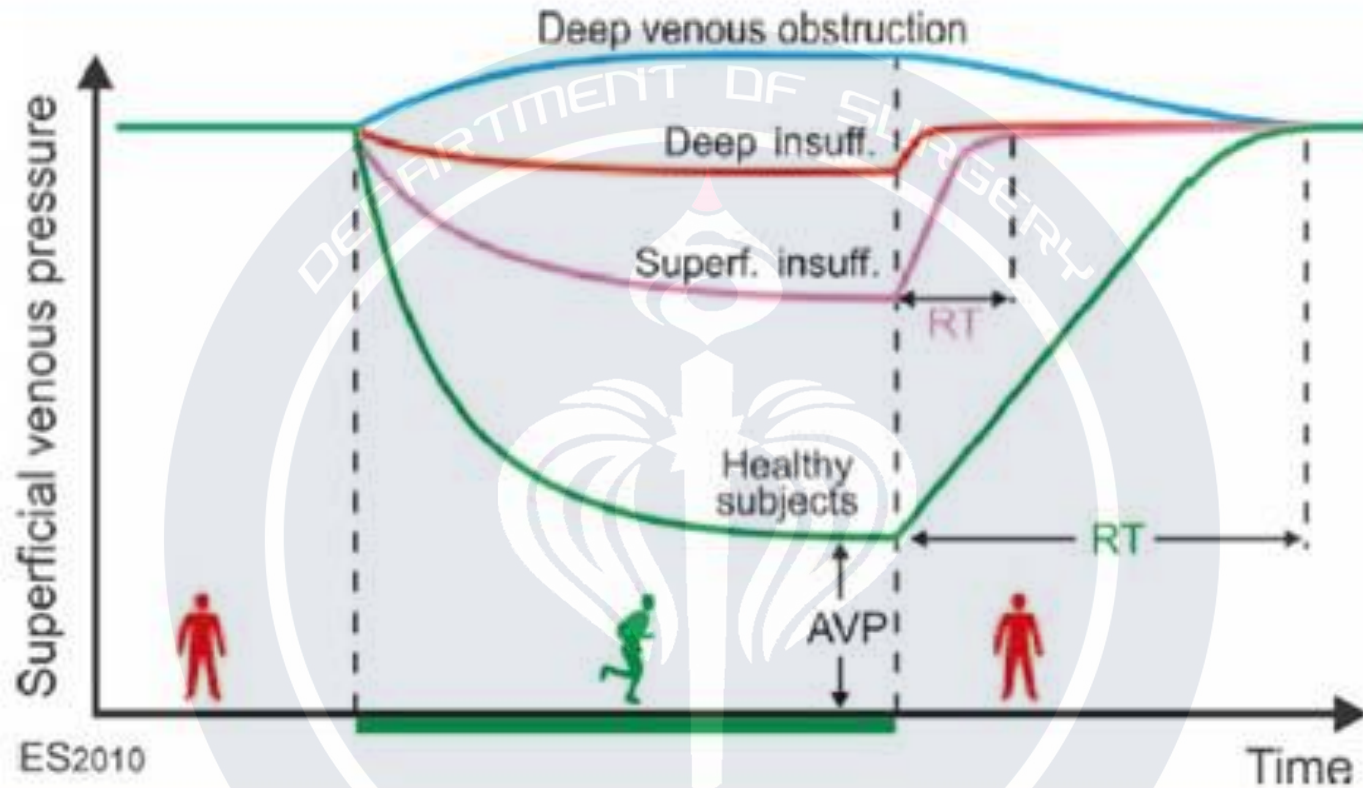
Healthy



Venous Obstruction & Incompetent Valves



Ambulatory Venous Pressure



Stranden E., *Phlebology*. 2011;18(1):3-14.

RT = Recovery Time (refilling time)

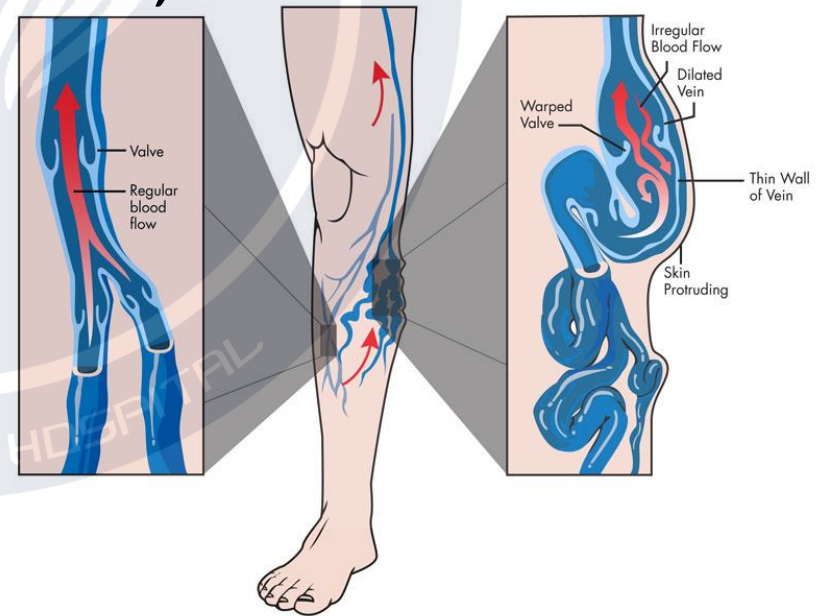
**AVP = Ambulatory venous pressure;
normal: 30 mmHg**

Venous Abnormalities

- Venous Obstruction
 - Pain, edema, hyperpigmentation, ulceration
 - leads to venous hypertension & valvular incompetent
- Valvular incompetent
 - Varicose vein (superficial)



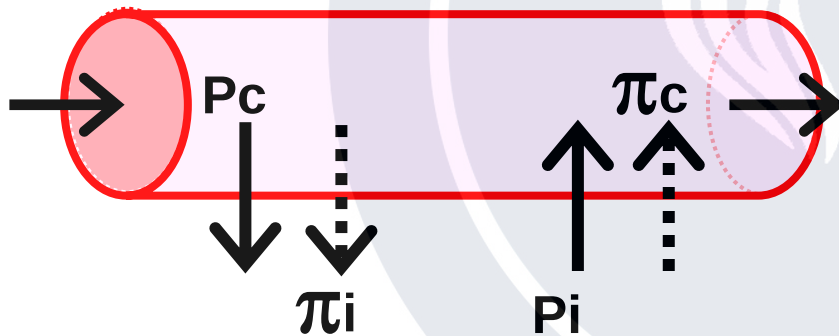
Venous
Hypertension



Edema

- Edema is pathological symptom of excessive water accumulation in interstitial space.
- It occurs when capillary filtration is higher than capillary fluid reabsorption.

