Introduzione ai vasi

Arti Ahluwalia

Arti.ahluwalia@ing.unipi.it

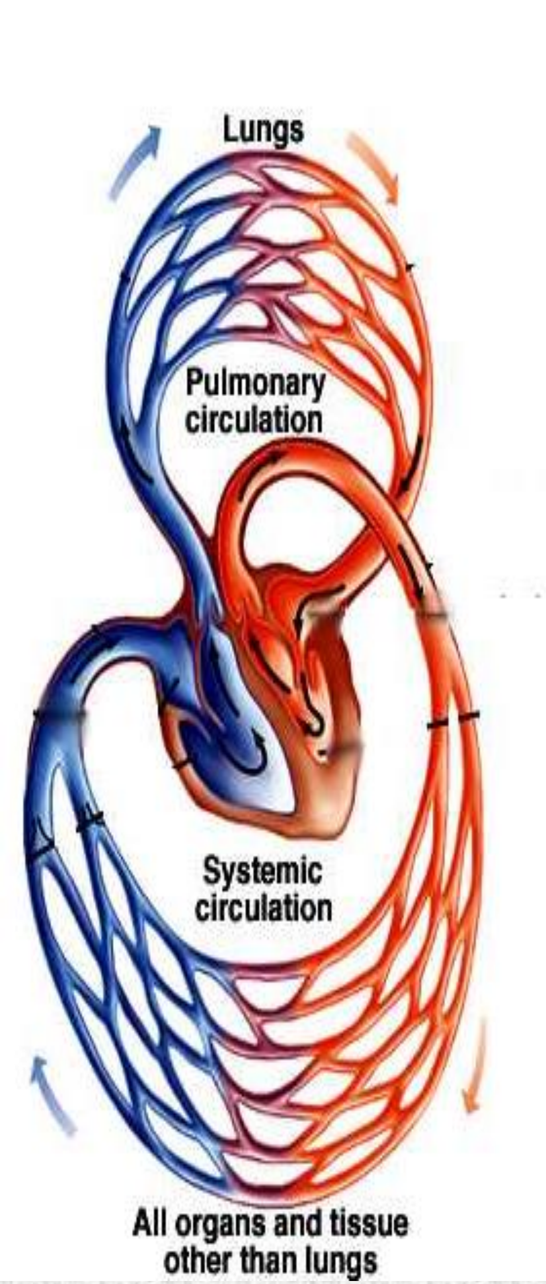
Address: Centro Interdipartimentale di Ricerca “E. Piaggio”, Facoltà di Ingegneria

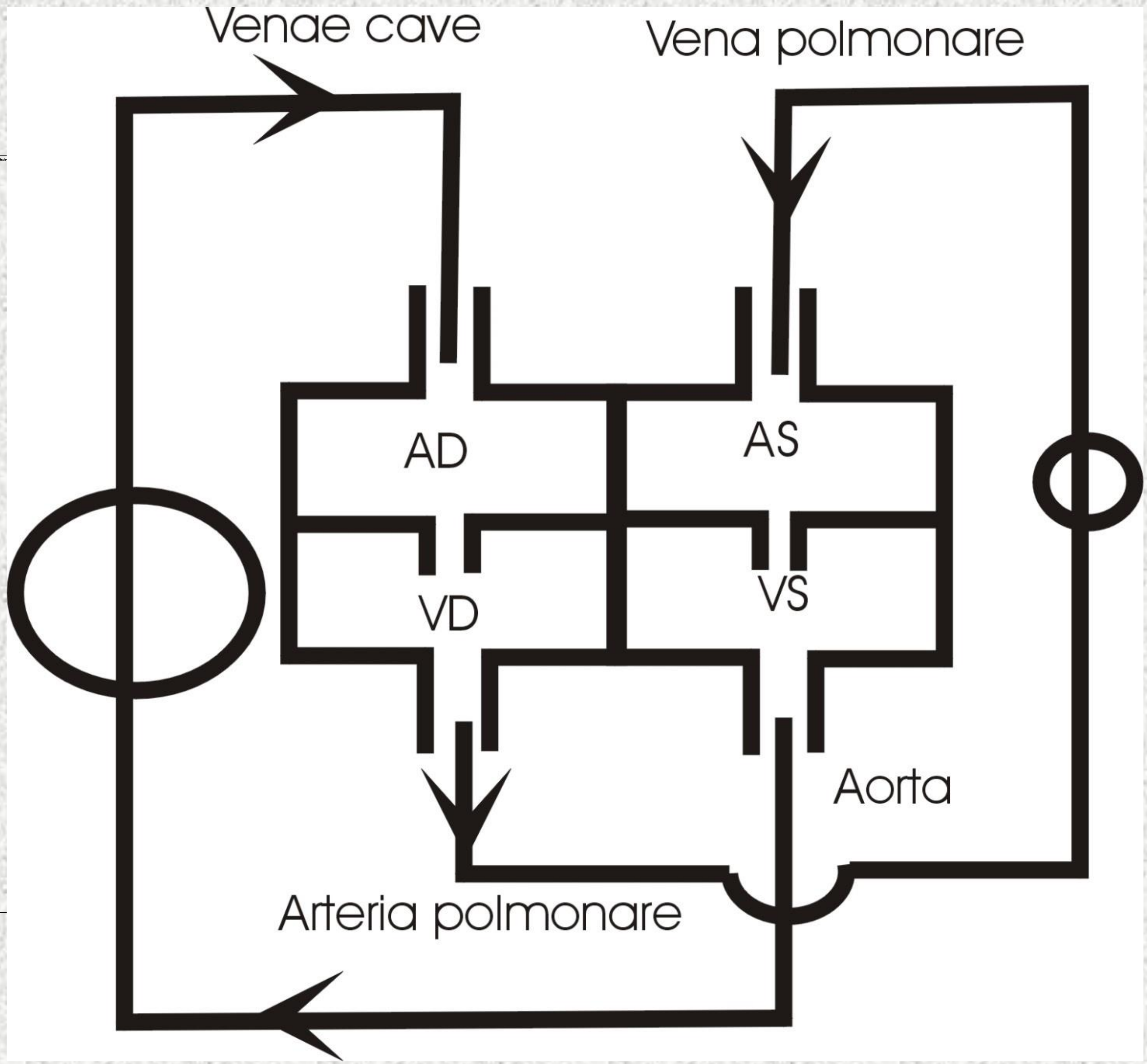
Sistema Cardiovascolare

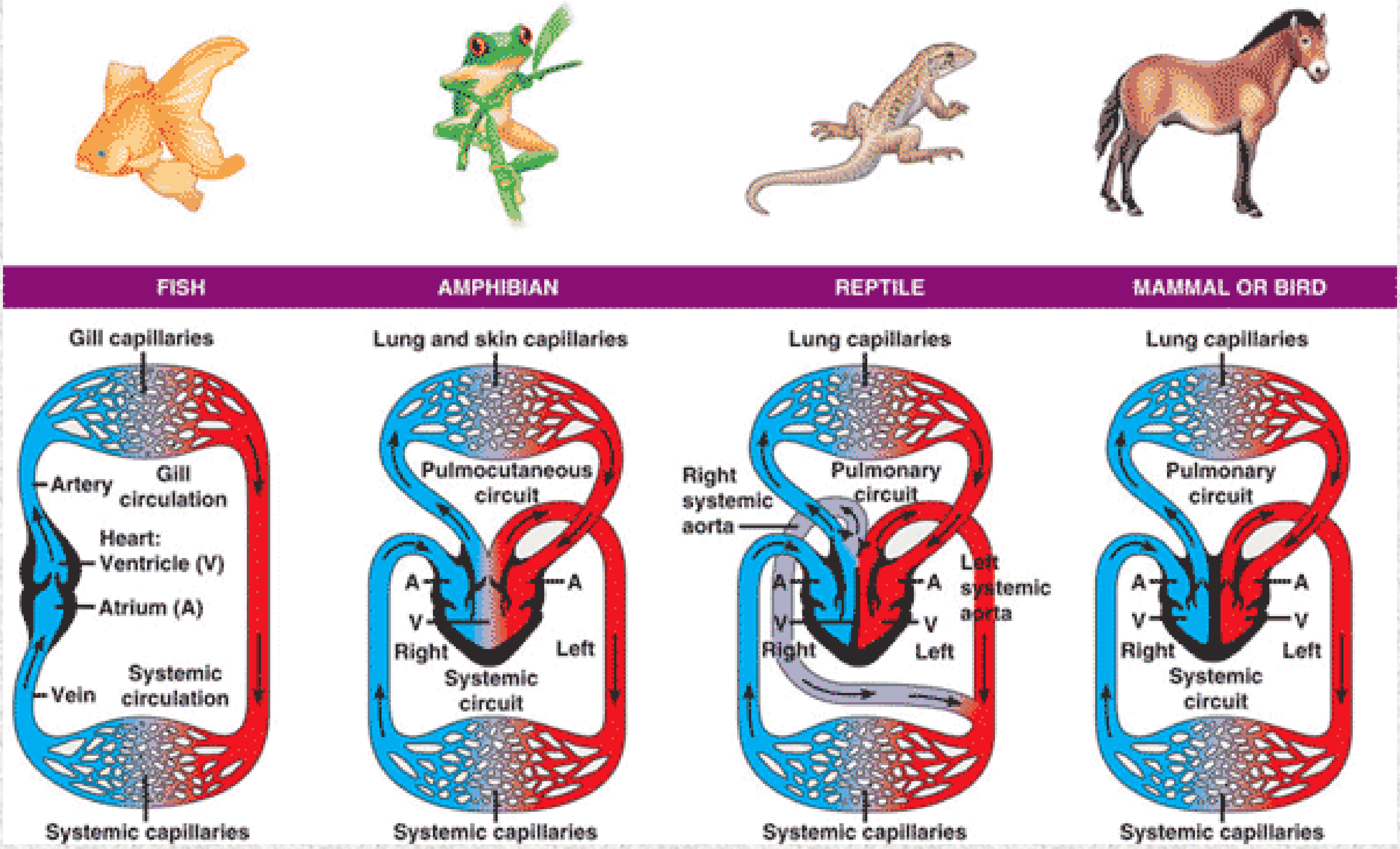
- I vasi sanguini formano un sistema chiuso che parte dal cuore
- E' un sistema di strutture dinamiche, che si dilatano, contraggono , pulsano e proliferano per adattarsi ai bisogni del corpo.
- La rete di distribuzione del sangue ha una lunghezza di circa 96,000 km

Funzioni

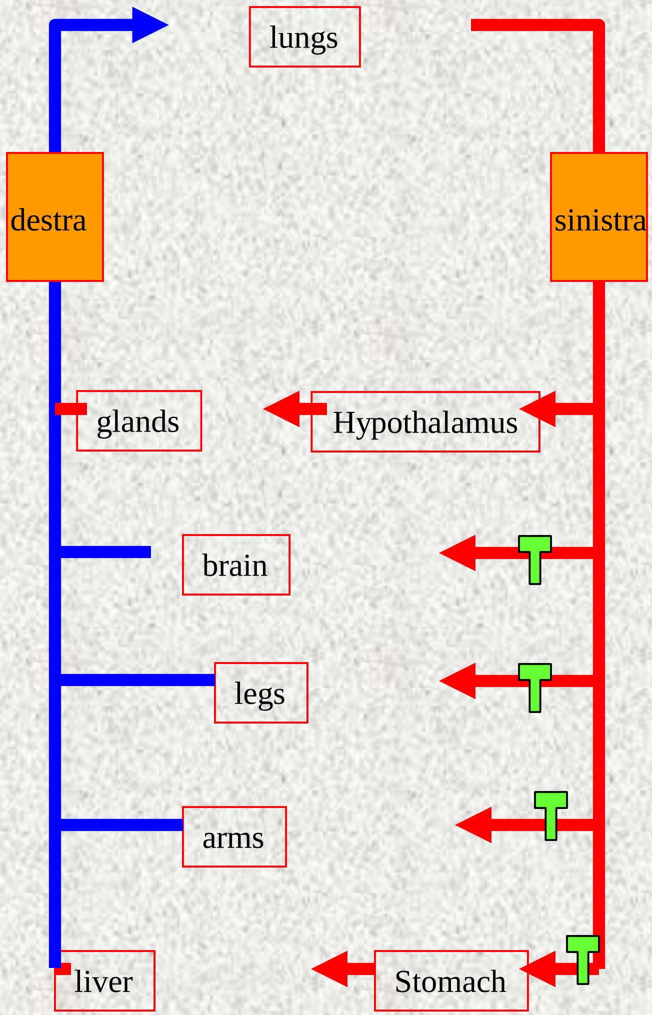
- Transporto
  - O_2 e CO_2
  - Nutrienti
  - Metaboliti
  - Ormoni
  - Calore
- Affidabilita'
  - Quanti battiti fa in una vita?
- Flessibilita'
  - Pompa puo' cambiare portata
  - Vasi possono cambiare direzione di flusso



