Cardiovascular Biomaterials

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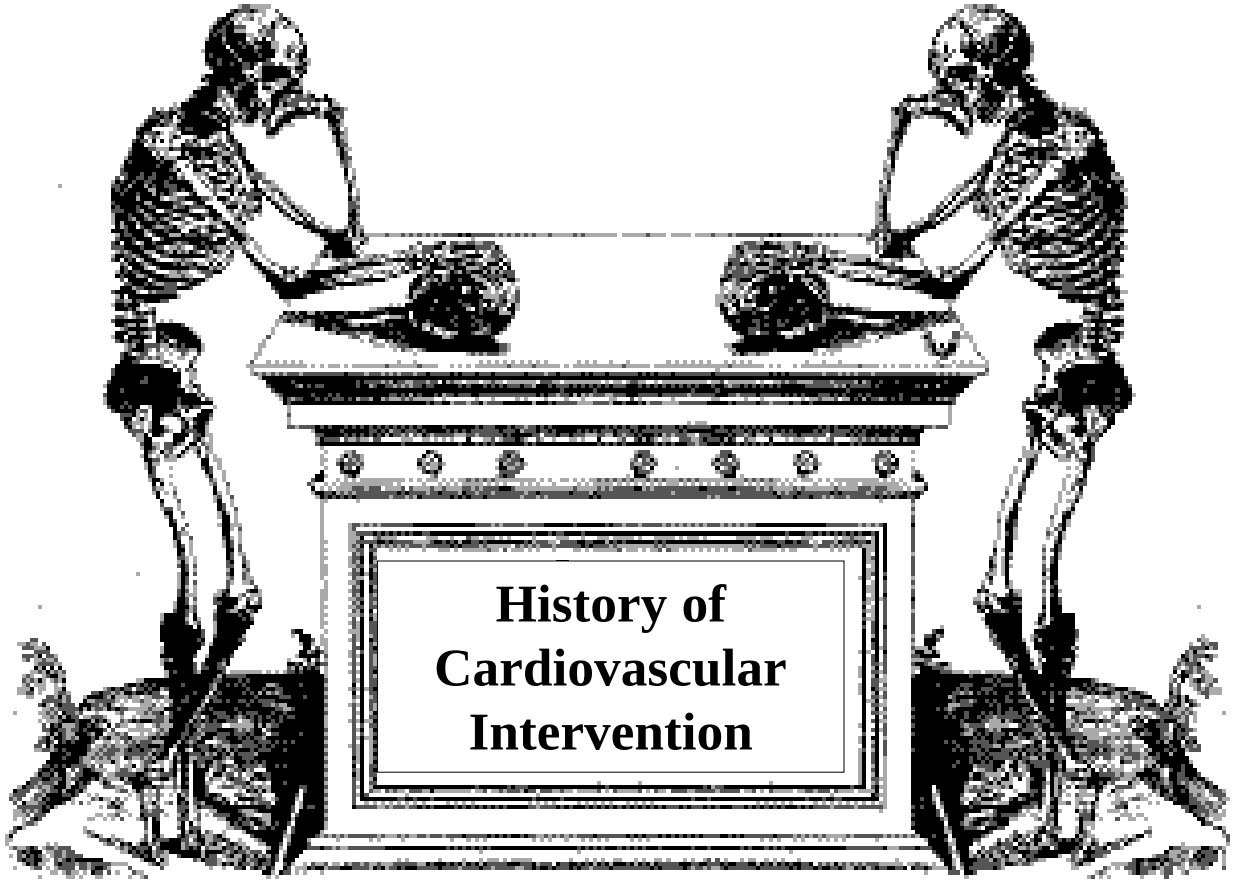
Overview

History

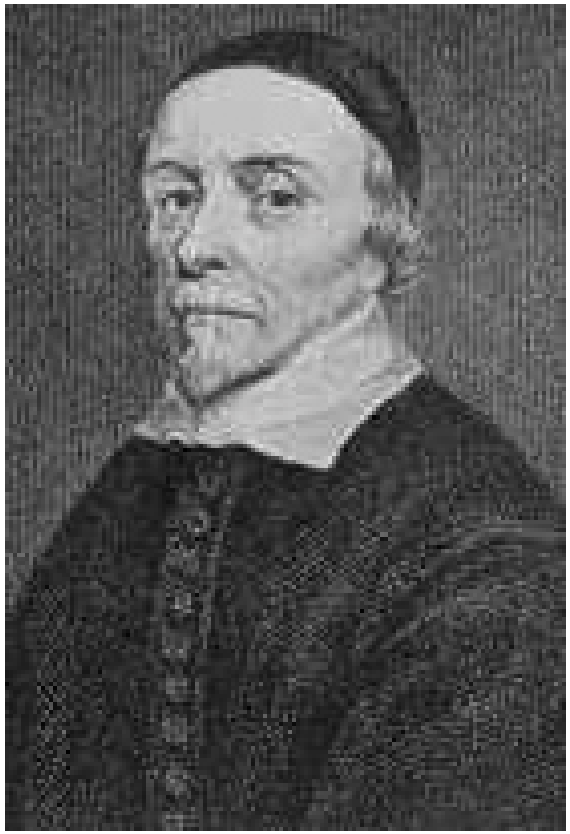
Blood Material Interactions

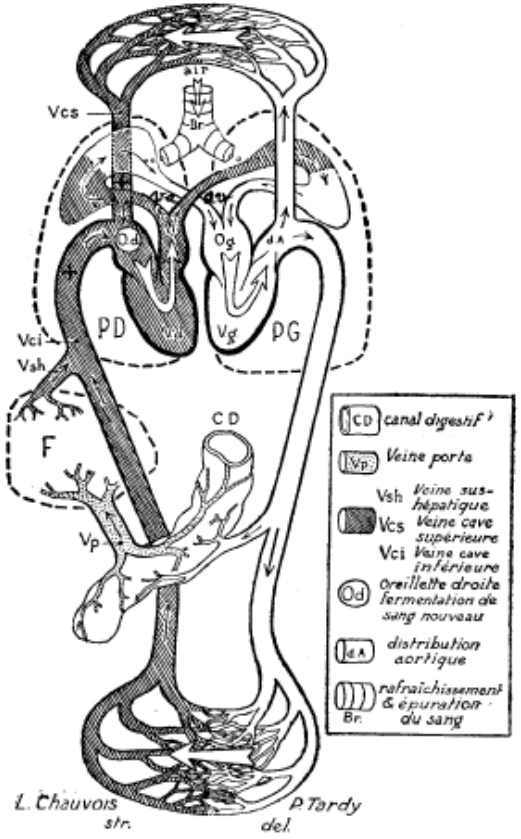
Specific Applications

Future Directions


History of
Cardiovascular
Intervention

Historical





1628 - William Harvey, English Physician, describes blood circulation.

Historical

1706 - Raymond de Vieussens, French anatomy professor, first describes the structure of the heart's chambers and vessels.

1733 - Stephen Hales, English clergyman and scientist, first measures blood pressure.

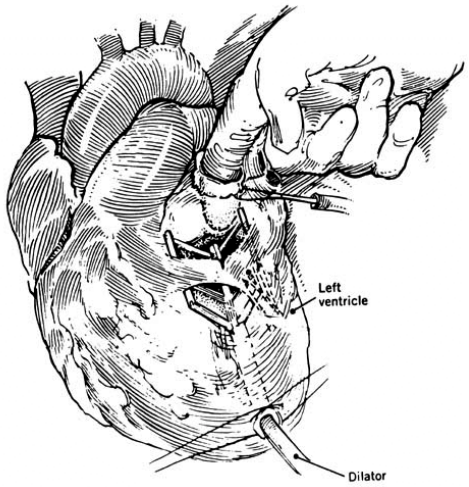
1816 - Rene Laennec, French physician, invents the stethoscope.

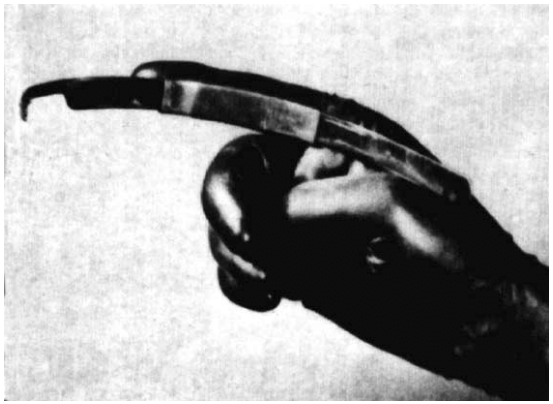
1903 - Willem Einthoven, Dutch physiologist, develops the electrocardiograph.

1912 - James Herrick, American physician, first describes heart disease resulting from hardening of the arteries.

Historical

1948 - Dwight Harken, American surgeon, performs first closed mitral commisurotomy.





Historical

1951 - Charles Hufnagel, American surgeon, develops a plastic valve to repair an aortic valve.

1952 - F. John Lewis, W. Lillehei, American surgeons, perform first successful open heart surgery (VSD repair).

Historical

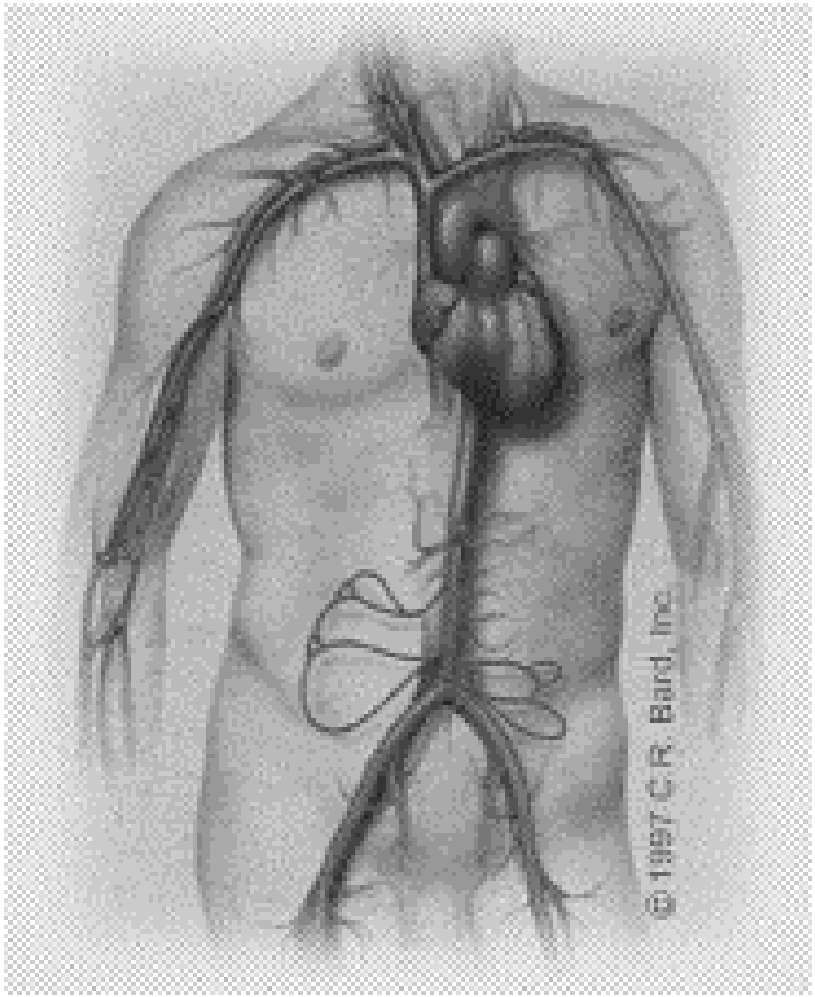
1953 - John H. Gibbon, American surgeon, first uses a mechanical heart and blood purifier.

1965 - Michael DeBakey and Adrian Kantrowitz, American surgeons, implant mechanical devices to help a diseased heart.

1967 - Christiaan Barnard, a South African surgeon, performs the first whole heart transplant from one person to another.

1982 - Willem DeVries, an American surgeon, implants a permanent artificial heart, designed by Robert Jarvik, an American physician, into a patient.

Cardiovascular System



Devices

Heart Valves	**52,000**
Mechanical	**(32,000)**
Bioprosthetic	**(20,000)**
Pacemakers	**144,000**
Vascular grafts	**160,000**
Oxygenators (CPB)	**260,000**
Heart Assist	**31,717**
IABP	**(31,300)**
VAD	**(400)**
TAH	**(17)**

Blood Material Interactions

Detrimental effects on material/device

Detrimental effects on blood/tissue/organ

Effect on Materials/Device

Adsorption of plasma proteins, lipids, calcium

Adhesion of platelets, leukocytes, erythrocytes

Formation of pseudointima or capsule

Alteration of mechanical properties

Effect on Subject

Activation of coagulation, fibrinolytic, or immunologic pathways

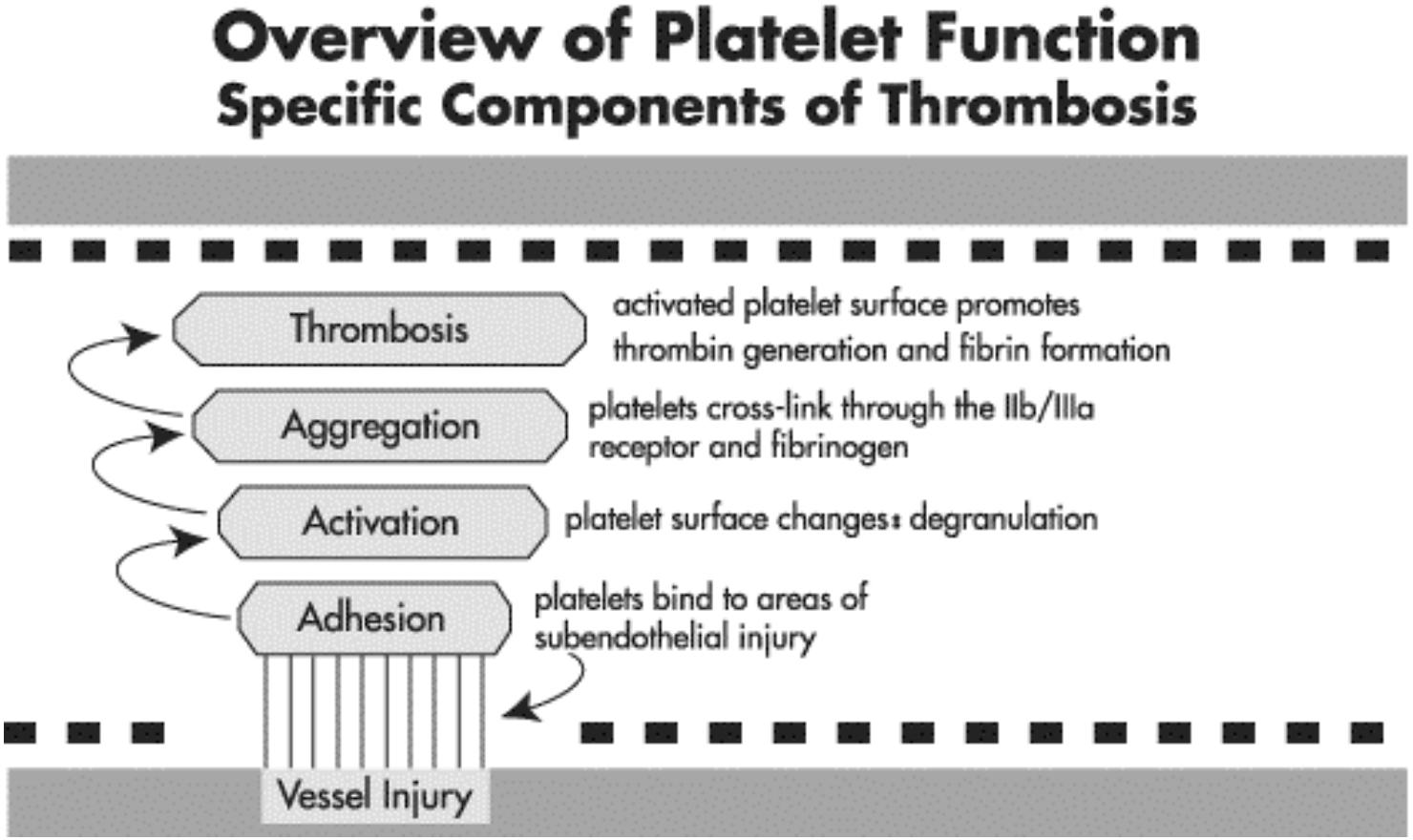
Formation of thrombi and/or embolization