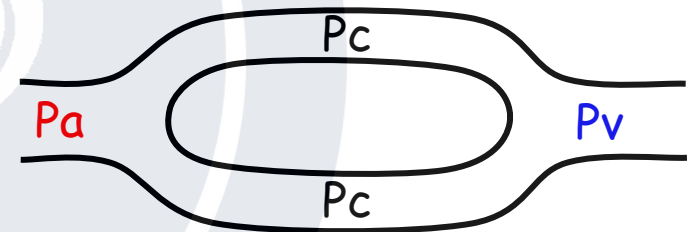
$$\text{Net filtration} \propto (P_c + \pi_i) - (P_i + \pi_c)$$



$$\text{Edema} = (P_c + \pi_i) > (P_i + \pi_c)$$

$$P_c \propto \frac{\text{Arterial P } (P_a) \bullet \text{ Venous P } (P_v)}{\text{Arteriole Constriction}}$$

- High P_a increases high blood flow into capillary bed.
- High P_v blocks blood flow out of capillary bed (remaining in capillary).



$$P_c = 0.13P_a + 0.87P_v$$

“Edema by cardiovascular defect occurs by changing of P_c and π_c .”

Venous Thrombosis

Treatment:

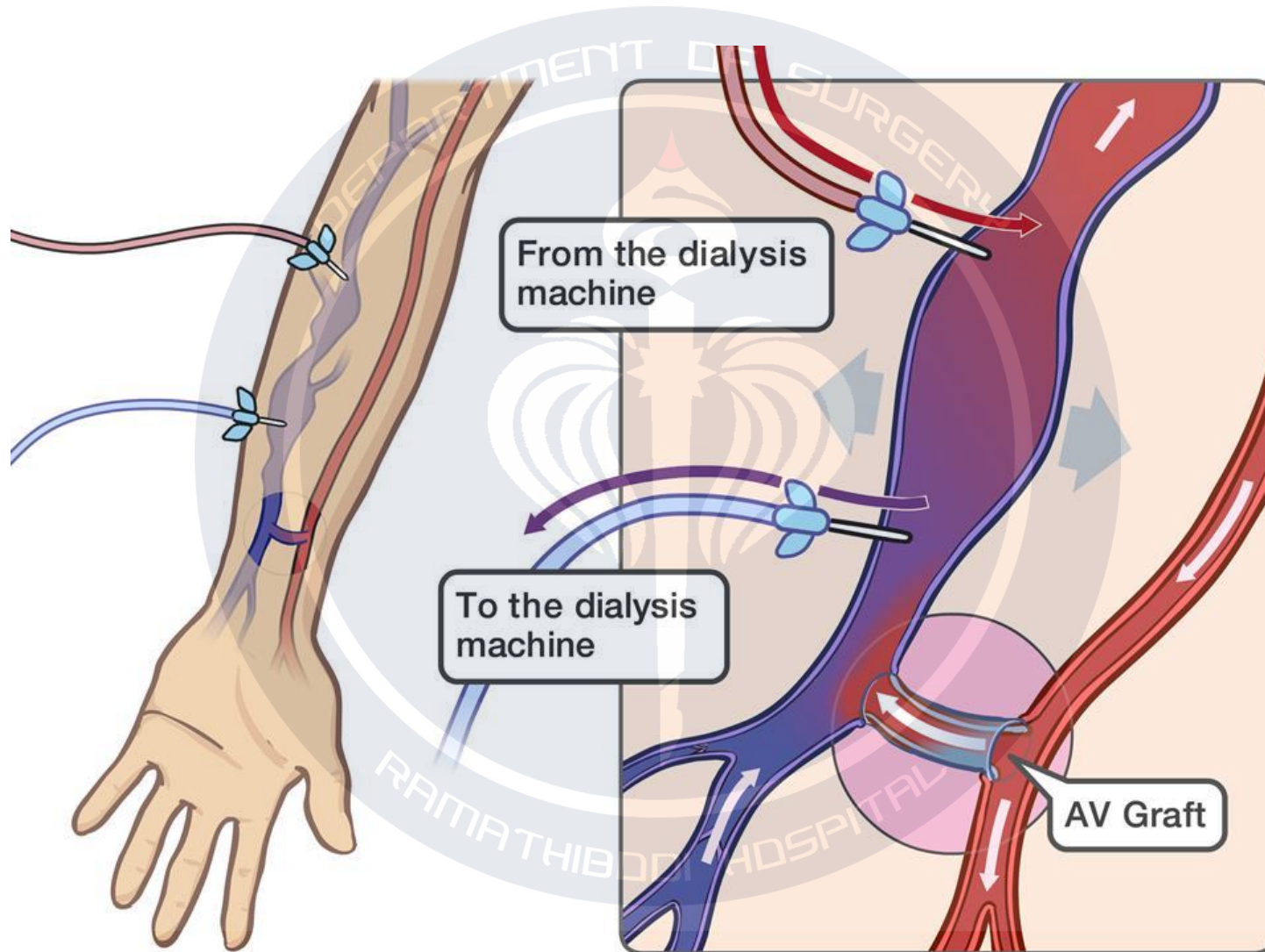
- Anti-coagulation
- Thrombolysis
- Thrombectomy
- Inferior vena cava filter

Varicose Vein

Treatment:

- Sclerotherapy
- Vein stripping
- VNUS Closure (endovenous)

