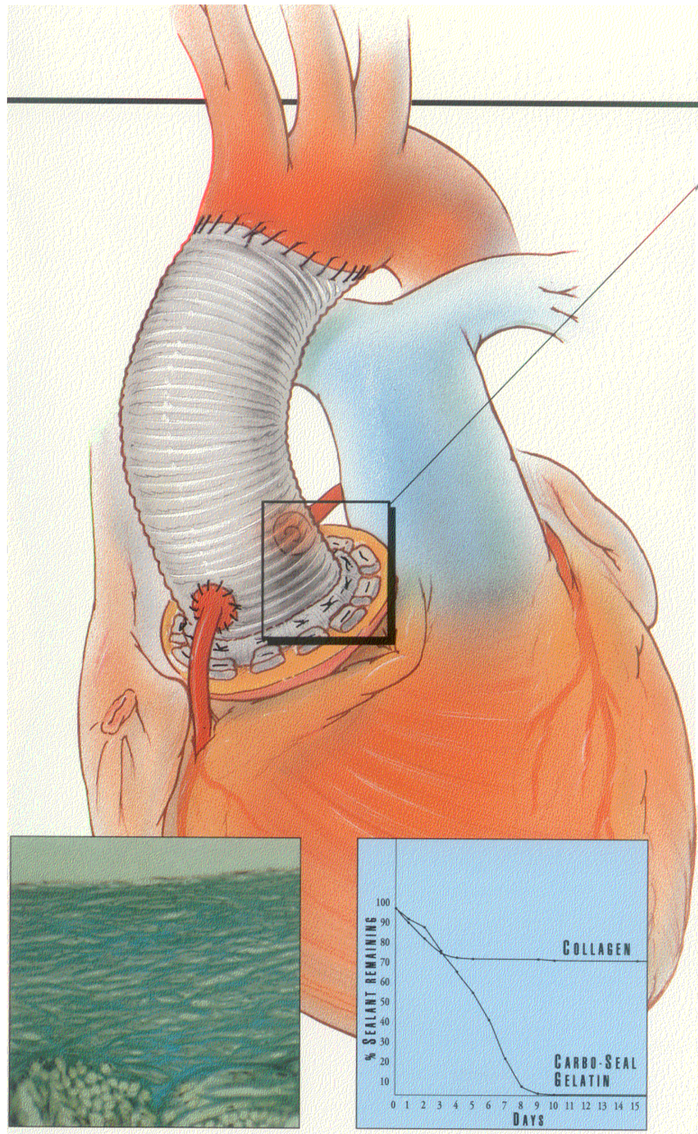
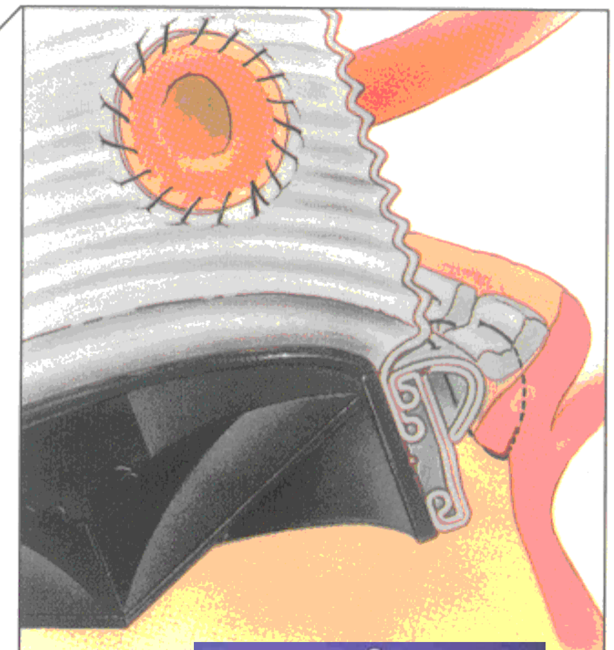
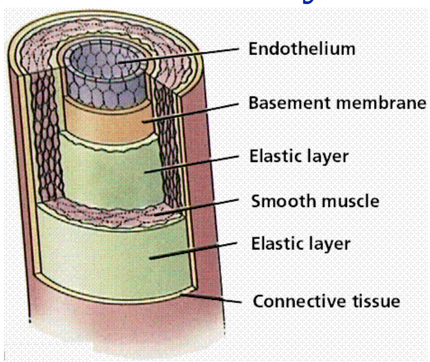
Vascular prostheses
Aortic conduits Vascular stents

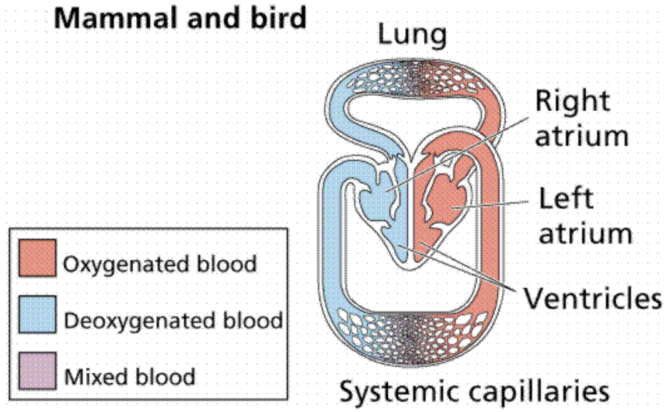




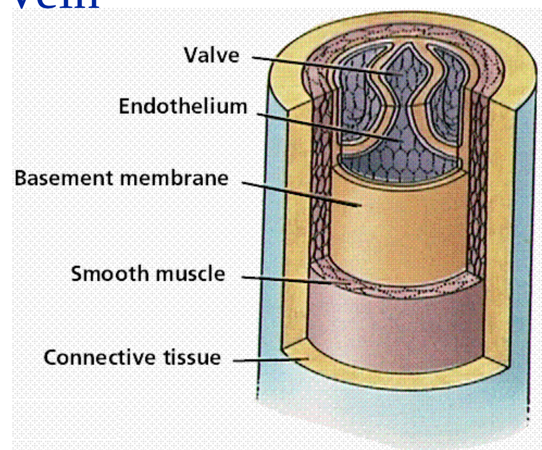
Blood circulation
Arteries, capillaries, veins