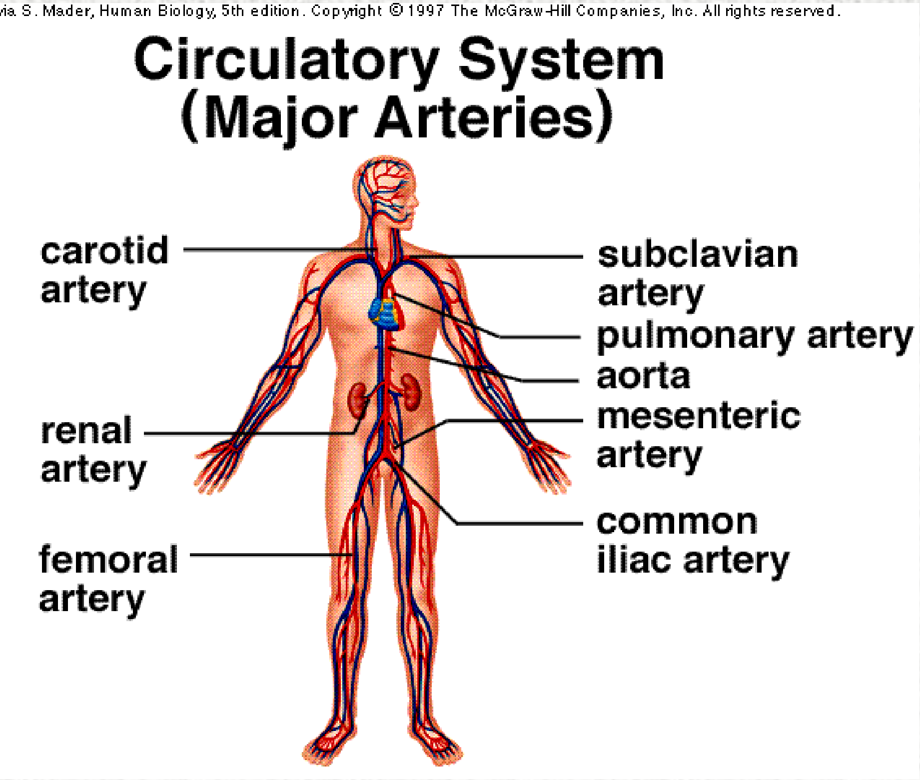

Venae cave
Vena polmonare
AD
AS
VD
VS
Aorta
Arteria polmonare


FISH
AMPHIBIAN
REPTILE
MAMMAL OR BIRD
Gill capillaries
Artery
Gill circulation
Heart:
Ventricle (V)
Atrium (A)
Vein
Systemic circulation
Systemic capillaries
Lung and skin capillaries
Pulmocutaneous circuit
A
A
V
Right
Left
Systemic circuit
Systemic capillaries
Lung capillaries
Right systemic aorta
Pulmonary circuit
Left systemic aorta
A
A
V
V
Right
Left
Systemic capillaries
Lung capillaries
Pulmonary circuit
A
A
V
V
Right
Left
Systemic circuit
Systemic capillaries

Struttura del sistema SCV



- Le pompe D e S, devono essere uguali in uscita
- I letti vascolari sono in parallelo
  - Tutti tessuti vengono ossigenati
  - In zone localizzate, il flusso puo essere ridirezionato
  - Il flusso può essere redirezionato attraverso vasocostrizione e vasodilatazione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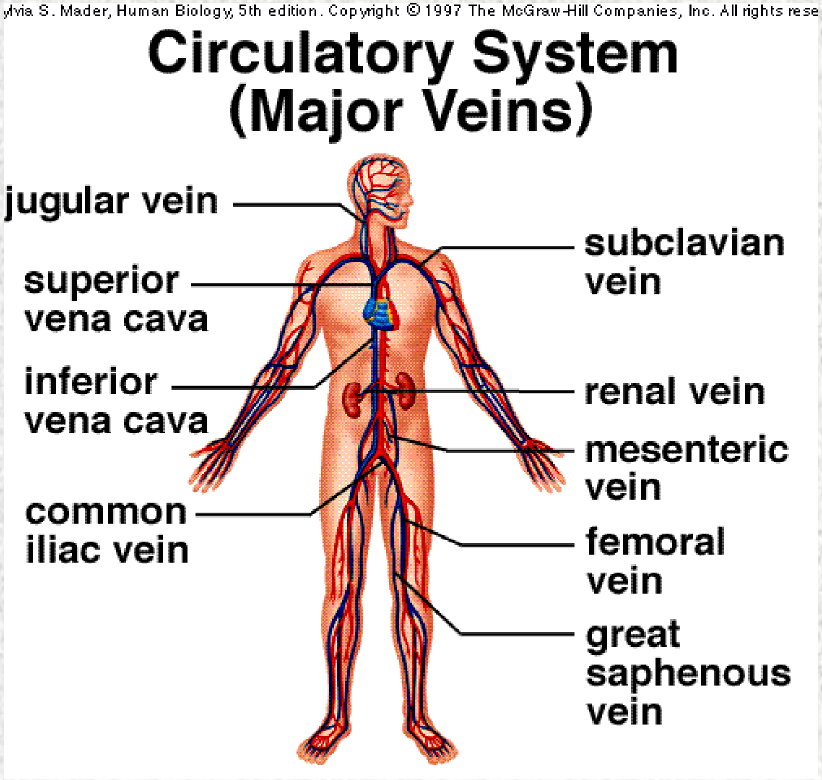
Circulatory System (Major Arteries)
carotid artery
renal artery
femoral artery
subclavian artery
pulmonary artery
aorta
mesenteric artery
common iliac artery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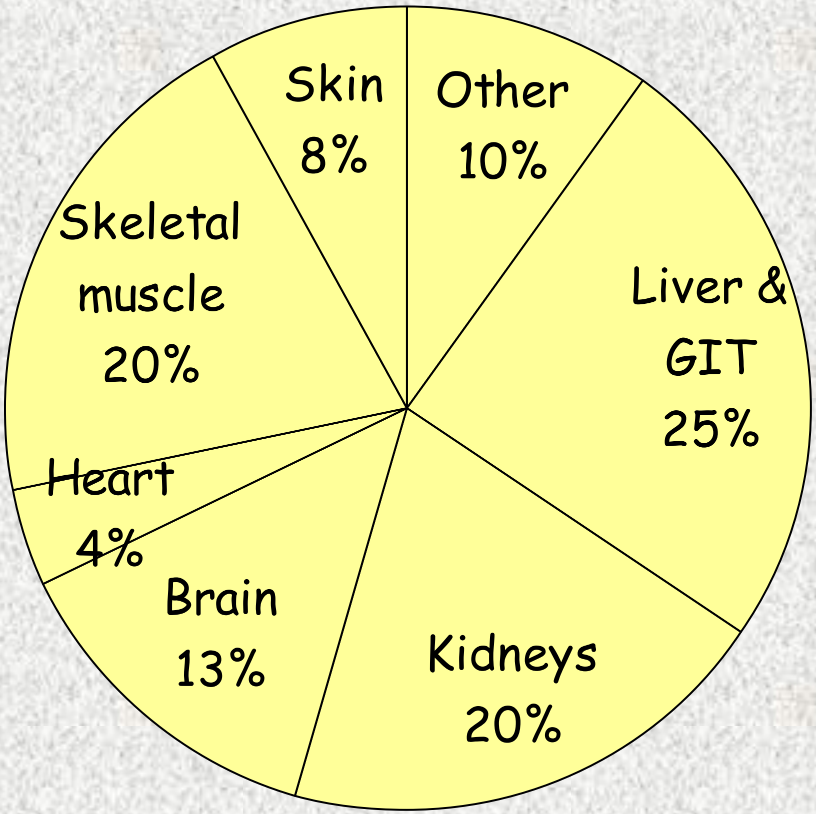
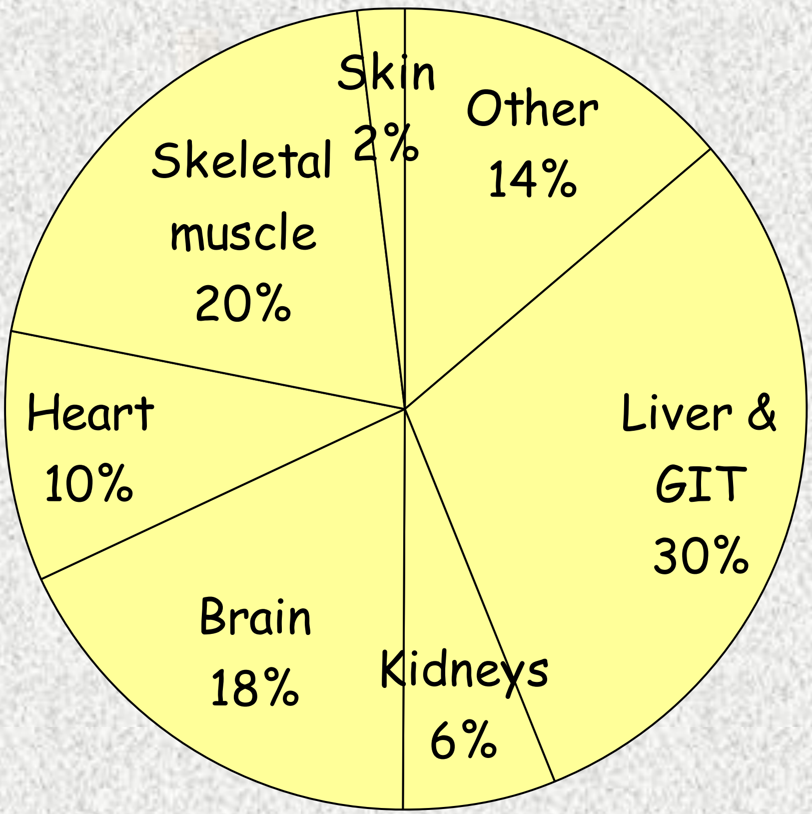
Circulatory System (Major Veins)
jugular vein
superior vena cava
inferior vena cava
common iliac vein
subclavian vein
renal vein
mesenteric vein
femoral vein
great saphenous vein