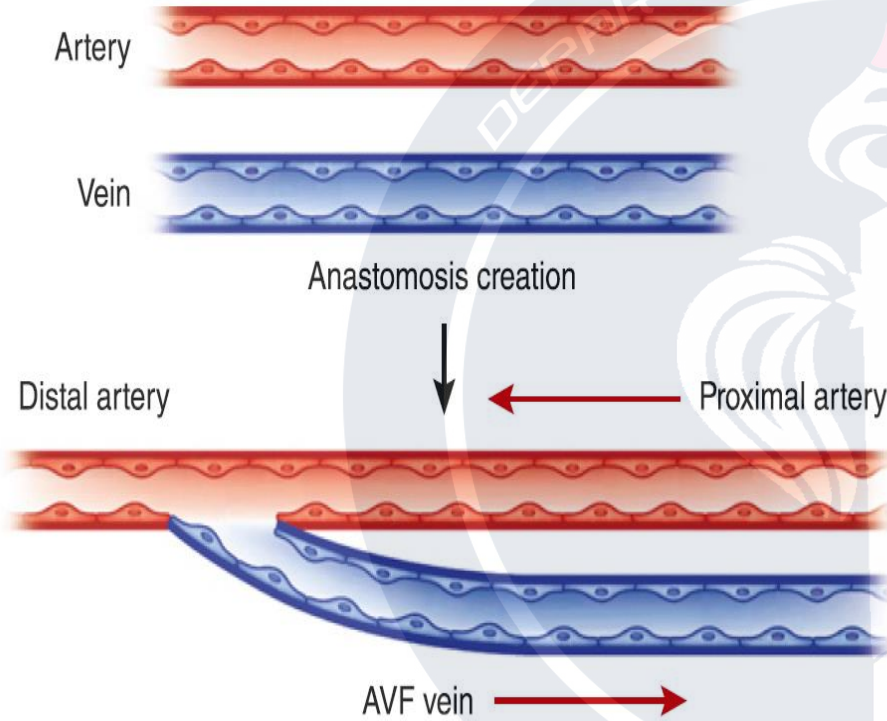
Arteriovenous Fistula



© AboutKidsHealth.ca

Arteriovenous Fistula

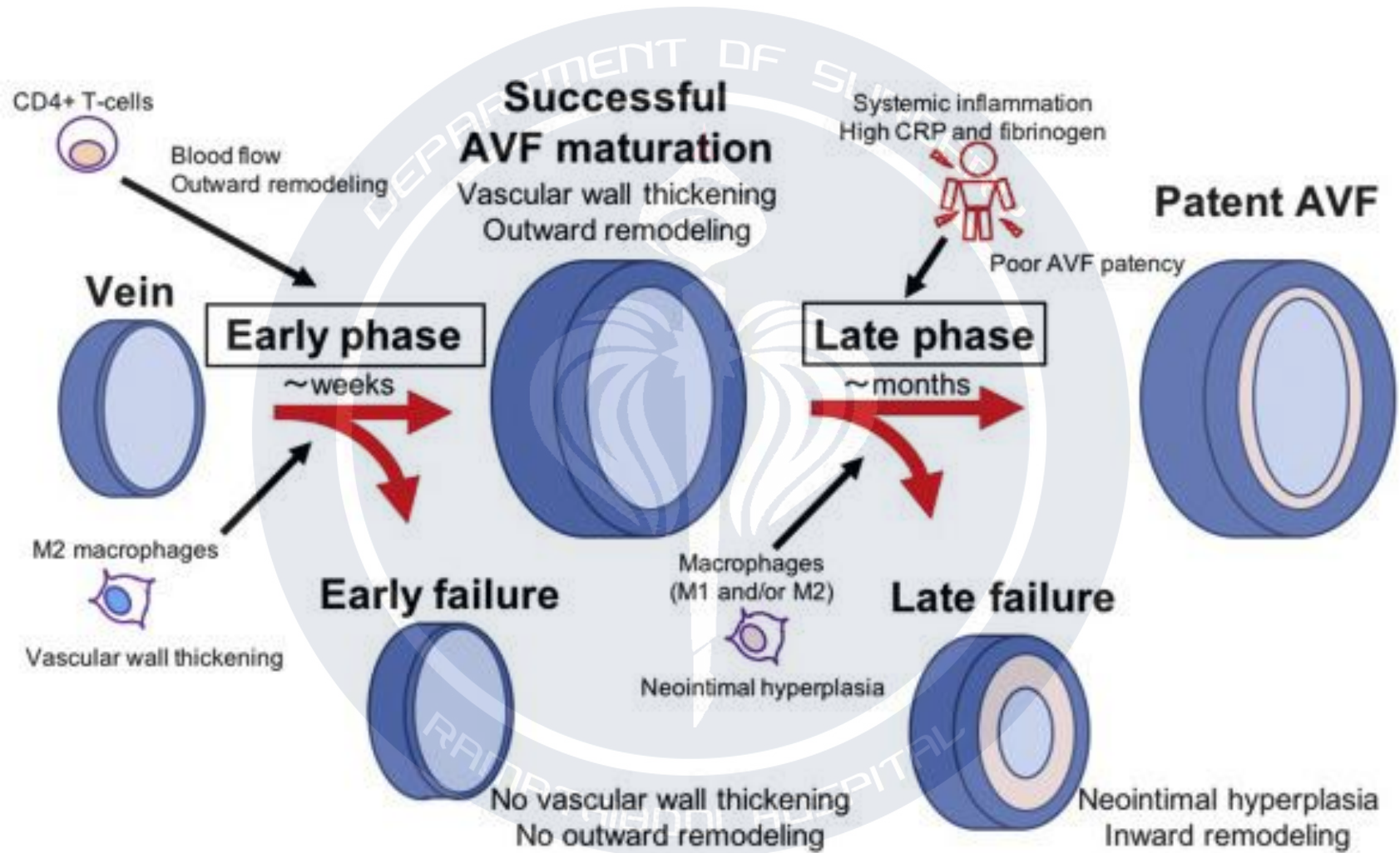
Clin J Am Soc Nephrol 11: 1504–1512, 2016.



Venous Maturation

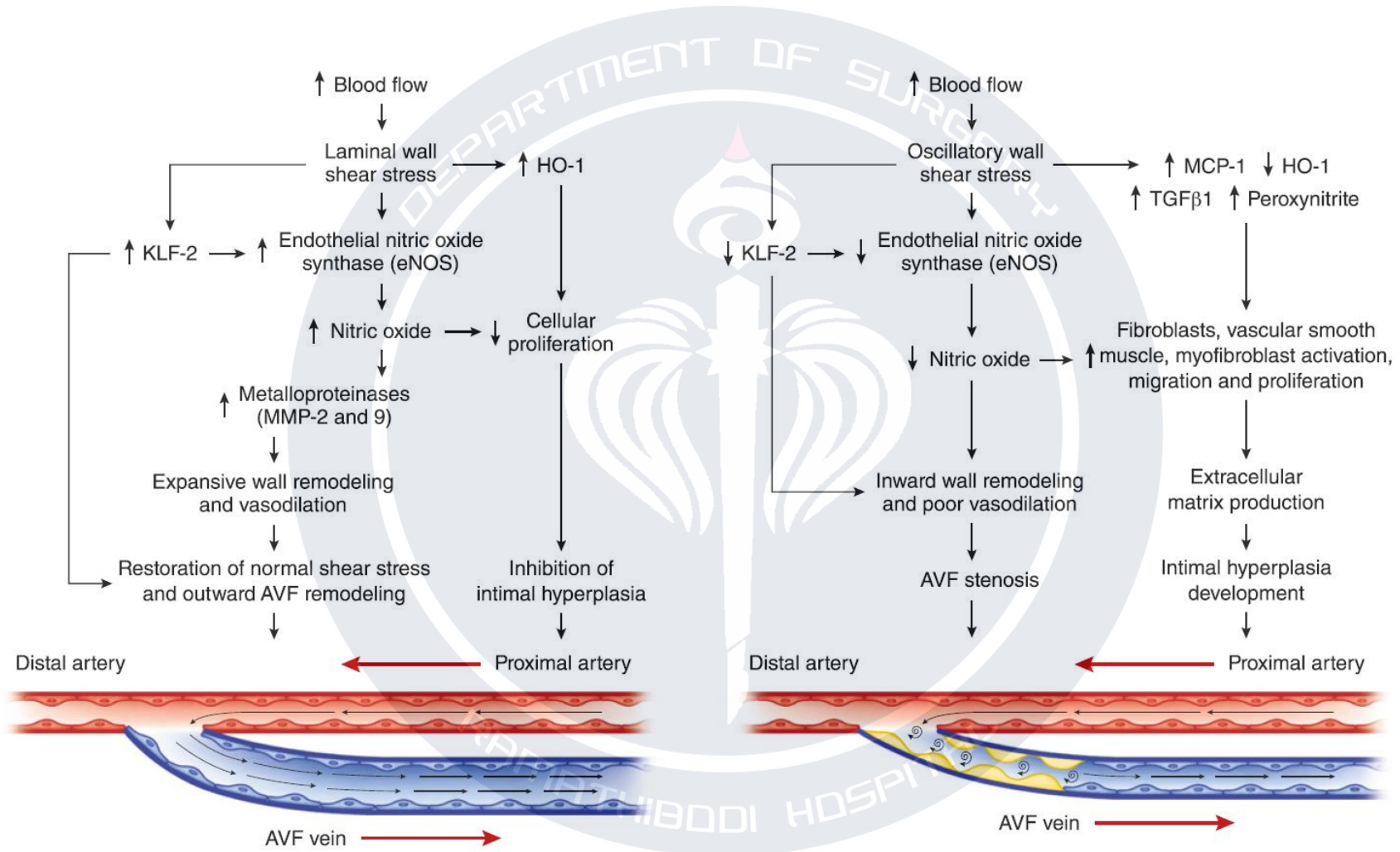
- High flow velocity
- High WSS
- High Blood Pressure