Artery

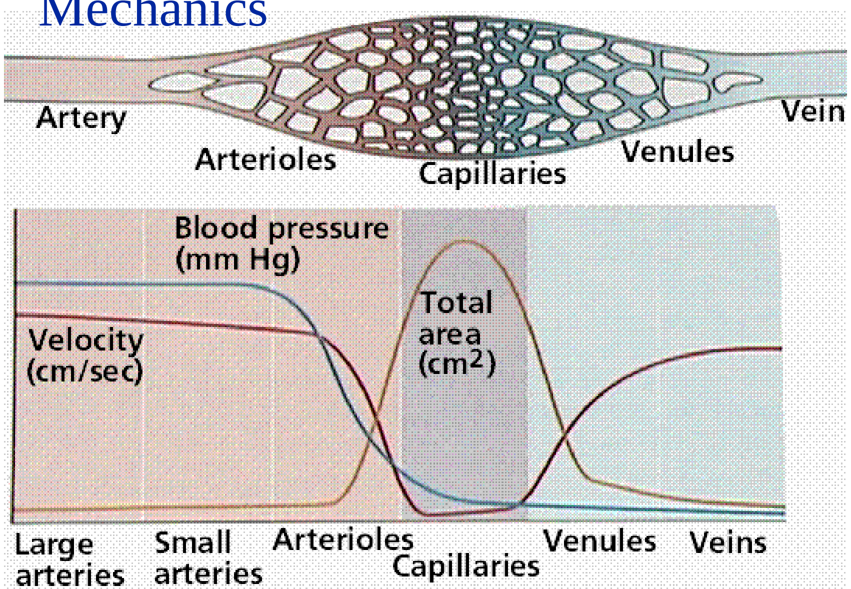


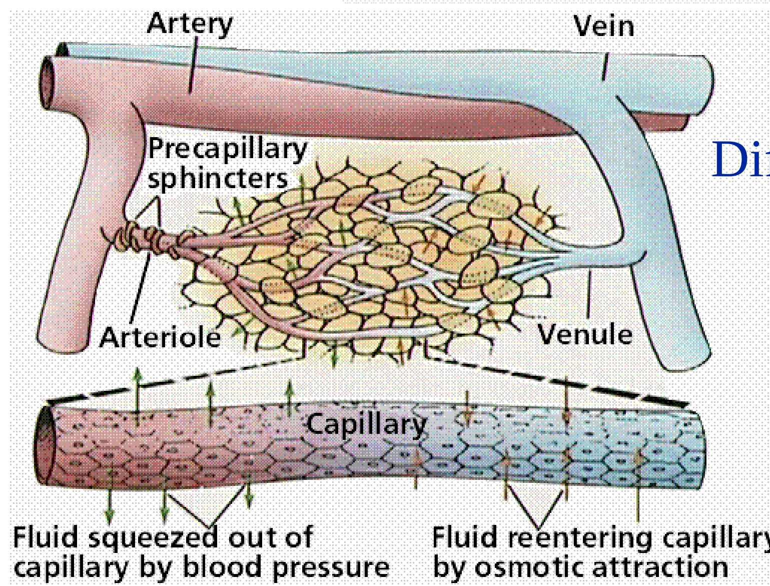


Vein



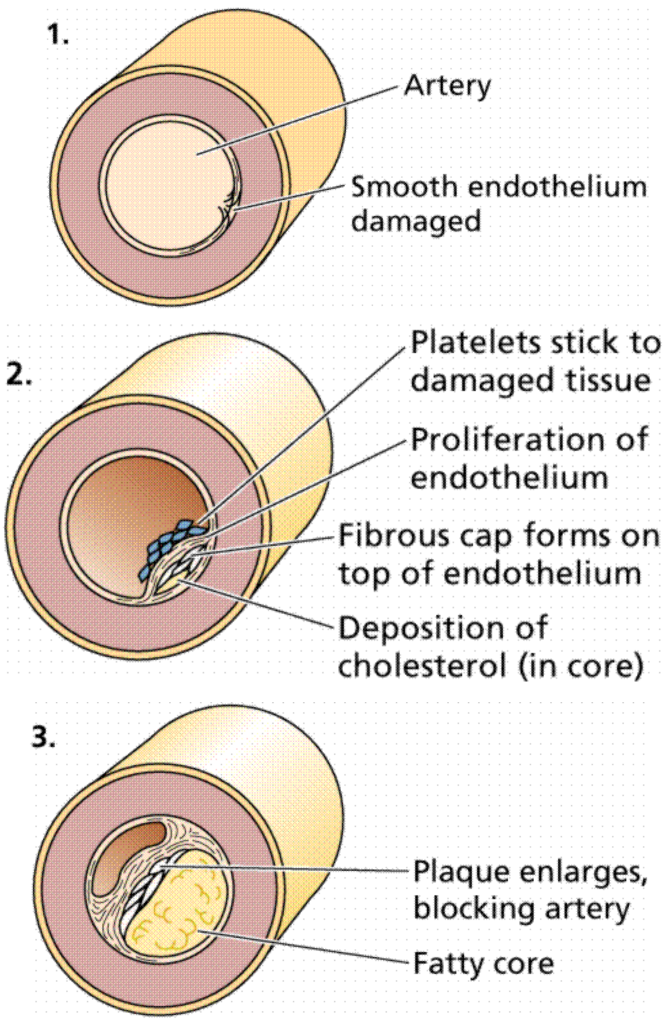
Mechanics

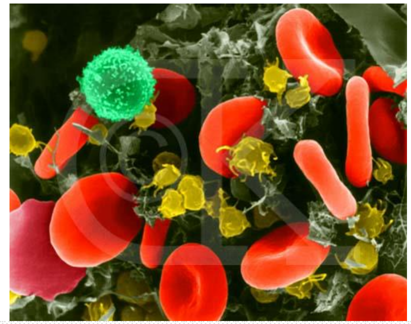


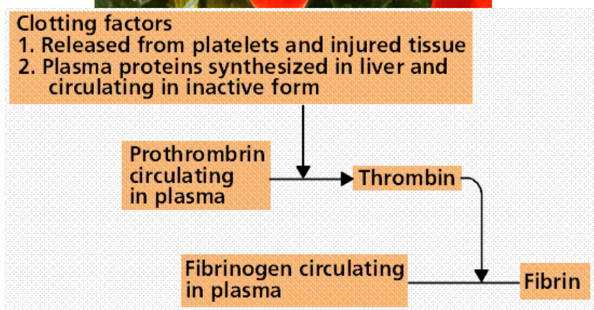


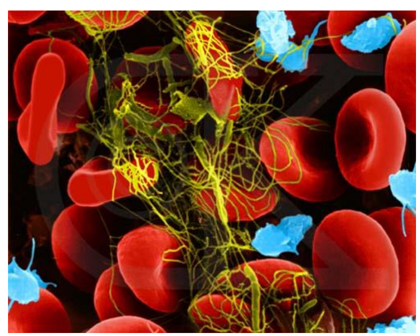
Diffusion

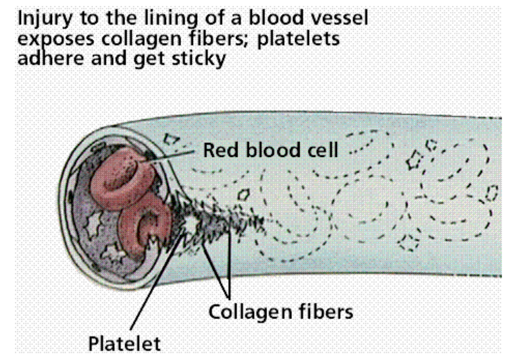
Vascular pathology - Atherosclerosis

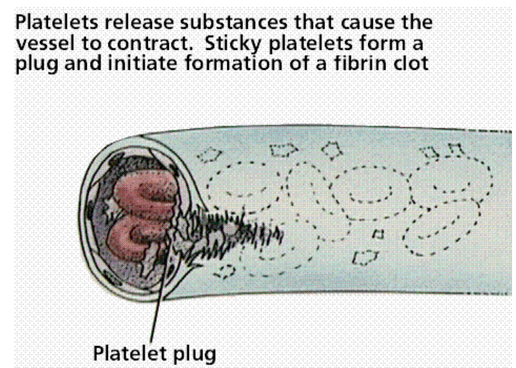


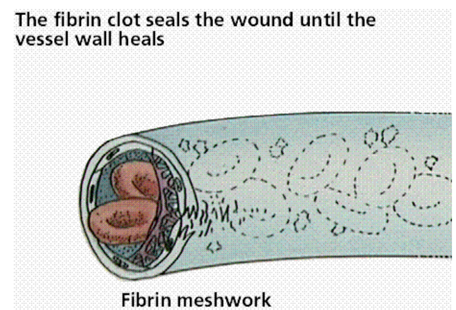












Vascular Grafts

- Must be flexible.
- Designed with open porous structure.
- Often recognized by body immunoprotective system as foreign material.

Review article

J. Funct. Biomater. **2015**, *6*, 500-525; doi:10.3390/jfb6030500

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Review

Medical Textiles as Vascular Implants and Their Success to Mimic Natural Arteries

Charanpreet Singh [1,†], Cynthia S. Wong [1,†] and Xungai Wang [1,2,†,*]

Vascular Grafts: optimal specifications

- Achieve and maintain homeostasis.
- Porous.
- Permeable.
- Good structure retention.
- Adequate burst strength.
- High fatigue resistance.
- Low thrombogenicity.
- Good handling properties.
- Biostable.