Uscita cardiaca



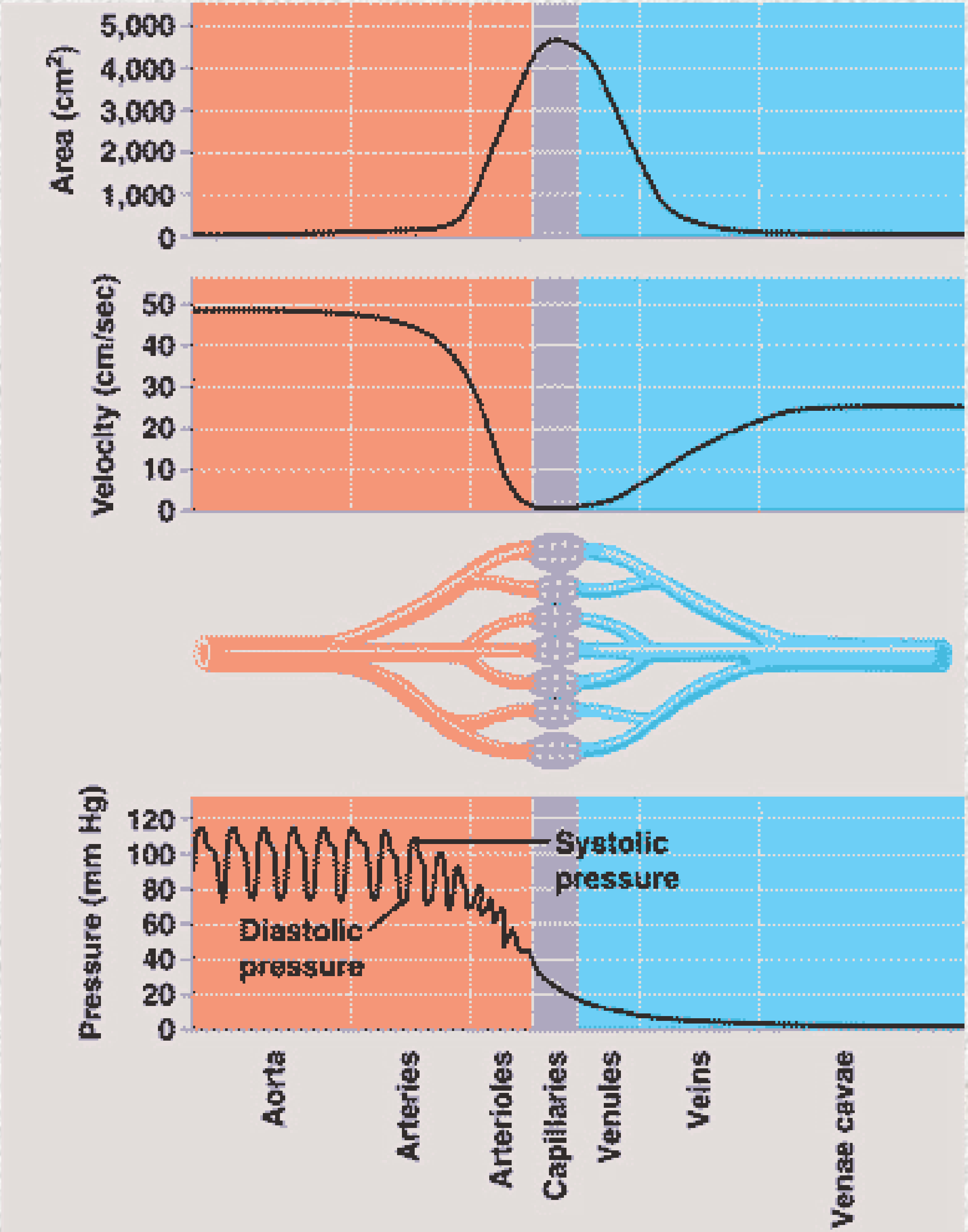
Consumo di O_2



Come viene ridirezionato l'uscita durante uno sforzo fisico?

Classificazione dei Vasi

- Arterie elastiche eg aorta
  - Lume grande, parete elastica
  - Per smorzare variazioni di pressione (perche?)
- Arterie Muscolari eg altre arterie
  - Lume grande, parete forte non- elastica
  - Condotto con bassa resistenza
- Vasi con resistenza eg arterioli
  - Lume piccolo, parete spessa e contrattile
  - Possono controllare resistenza e flusso
  - Permettano la ridirezione del sangue
- Vasi di scambio, eg capillaries
  - Lume piccolo, parete piccolo
- Vasi con elevata capacita' eg venule & vene
  - Lume grande, parete distensibile
  - Condotto di bassa resistenza



Area (cm^2)
5,000
4,000
3,000
2,000
1,000
0
Velocity (cm/sec)
50
40
30
20
10
0
Pressure (mm Hg)
120
100
80
60
40
20
0
Systolic pressure
Diastolic pressure
Aorta
Arteries
Arterioles
Capillaries
Venules
Veins
Venae cavae

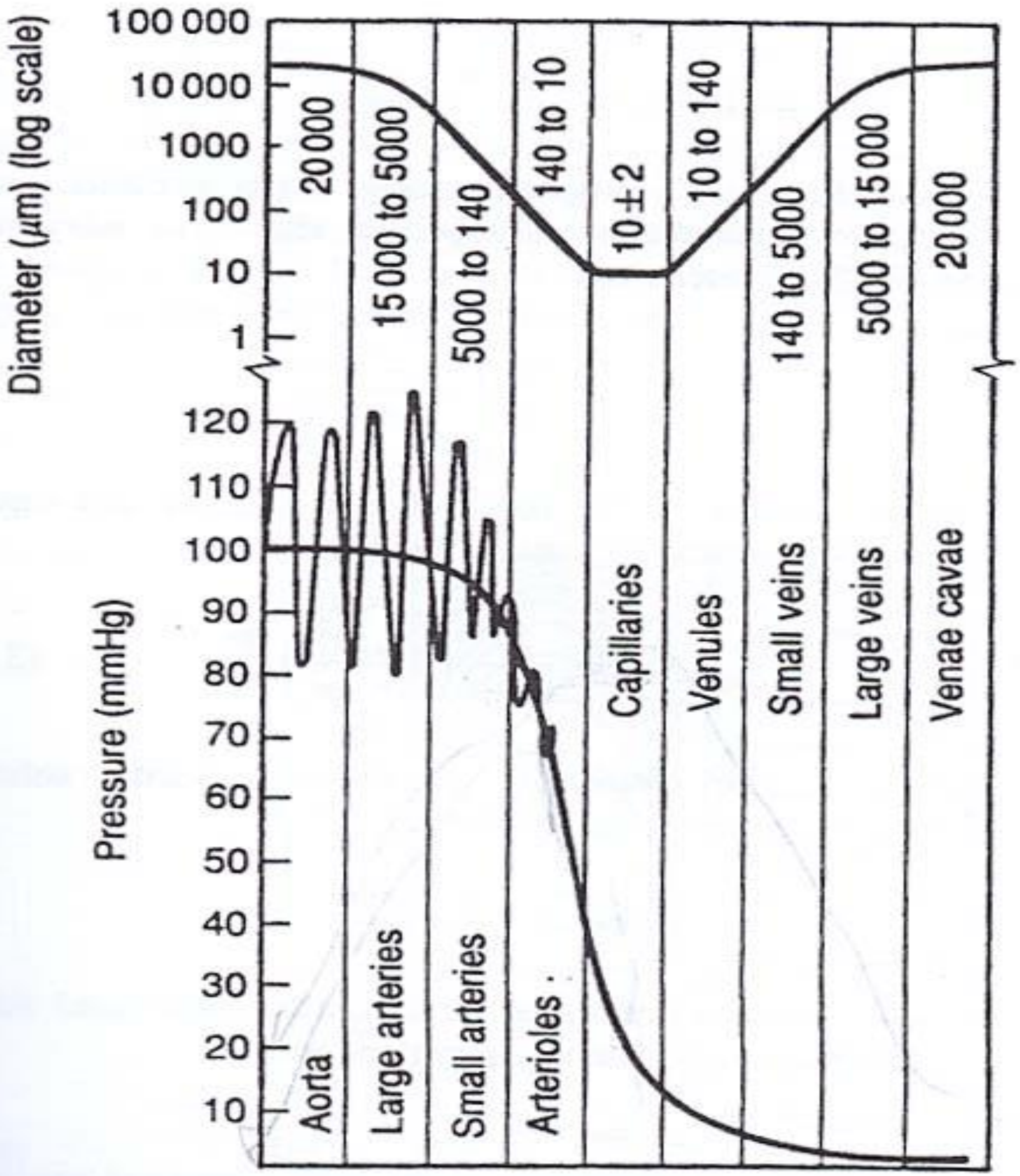


Fig. 3.4 Pressure variation in the systemic circulation.

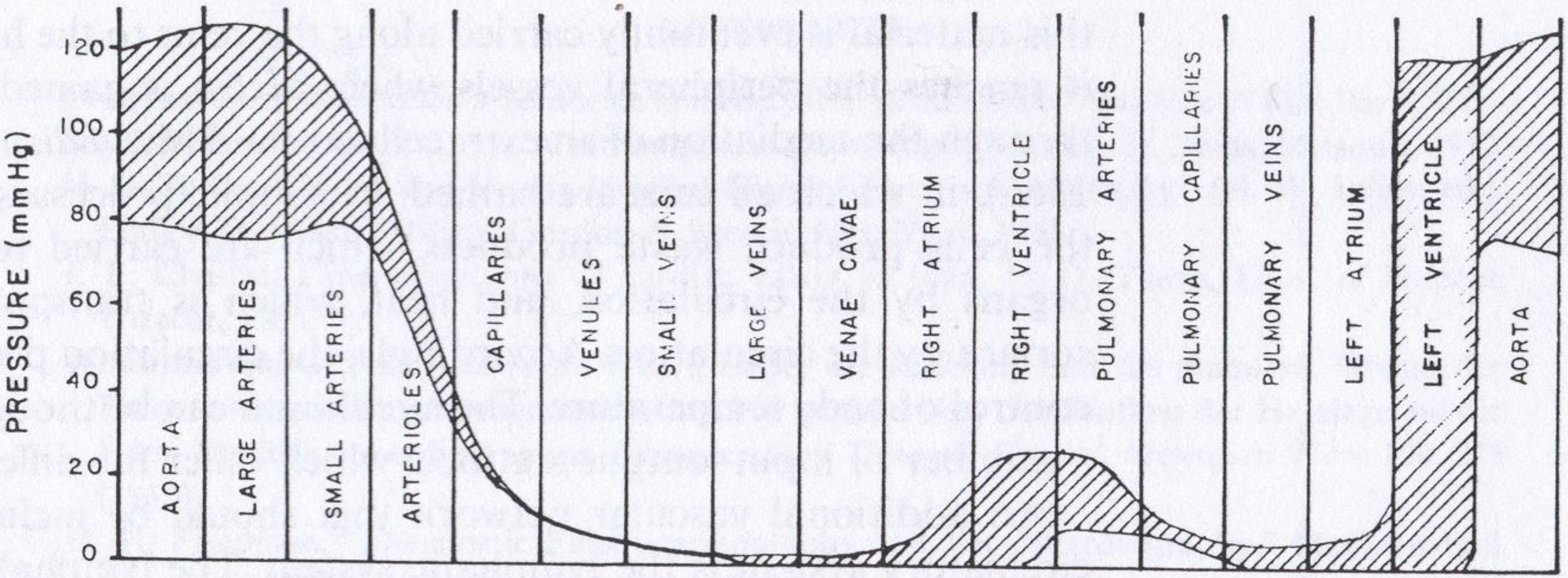
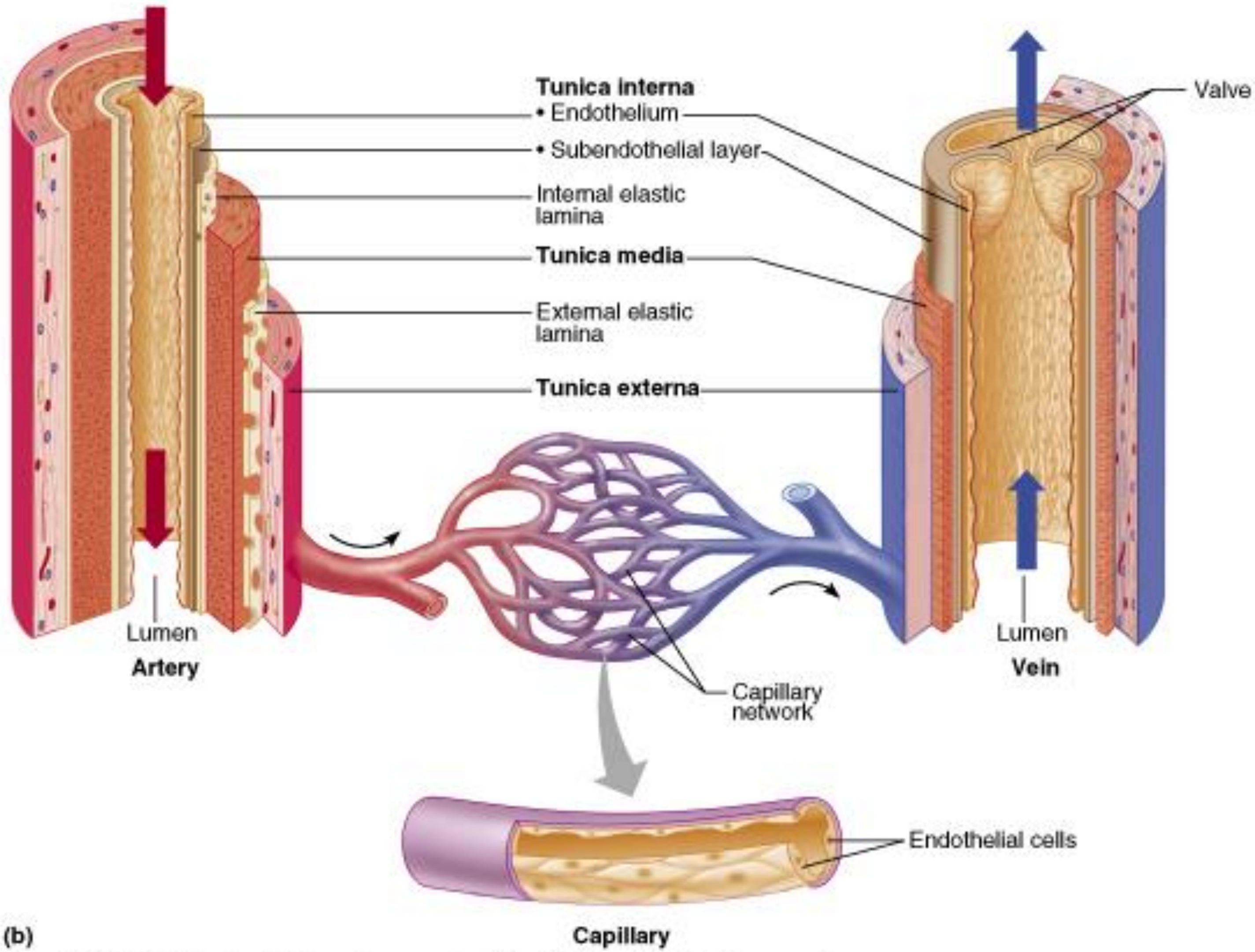