Arteriovenous Fistula

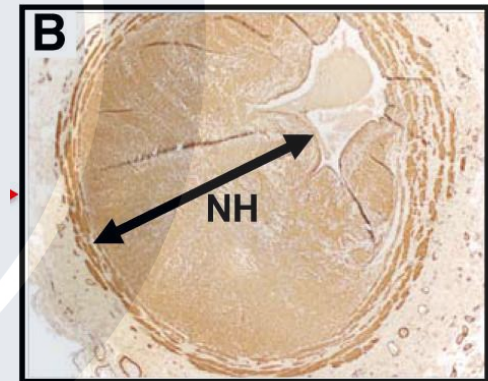
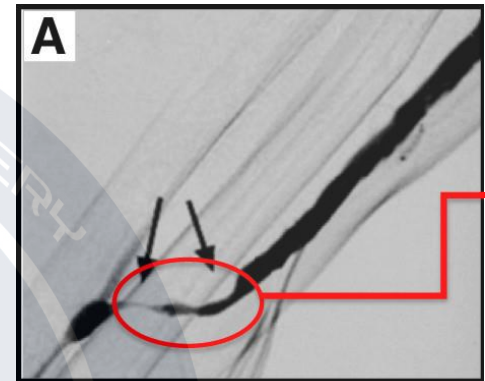
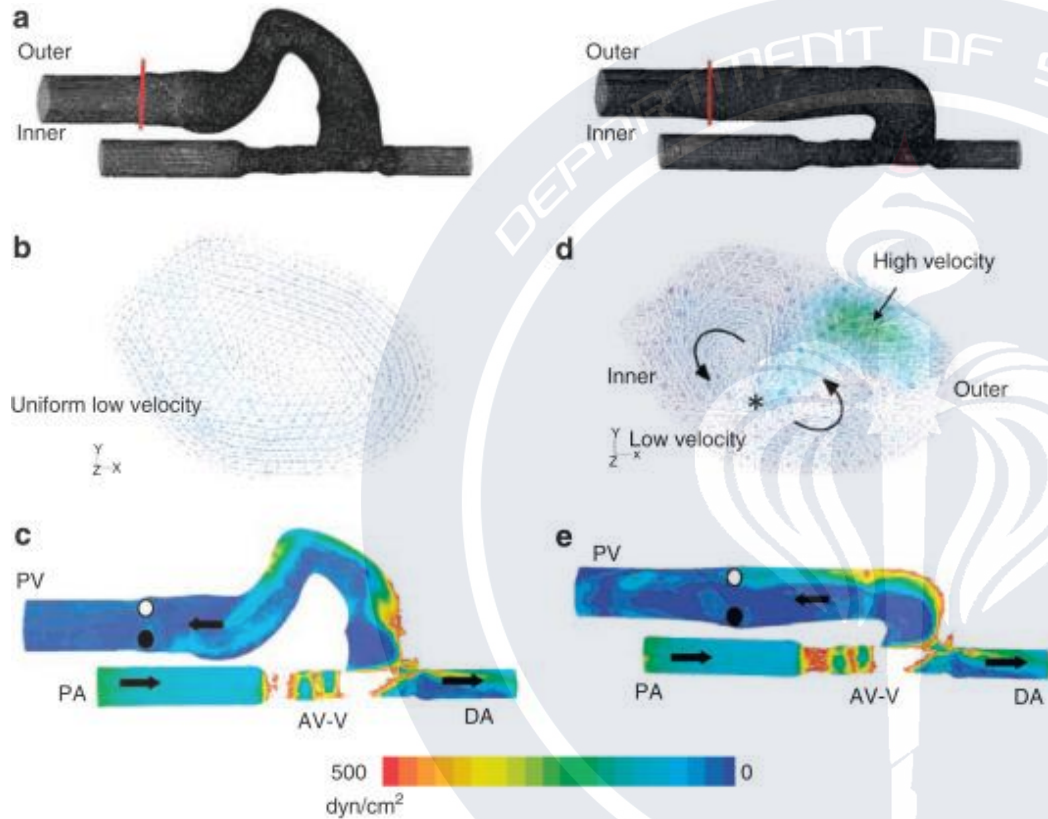


Arteriovenous Fistula

Clin J Am Soc Nephrol 11: 1504–1512, 2016.