J. Funct. Biomater. **2015**, *6*

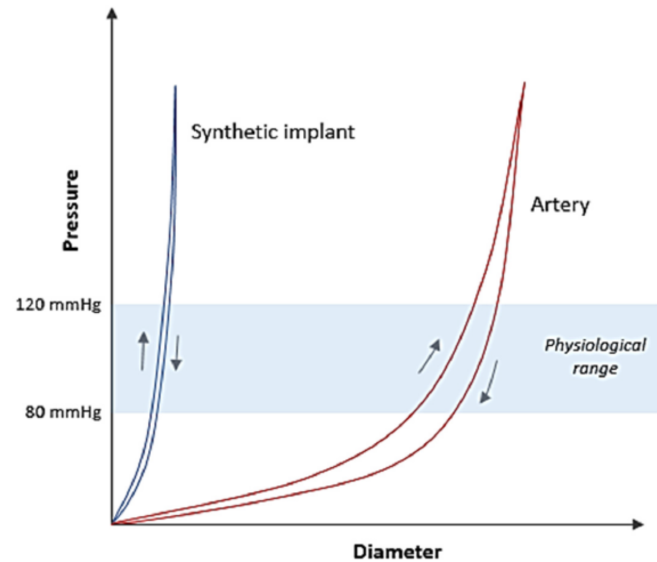
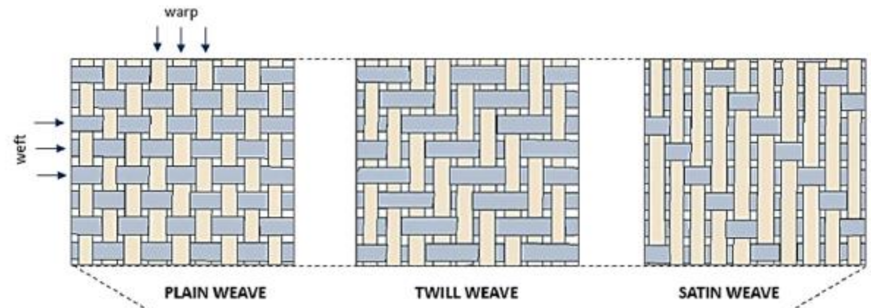


Figure 1. Comparison of pressure-diameter curves between an artery and a synthetic implant.

Vascular Grafts: Textile Materials Design Waves

- Manufactured by interlacing two sets of yarns (warp and weft) oriented at 90° to each other.
- Low axial stretch - Poor radial compliance
- Crimping gives some axial elasticity and bending ability
- Poor compliance can be fatal as it can change the transmission characteristics of pulse waves



5.6 Pulse Wave Velocity and the Moens–Korteweg Equation

$$c \cong \sqrt{\frac{Eh}{2r_i \rho}}$$

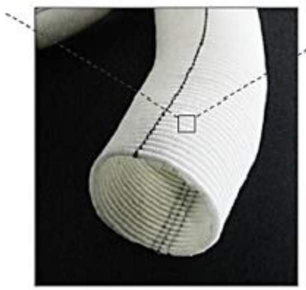


Figure 4. Structural design patterns of a woven Dacron® graft.

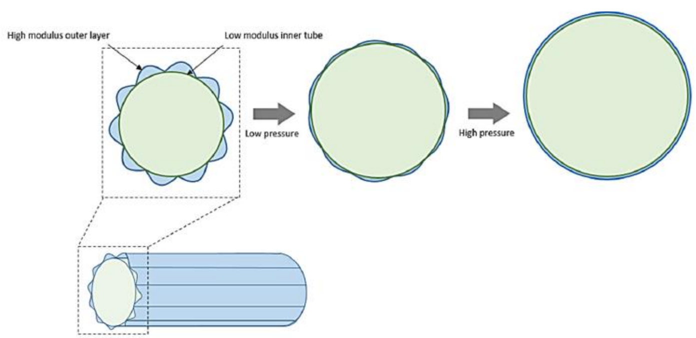


Figure 5. An explanation of thebilayer woven graft design concept proposed by Chen *et al.* [46].

Vascular Grafts : Textile Materials Design Knits

- Looped filament construction: a continuous interconnecting chain of yarn loops spirals around the graft circumference
- Better matching vascular biomechanics – long term failure *in vivo*
- Different technics proposed in combination with basic Knitted structure to overcome that weak point.

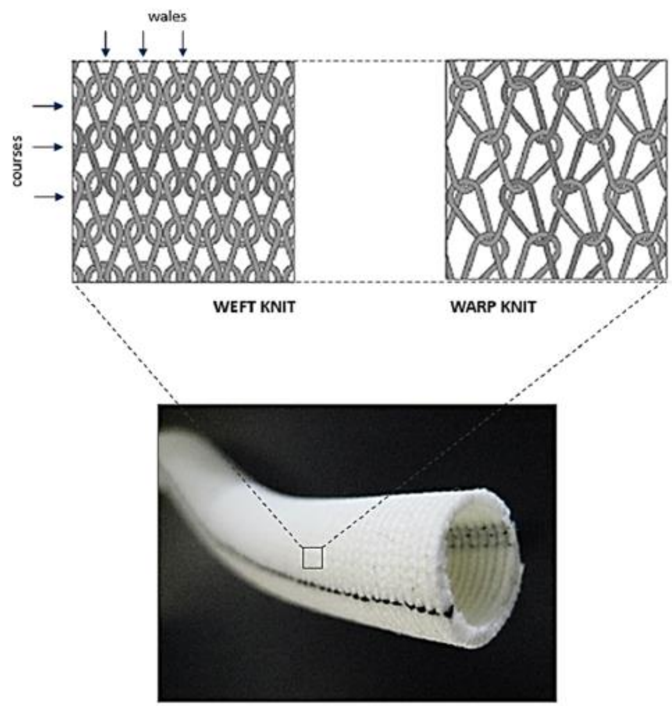


Figure 6. Structural design patterns of a knitted Dacron® graft.

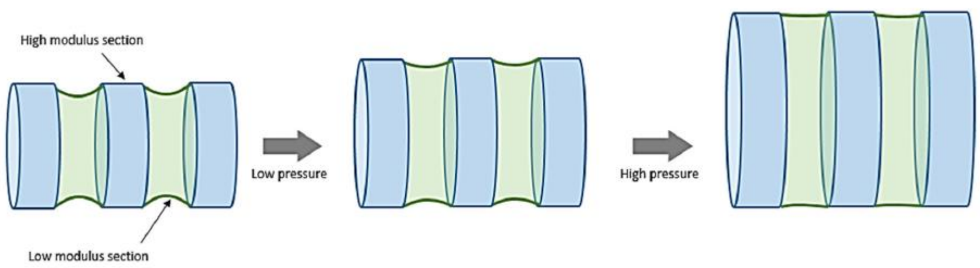


Figure 7. The segmented design concept as proposed by Singh and Wang to improve the compliance property of a knitted vascular implant [70,71].

Vascular Grafts : Textile Materials Design Braids

- Like Woven textiles but the yarns are in angle each other (different than 90^{o})
- Better radial dilatation
- Axial stretching/lateral compression – good for endovascular stenting (in conjunction with metallic mech)

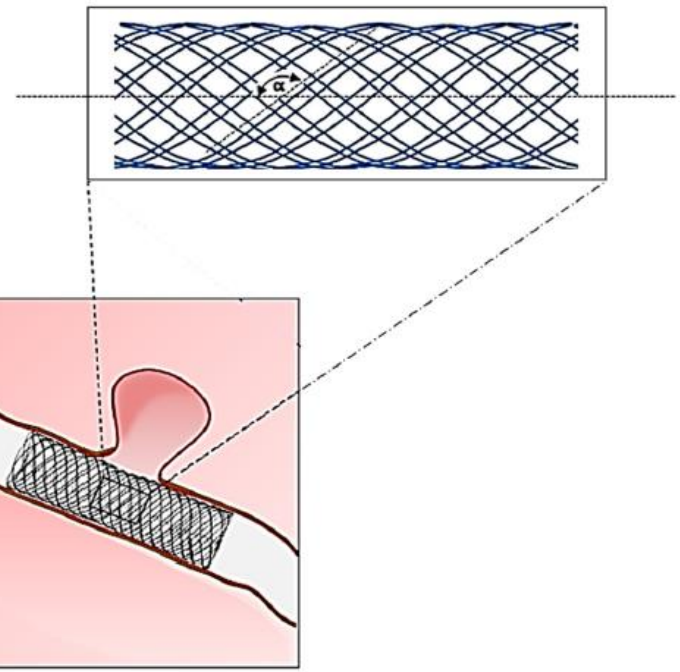
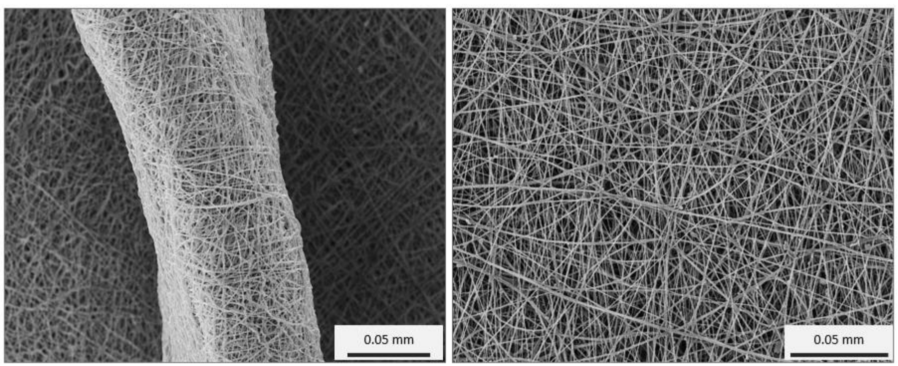


Figure 8. Structural geometry of a braided metallic stent (α = braid helix angle).

