Vascular Grafts

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Vascular Graft

• Prosthetic implant used to repair, replace or bypass sections of blood vessels
A History of Vascular Surgery

• First half of the 18th century
  – Chemical styptic
  – Cauterization
  – Ligation

15th century Turkish manuscript depicting cauterization


Ancient Greek painting in a vase, showing an iatros bleeding a patient

Bloodletting in 1860
1759: First Lateral Arteriorrhaphy

- Brachial artery damage caused by phlebotomy was common
- English surgeon Richard Lambert examined a patient suffering a traumatic brachial artery aneurism
- Lambert asked his colleague to suture the wound rather than tie up the trunk of the vessel
- Hallowell elevated the edges of the laceration with a half-inch steel pin and tied a figure eight stitch about it
A History of Vascular Surgery

- **1879**: Eck performed a lateral anastomosis of the portal vein to the inferior vena cava using fine silk sutures
- **1902**: Carrel began animal experiments with arterial anastomoses; developed concept to use veins to replace arterial segments (1905)
- **1938**: Gross and Hubbard successfully ligated a patent ductus arteriosus

Illustration of the technique used for the first successful arterial anastomosis
1940s: Cardiovascular Renaissance

- **1942**: Blakemore and Lord use vitalium tubes for nonsuture anastomosis
- **1945-1950**: Hufnagel develops arterial preservation methods
  - Sterile arterial segments frozen rapidly in helium filled tubes
  - Immersed in dry ice and alcohol
  - 4-6 month shelf time in a dry ice refrigerator
- **1949**: Kunlin bypasses obstructed arteries with autogenous vein segments
1950s: Polymeric Vascular Prostheses

• Clinical use of Vinyon-N, a nylon derivative
  – Rapidly lost its tensile strength in tissue

• Orlon and Dacron found to be superior
  – Extremely durable; displayed high patency rates in aorta and iliac arteries

• Columbia-Presbyterian Hospital
  – 1952: Vinyon-N tube to replace ruptured artery

• Georgetown University Hospital
  – 1953: First implant of Orlon prosthesis in human
1950s: Polymeric Vascular Prostheses

• Tubes were flat sections of cloth sewn to form crude tubes
• Lacked elasticity and flexibility of modern day grafts
• Required cuffing at ends to prevent fraying
Ideal Vascular Graft (AAMI)

1. It should be available in a **wide range of sizes**
2. It should be **bio-compatible**, allowing healing with a **non-thrombogenic surface**
3. It should have **low infection rate**
4. It should be durable, strong and last the **life expectancy** of the patient
5. It should have easy handling, including **sutureability**
6. It should have a proven **high patency**
Biomaterials used for Vascular Grafts

• Polytetrafluoroethylene or PTFE (Teflon)
• Polyethylene Teraphthalate or PET (Dacron)
• Polyamide (Nylon)
• Polyurathanes
Figure 1.3: Mechanical behavior in circumferential direction of several vascular prostheses and arterial tissues in circumferential direction: 1: PET woven; 2: PTFE woven; 3: PET knitted; 4: PTFE knitted; 5: iliac artery; 6: distal abdominal aorta; 7: femoral artery; 8: proximal abdominal aorta; 9: distal thoracic aorta; 10: proximal thoracic aorta; (after Pietrabissa (1996)).
Biomaterials used for Vascular Grafts (cont.)

• Teflon
  – Great tensile strength, mechanical toughness and durability

• Dacron
  – Very similar to Teflon
  – Can be shrunk by heat exposure
  – Thread available in many different sizes
Fibre Configurations

- There are three main configurations of vascular grafts:
  1. Tightly woven
  2. Warp-Knit
  3. Velour-Knit
Fibre Configurations

• Porosity in vascular grafts provide a scaffold for the rebuilding of perivascular tissue to some extent
• Highly porous (knitted) materials allow for cellular growth within the graft walls.
• Preclotting for highly porous grafts is required before surgical procedure to reduce/eliminate initial blood loss
# Microporous Vs Macroporous (Tightly woven Vs Knitted)

<table>
<thead>
<tr>
<th>Microporous</th>
<th>Macroporous</th>
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<tbody>
<tr>
<td>Requires minimal/no preclotting</td>
<td>Preclotting is required</td>
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<tr>
<td>- More difficult to suture</td>
<td>- Easier to suture</td>
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<tr>
<td>- More stiff vessel</td>
<td>- More comfortable for patients</td>
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<tr>
<td></td>
<td>- Better Healing</td>
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Healing Process

• Fibrin surfaces on both interior and exterior walls mature and dimensions stabilize after 24 hours

• Pseudointimal formation:
  – coating of surfaces with proteins and non endothelial cells

• Neointimal formation:
  – Endothelial cells line the surfaces of implant
Anatomy of a Blood Vessel

- vasa vasorum
- nerve
- tunica adventitia
- external elastic lamina
- smooth muscle cells
- internal elastic lamina
- smooth muscle + connective tissue
- basale membrane
- endothelium
- tunica media
- tunica intima
Complications of Vascular Grafts

- Compliance mismatch at the anastomosis
- Intimal hyperplasia
- Thrombogenicity
- Poor haemodynamics
Minimize Differential Compliance

• Interruption causes stresses at the anastomosis
• Stresses may lead to disruption of the suture, false aneurysm, and intimal hyperplasia
• High pressure systems such as the aorta require stiffer and stronger materials
• In smaller diameter vessels, radial compliance is more important than strength
Modes of Biodegradation

• May cause irreversible change in the characteristics of the graft
• Toxic byproducts may be released postdegradation
• Consist of physical and chemical changes
Physical Changes

- Swelling
- Plasticization
- Fatigue
- Creep
- Kinking
Chemical Changes

- Hydrolysis of susceptible bonds
- Oxidation by inflammatory mediators
- Calcification
Blood Clotting

- Formation of a gel of insoluble fibrin threads trapping formed elements of the blood

(Saltzman, Biomedical Engineering Bridging Medicine and Technology, 2009)
Anticoagulants

• Delay, suppress, or prevent blood clotting
• Naturally present in blood
• **Antithrombin** suppresses action of Factors XII, X, and II (prothrombin)
• **Heparin** combines with **antithrombin** to boost its effectiveness in blocking thrombin
Surface Modifications for Improving Biocompatibility

- Prevention of thrombus formation important in vascular grafts
- **Heparin** end-point covalently bonded to the luminal surface of the graft
- **Polymeric fluorocarbon coatings** deposited from a tetrafluoroethylene gas discharge have been found to greatly enhance resistance to both acute thrombotic occlusion and embolization in small diameter Dacron® grafts [The Biomedical Engineering Handbook].
Patency vs. Circumferential Thrombus

Circumferential thrombus
1mm in depth
reduces flow area by:

- 20.0mm → 19%
- 15.0mm → 25%
- 10.0mm → 36%
- 5.0mm → 64%
- 2.5mm → 96%
Common Vascular Surgeries

- Vascular surgeries are required to repair aneurysms, arterial stenosis, and unwanted blood clots.
- Typical surgeries performed on arteries of the heart (coronary arterial bypass), kidneys, legs (femoropopliteal bypass), and abdominal aorta.
Future Prospects

• Introduction of biodurable and compliant polyurethene grafts
• Advancements in tissue hydrogels which incorporate signals and biological factors into replaced tissues.
• Incorporating fibronectin to inner walls of protheses to promote neointimal healing
• Autologous tissue engineered grafts