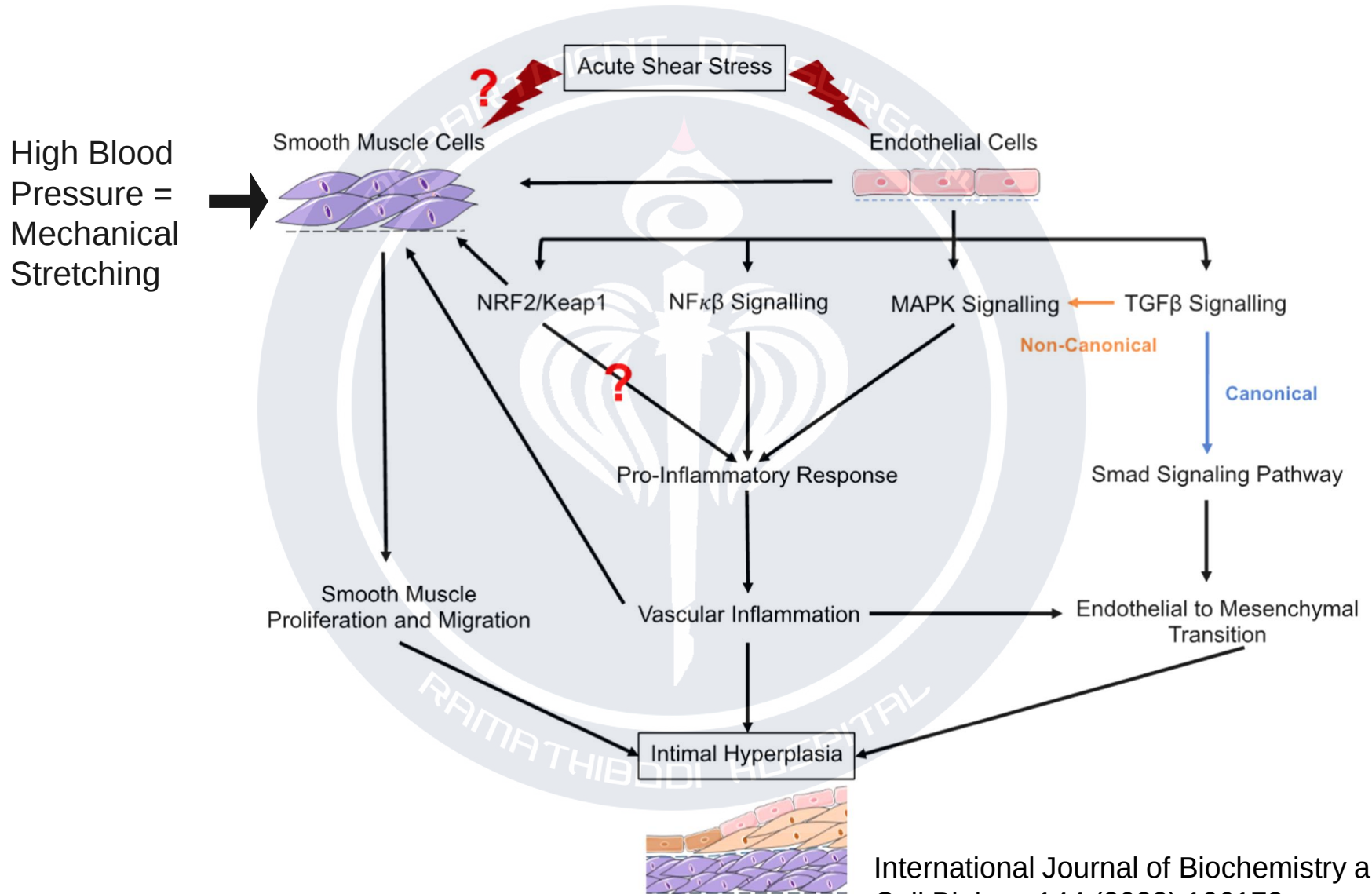
AVF Wall Shear Stress



Kidney International (2008)74,1410–1419

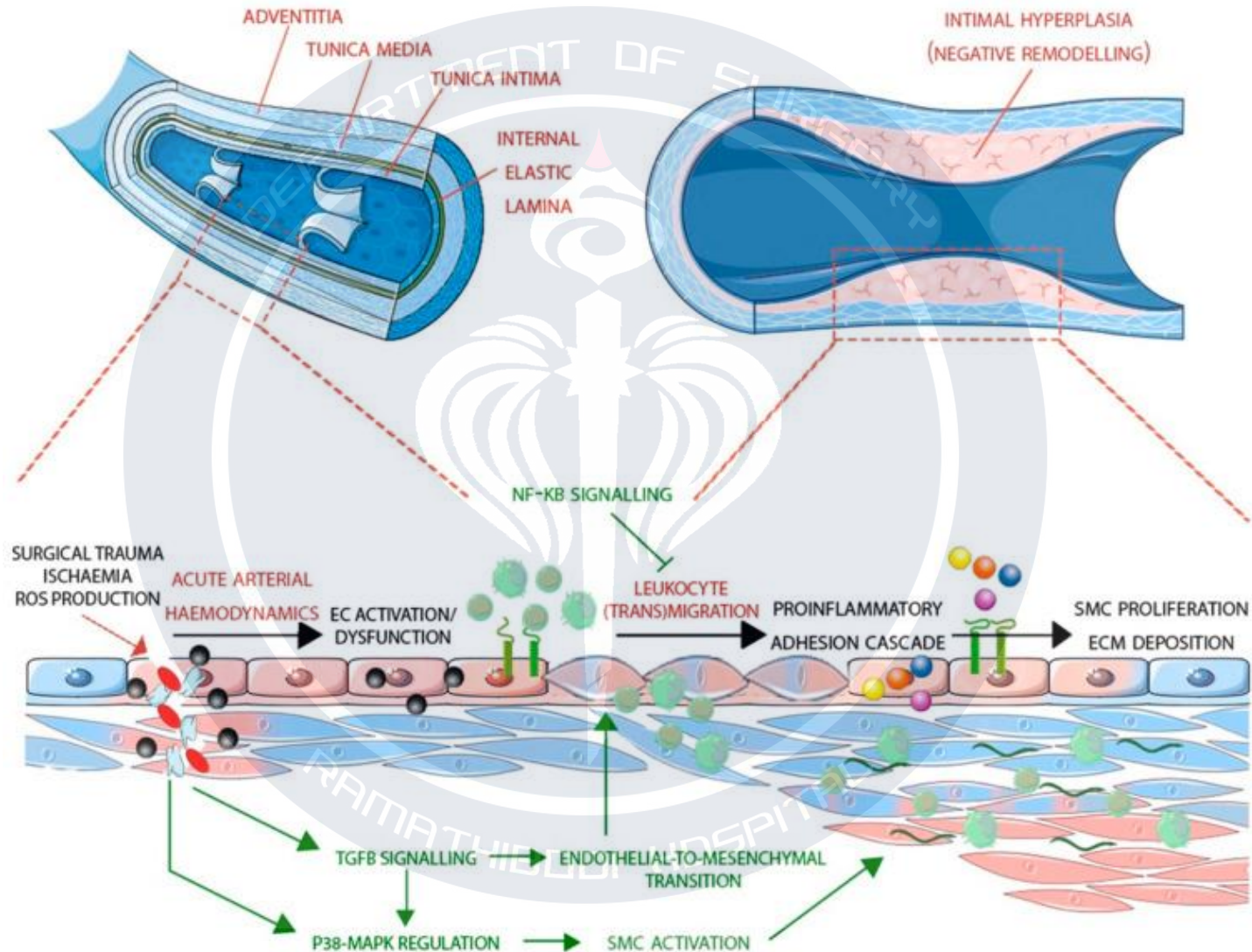
Clin J Am Soc Nephrol 11:
1504–1512, 2016.