Vascular Grafts : Textile Materials Design

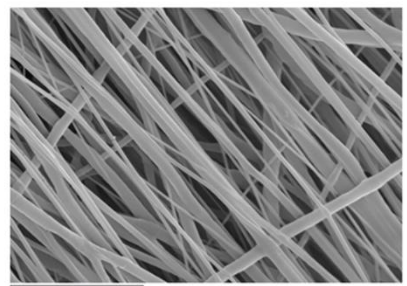
- Electrospun

High DC voltage pulls polymer solution from a syringe tip to a metallic collector. As the solute evaporated the dry yarns deposited to the collector surface



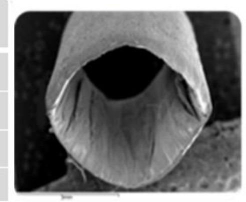
A novel polymeric fibrous microstructured biodegradable small caliber tubular scaffold for cardiovascular tissue engineering

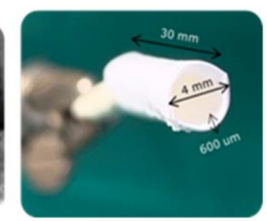
*Andreas Dimopoulos[1], Dionysios N. Markatos[1], Athina Mitropoulou[1], Ioannis Panagiotopoulos[2], Efstratios Koletsis[2] and Dimosthenis Mavrilas[1]**



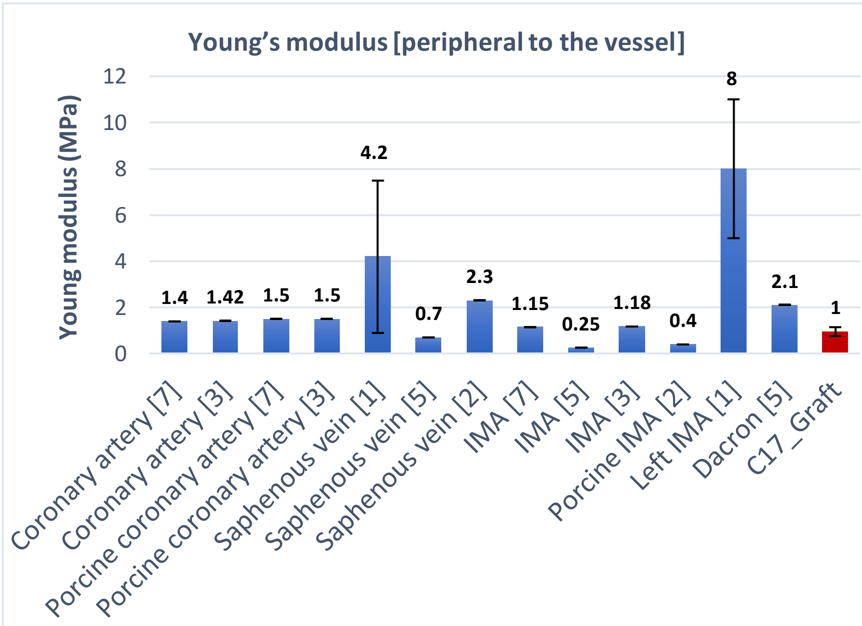
Axially aligned PCL microfibers

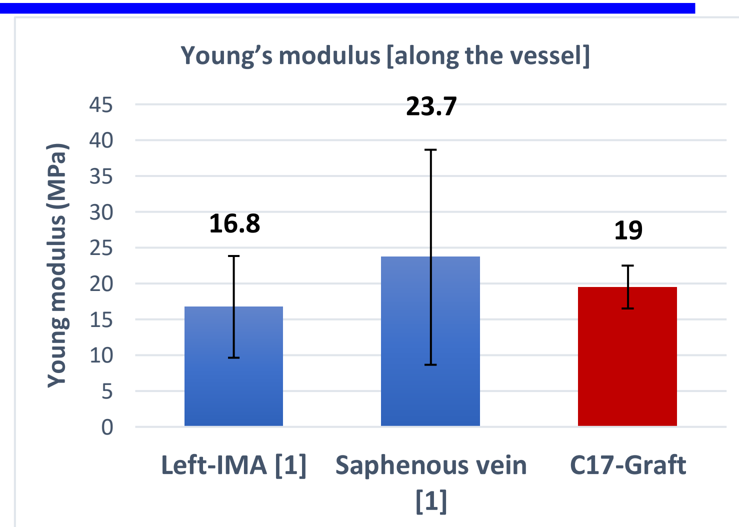
Pressure Range (mmHg)	Compliance (%)
50 - 90	7.01±0.94
80 - 120	5.04±0.82
110 - 150	4.80±1.06
140 - 180	4.61±0.96





Comparable to the natural vessels (veins and arteries)

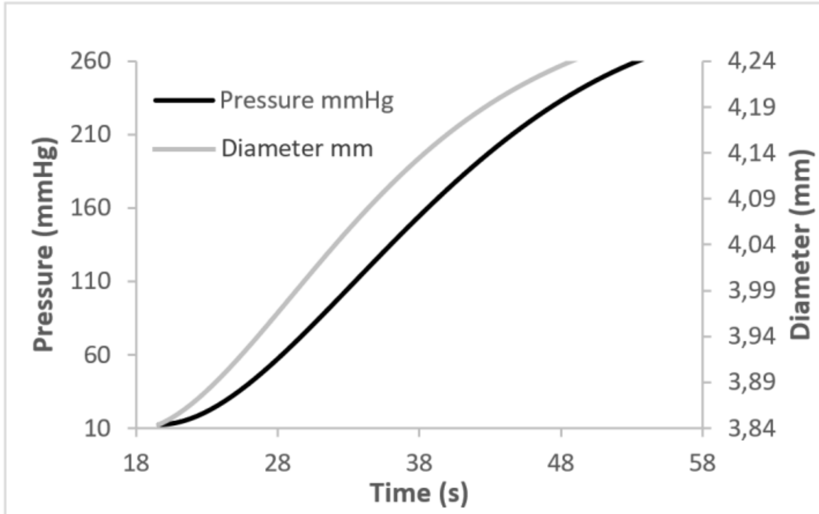




1. *Jenkins, T. L. et Al.,(2019)*
2. *Lorenzo S. et Al., (2010)*
3. *Hao-Yang Mi et Al., (2019)*
5. *Steven G. et Al., (2011)*
7. *Hao-Yang Mi et Al., 2018*

Vascular Grafts: Properties under consideration

- Braids, weaves, and knits.
  - Porosity
  - Permeability
  - Thickness
  - Burst strength
  - Kink resistance
  - Suture retention
  - Wall thickness
  - Tensile properties
  - Ravel resistance



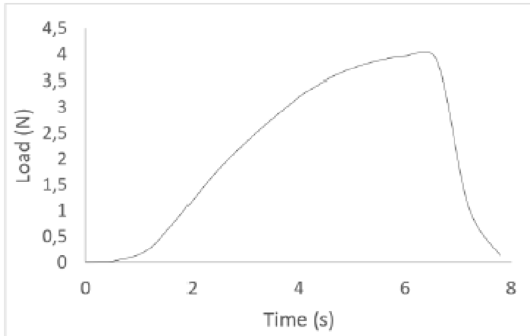


Figure 7: Load-time plot of the sutured PCL electrospun scaffold

Vascular Grafts Permeability

- E.g.: ISO 7198:2016/2017
- Braids
  - 350 to 2500 $(ml/cm^2)/min$)
- Knits
  - Loosely Woven Knits
    - » 1200 to 2000 $(ml/cm^2)/min$
  - Tightly Woven Knits
    - » 2000 to 5000 $(ml/cm^2)/min$
- Weaves
  - Below 800 $(ml/cm^2)/min$

Arterial grafts
Mechanical – geometrical mismatch

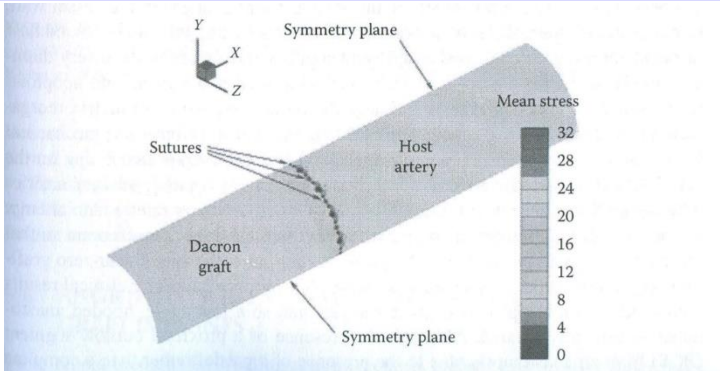


FIGURE 9.17 Mean stress distribution at the end-to-end Dacron graft-artery anastomosis projected onto a three-dimensional image of the geometry. (From *J. Biomech.*, 31, Ballyk, P.D. et al., 232, Copyright (1998), with permission from Elsevier.)