Anemia, hemolysis, leukopenia, thrombocytopenia, altered RBC function

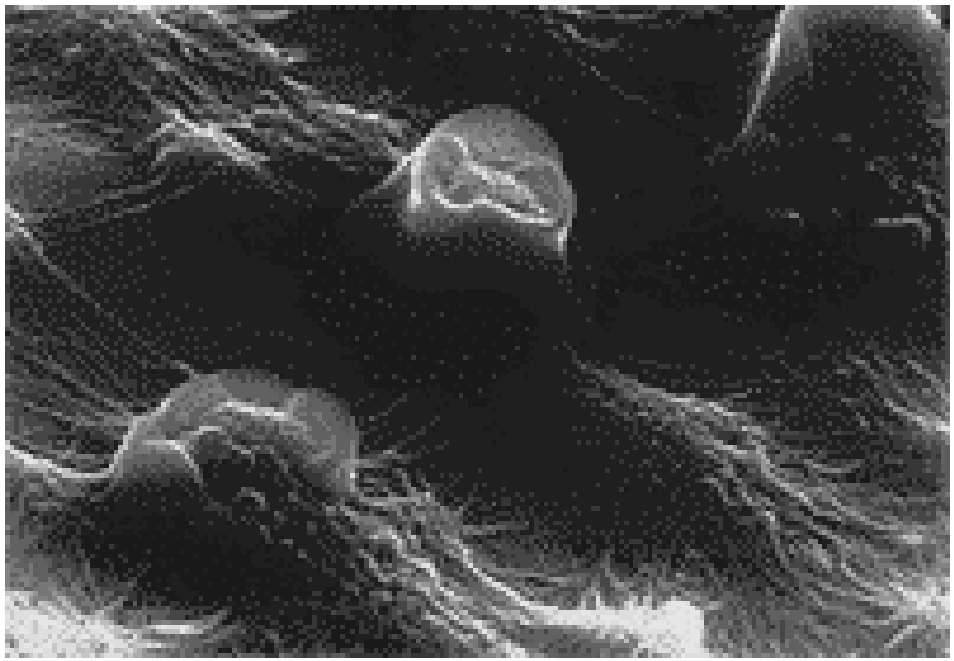
Cell and/or tissue injury

Intimal hyperplasia, capsule affecting function

Platelets / Thrombosis



Platelets / Thrombosis



Electron micrograph of thrombus with leukocytes surrounding deposited platelets

Specific Applications

Heart surgery

Vascular surgery

Heart Assist

Other

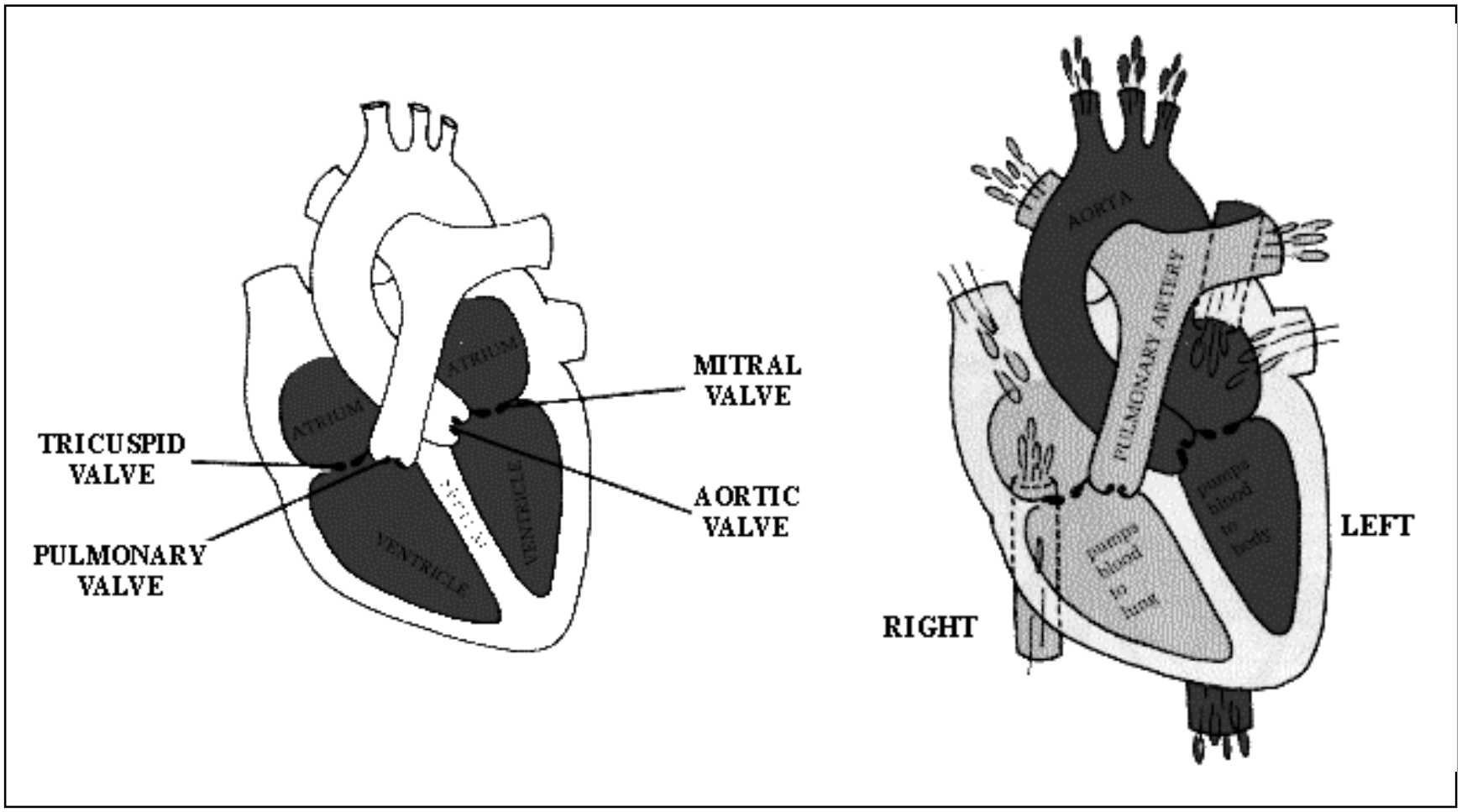
Heart Surgery

Cardiopulmonary bypass

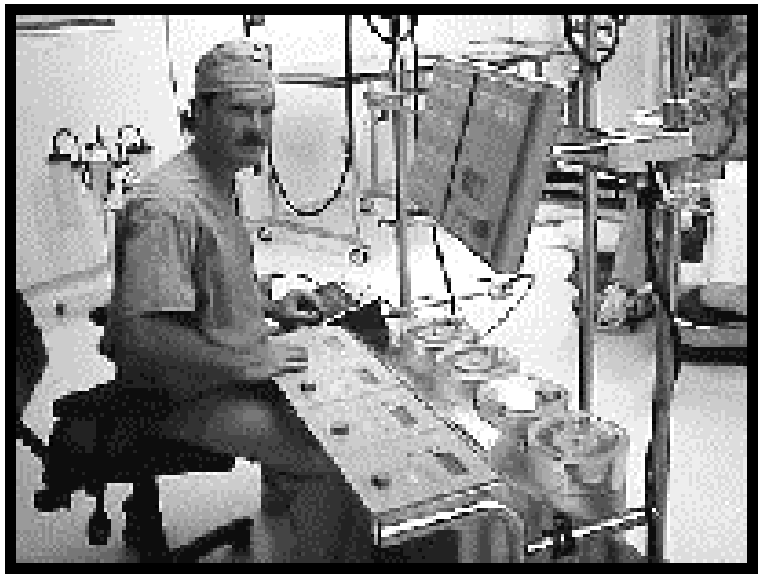
Coronary artery interventions

Heart valves

Cardiac anatomy / circulation



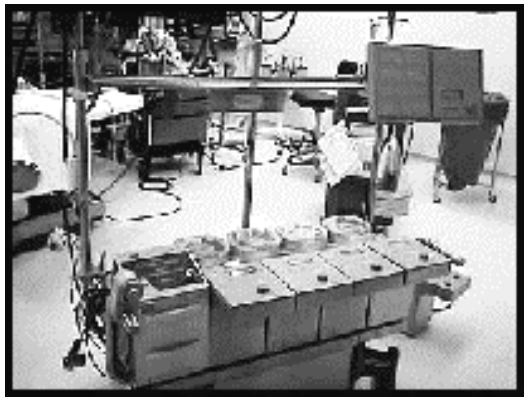
Cardiopulmonary Bypass

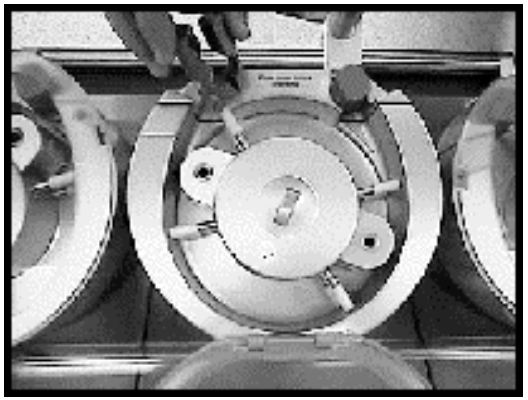


Pumps unoxygenated venous blood through oxygenator, and back to arterial system

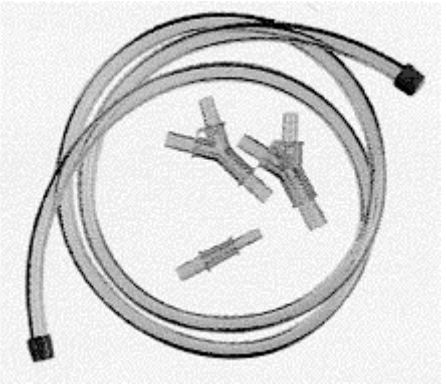
Allows open heart surgery, ECMO, ARDS treatment

CPB components (1)



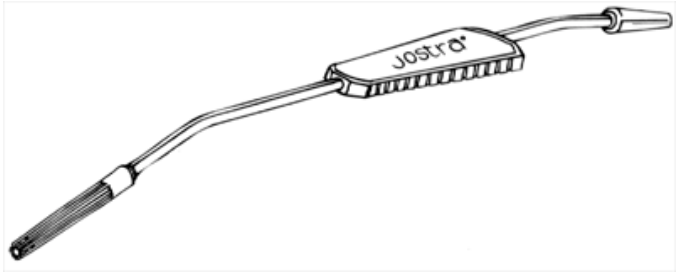


Blood pumps (roller head, vortex)



Tubing, connectors

Oxygenators (membrane, bubbler)



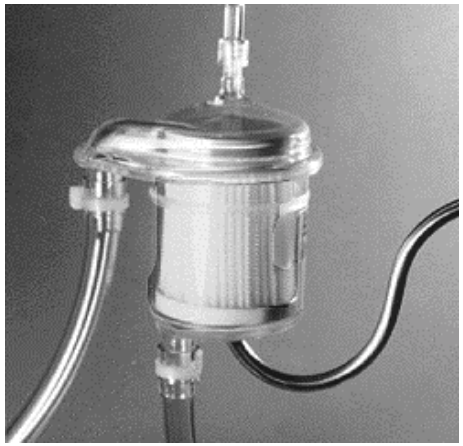
Suction

CPB components (2)

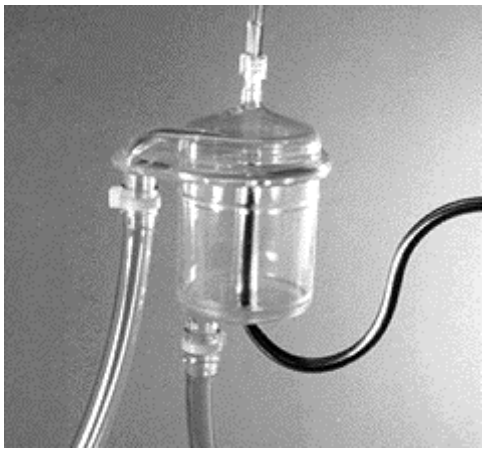
Cardioplegia

Resevoirs (hard shell, membrane)

Heat exchanger



Arterial filter



Bubble trap

CPB

Materials used:

- **Silicone elastomers**
- **Microporous polypropylene**
- **Polyester (mesh in filter)**
- **Acrylonite-styrene polymers**
- **Polyurethane**
- **Polycarbonate**
- **Stainless steel**

CPB

Clinical benefits:

- **Allows open heart surgery, complex repairs**
- **Allows recovery from RDS, trauma**

Problems to overcome:

- **Major activation of coagulation and complement**
- **Requires systemic anticoagulation**

Oxygenators

-Complement activation (contact, coagulation, fibrinolytic pathways activated)

-Platelet function abnormalities, bleeding, transfusions

-Post perfusion lung syndrome, neuropsych complications (due to platelet or leukocyte aggregates, or microbubbles)

Oxygenator comparison

Bubble oxygenators

- **Respiratory gas in contact with blood**
- **Requires defoamer + bubble trap**
- **Increased blood trauma**

Membrane oxygenators

- **Blood and gas separated**
- **hollow fiber (polypropylene, polyurethane epoxy)**
- **Coated aluminum tubes (heat exchangers)**
- **Less hemolysis, less protein denaturation**
- **Better preservation of platelet count and function**