AVF Neointimal Hyperplasia



International Journal of Biochemistry and Cell Biology 144 (2022) 106173

AVF Neointimal Hyperplasia



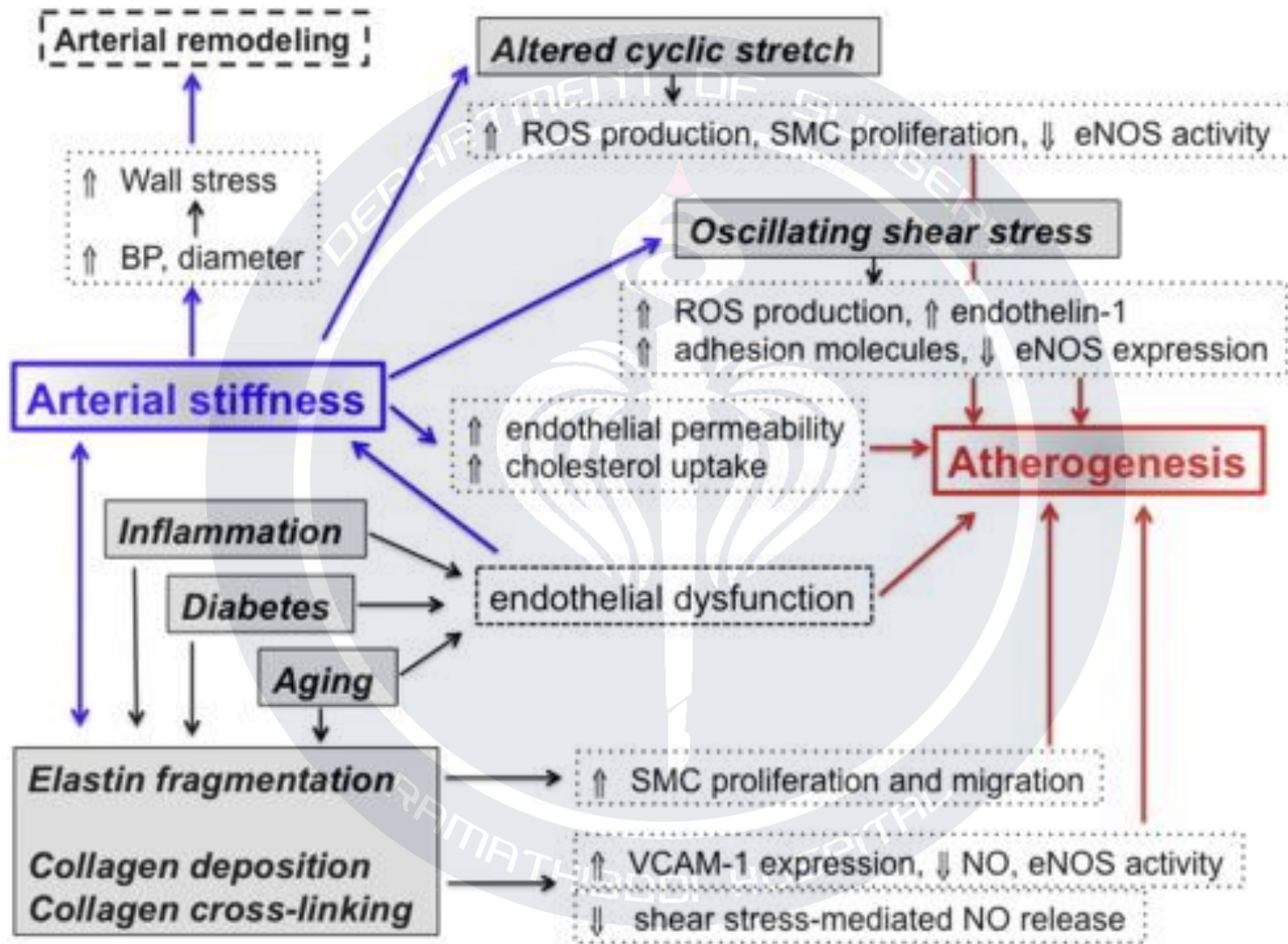
Techniques to Preserve Endothelial Cells in Vein Grafts

Ladak *et. al.* Cells 2022, 11, 3066.

- Harvesting with minimal damage
- Storage with proper solution (muscle relaxant could prevent venospasm)
- Aspirin prevents Platelet aggregation and increases endothelial NO synthesis
- Statins increases endothelial NO synthesis
- ACE Inhibitors/AR blocker attenuates inflammation and oxidative stress. (relate with fibrosis formation)
-

Thank you





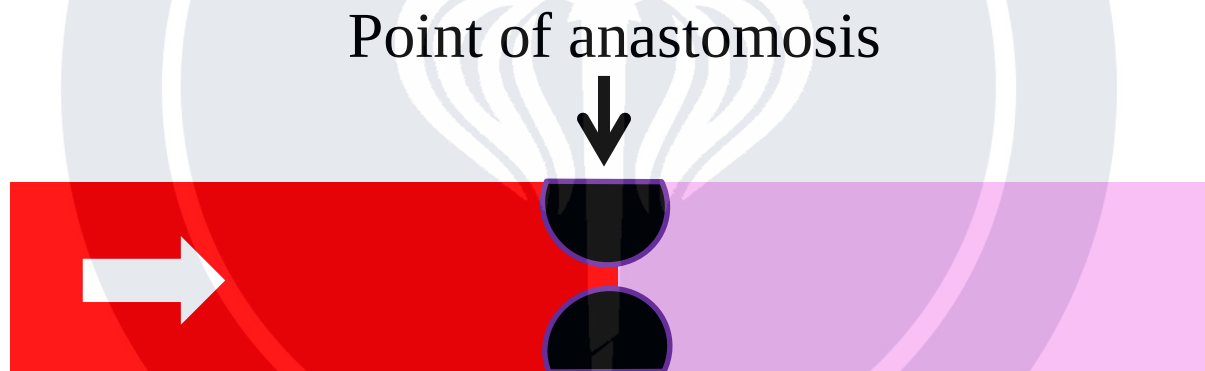
AVF Maturation

Rule of six” in fistula assessment

- 6 week post-creation
- 6 mm deep from skin surface (no more)
- 6 mm fistula (lumen) diameter (at least)
- 600 mL/min of blood flow

QUIZ?

During operation, how do you recognize the point of stenosis or obstructive artery?



QUIZ?

Below are two characters of arterial stenosis. One is continuous plaque, while another is discontinuous. Compare pressure difference between two sides (P_1 - P_2) of these arteries



QUIZ?

In bypass grafting, graft vessel should have *high* or *low* or *no* compliance?