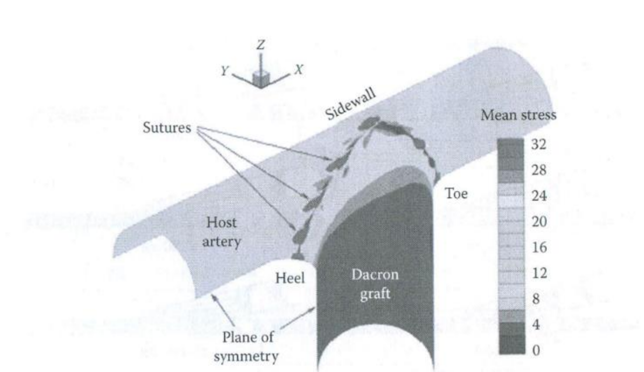


FIGURE 9.18 Mean stress distribution at the end-to-side Dacron graft-artery anastomosis projected onto a three-dimensional image of the geometry. (From *J. Biomech.*, 31, Ballyk, P.D. et al., 232, Copyright (1998), with permission from Elsevier.)

- Stress distribution <u>end to end</u> anastomosis vessel to graft
- Stress distribution <u>side to end</u> anastomosis vessel to graft
- Anastomosis angle before a bifurcation

Arterial grafts
Mechanical – geometrical mismatch

- Arterial compliance restores part of the pulse wave energy during ejection
- It is reimbursed during diastole (no cardiac ejection phase)
- Smoothening of the hydraulic shock
- Partial filtration of the pulsation of blood flow

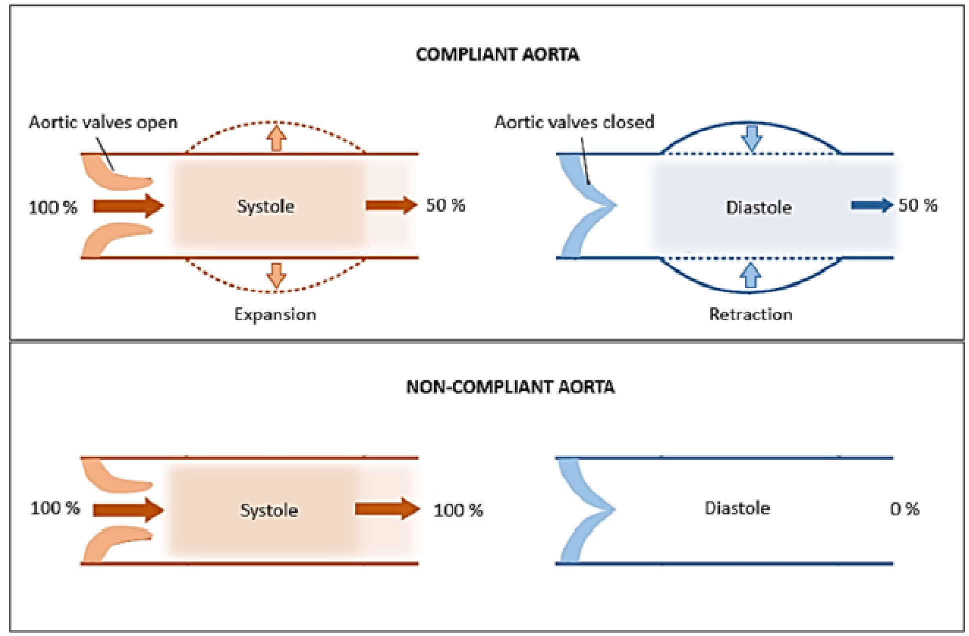


Figure 3. The role of compliance in the windkessel function of aorta.

Mechanical mismatch
Resulted distal complications

5.6 Pulse Wave Velocity and the Moens–Korteweg Equation

$$c \cong \sqrt{\frac{Eh}{2r_i\rho}}$$

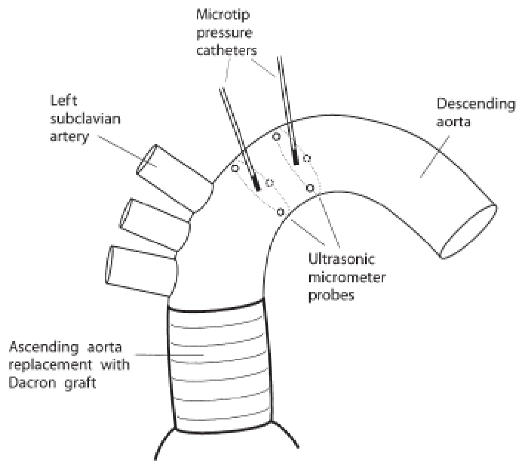


Fig 1. Schematic drawing of the test arrangement illustrates the positioning of the ultrasonic micrometer probes and pressure catheters.

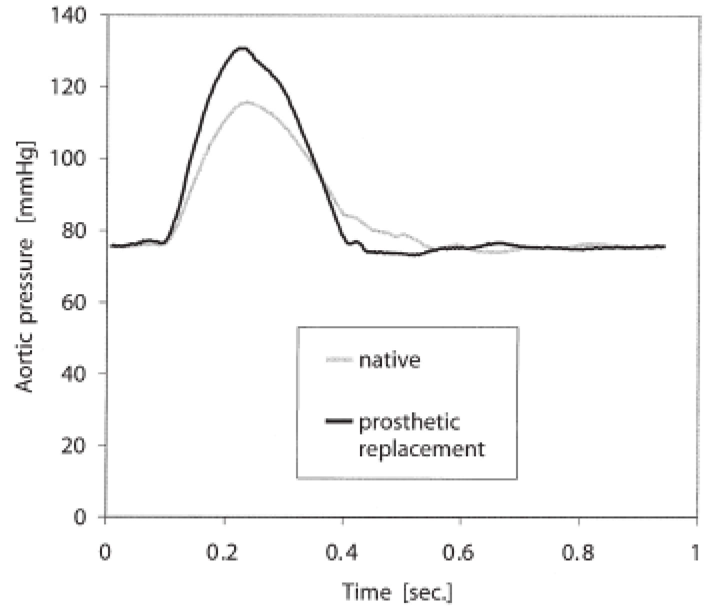


Fig 2. Representative changes in proximal descending aorta pressure waveform after prosthetic replacement (dark line) of the ascending aorta compared with the native condition (gray line). Note the increase in peak pressure and rate of pressure rise at the prosthetic pressure trace.

Ann Thorac Surg
2007;83:954–7

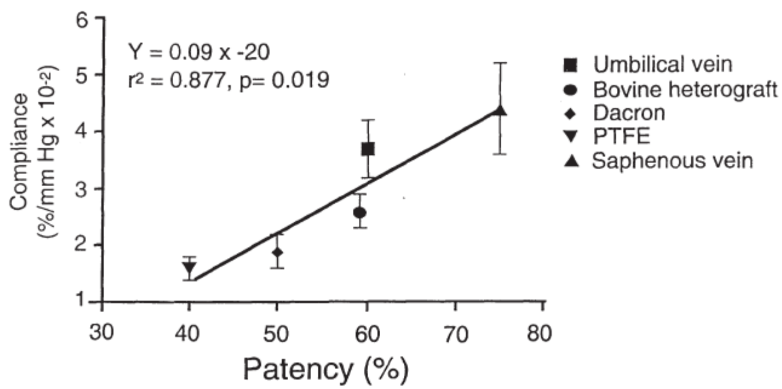


Figure 4. Data reported from compliance of various biological and prosthetic grafts versus patency rate.