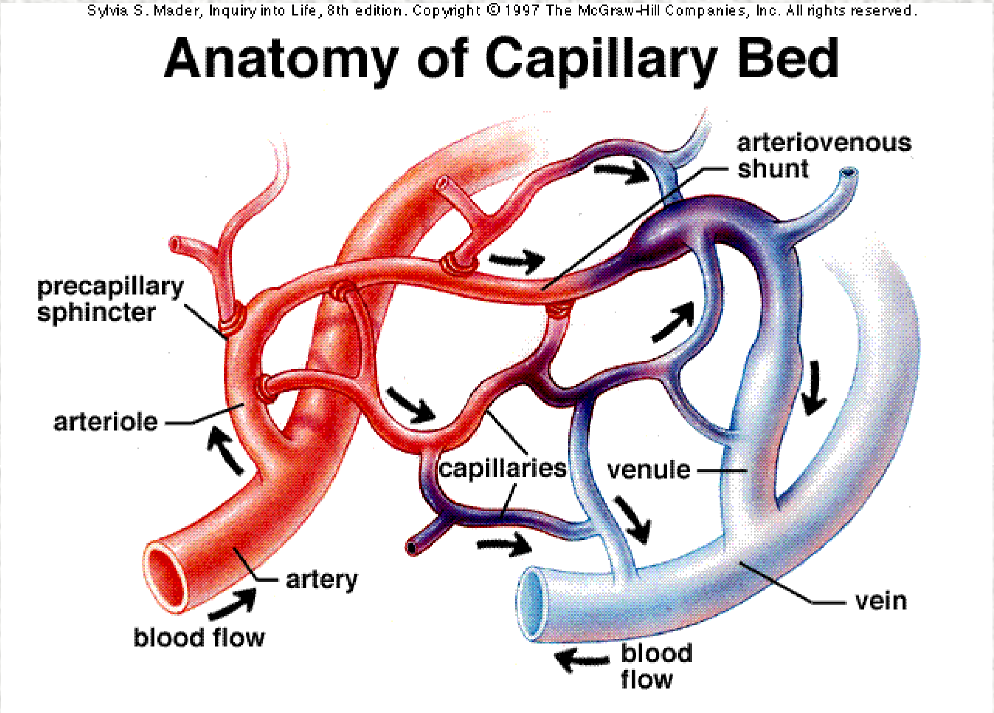
Fig. 1-8. Pressure levels, including oscillatory magnitudes, around the circuit.

Struttura dei vasi: 3 tipi

- Arterie
  - Elastiche, muscolari, arteriole
- Capillari
  - Sangue fluisce da arterioli a capillari
  - Lo scambio di O_2 occore tra le pareti
  - Poi dai capillari passa al sistema venoso.
- Vene (hanno valvole)
  - Venule, vene piccole, medie o grandi


Tunica interna
• Endothelium
• Subendothelial layer
Internal elastic lamina
Tunica media
External elastic lamina
Tunica externa
Valve
Lumen
Artery
Lumen
Vein
Capillary network
Endothelial cells
(b)
Capillary

- La rete parte con arterie → arterioli → capillari → venule → vene
- Solo i capillari vengono in contatto intimo con cellule e tessuti



Grandezza e Composizione

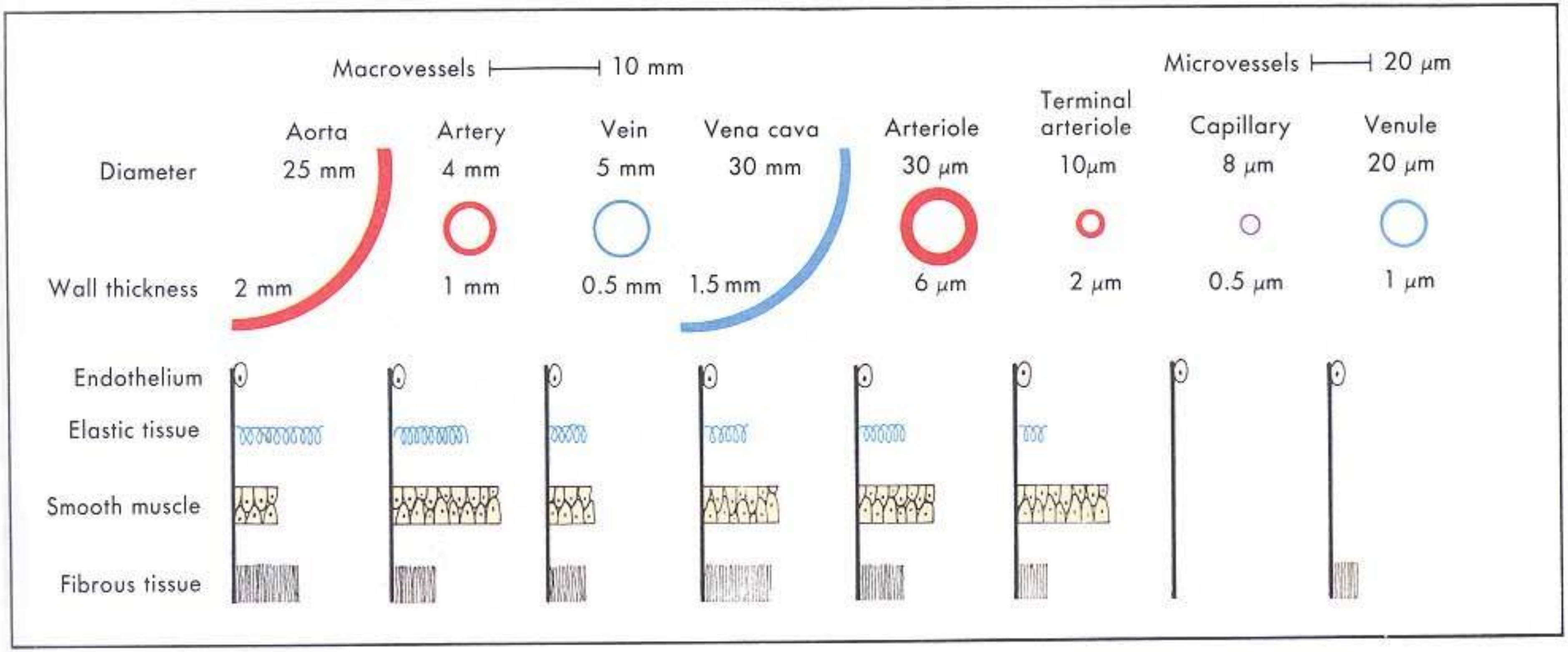


FIGURE 15-1 Internal diameter, wall thickness, and relative amounts of the principal components of the vessel walls of the various blood vessels that compose the circulatory system. Cross sections of the vessels are not drawn to scale because of the huge range from aorta and venae cavae to capillary. (Redrawn from Burton AC: Physiol Rev 34:619, 1954.)

Table 3.1. Some properties of the circulation and blood

Number of red blood cells (mm^{-3})	5×10^6	Specific gravity	1.06
Number of white blood cells (mm^{-3})	10^4	Heart rate (min^{-1})	60–70
Blood volume (L)	5–6	Cardiac output ($L\ min^{-1}$)	5–6
Viscosity of whole blood (mPa s; cP)	3–4*	Stroke volume (mL)	70

Vessels	Diameter (mm)	Length (cm)	Wall thickness (mm)	Contained volume (cm^3 or mL)	Mean pressure (mmHg)	Average velocity ($cm\ s^{-1}$)	Reynolds number	
							Average	Maximum
Aorta	25.0	40.0	2.0	100	100(av.)	40(av.)	3000	8500
Arteries	15–0.15	15.0	0.8	350	90(av.)	40–10	500	1000
Arterioles	0.14–0.01	0.2	0.02	50	60	10–0.1	0.7	—
Capillaries	0.008	0.05	0.001	300	30–20	<0.1	0.002	—
Venules	0.01–0.14	0.2	0.002	300	20	<0.3	0.01	—
Veins	0.15–15	18.0	0.6	2500	15–10	0.3–5	150	—
Vena cava	30.0	40.0	1.5	300	10–5	5–30	3000	—