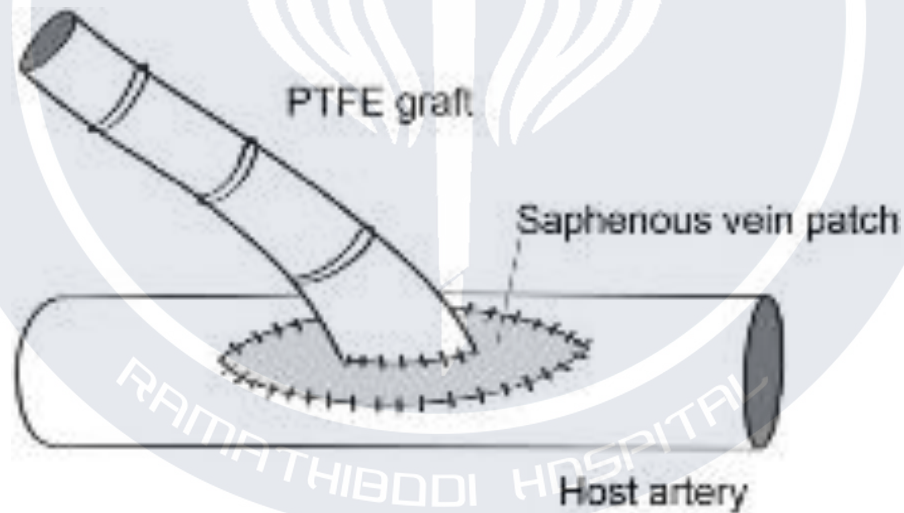
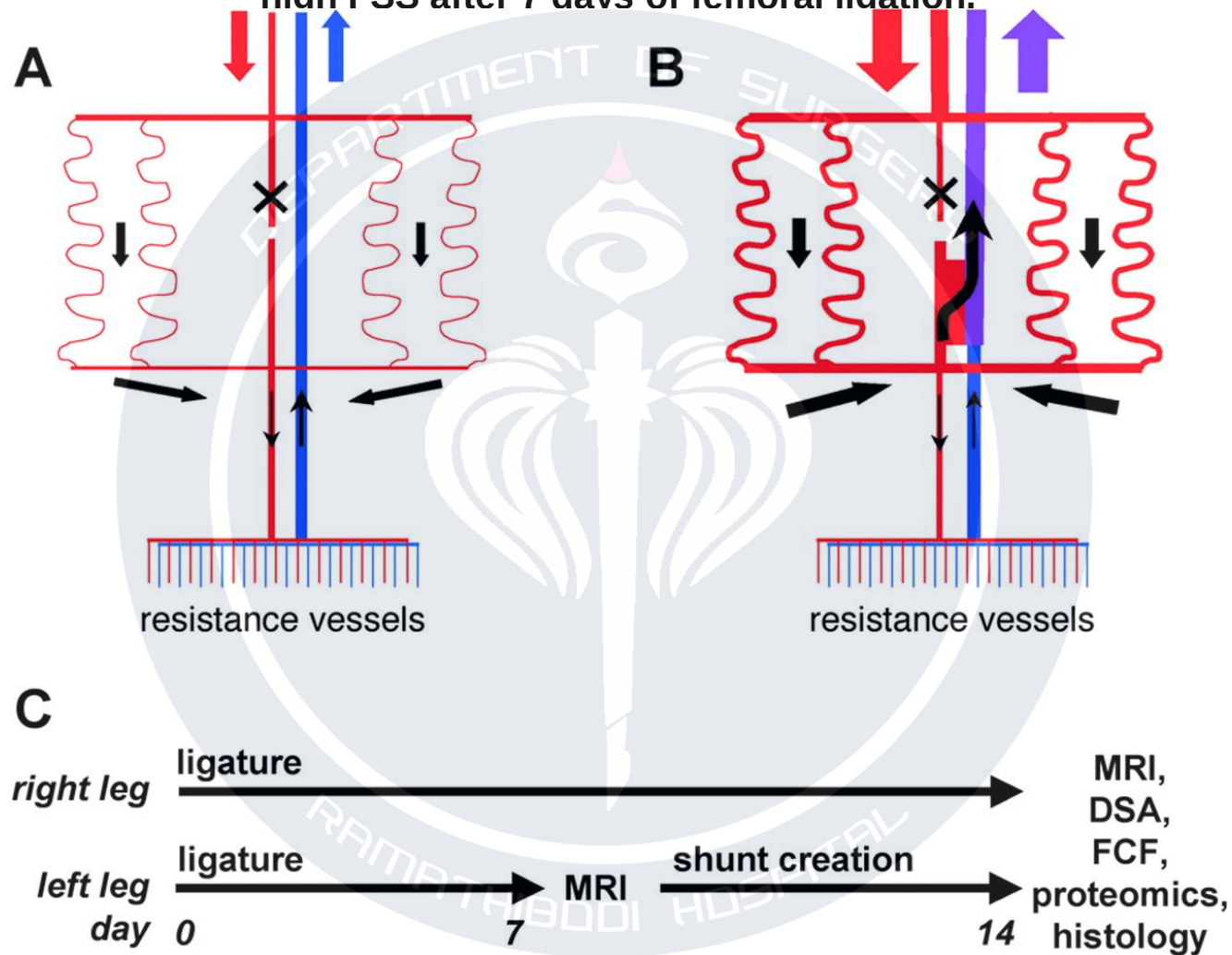


Figure 1. Schema presenting the hemodynamic situation after control ligation (A) or shunt ligation (B) and the experimental timetable (C) of this study, eg, the onset of shunt-related high FSS after 7 days of femoral ligation.