J Biomater Appl 2001 15: 241
DOI: 10.1106/NA5T-J57A-JTDD-FD04

See Chapter 9

Biofluid Mechanics

The Human Circulation

Krishan B. Chandran
Ajit P. Yoganathan
Stanley E. Rittgers

Aortocoronary bypass

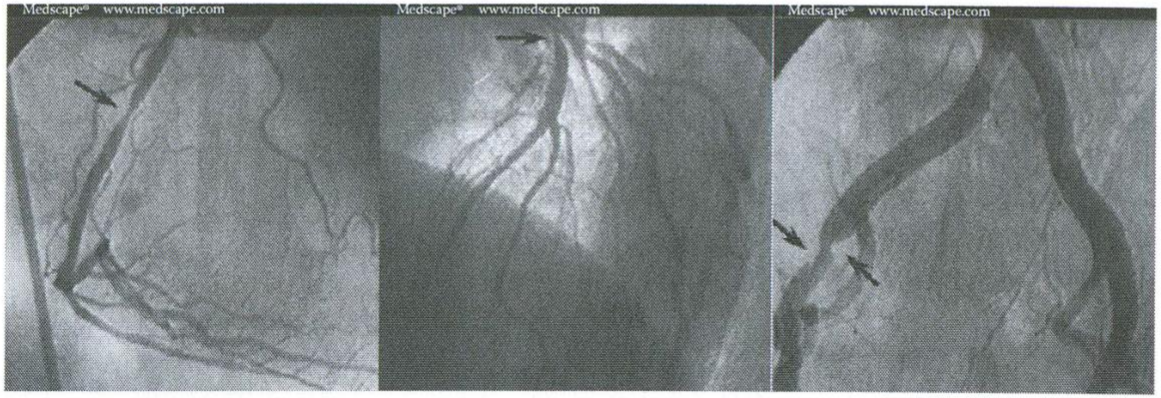
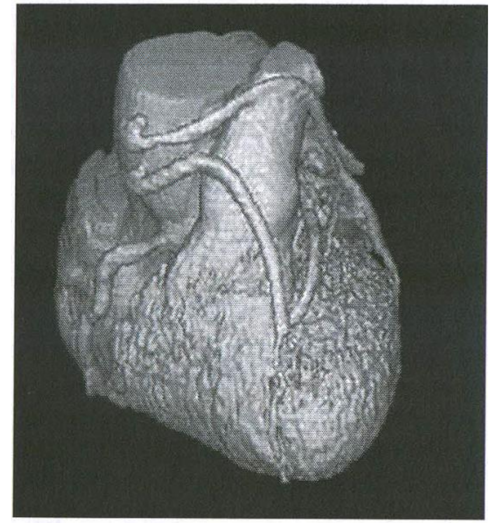
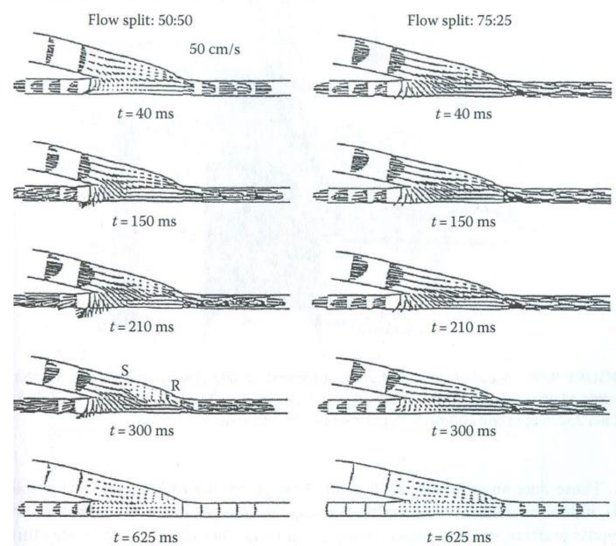


FIGURE 9.1 Angiogram of the left coronary system of a patent with severe coronary artery disease. (From Gotto, A.M., Jr. et al., *Atherosclerosis*, UpJohn, Kalamazoo, MI, 1997. With permission.)





- Design of anastomosis
- Autograft: Patient's artery or vein?
- Polymer grafts. Are they inappropriate?

Stented balloon angioplasty

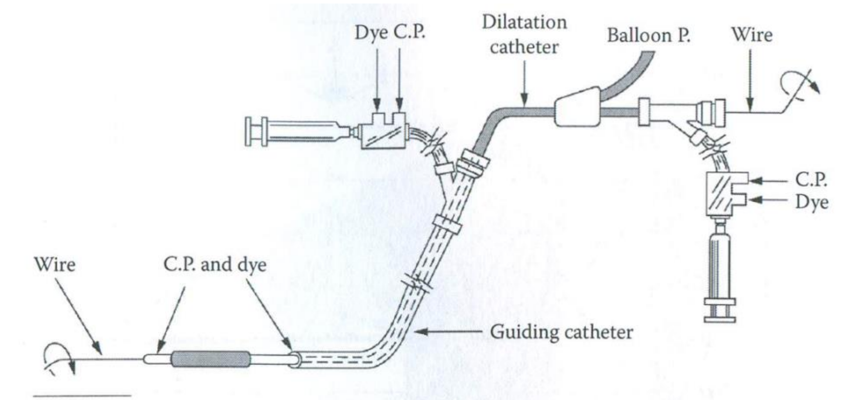
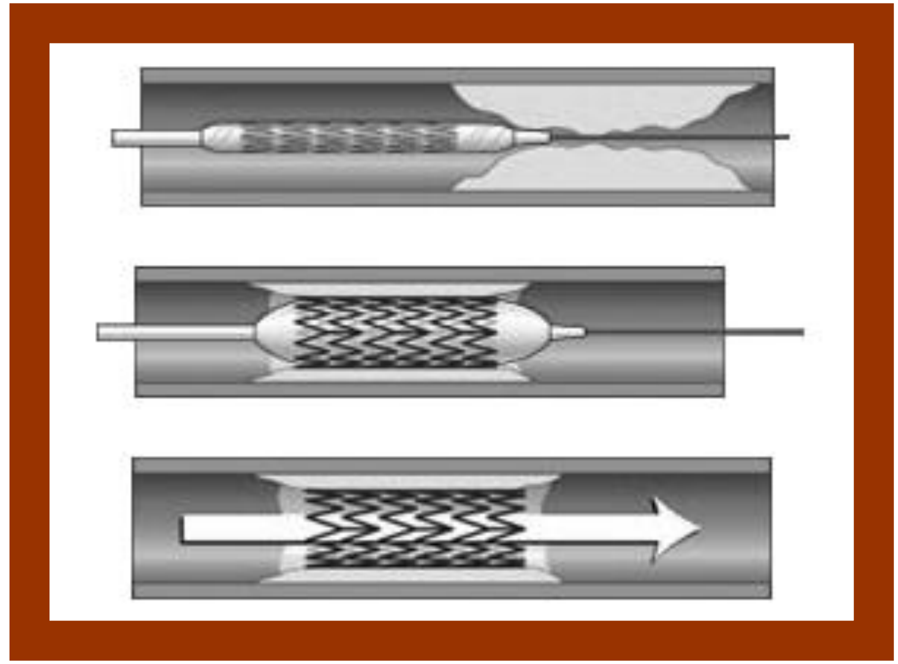


FIGURE 9.20 Schematic of a percutaneous balloon angioplasty device showing guide wire (Wire), catheter, and ports for balloon pressure (Balloon P.), dye injection (Dye), and catheter pressure (C.P.).