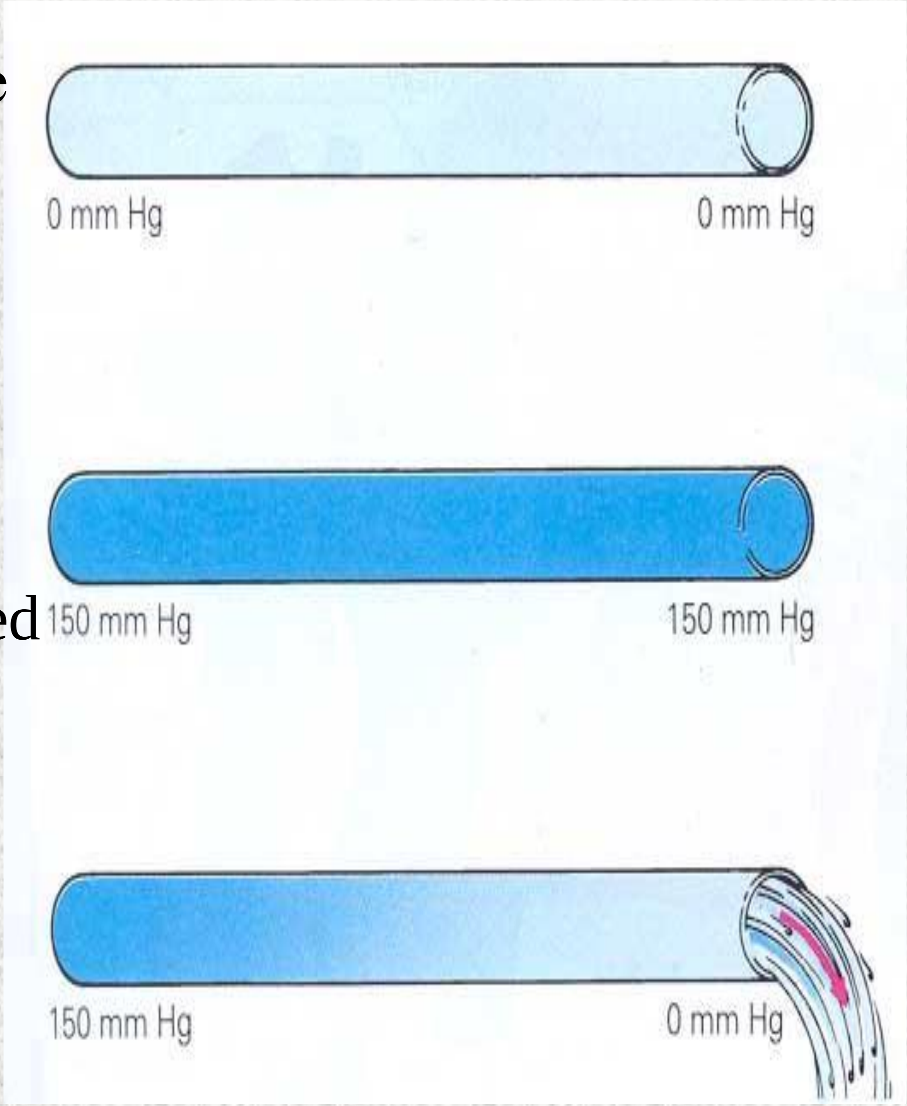
Rapporto tra flusso e pressione

Flusso (Q) e' il volume che pass per secondo

$$\dot{Q} = \frac{\Delta Q}{\Delta t}$$

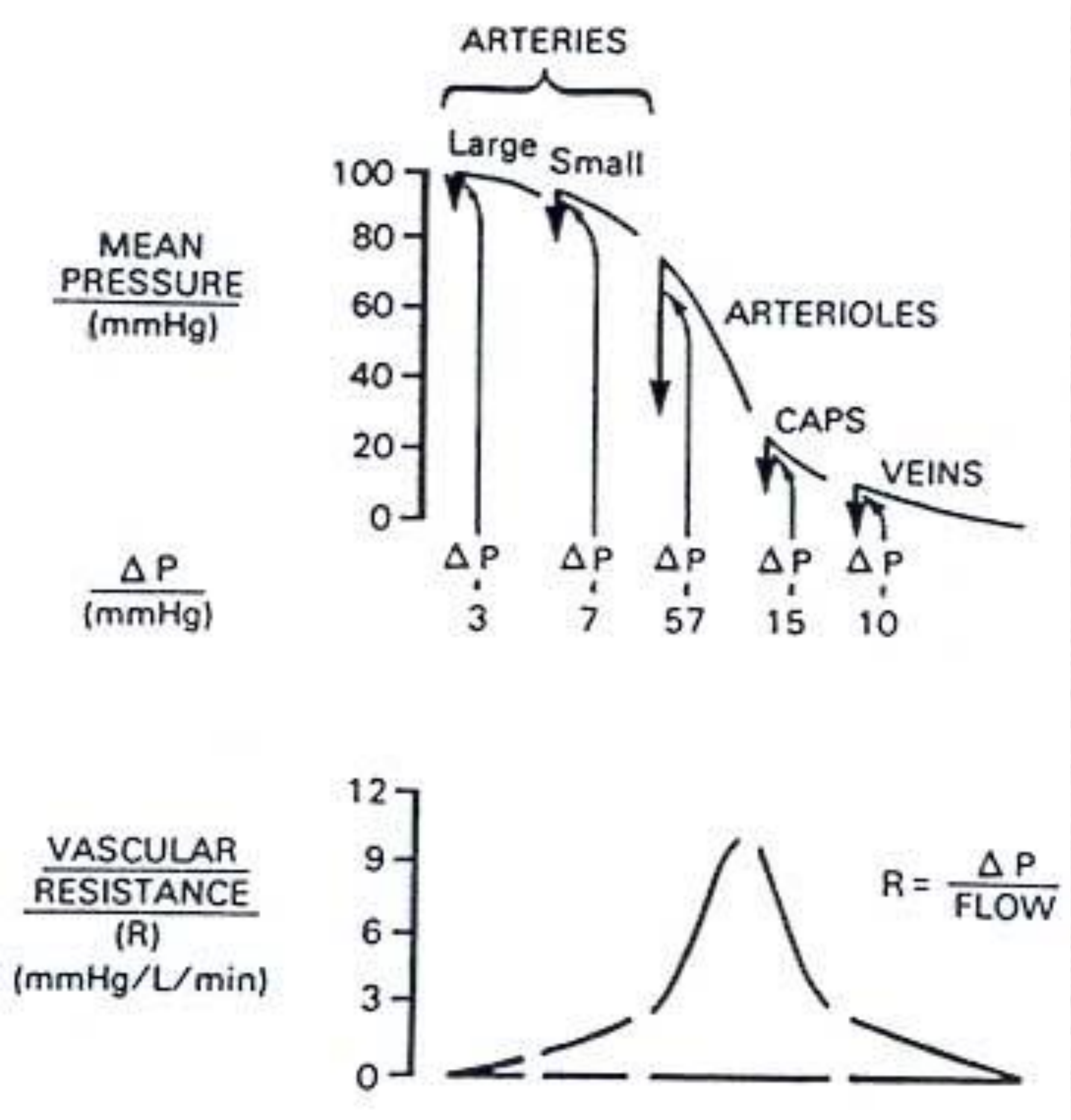
Il flusso nel sistema CVS e' dovuto alla differenza di pressione tra arterie e vene, ed e' proporzionale alla differenza di pressione.

$$\dot{Q} = \frac{P_a - P_v}{R}$$



R è la resistenza vascolare

Resistenza lungo il sistema vascolare



La resistenza e' massima nelle arteriole.

La resistenza totale e' controllata dalle arteriole.

Le arteriole controllono la perfusione attraverso gli organi e la distribuzione del uscita' cardiaca. Come?

Mechanical Properties of Blood Vessels

Blood vessels are composed of a variety of materials, principally collagen and elastin. The stress strain curve can be modeled quite well using the recruitment model.

The mechanical properties arise from the orientation of the proteins and cells in the various layers, their interaction, not possible to reproduce with synthetic materials

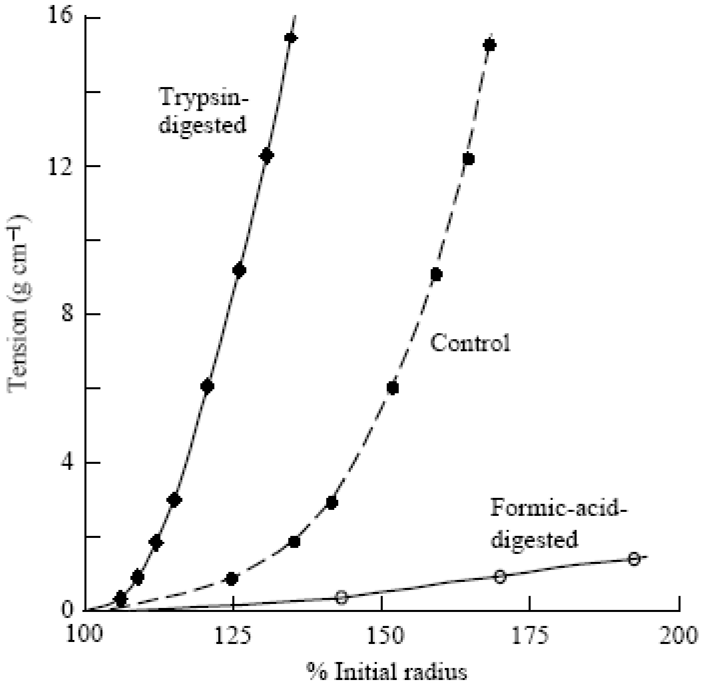
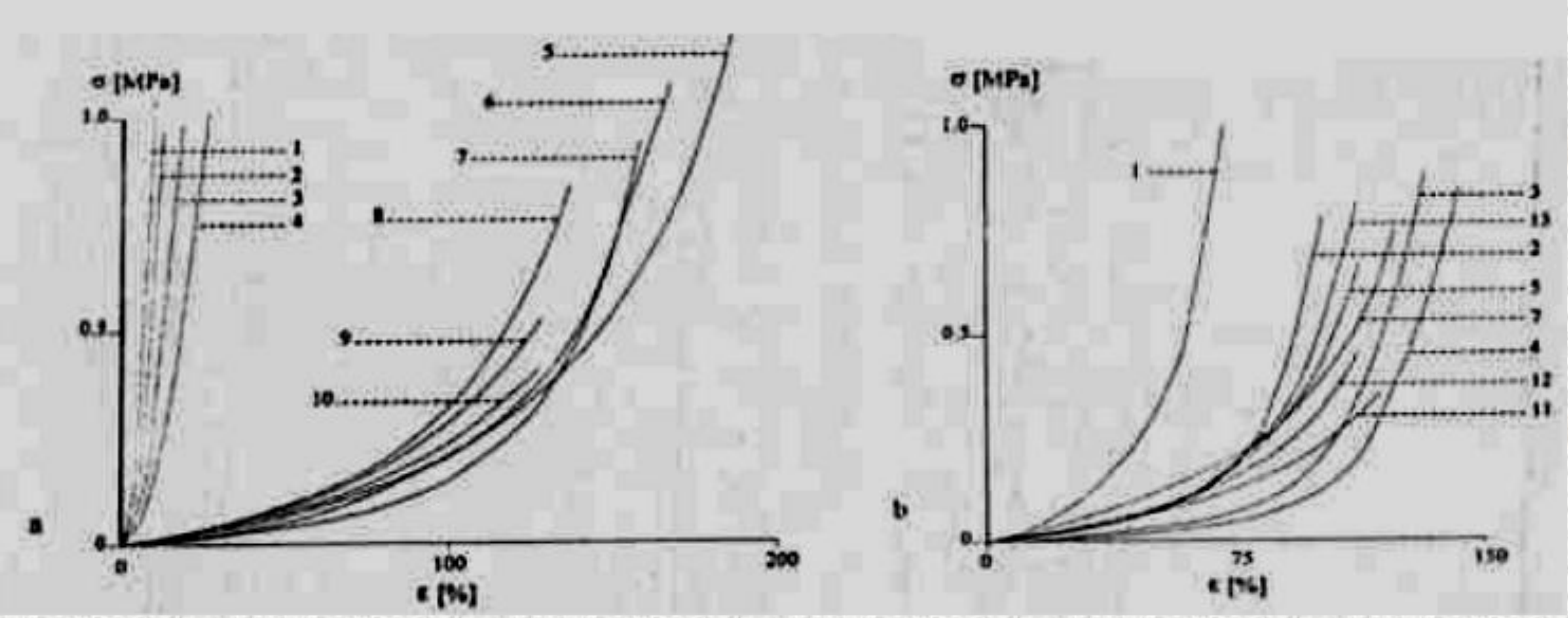


Fig. 4. The contributions of elastin and collagen to the tension–length response of human iliac arteries. When elastin is removed by trypsin digestion, the curve (diamonds) represents the properties of the remaining collagen. Alternatively, when collagen is removed by formic acid digestion, the curve (open circles) represents the properties of the elastin fibres. The broken curve (filled circles) is for an untreated artery (redrawn from Roach and Burton, 1957).