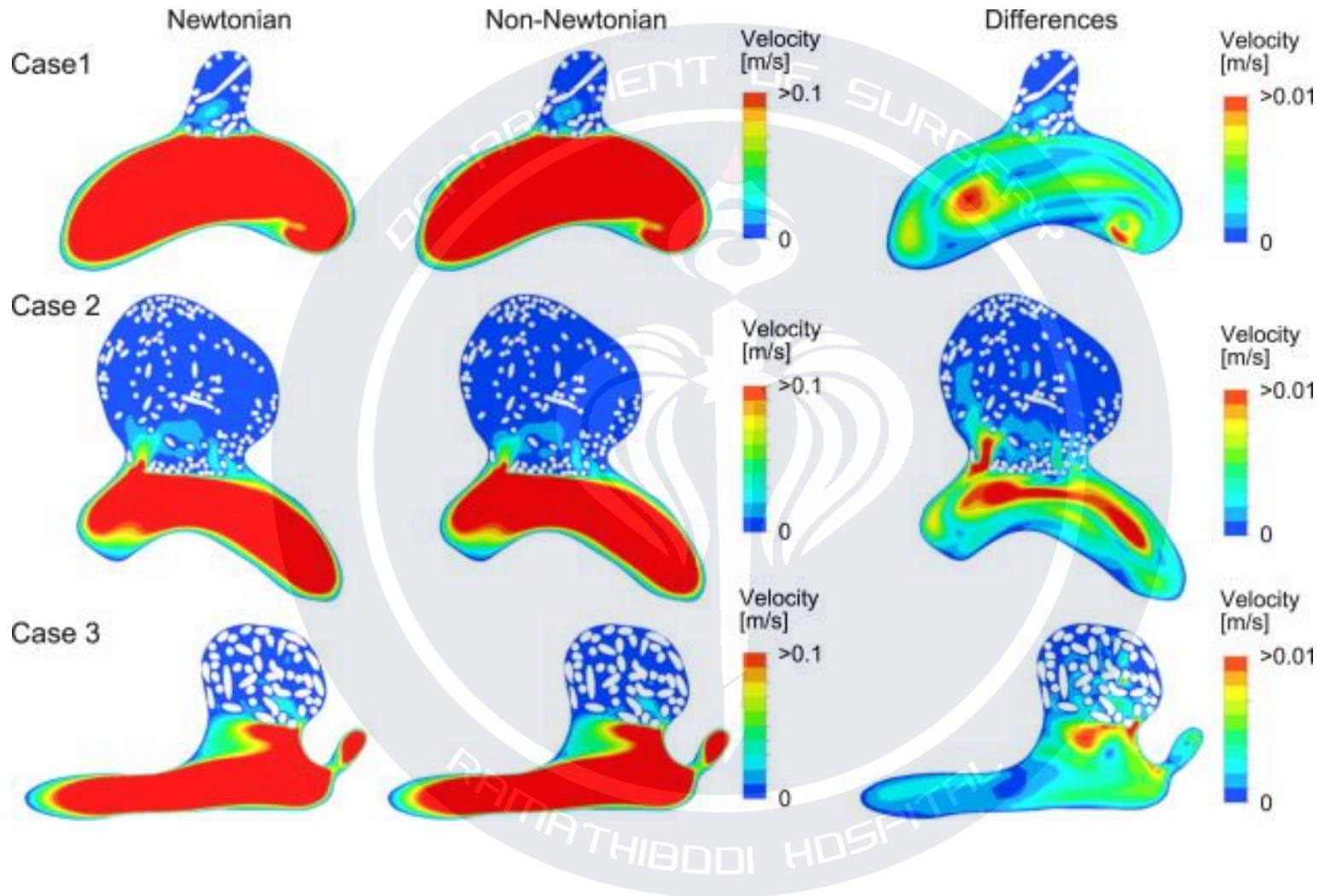
Frederic Pipp et al. Arterioscler Thromb Vasc Biol.
2004;24:1664-1668



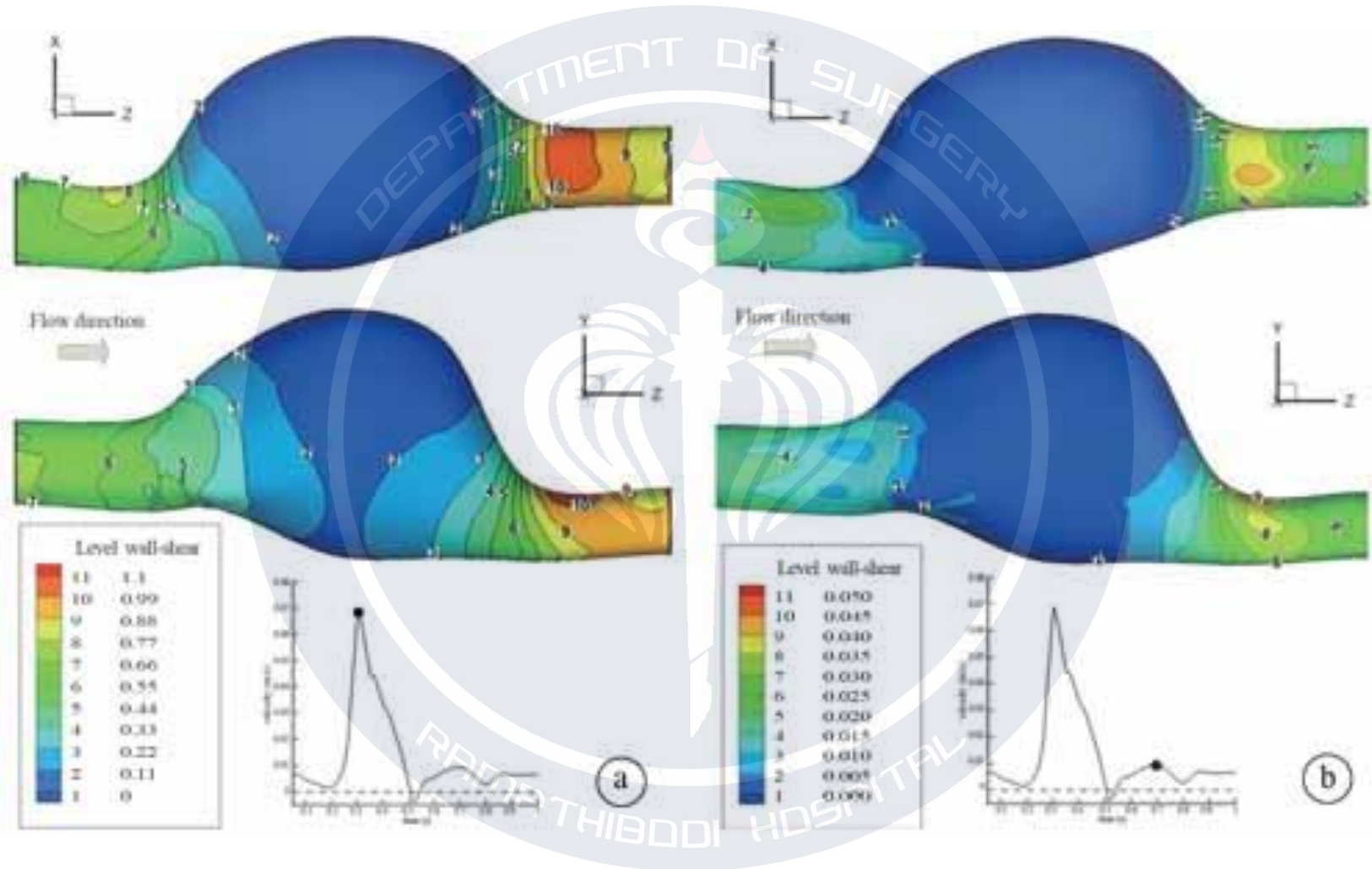
American
Heart
Association

Versus Physiology: รศ.ดร.เทพพนัส บุญผด้อย (02/04/67)

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Wall shear stress analyses of abdominal aortic aneurysm



Bernad et. al. 2009