-

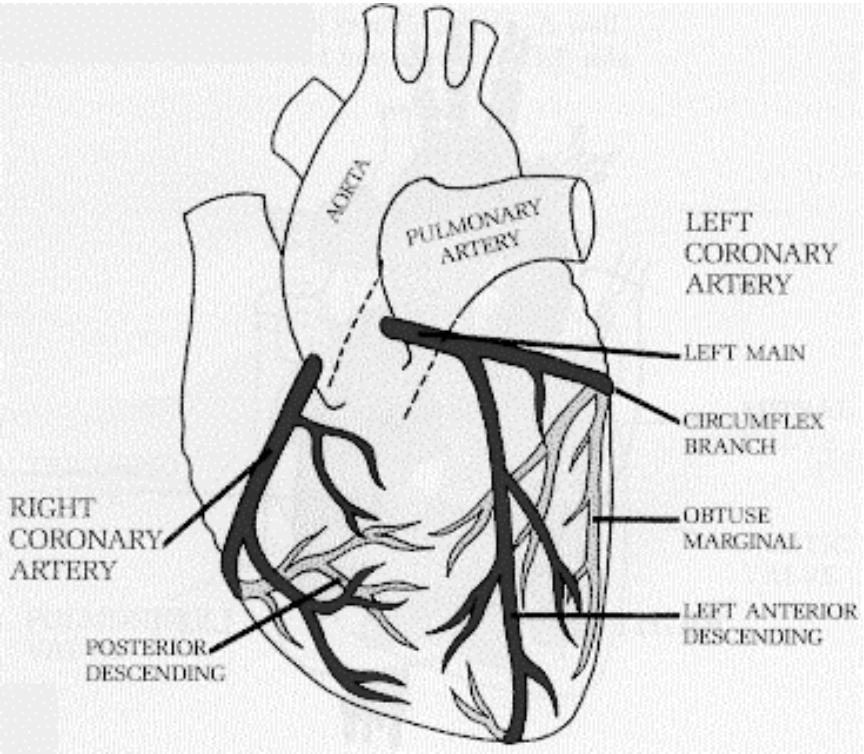
Coronary Artery Intervention

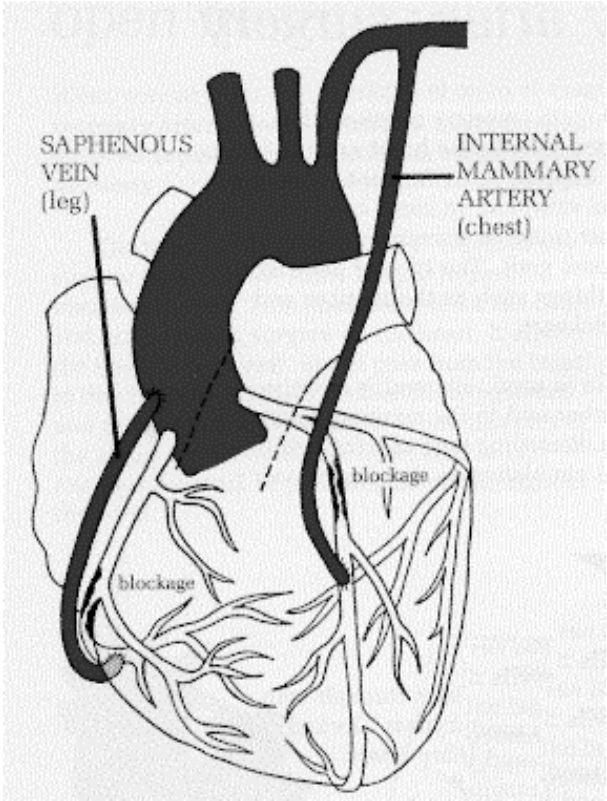
CABG (coronary artery bypass graft)

Catheters/Cannula

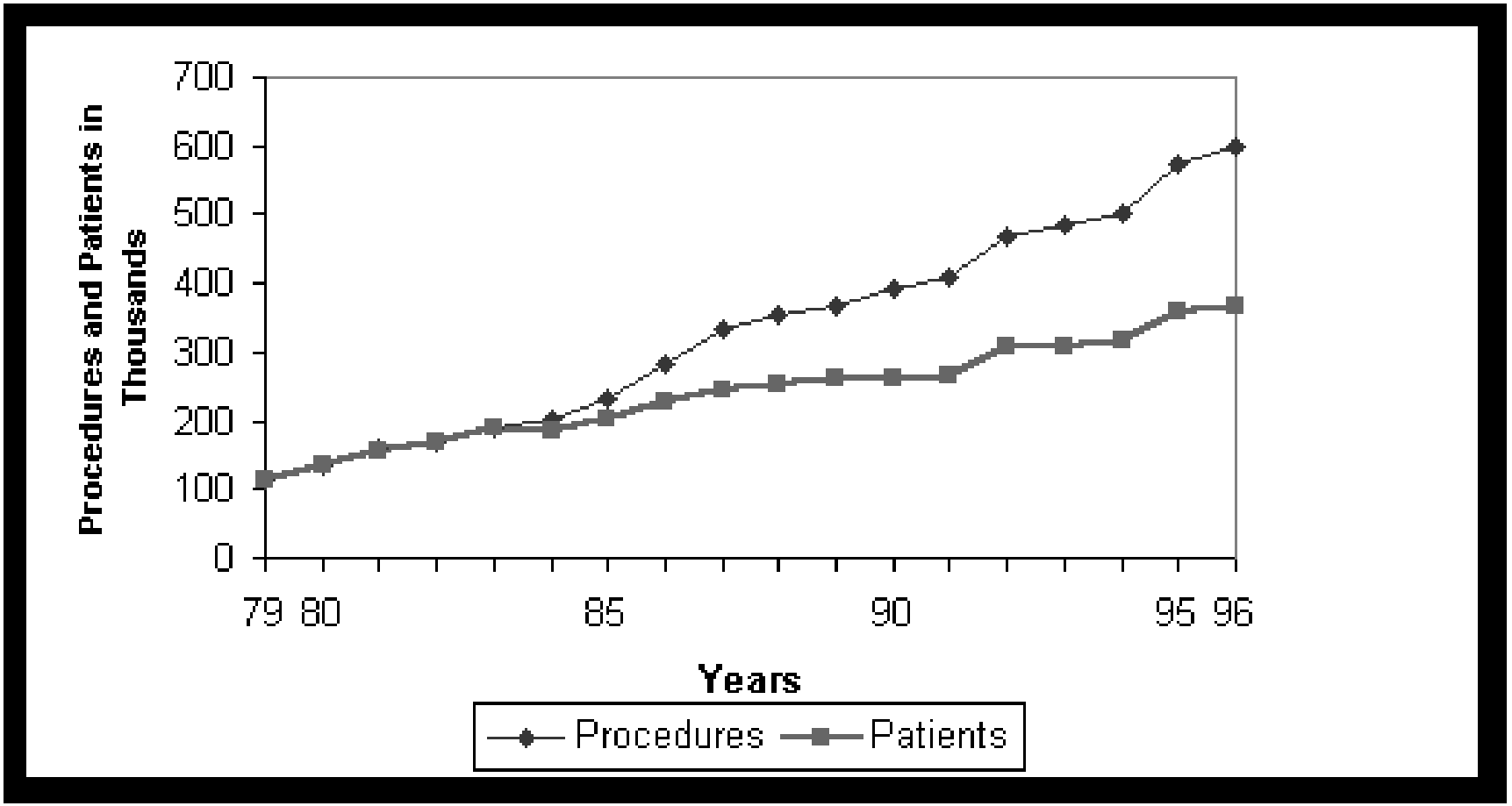
PTCA (percutaneous transluminal coronary angioplasty)

Coronary anatomy





CABG

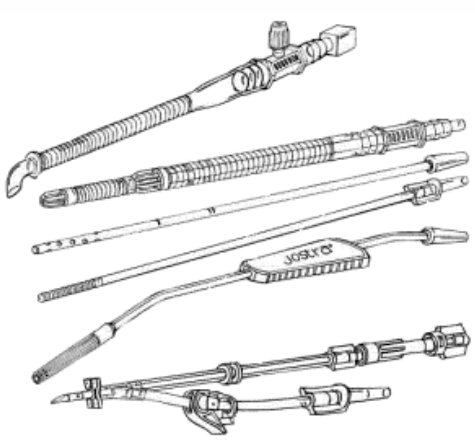

Procedures and Patients in Thousands
700
600
500
400
300
200
100
0
79 80
85
90
95 96
Years
Procedures
Patients

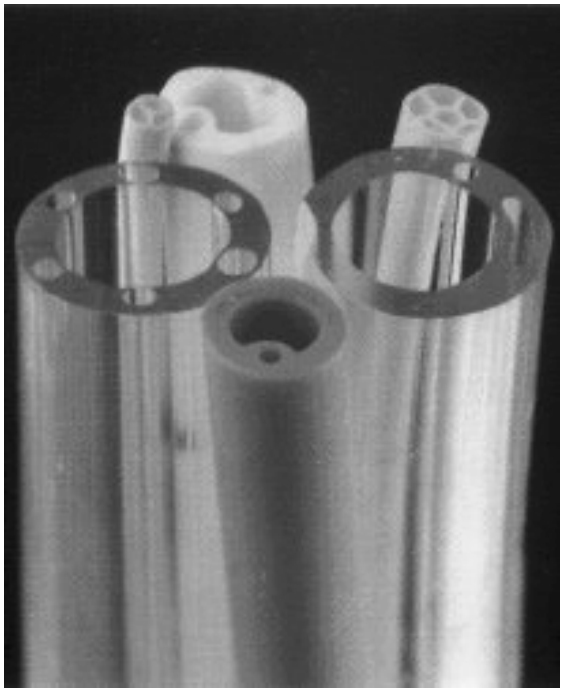
Catheters, Cannulas

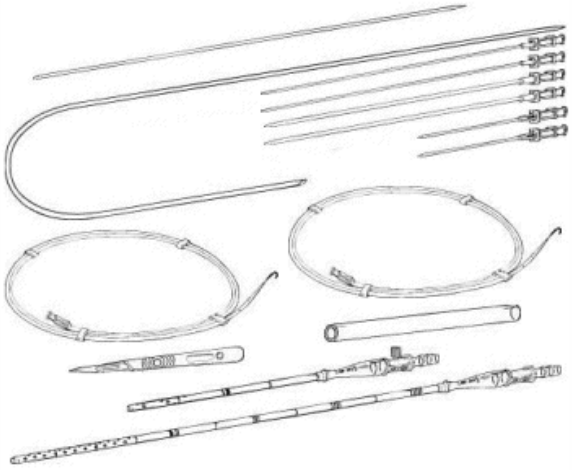
Placed in virtually every portion of arterial+venous circulation

Administering fluids, withdrawing blood specimens, pressure monitoring, other data monitoring

Catheters, cannulas







Catheters/Cannulas

Materials used:

Polyurethane, etc.

Silicone elastomers

Clinical benefits:

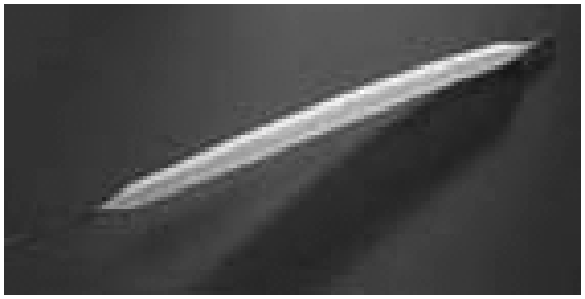
Widespread appliacations for administering fluids, monitoring patient conditions

Problems to overcome (few):

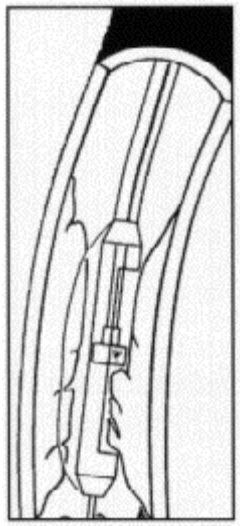
Vascular endothelium injury

Thromboembolism

PTCA / DCA

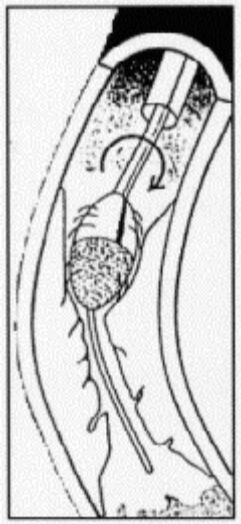


Percutaneous transluminal coronary angioplasty

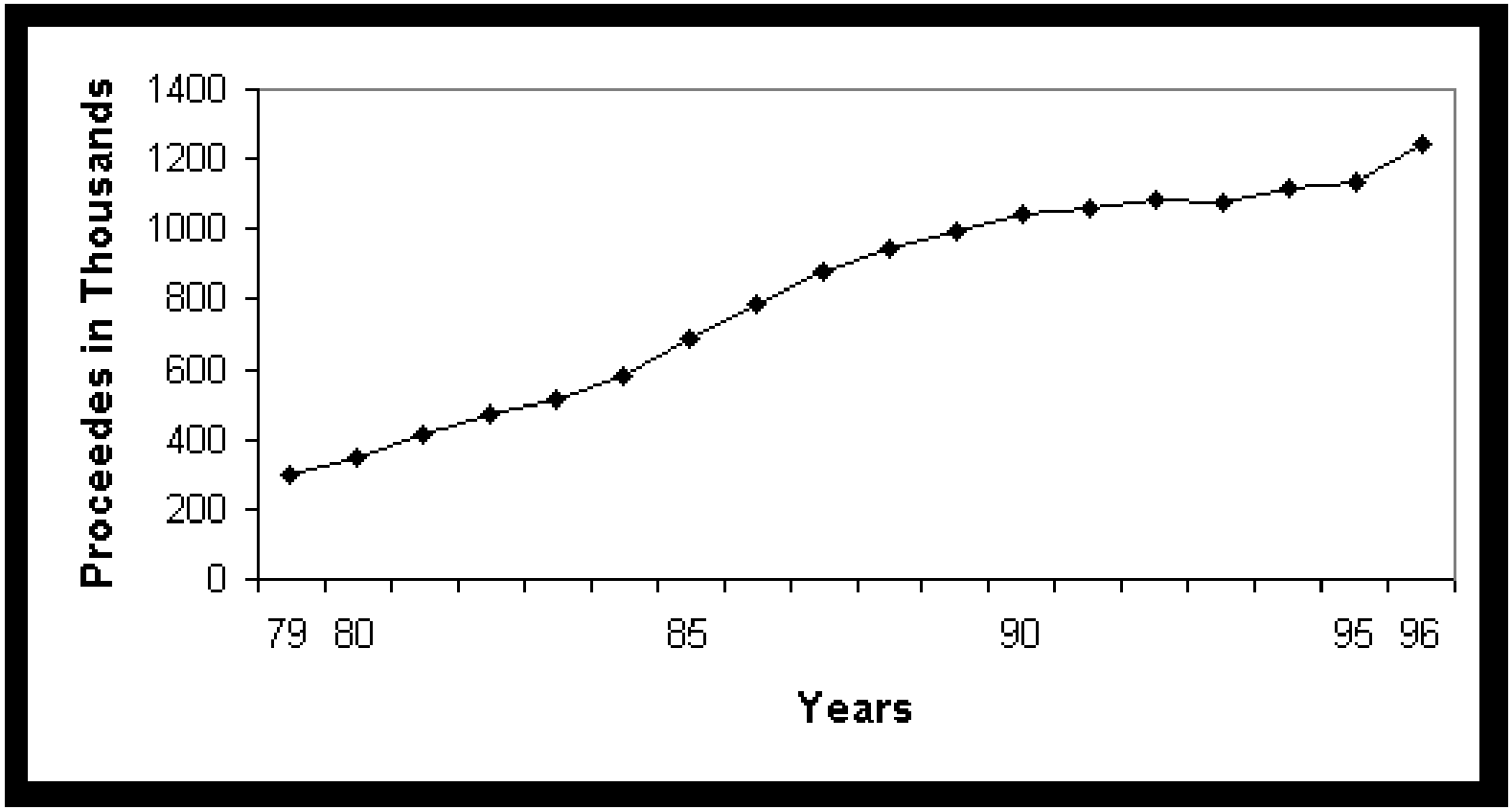


Direct coronary atherectomy

Rotoblader



PTCA


Proceedes in Thousands
1400
1200
1000
800
600
400
200
0
79
80
85
90
95
96
Years

PTCA / DCA

Materials used:

- **Polyurethane**
- **Silicone elastomers**
- **Stainless steel**

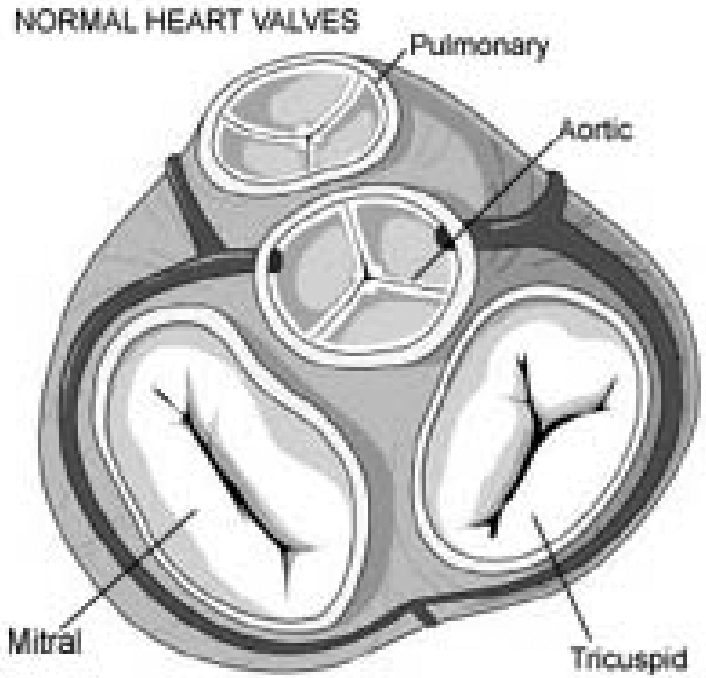
Clinical benefits:

- **Allows correction of stenosis without surgery**

Problems to overcome

- **Vascular endothelium injury**
- **Restenosis rate**

Heart Valves



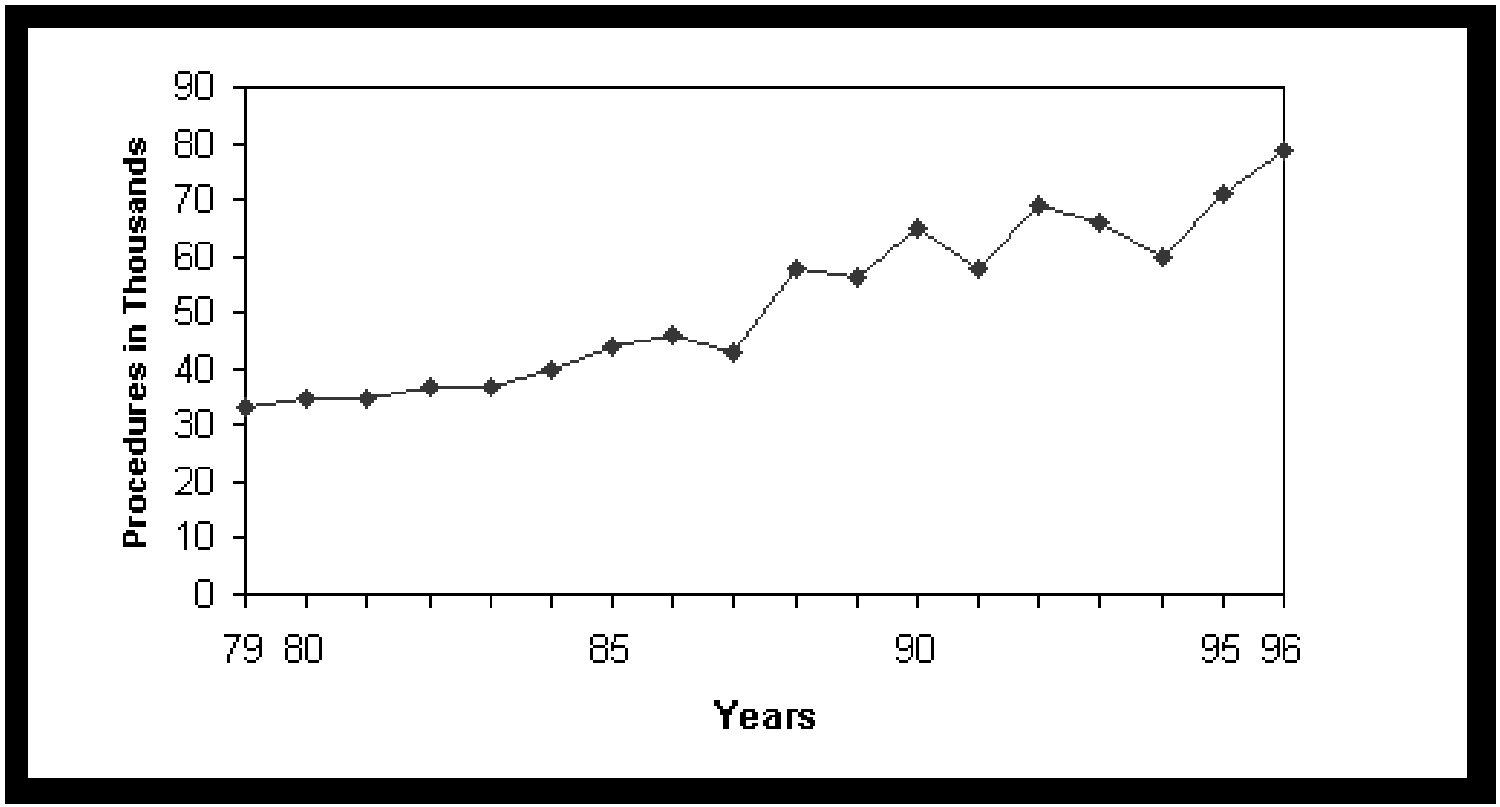
Mechanical Valves

Bioprosthetic Valves

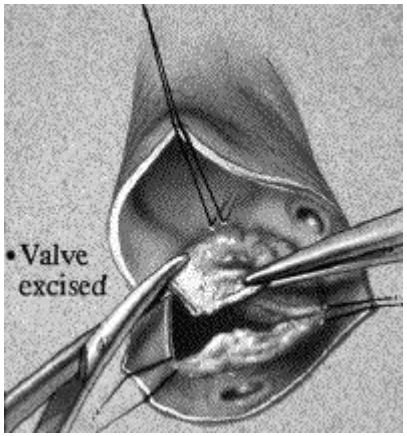
Valve repair

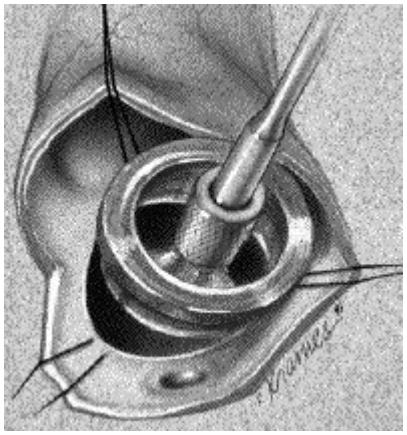
Homografts

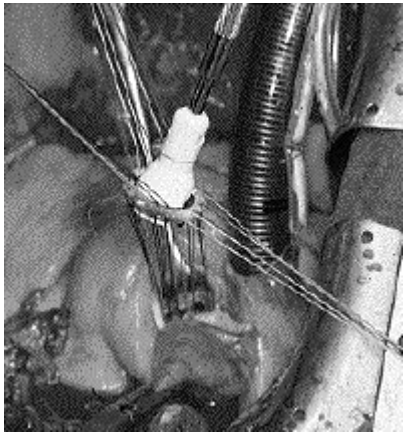
Valve Replacement Procedures

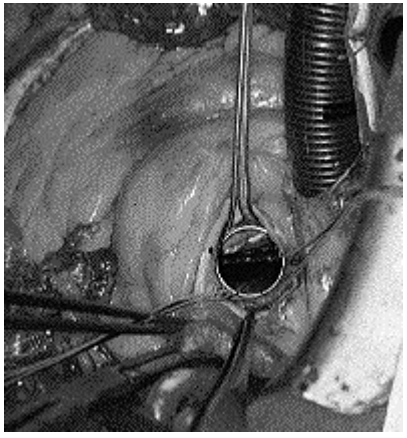


Valve Replacement Procedure

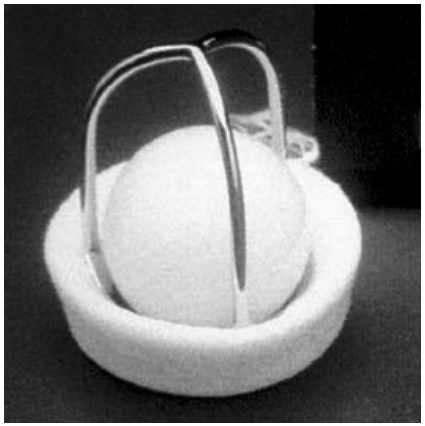




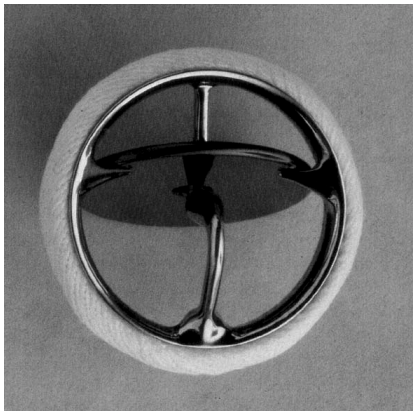




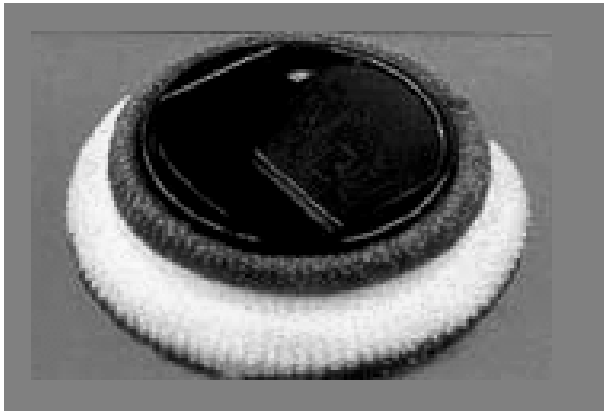
Mechanical Valves



Ball and cage



Tilting disk



Bileaflet valve

Mechanical valves

Materials:

- **Silicone elastomer**
- **Cobalt-chrome alloys**
- **Pyrolytic carbon**
- **Titanium**
- **Dacron**

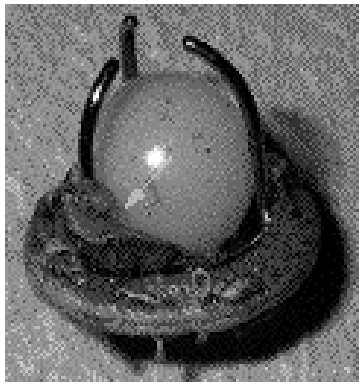
Mechanical valves

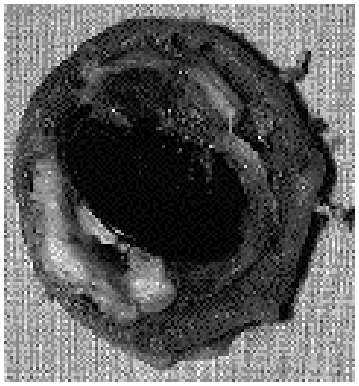
Clinical benefits:

- **Correct significant symptoms**

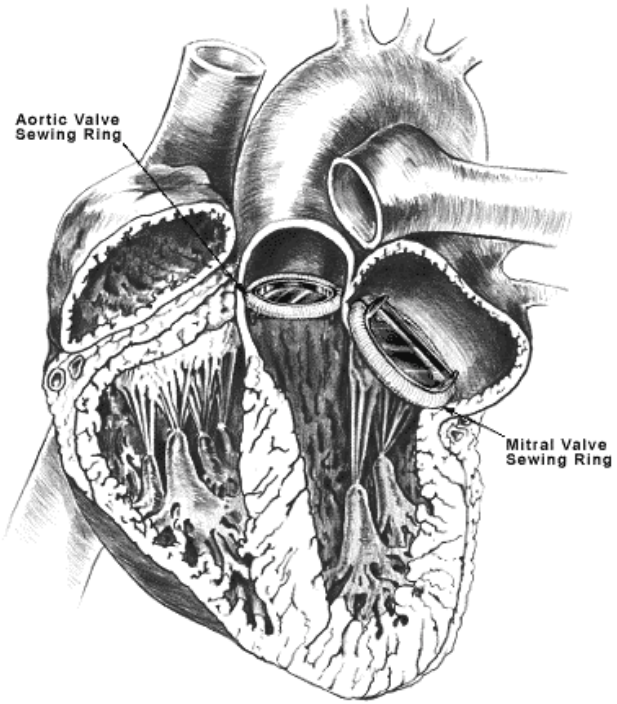
Problems to overcome:

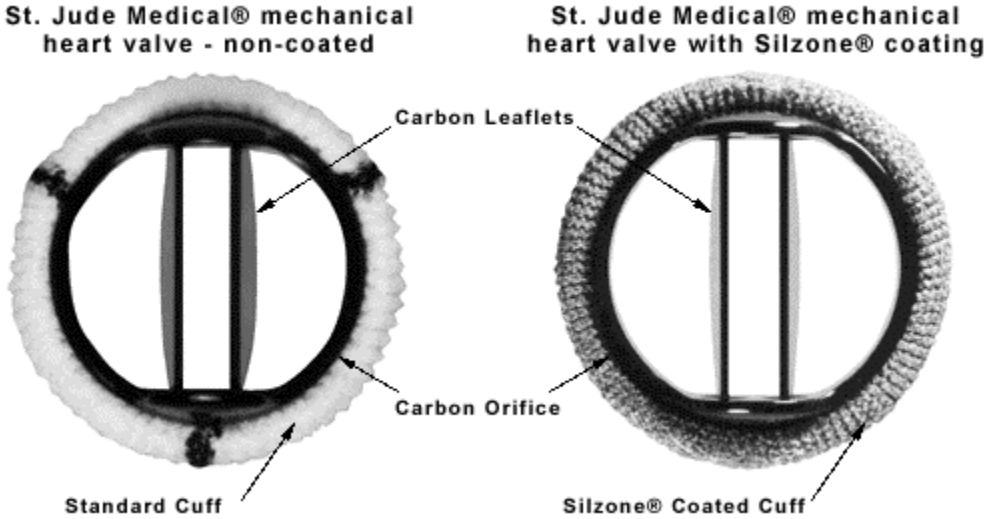
- **Thromboembolism**
- **Bleeding**
- **Structural failure**
- **Endocarditis**



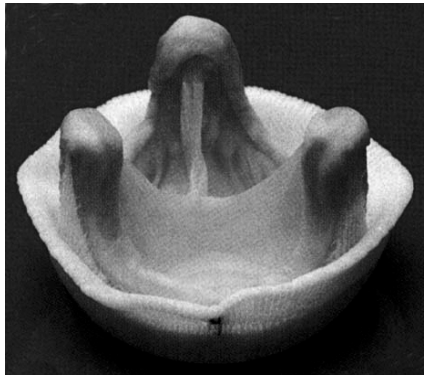


Mechanical valves

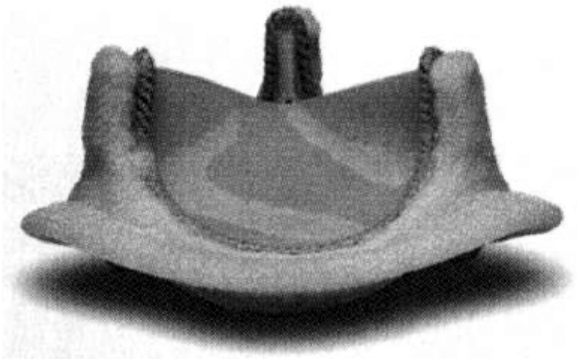




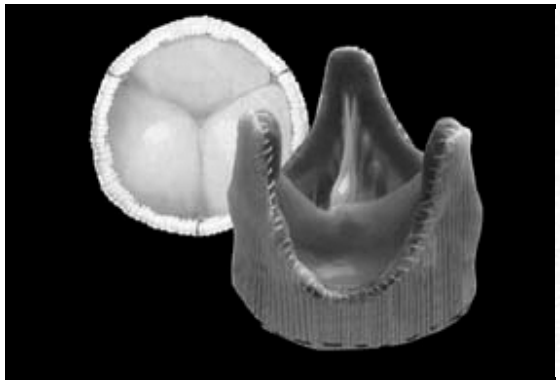
Bioprosthetic Valves



Stented Porcine



Stented Pericardial



Stentless Porcine

Bioprosthetic valves

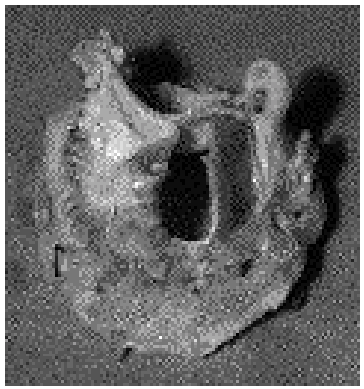
Materials:

- **Porcine cross-linked valve tissue**
- **Pericardial cross-linked tissue**
- **Titanium struts**
- **Dacron covering**

Bioprosthetic valves

Clinical benefits:

Correct significant symptoms



Problems to overcome:

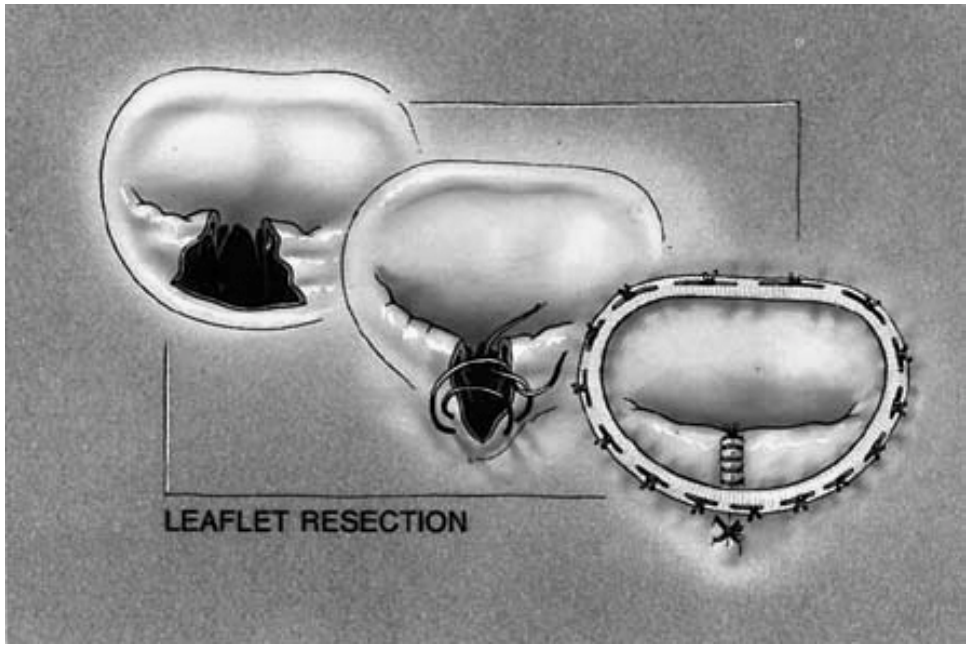
Calcification

Structural deterioration

Antigenic reactions

Endocarditis

Valve repair



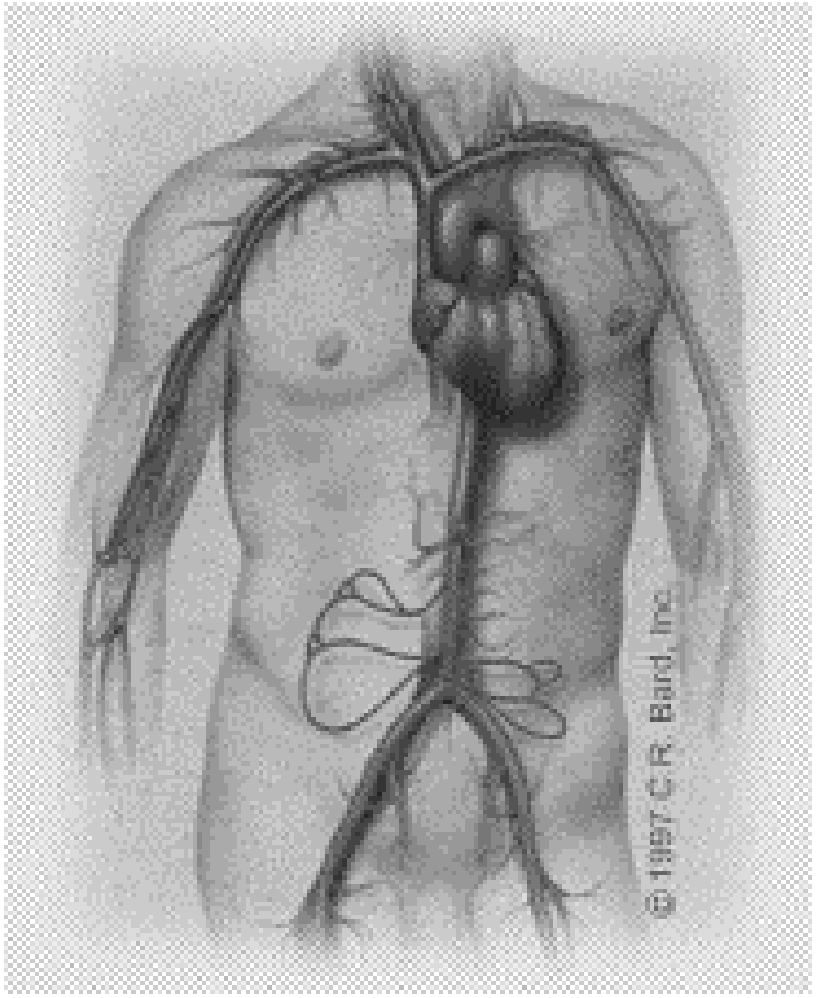
Homografts

Aortic

Pulmonary

Mitral

Vascular Surgery

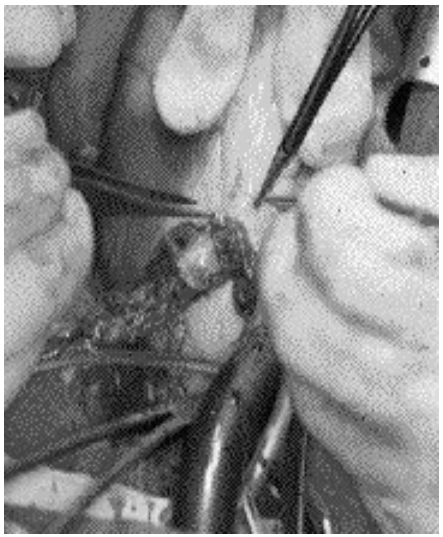


Grafts

Vascular access

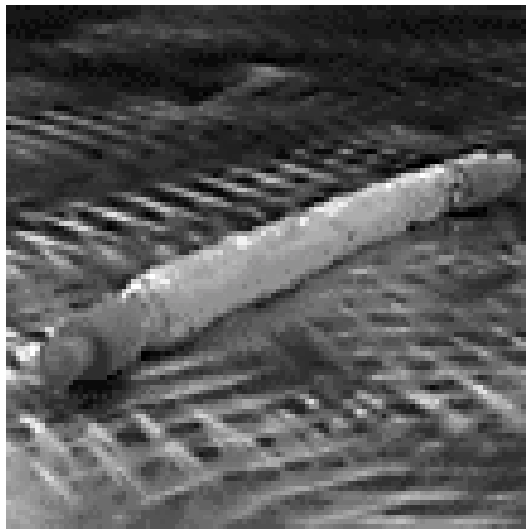
Stents

Biologic Grafts



IMA

Saphenous vein



Femoral vein

Biologic grafts

Materials used:

- **Arterial conduits**
- **Saphenous vein**

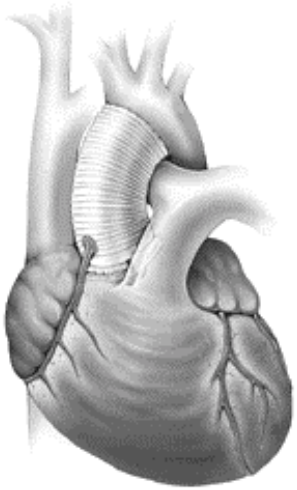
Clinical benefits:

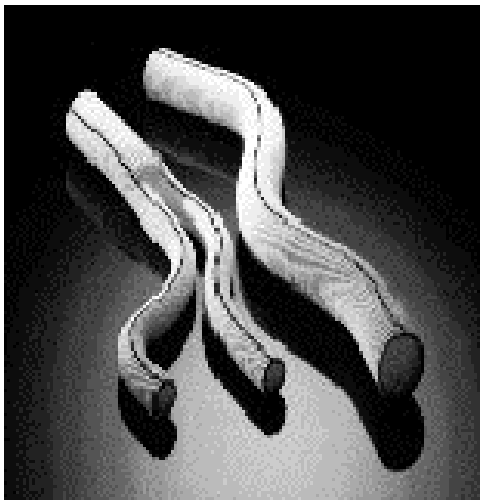
- **Replace blocked arteries, no anti-coagulation**

Problems to overcome:

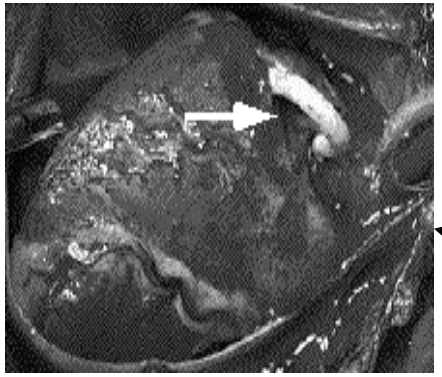
- **Availability, quality, spasm**
- **Thrombosis, neointimal hyperplasia**

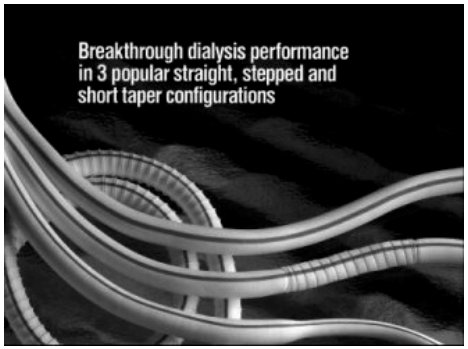
Synthetic Grafts





Large diameter





Small diameter

Sythethtic grafts

Materials used:

Dacron

ePTFE

Clinical Benefits:

Replace blocked arteries, readily available

Problems to overcome:

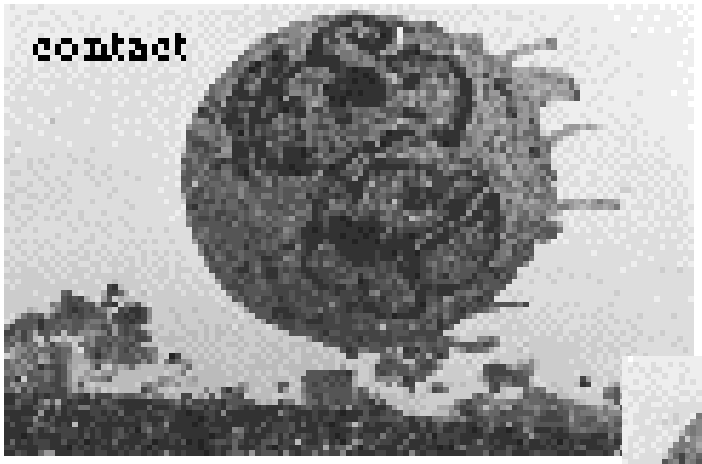
Thrombosis, neointimal hyperplasia

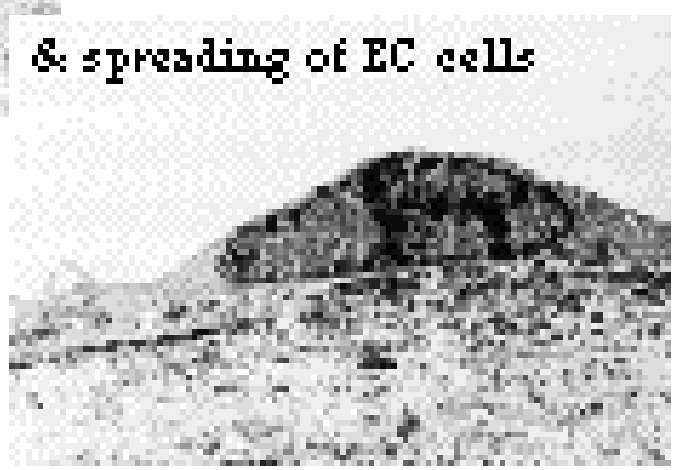
Material treatment

Treatment methods

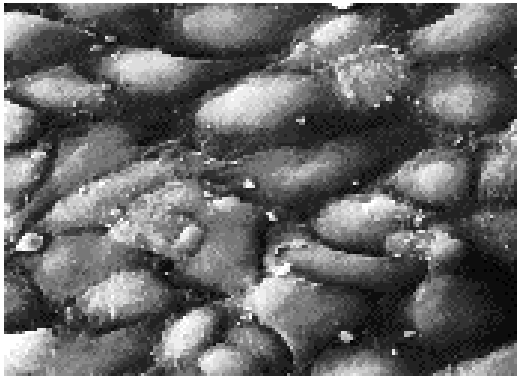
- **Heparin (-coagulation)**
- **Prostacylcin, or dipyriadomole (-platelets)**
- **Urokinase (+fibrinolysis)**
- **Heparin fraction (-intimal hyperplasia)**
- **Seeding / sodding endothelial cells**
- **Compliance matching**