Blood vessels are highly anisotropic: Left: Stress strian in the circumferential direction, Right: longitudinal 1: prosthesis in PET woven, 2: woven PTFE 3: knitted PET a; 4: PTFE knitted; 5. iliac artery; 6: aorta
Distal abdominal artery 7: femoral artery; 8: abdominal artery , others

Qunidi resistenza vascolare è $$R = \frac{dp}{Q} = \frac{8\mu L}{\pi a^4}$$

Un piccolo cambiamento in a cambia molto la resistenza al flusso. Questo è la base di vasodilatazione e vasocostrizione. Quindi l'ipertensione puo essere ridotto usando farmaci che rilassano i muscoli, diminuendo la viscosità del sangue o riducendo la quantità di sale (perche?)

E' utile misurare la resistenza vascolare, ma non

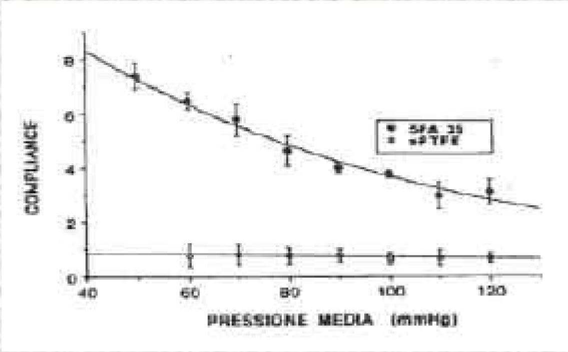
- Indica il luogo della costrizione or dilatzione
- Indica la causa
- Informazione è netta non locale
- Non è capace di distinguere tra formazone di nuovi vasi, dilatazione o emorragia

Characterisation of vascular grafts and vessels

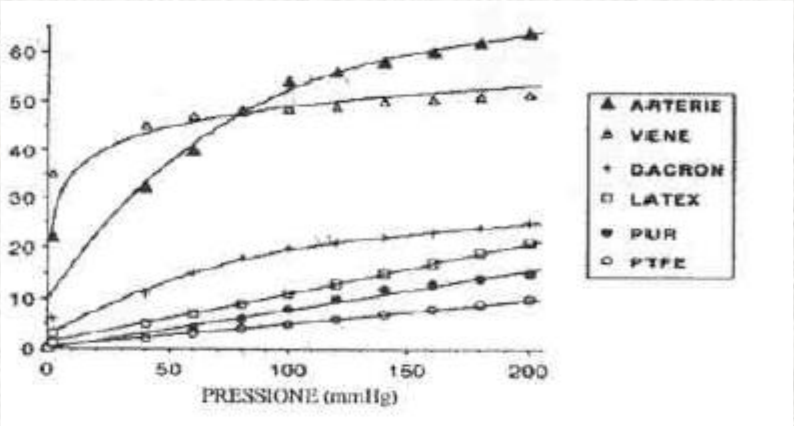
The most important parameters to consider are permeability, porosity, compliance, tensile strenghth, burst strength and durability.

Compliance is a measure of radial distensibility of a vessel, and is the parameter which is most difficult to reproduce in synthetic materials.

Dacron	Permeabilità [ml/min*cm^2]	Precoagulazione
Protesi a rete	50÷200	No
Protesi a maglia	2000 (media)	Sì
Protesi con velour	1300 (uniforme)	Sì

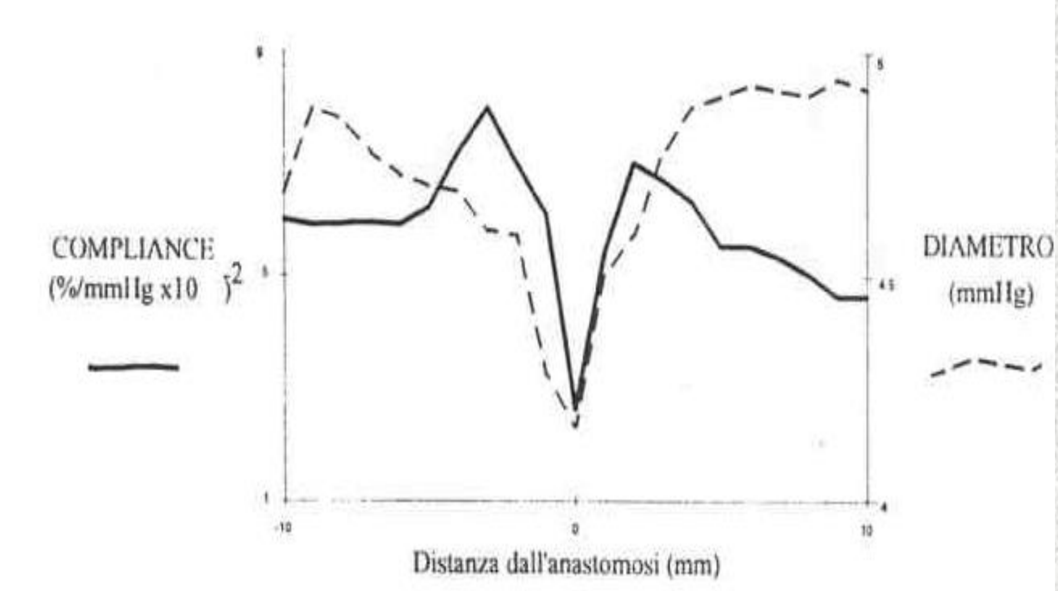


$$\frac{\Delta d}{d}\%$$



Supponendo che abbiano lo stesso modulo elastico, stimare lo sforzo sulla parete dei seguent vasi. Spiegare il significato del segno ottenuto.

Vaso	**Diametro interno**	**Diametro esterno**	**Pressione**
Aorta		3.2 cm	120 mmHg
Arteriola	1 mm	1.1mm	39 mmHg
Vena	1 cm	1.1 cm	3 mmHg



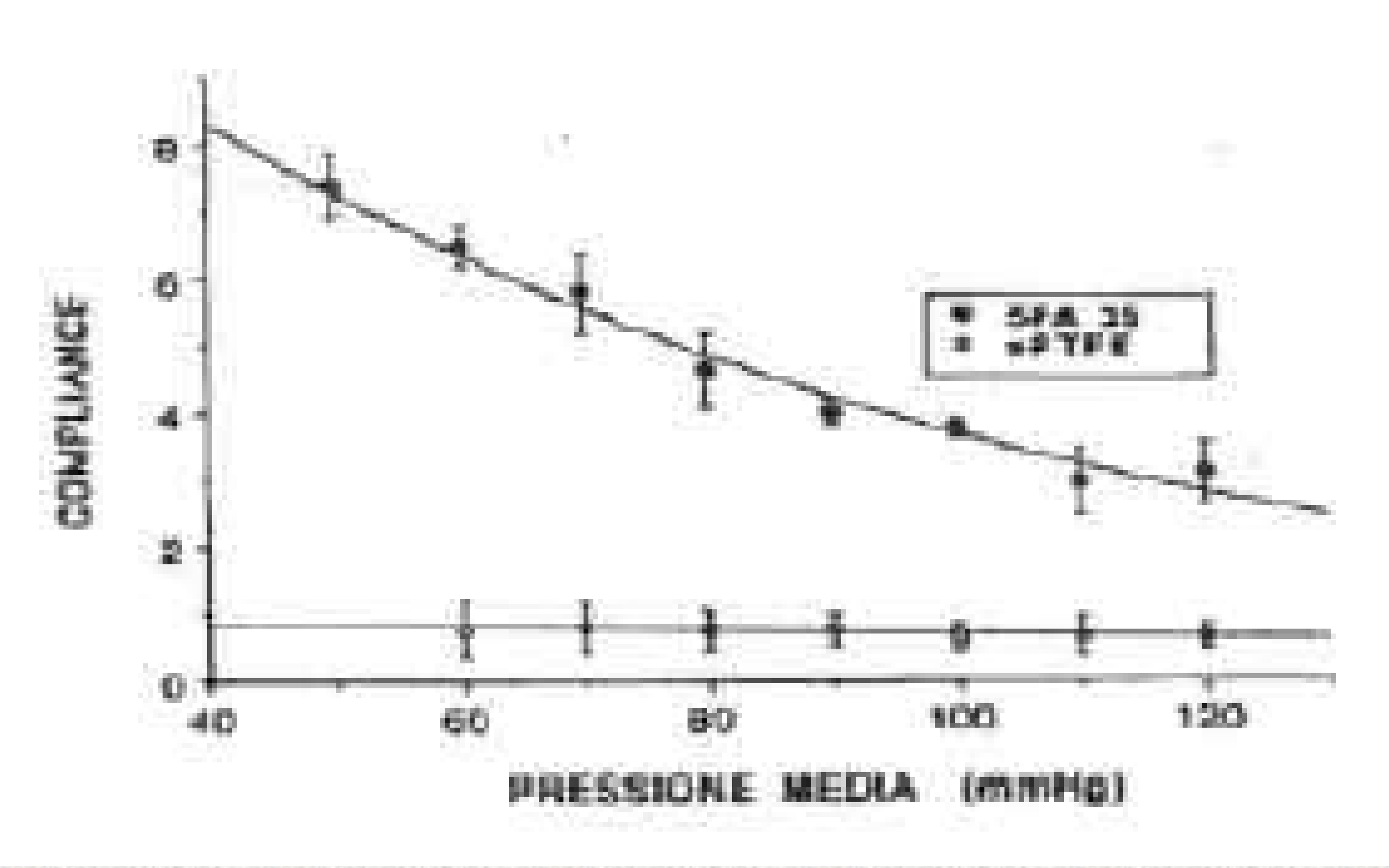
Compliance mismatch at a suture is a major problem in synthetic vessels. It results in:

- Turbulence : no neo intima formed and damage of suture (weakest point)
- Synthetic vessel cannot absorb pressure pulses
- Increase in resistance: heart works harder

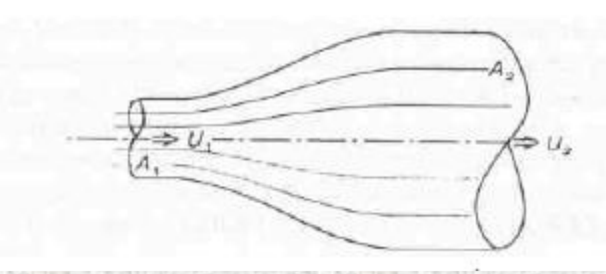
Compliance values at 100 mmHg (%*10/100 mmHg)

DACRON woven	1.97
DACRON coated with gelatin	0.9
DACRON knitted	0.8
ePTFE standard wall	0.2

Compare with blood vessel


COMPLIANCE
8
6
4
2
0
40
60
80
100
120
PRESSIONE MEDIA (mmHg)