- Stent material
- Design of final configuration
- Contraction techniques – installation in catheter καθετήρα
- Dilation - anchoring techniques. Possibility for overstressing vascular wall
- Possible malfunctions: slippage – restenosis
- Drag eluted stents

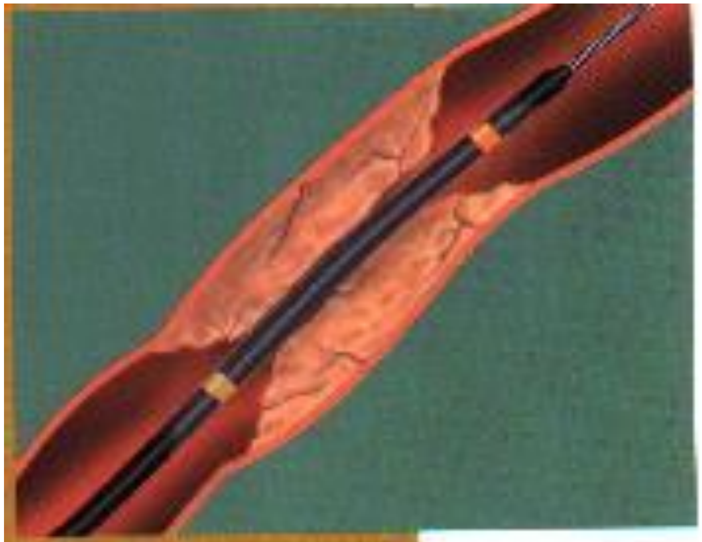
Details

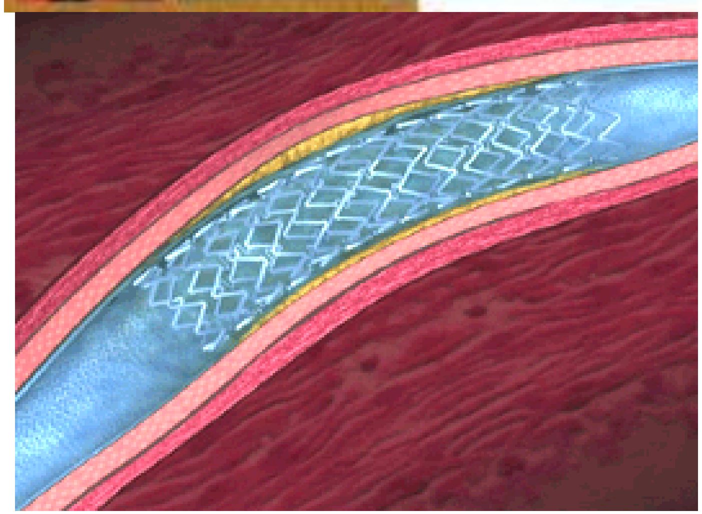
Stenting results in stiffening of the vascular site

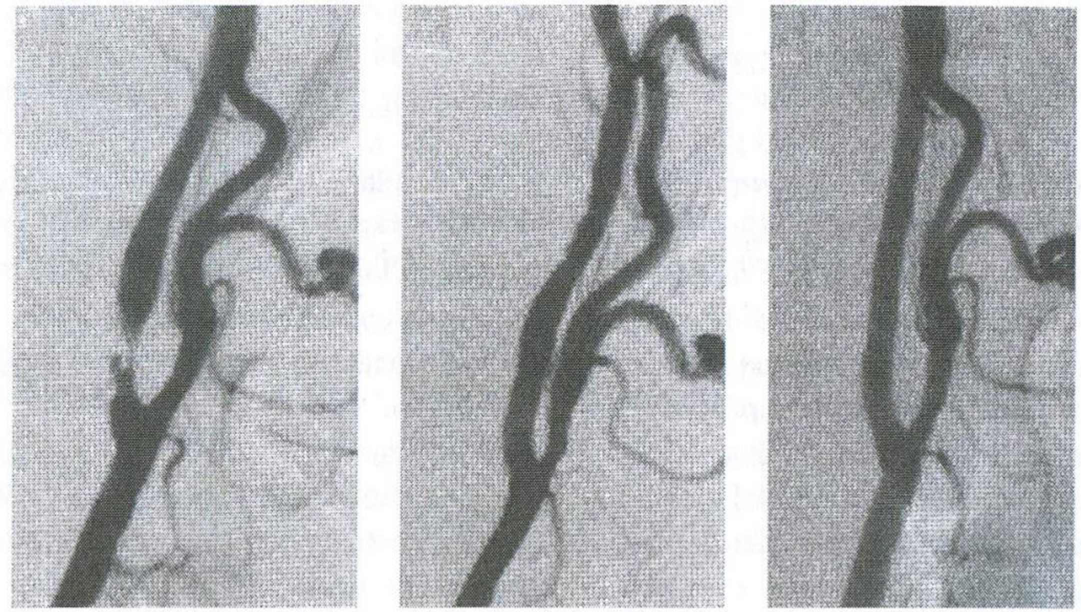
5.6 Pulse Wave Velocity and the Moens–Korteweg Equation

$$c \cong \sqrt{\frac{Eh}{2r_i \rho}}$$

Flow recovery in stenosed artery







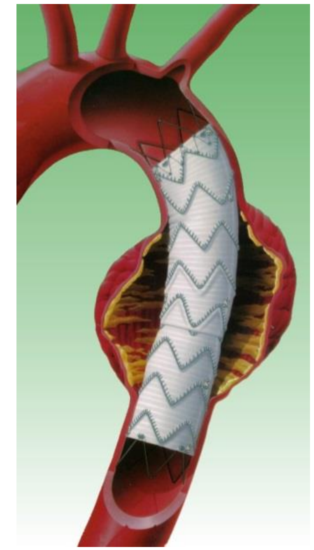
(a) (b) (c)

FIGURE 9.21 Digital subtraction angiograms showing excellent immediate and long-term results of percutaneous transluminal angioplasty in a patient with severe ulcerated internal carotid stenosis (a) immediately before angioplasty; (b) immediately after angioplasty; and (c) 1 year after angioplasty. (From *Adv. Vasc. Surg.*, 4, Whittemore, A.D., Copyright (1996), with permission from Elsevier.)

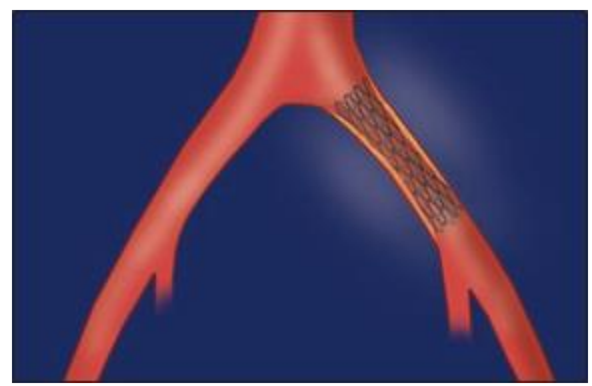
Stenting results in stiffening of the vascular site

Endoprosthesis in abdominal aorta aneurysm including iliac arteries

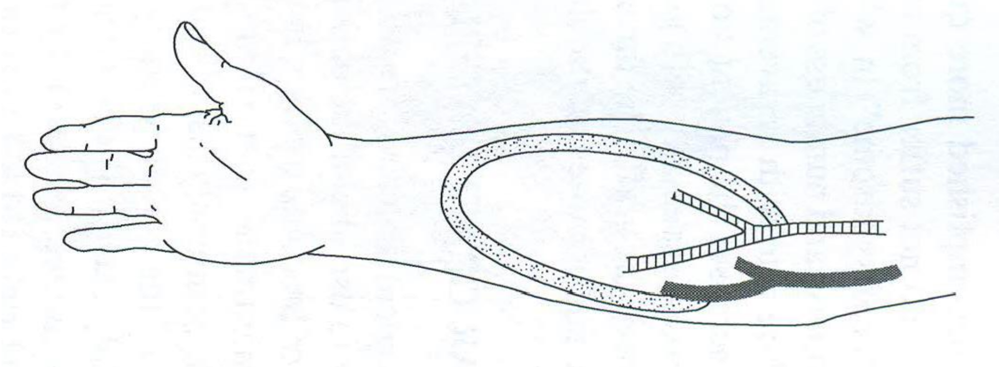
http://www.goremedical.com/contentTypeDetail.jsp?action=contentDetail&N=8062%208239&contenttype=8754&R=1276626160078