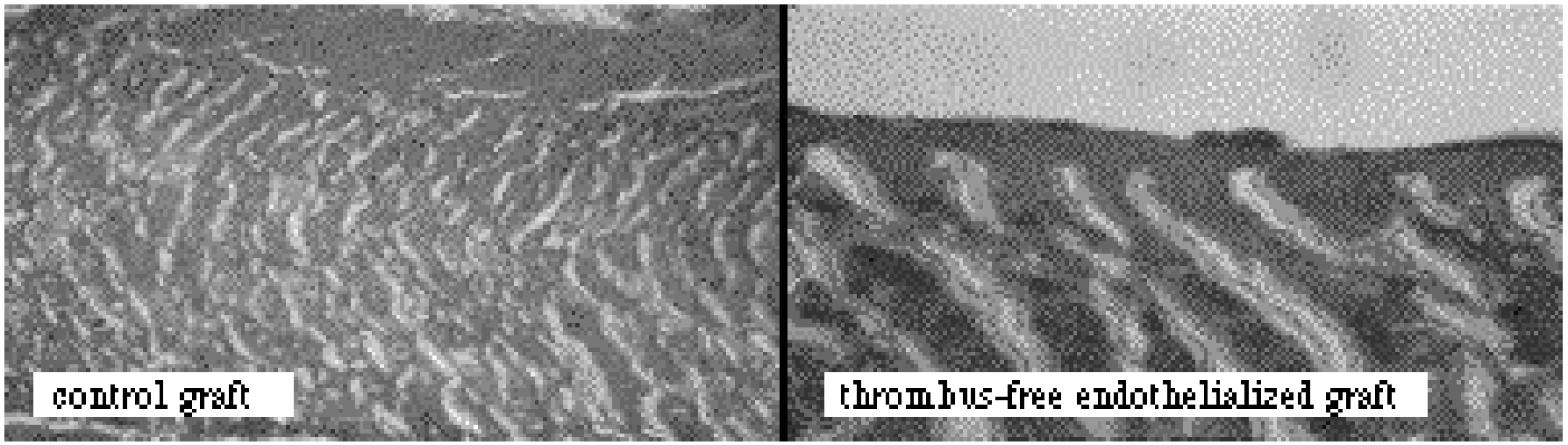
EC adherence



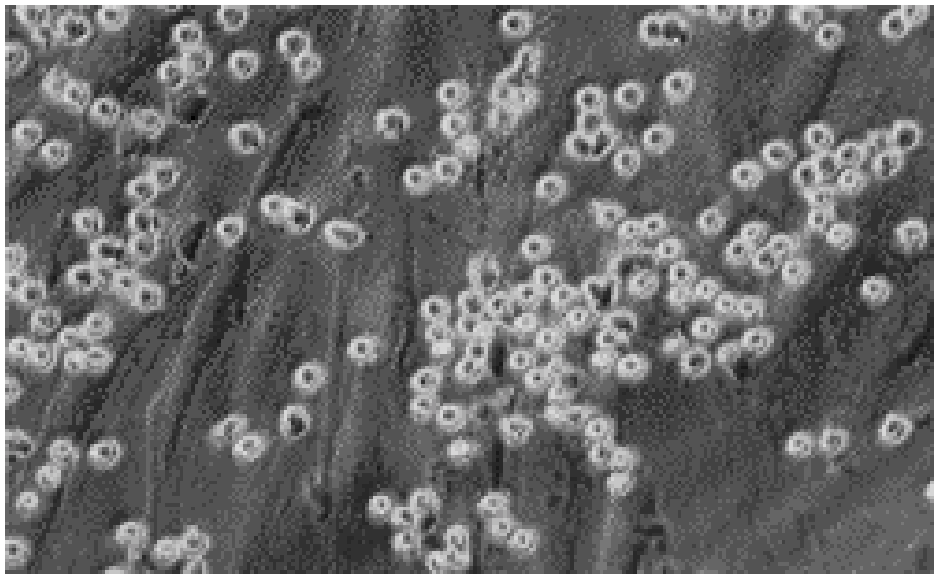


EC adherence

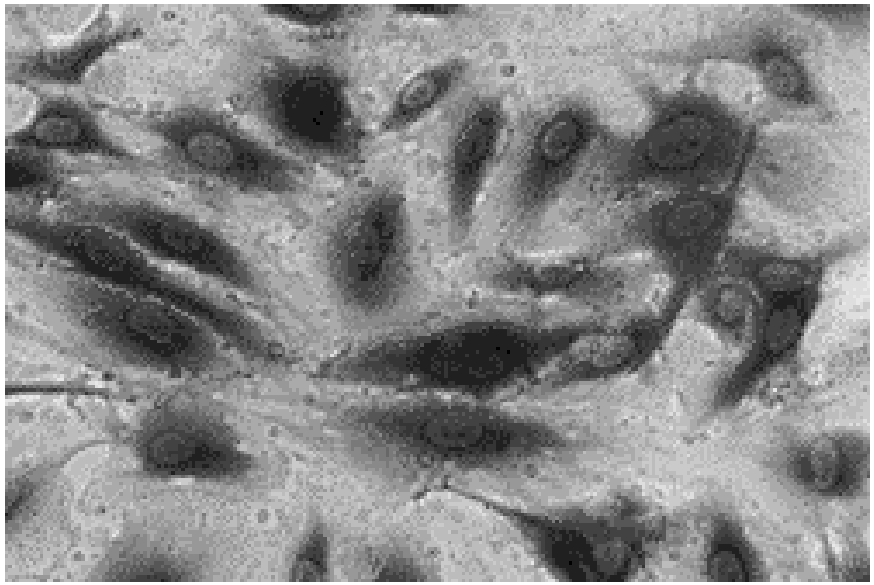




EC adherence

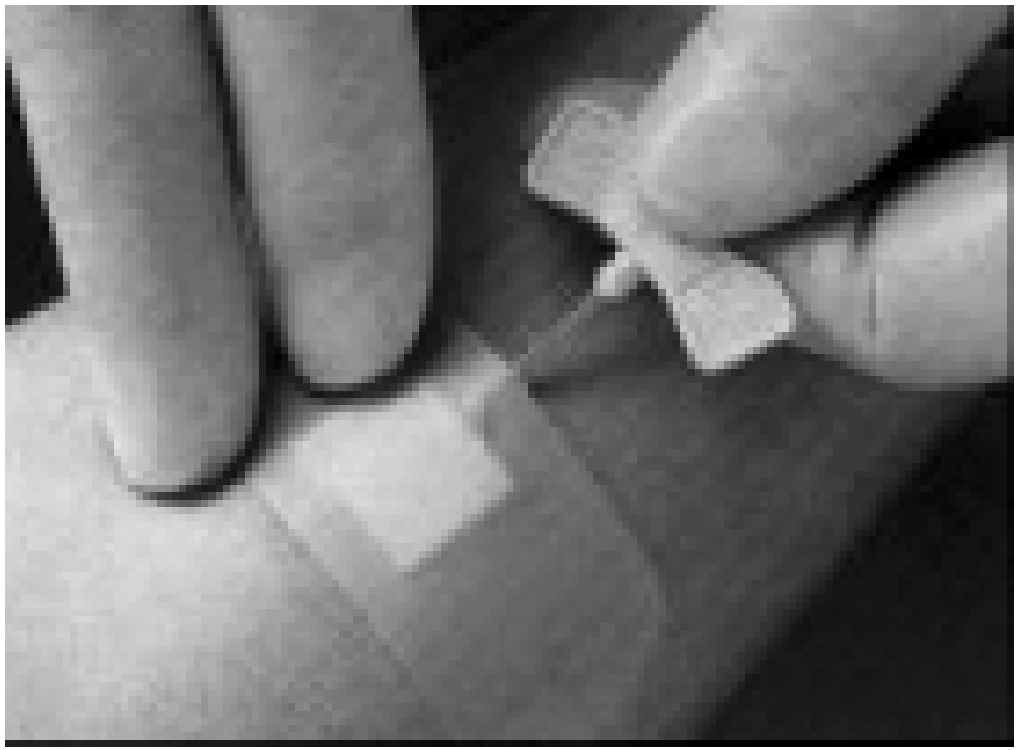


Polymorphonuclear leukocytes adherent to inflamed human microvascular endothelial cells



Retrovirally transfected human microvascular endothelial cells

Vascular access



Vascular access

Materials used:

Polyurethane

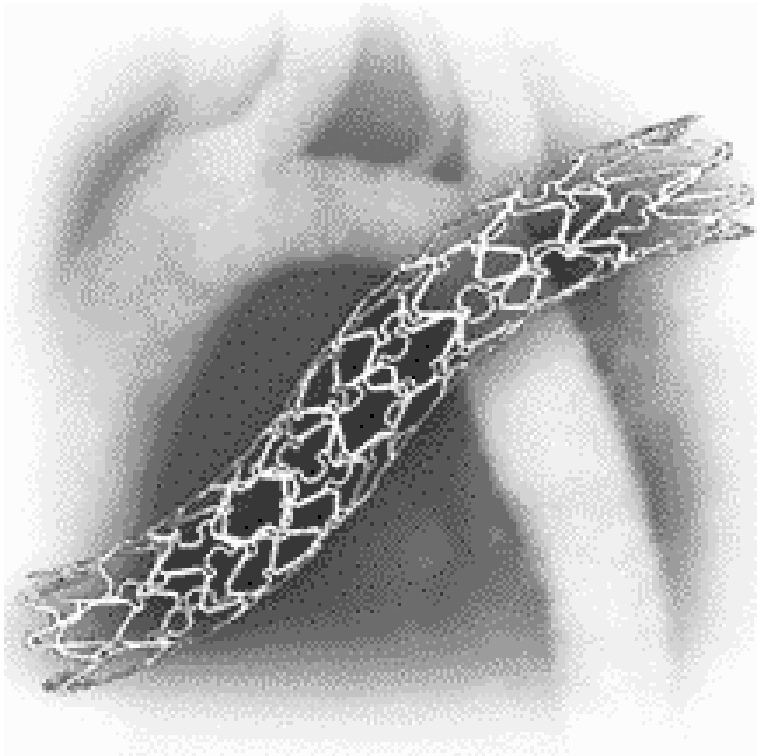
Clinical benefits:

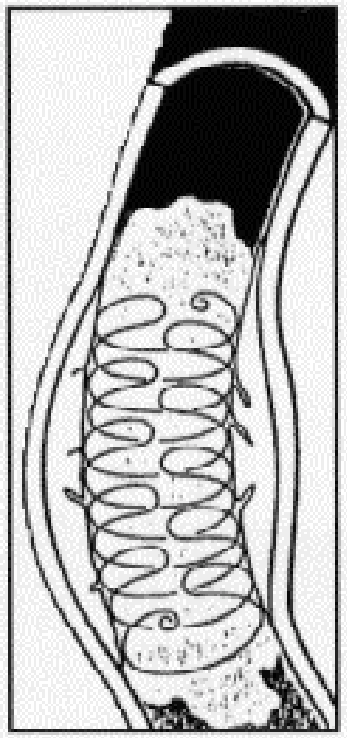
Access for chronic IV therapy, dialysis

Problems to overcome:

Epithelial downgrowth, expulsion

Stents





Stents

Materials used:

- **Nitinol (memory metal)**
- **Biodegradable polymers**

Clinical benefits:

- **Open blocked arteries**

Problems to overcome:

- **EC injury due to insertion**
- **Thrombus, intimal hyperplasia, restenosis**

Heart Assist

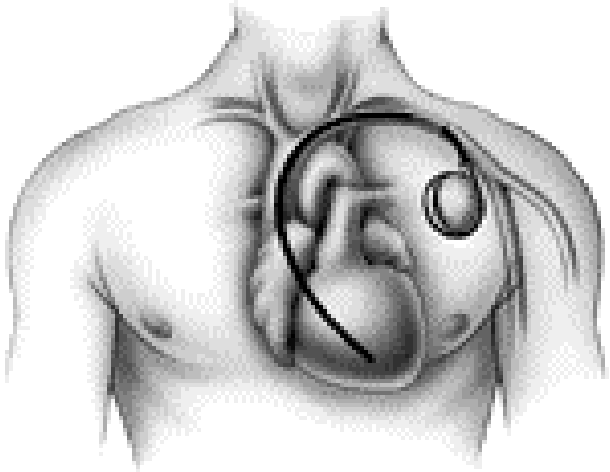
Pacemakers

Intra-aortic balloon pump

Ventricular assist devices

Artificial hearts

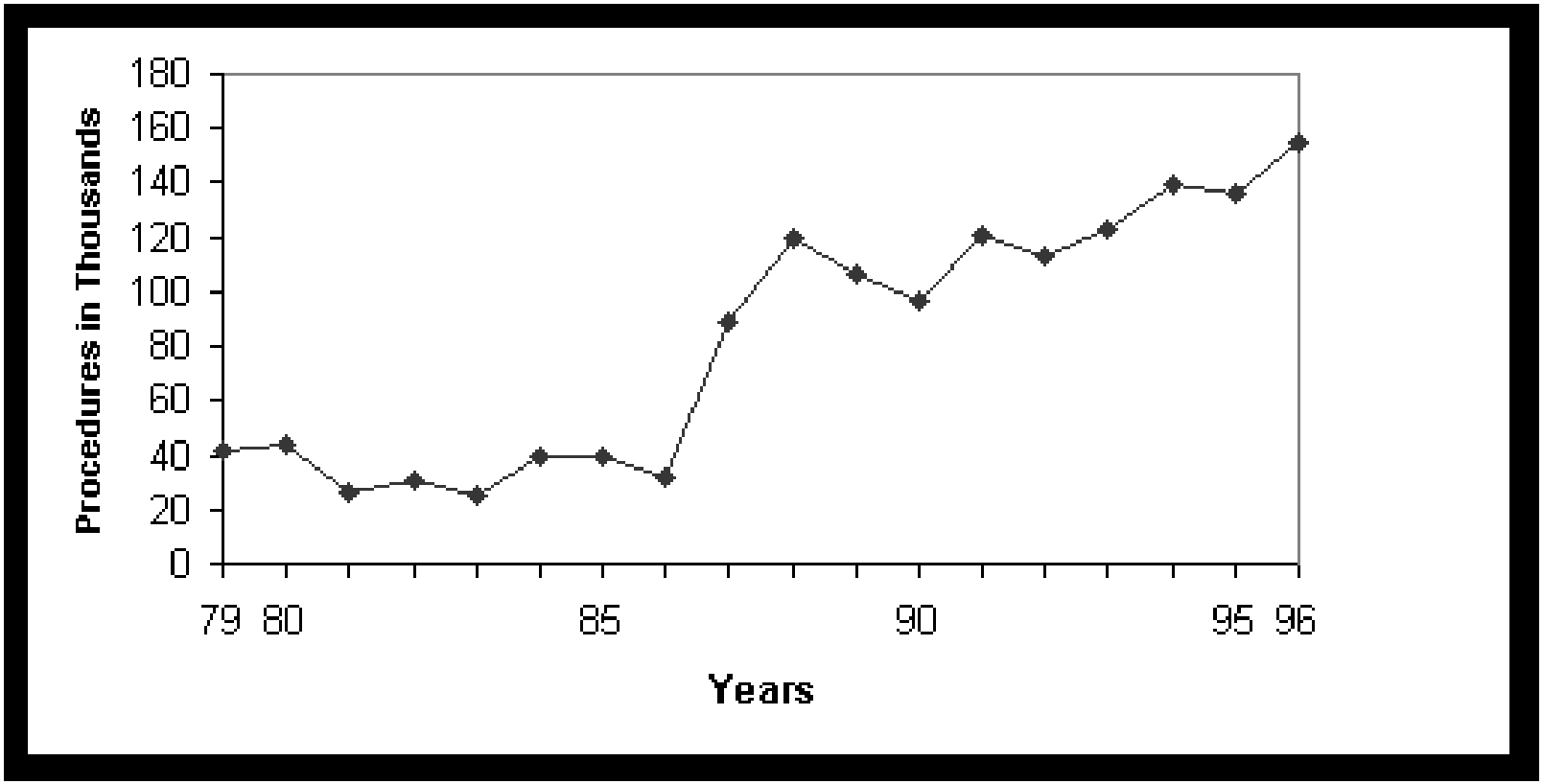
Pacemakers



Pacemaker

ICD

Pacemaker


Procedures in Thousands
180
160
140
120
100
80
60
40
20
0
79
80
85
90
95
96
Years

Pacemaker

Materials used:

- **Leads: platinum, silver, titanium, steel, cobalt**
- **Lead sheaths: silicone rubber, polyurethane**
- **Lead connector: polyether urethane**
- **Casing: titanium**

Clinical benefits:

- **Overcome abnormalities in heart rhythm**

Problems to overcome:

- **Rare complications, (localized inury)**

IABP

Principle of counterpulsation

Reduce workload

Increase coronary artery perfusion

IABP

Materials used:

Polyurethane balloon

Clinical benefit:

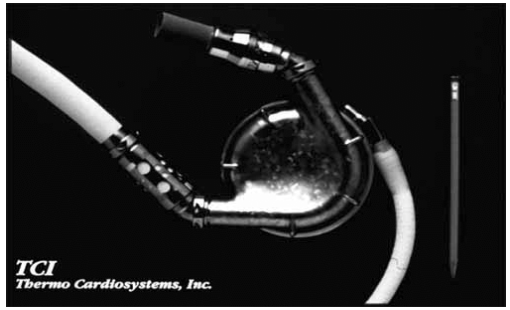
Reduces workload on heart

Increases coronary and systemic flow

Problems to overcome:

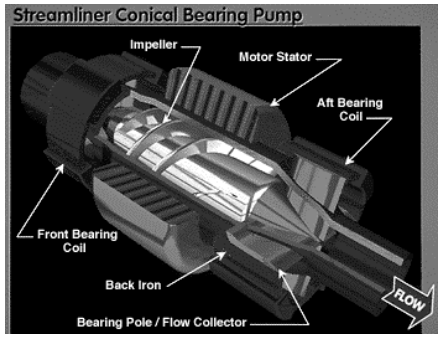
Surgical complications, gas leak

Ventricular Assist Devices (VADs)

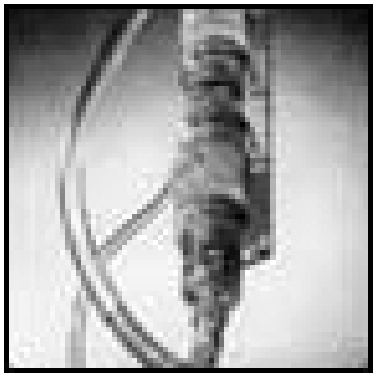


Pneumatic

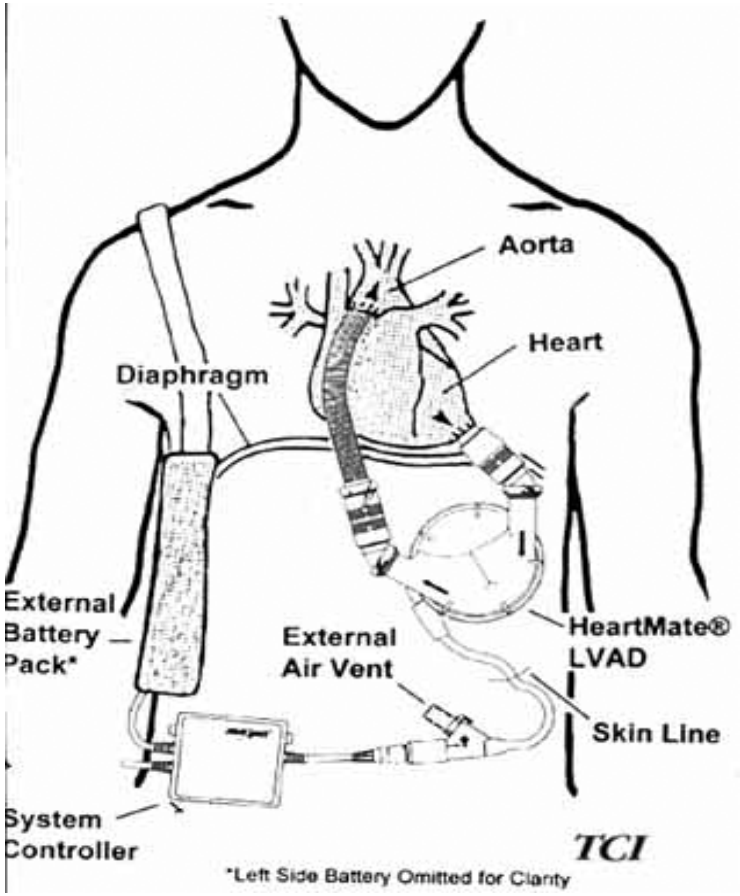
Rotary



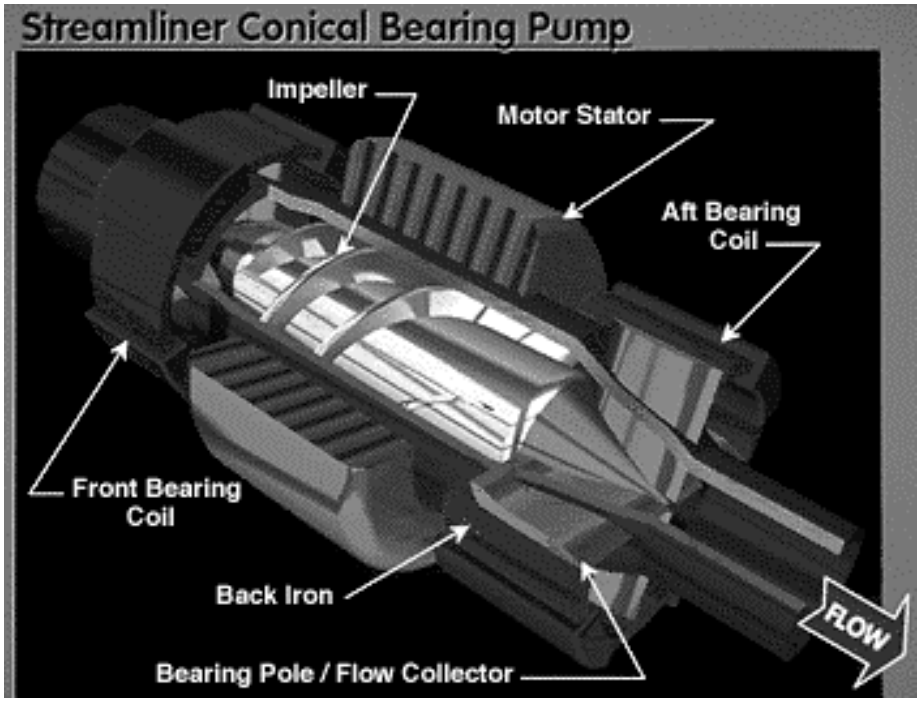
Abiomed

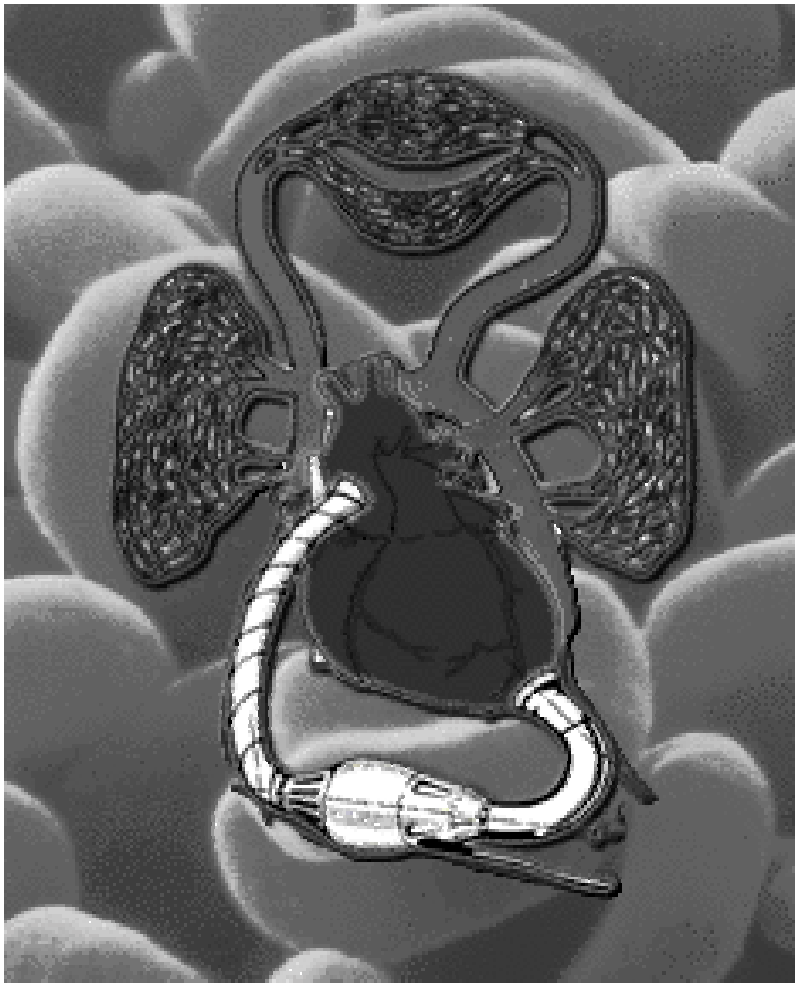


Pneumatic


Aorta
Heart
Diaphragm
External
Battery
Pack*
External
Air Vent
HeartMate®
LVAD
Skin Line
System
Controller
TCI
*Left Side Battery Omitted for Clarity

Rotary

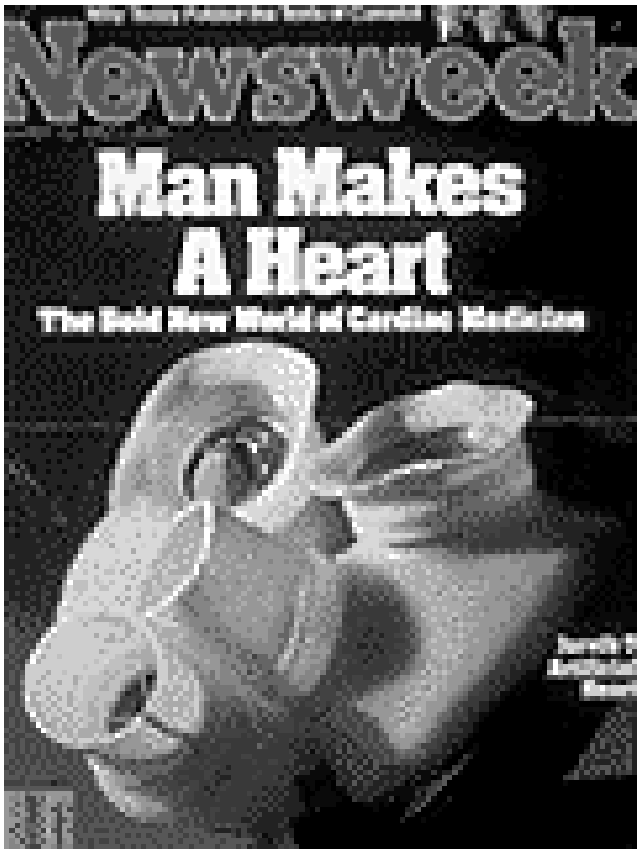

Streamliner Conical Bearing Pump
Impeller
Motor Stator
Aft Bearing Coil
Front Bearing Coil
Back Iron
Bearing Pole / Flow Collector
FLOW



Abiomed

The BVS console features a patented closed loop control system designed to continuously optimize blood flow to its companion pumps without the need for a dedicated operator. With the touch of an "ON" button, it can provide pulsatile left, right or bi-ventricular support by pneumatically driving either one or two BVS blood pumps.