Other aspects to discuss: application of Bernoulli to stenosis and aneurism



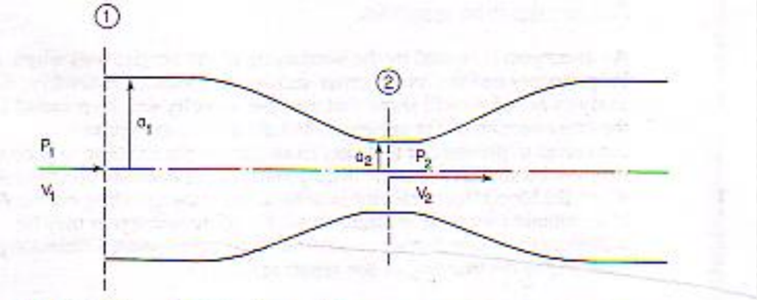
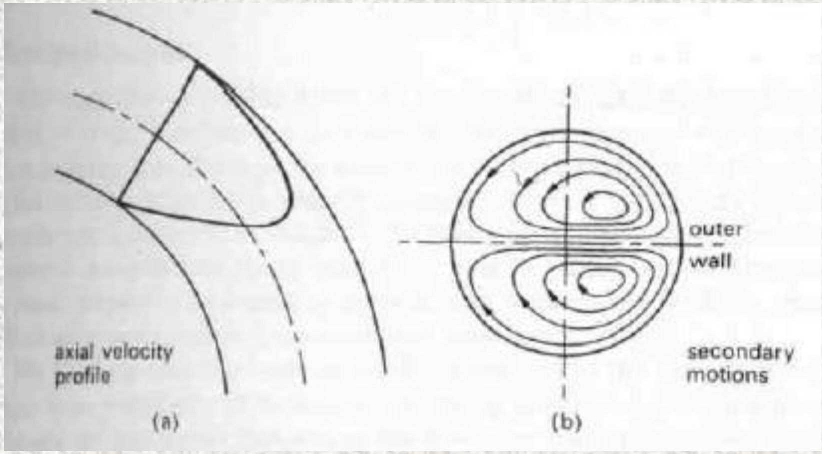
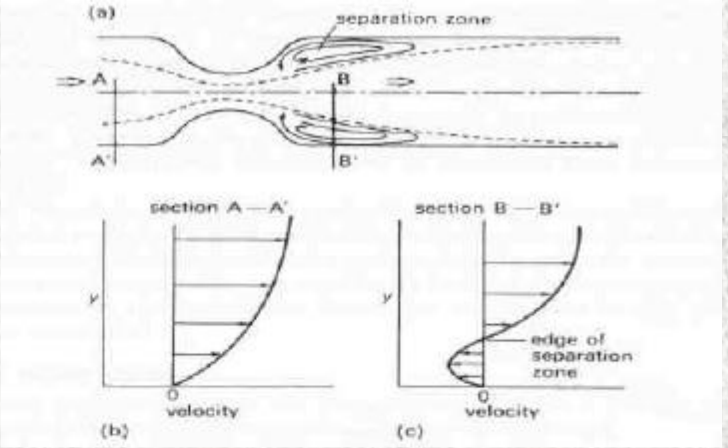
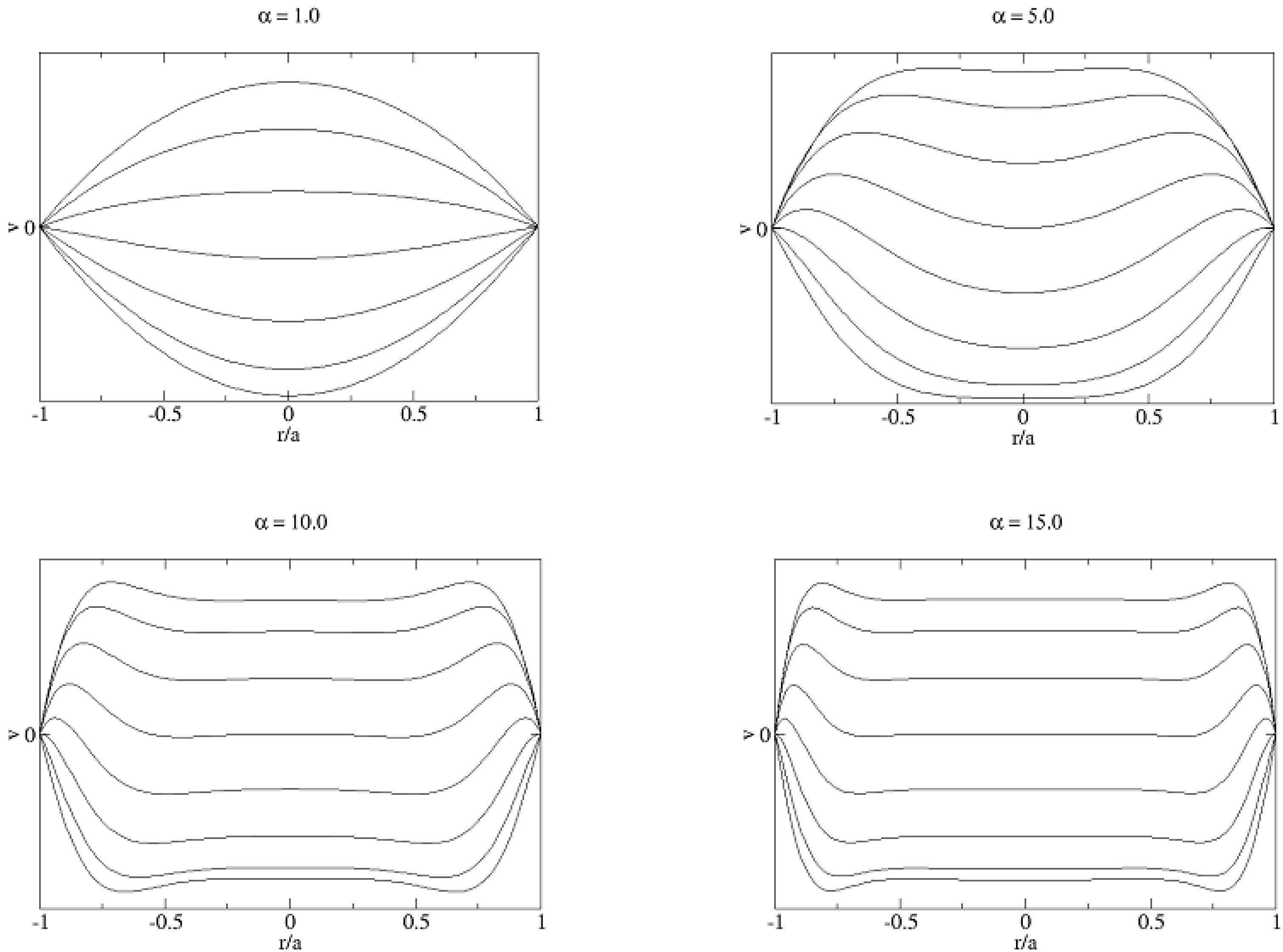


Figure 4.4 Application of Bernoulli equation to an arterial stenosis.

Flow with radius of curvature and flow separation






α = 1.0
α = 5.0
α = 10.0
α = 15.0
v 0
-1
-0.5
0
0.5
1
r/a

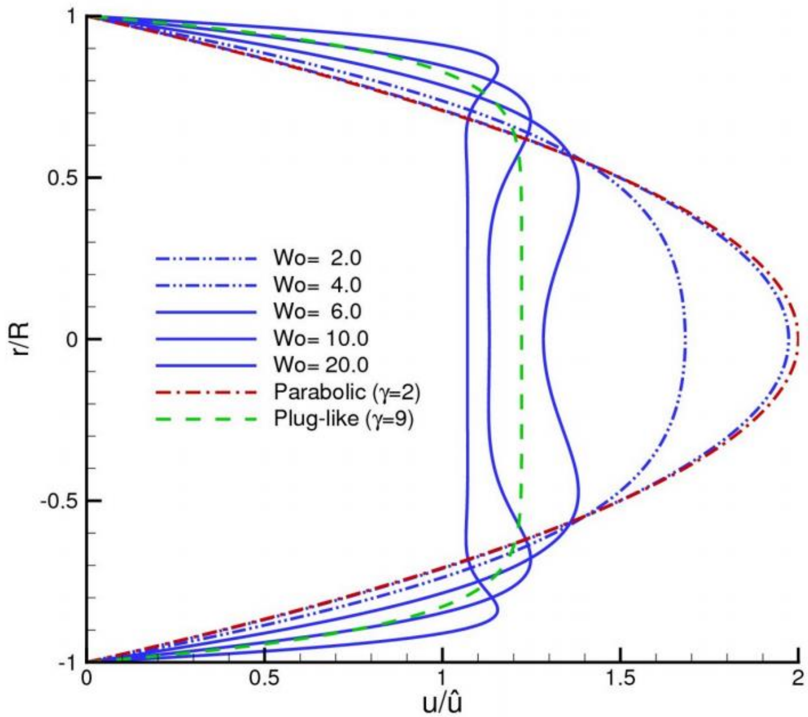
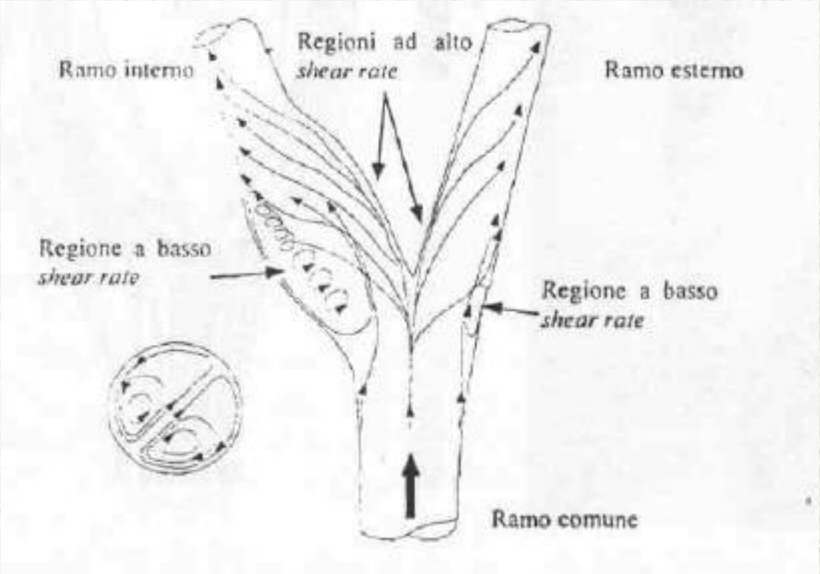
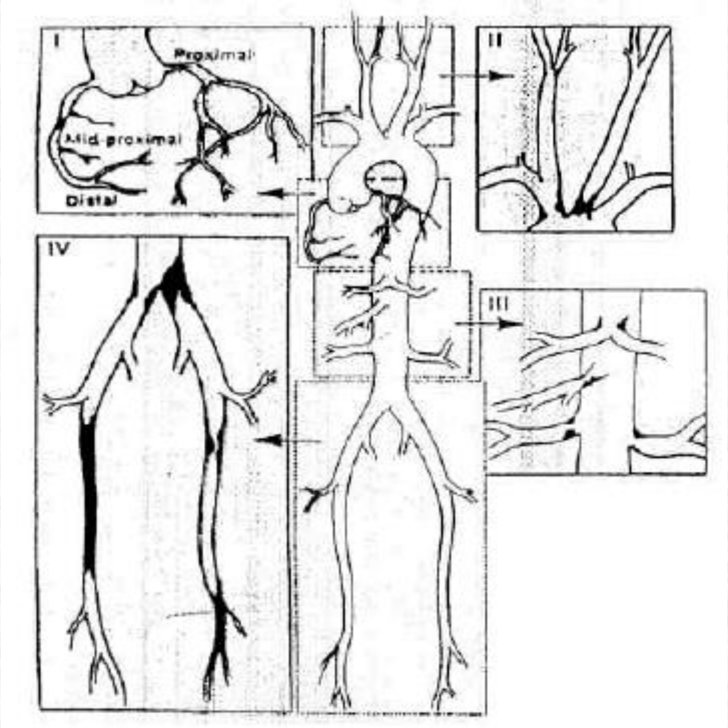


Fig. 1. Steady Hagen-Poiseuille parabolic ($\gamma = 2$) and plug-like($\gamma = 9$) velocity profiles and five representative snapshots of the peak velocity profiles of the transient Womersley flow.