Video

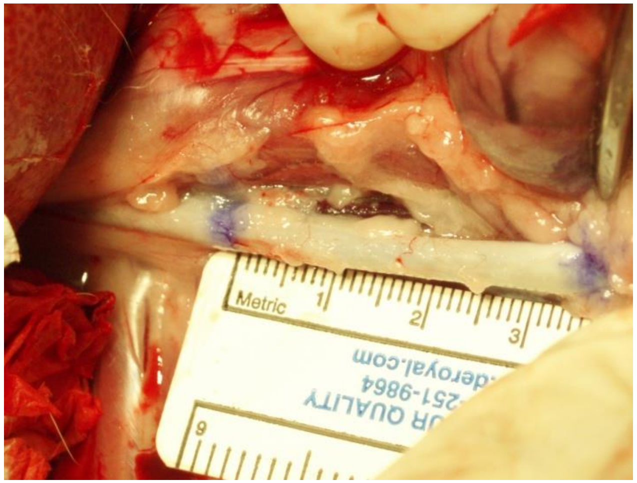


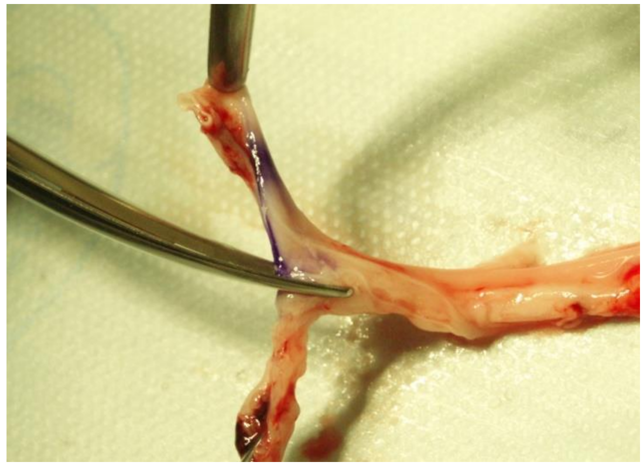
Arteriovenular bridge anastomosis (fistula)

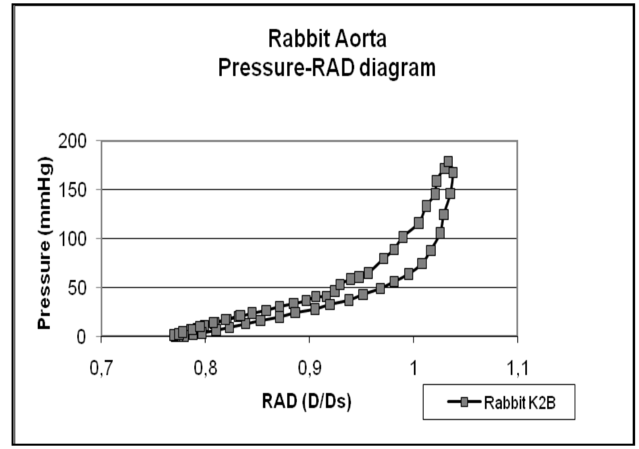


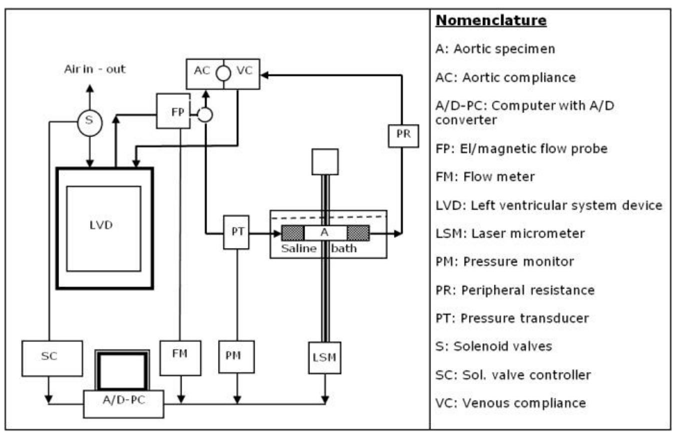
- Concerns all people imposed in extracorporeal haemofiltration (3 times/week)
- Alternatively percutaneous haemofiltration
- Hydraulic join of artery - vein
- Big blood velocities (low resistance)
- Conditions appropriate for extracorporeal blood circulation (hemofiltration)
- Longevity: 1-2 years

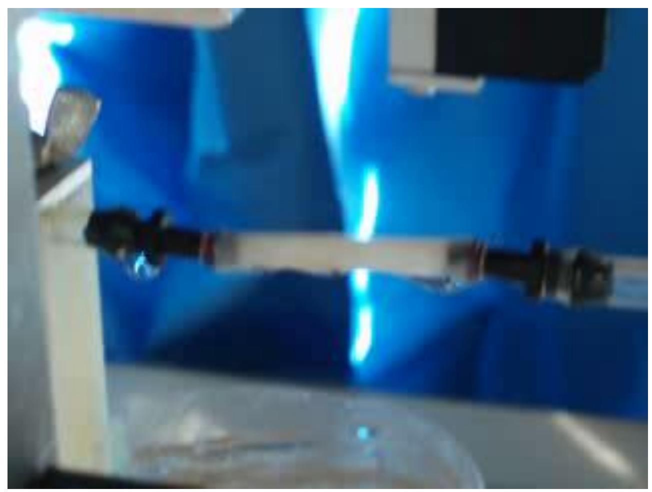
Measuring arterial stiffness











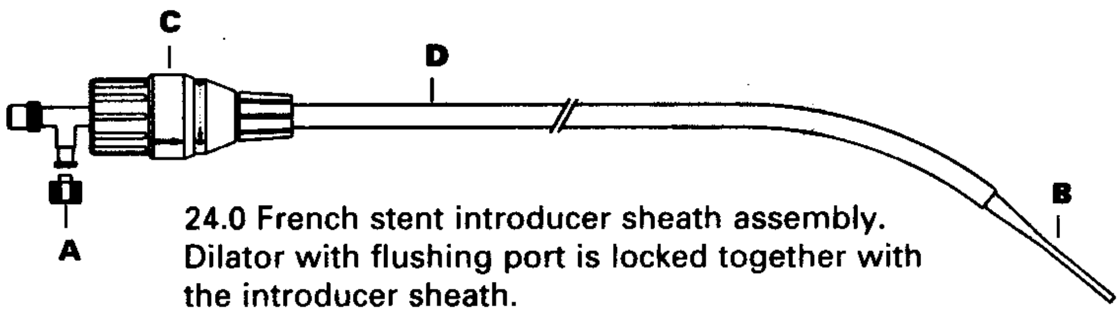
RAD = D/Ds

$$E_{Pm} = \Delta P/(\Delta D/D_S)$$

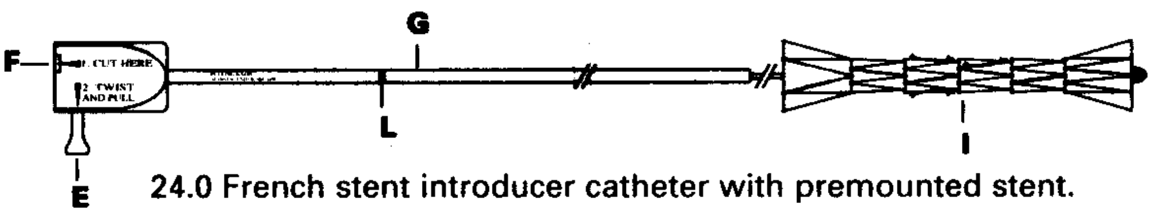
Koniari *et Al*, 2013, 2015

Video

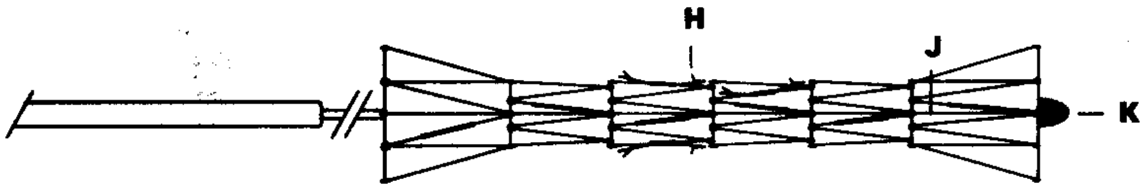
Angioplasty: Esophagus stent



24.0 French stent introducer sheath assembly. Dilator with flushing port is locked together with the introducer sheath.



24.0 French stent introducer catheter with premounted stent.



Diameter of stent body: 18 mm.
Diameter of proximal and distal ends of stent: 25 mm.

Catheterization: Esophagus stented endoprostheses

SUGGESTED INSTRUCTIONS FOR USE