Total Artificial Heart (TAH)



VADs / TAH

Materials used:

Blood pump sac	**Segmented polyether/polyurethane**
Valves	**Mechanical, bioprosthetic**
Casing	**Titanium + silicone**
Conduits	**Dacron vascular grafts**
Power unit	**Titanium**
Belt transformer	**Silicone covering, silver contacts**
Connecting leads	**Silicone**
Pump drive unit	**Titanium, copper coils**
Volume compensator	**Structural composite**
Energy control unit	**Ni-Cad**
2nd skin transformer	**Silver, copper**

VADs / TAH

Clinical benefit:

- **Can function as heart**

Problems to overcome:

- **Thrombosis**
- **Mechanical failure**
- **Limited battery life / power issues**
- **Infection**
- **Complications can be fatal**

Other

Drug Delivery

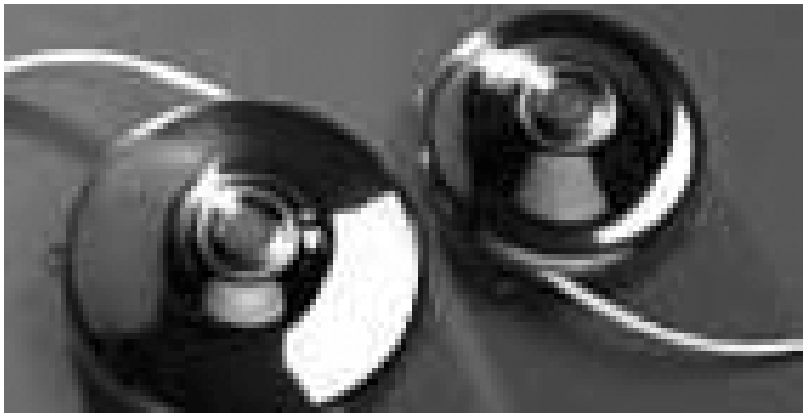
Blood Substitutes

Tissue Engineering

Hybrid organs

Hemostatic agents

Drug delivery



Drug delivery

Materials used:

Titanium case

Silicone elastomer delivery catheter

Clinical benefit:

Programmed, responsive drug delivery

Problems to overcome:

Thrombosis, encapsulation

Blood substitutes / oxygen carriers

Blood substitutes / O2 carriers

Materials used:

- **Perfluorocarbons**
- **Encapsulated hemoglobin**

Clinical benefit:

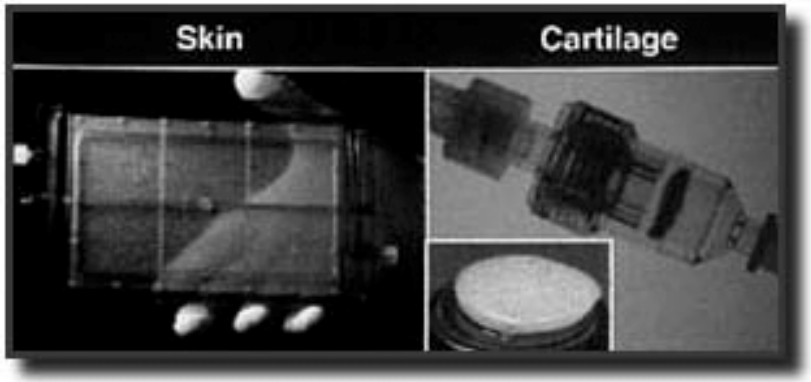
- **Increase oxygen delivery**

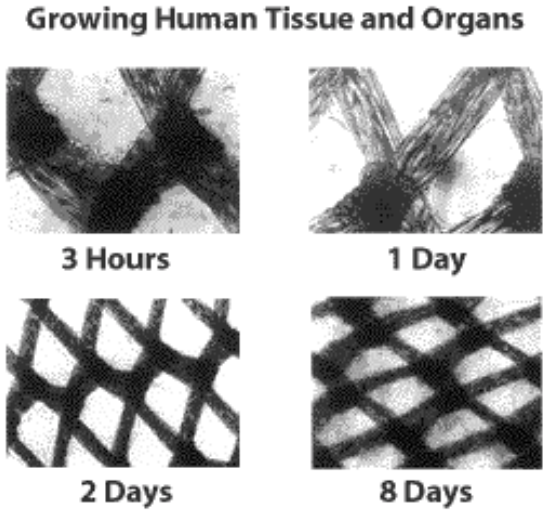
Problems to overcome:

- **Safety, efficacy not determined**

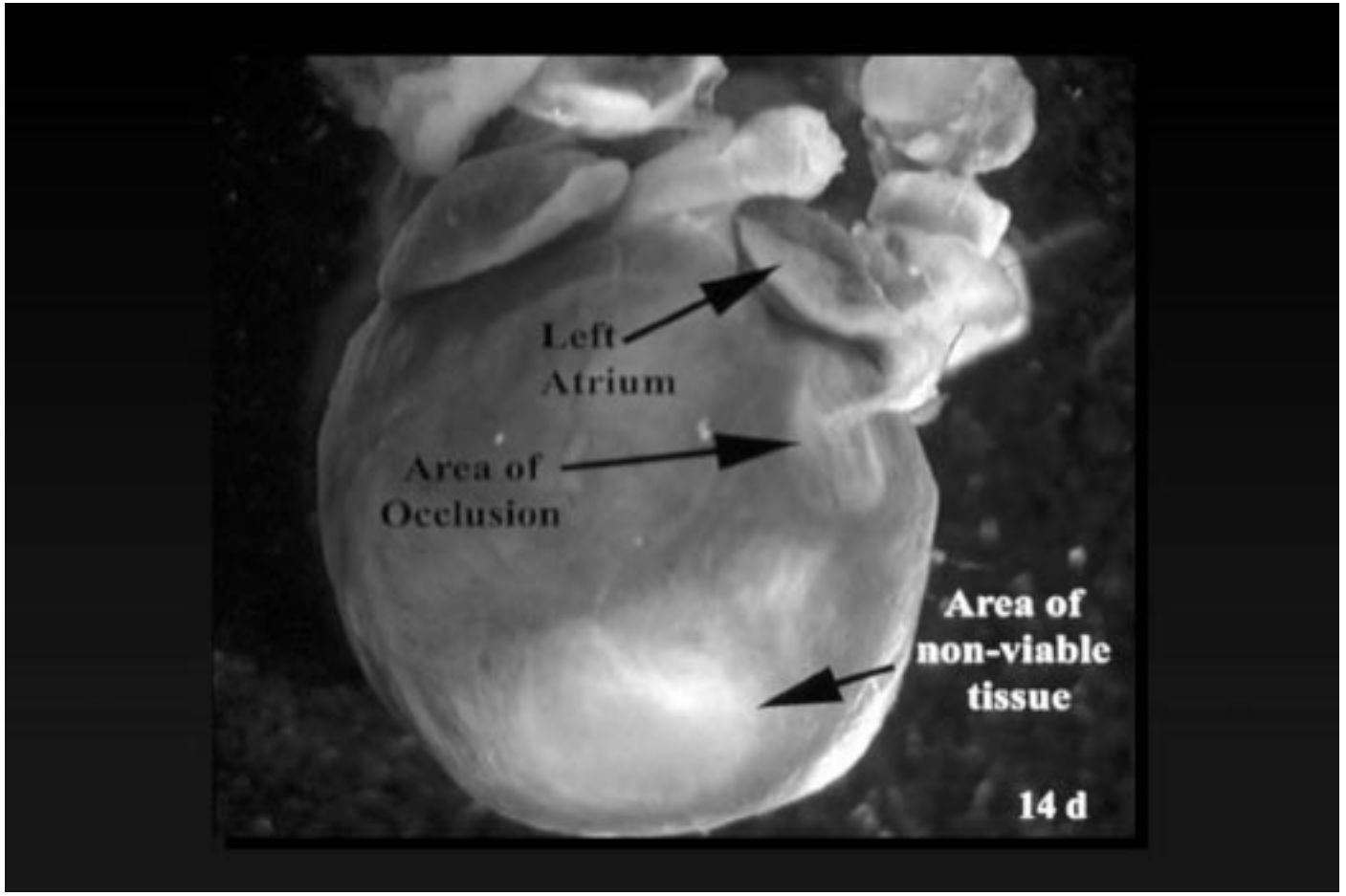
Tissue Engineering

Application of engineering principles to create devices for the study, restoration, modification, and assembly of functional tissues from native or synthetic sources.



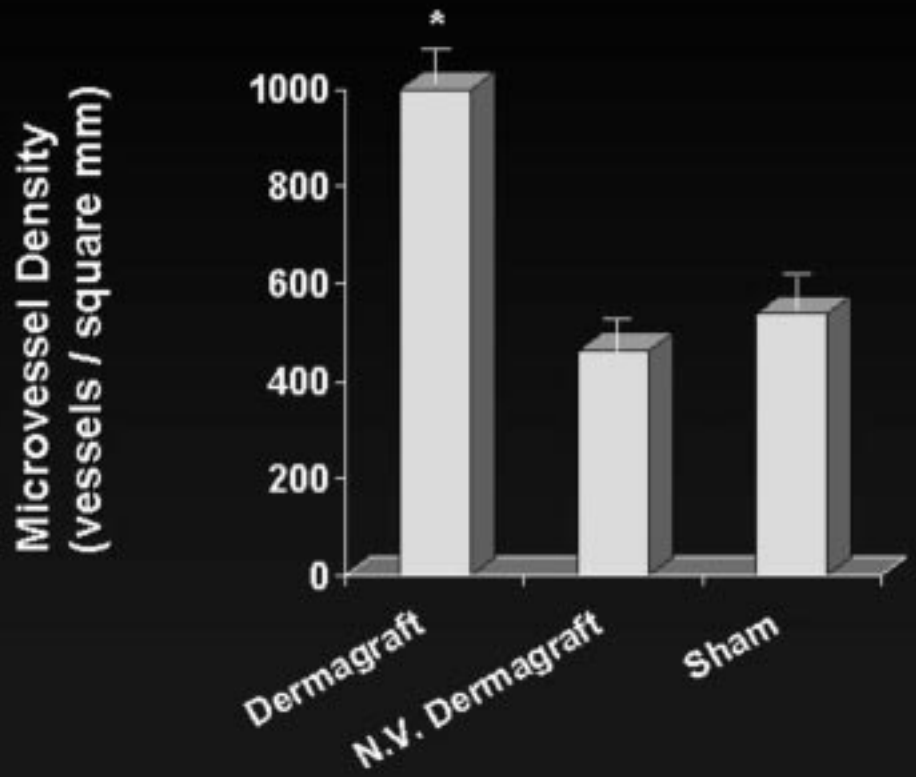


Ischemia / Angiogenesis



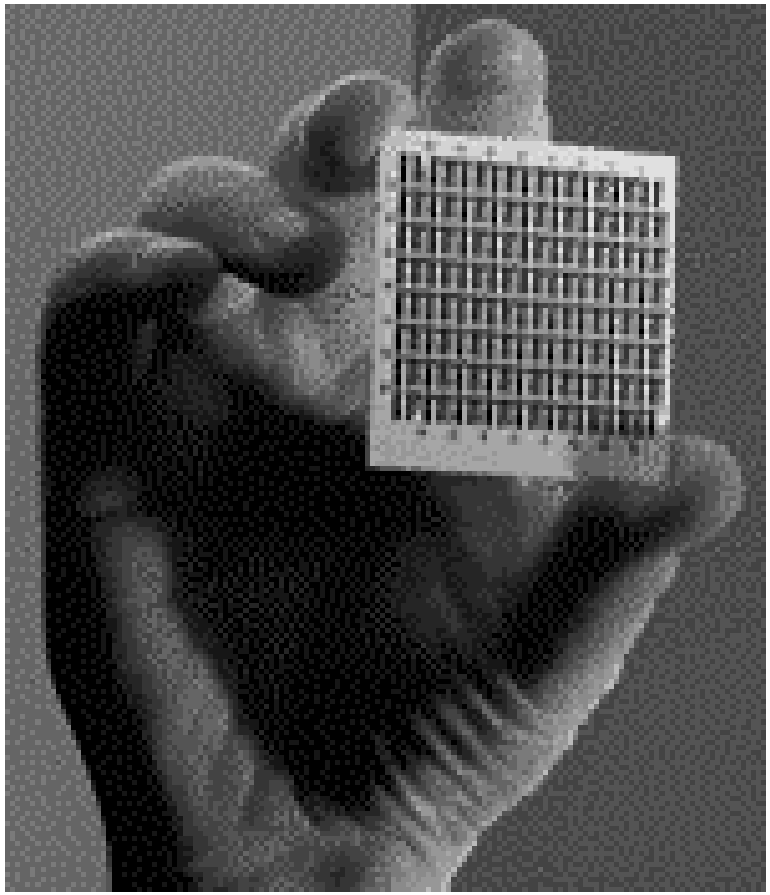
Ischemia / Angiogenesis

Microvessel Density (30 Days)



*p < 0.05

Hybrid organs



Tissue engineering / hybrids

Materials used:

- **Polystyrenes, PMMA, PDMS**
- **Collagen matrices**

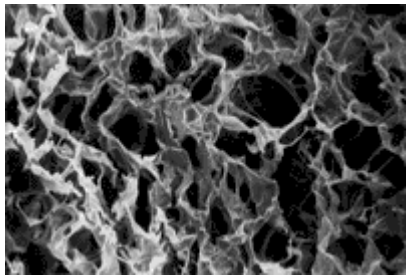
Clinical benefits:

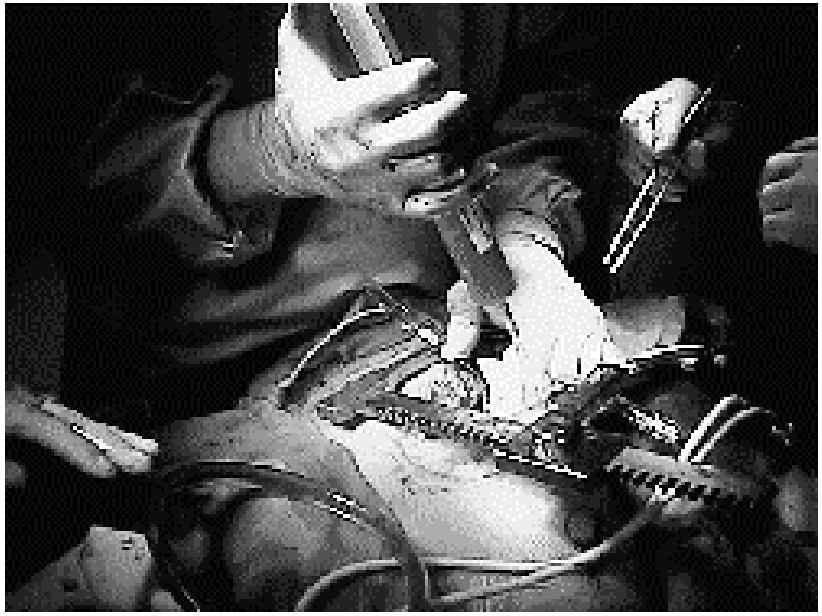
- **Possibly better incorporation?**
- **Increased longevity?**

Problems to overcome:

- **Large scale production**
- **Antigenicity issues**

Hemostatic agents





Hemostatic agents

Materials used:

- **Collagen, gelatin**
- **Oxidized regenerated cellulose**

Clinical benefits:

- **Control bleeding, reoperations**
- **Aneurysms, dissections**

Problems to overcome:

- **Antigenicity issues**
- **Proof of benefit**

Approaches to overcome thrombosis, hyperplasia

Binding, controlled release of heparin

Seeding with EC, fibroblasts

Peptide binding, stimulate EC adherence

Genetic engineering, tPA activity

Resorbable materials

Better hemodynamic design

Approaches to overcome infection

Binding, controlled release of antibacterials

Modify receptors on surface

Seeding with ECs

Genetic engineering, antimicrobial activity

Future directions

More emphasis on long term interfacial events

Target integration with environment

Tissue engineering

Thanks for your attention!