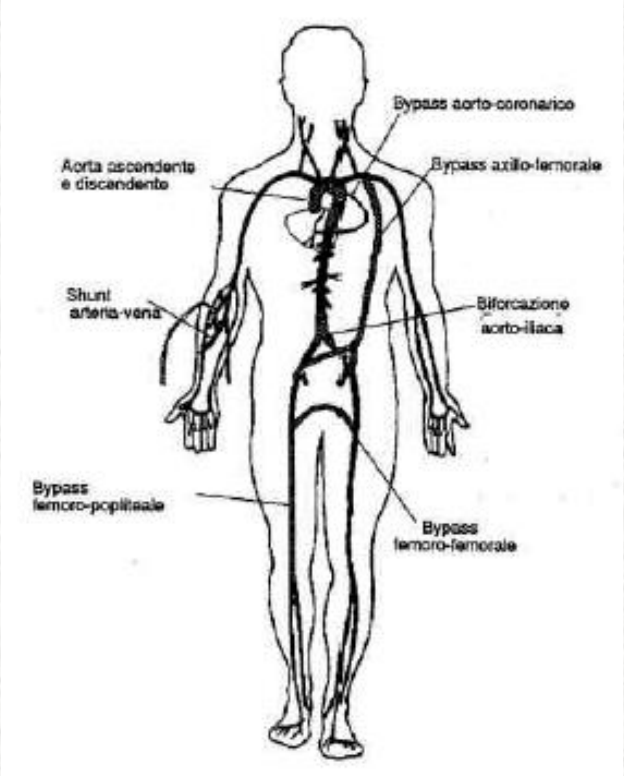


Derivation of entrance length: x=0.03 Re* radius of vessel, calculate this for aorta and discuss

Vascular Prostheses: trauma, pathology



Zones most likely to suffer from plaques



Principal sites for vascular prosthesis

Classification of vascular Prostheses

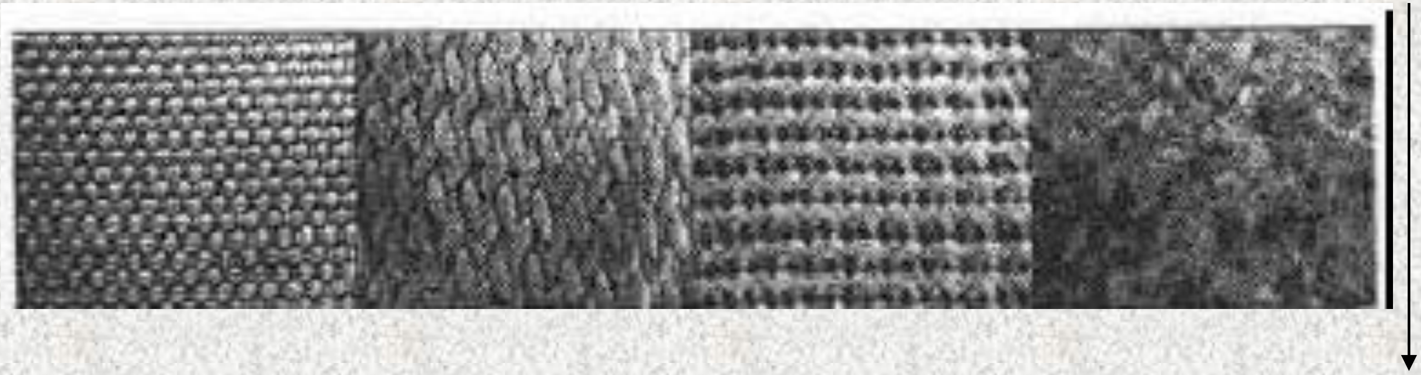
Two main classes can be identified.

<u>Biological Prostheses</u>

Homologus (saphenous vein, umbilicar vein mammary artery, iliac artery)

Heterologus (bovine carotide)

Hybrids



<u>Synthetic Prostheses</u>

textile

Nylon, vynion, orlon

Teflon (PTFE)

Dacron (PET),

Non textile

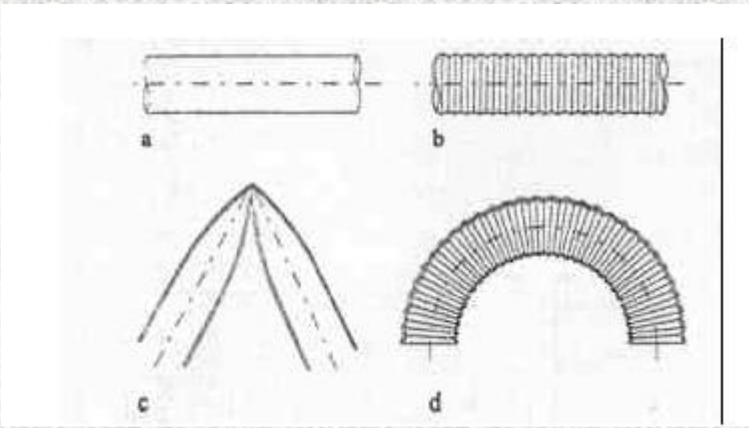
Gore-Tex (ePTFE).

Textile Prostheses can be further subdivided:

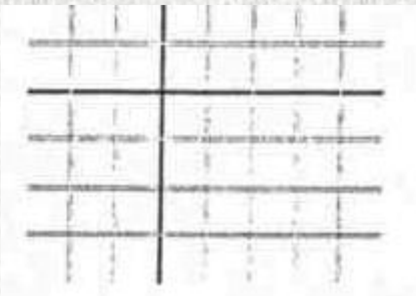
· woven (a)

· knitted –weft (b) and warp (c)

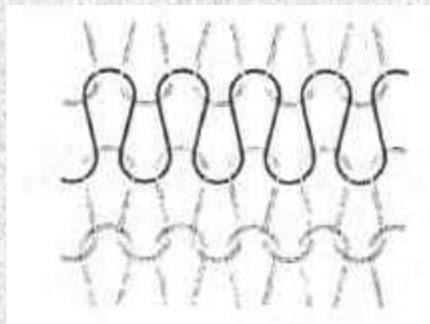
· velour (d)



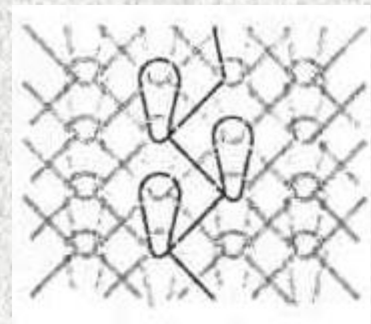
Why are they pleated?



woven

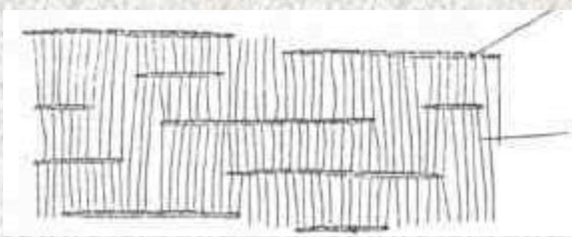


Knitted, weft

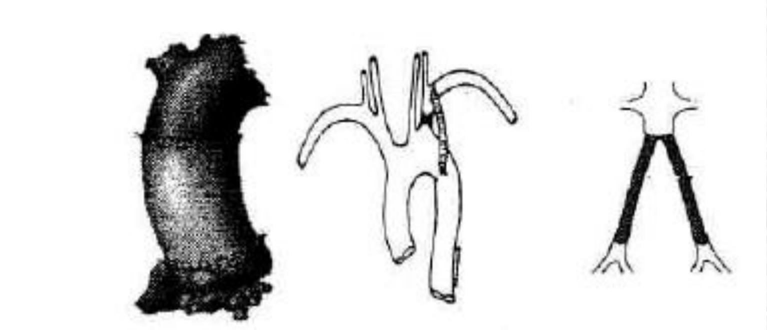


Knitted, warp

velour



Non porous



Different types of intervention: substitution, bypass, bifurcation

Problem: synthetic vascular prostheses are limited to a minimum diameter of 6 mm. Why?

The permeability of a vessel is the volume of water which passes through unit area of the material in unit time. It is ususally referred to a pressure of 120 mmHg. (ml/min/cm^2)

P=Q/A

Permeability is one of the most important factors in synthetic vessel rehabilitation. In general, permeabile prostheses have a higher chance of success, but a higher risk of hemorrage.

Interaction of blood

- Fibrin filaments coagulate at wall
- Clots penetrate into pores
- Fibroblasts invade pores and secrete fibrous tissue
- Increase in collagen in pores
- Formation of neo intima at vessel wall

This process prevents thrombus formation and can take several months, many prostheses are precoated with proteins or pyrolytic carbon, and presoaked in pateient’s blood to encourage neo intima.

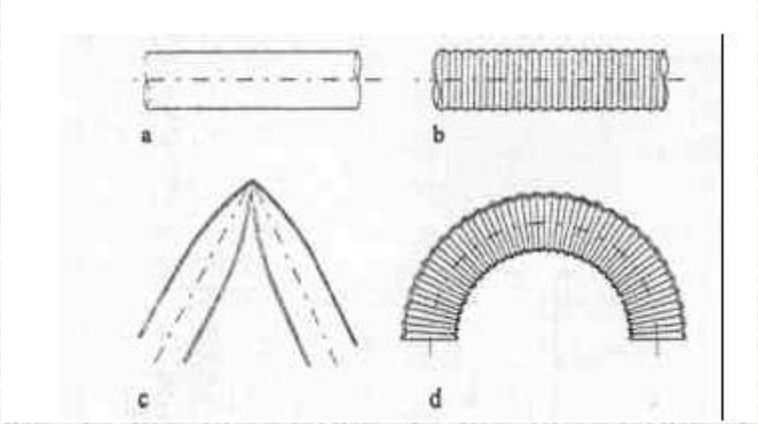
Dacron	Permeabilità [ml/min*cm^2]	Precoagulazione
Protesi a rete	50÷200	No
Protesi a maglia	2000 (media)	Sì
Protesi con velour	1300 (uniforme)	Sì

Porosity is defined as the % ratio between empty spaces volume and total volume of a material.
It can be measured in 2 ways:
Plannimetric: area of holes/total area using a microscope
Gravvimetric: calculating apparent density and comparing with real density

Derive equations for porosity
A nice exercise is to give students a piece of material and get them to measure porosity and permeability. Also discuss the two in terms of microstructure of a material.

Burst Strength: A balloon is placed inside the tube and pumped till it bursts. For a large artery it is about 1000 mmHg

Duration: In physiological conditions, the tube is subject to plusatile flow. The pulse frequecy is increased to 5-10Hz to decrease testing time.



Why are prosthese pleated?

Complications:

The most common complications are:

1. Ageging, hyperplasia along the suture line, sclerosis along inner wall, mineralisation, aneurysms
2. In the case of biological prostheses, degradation and reabsorbtion .
3. Infection : it is the most serious complication and often leads to removal.
4. Dilation or breakage, degradation of velour
5. Disinsertion: all types, due to due much stretching, alteration of arterial wall, hypertension or fragmentation (knitted weft).
6. Occlusion. This is due to formation of thrombi which are not washed away: small diameter low flow, or lack of formation of an endothelial layer.

Why only arteries?

	Dacron, weft, no support	Dacron warp	Dacron weft, external suppoprt	ePTFE	Autologus saphenous vein	Internal mammary arterty
Coronary aortic bypass					70%	93%
Aortic bifurcation	99.6%	100%				
Aorta-femoral bypass	98%	100%				
Femoral-femoral bypass	80%	93%				
Axillo-femoral bypass	67%		97%			
Femoral-popliteal bypass	53%		84%		61%	
Femoral-popliteal bypass			63%	49%	76%	

Supponendo che abbiano lo stesso modulo elastico, stimare lo sforzo sulla parete dei seguenti vasi. Spiegare il significato del segno ottenuto.
Dato che la pressione di scoppio dell'aorta e' 1000 mmHg, stimare il modulo elastic del vaso.

Vaso	Diametro interno	Diametro esterno	Pressione
Aorta		3.2 cm	120 mmHg
Arteriola	1 mm	1.1mm	39 mmHg
Vena	1 cm	1.1 cm	3 mmHg

Calcolare il diametro di un vaso in cui la viscosita apparente e' meta di quella nominale.