UNIT-V

MATERIALS USED IN MEDICINE

5.4 CARDIAC PROSTHESIS AND VASCULAR GRAFT MATERIALS

Cardiac Prosthesis: Types, Biomaterials, and Applications

Cardiac prostheses are **artificial devices used to replace or assist the function of the heart**. These include **heart valves, artificial hearts, and ventricular assist devices (VADs)**. The materials used in these devices must be **biocompatible, durable, hemocompatible (prevent clotting), and resistant to fatigue and corrosion**.

1. Types of Cardiac Prostheses & Biomaterials

A. Artificial Heart Valves

Heart valve prostheses are used to **replace damaged or diseased heart valves**. There are two main types:

🔹 **Mechanical Valves** – Long-lasting, but require lifelong anticoagulation therapy.

- **Materials:**
  - **Pyrolytic Carbon** – High strength & blood compatibility.
  - **Titanium & Cobalt-Chromium Alloys** – Corrosion-resistant.
  - **PTFE (Teflon) & Polyurethane** – Used in leaflets & sewing rings.

🔹 **Bioprosthetic (Tissue) Valves** – Made from animal or human tissue, no need for anticoagulants but shorter lifespan.

- **Materials:**
  - **Bovine (Cow) or Porcine (Pig) Pericardium** – Treated with glutaraldehyde for durability.
  - **Dacron (Polyester) & PTFE** – Used in sewing rings for secure attachment.

🔹 **Examples:**

- **St. Jude Mechanical Valve** – Pyrolytic carbon with a titanium ring.
- **Edwards LifeSciences Bioprosthetic Valve** – Bovine pericardium with a polymer frame.

B. Total Artificial Heart (TAH)

Used for patients with **severe heart failure** who need a complete heart replacement.

🔹 **Materials:**

- **Titanium Alloys** – Durable & biocompatible.
- **Polyurethane & PTFE (Teflon)** – Used for blood-contacting surfaces.

- **Silicone Rubber** – Flexible diaphragms for pumping action.

🔹 **Examples:**

- **SynCardia Total Artificial Heart** – Biopolyurethane ventricles with titanium components.

C. Ventricular Assist Devices (VADs)

Mechanical pumps that help a **weak heart pump blood**. Used for **bridge-to-transplant or long-term therapy**.

🔹 **Materials:**

- **Titanium & Stainless Steel** – Used in casing for durability.
- **Polyurethane & PTFE** – Blood-contacting surfaces to reduce clotting.
- **Magnetic & Hydrodynamic Bearings** – Reduce wear in rotary pumps.

🔹 **Examples:**

- **HeartMate 3 (Abbott)** – A fully magnetically levitated pump to minimize blood damage.

D. Pacemakers & Implantable Cardioverter Defibrillators (ICDs)

Electronic devices that regulate or correct **irregular heart rhythms**.

🔹 **Materials:**

- **Titanium Casing** – Corrosion-resistant & biocompatible.
- **Silicone & Polyurethane** – Used for lead insulation.

🔹 **Examples:**

- **Medtronic Micra™ Leadless Pacemaker** – Miniaturized, titanium-encased pacemaker.

2. Comparison of Cardiac Prosthesis Materials

Device	Key Materials	Advantages	Limitations
Mechanical Valve	Pyrolytic Carbon, Titanium, PTFE	High durability, long lifespan	Requires lifelong anticoagulants
Bioprosthetic Valve	Bovine/Pig Tissue, Dacron	No anticoagulants needed	Shorter lifespan (10-15 years)
Total Artificial Heart (TAH)	Polyurethane, Titanium	Life-saving for end-stage heart failure	Temporary solution, requires external power
Ventricular Assist Device (VAD)	Titanium, Polyurethane	Supports weak heart, bridge to transplant	Risk of infection, battery dependency

Device	Key Materials	Advantages	Limitations
Pacemaker/ICD	Titanium, Silicone, Polyurethane	Regulates heartbeat, long-lasting	Battery replacement required

3. Future Trends in Cardiac Prostheses

🔹 **Tissue-Engineered Heart Valves** – Made from **patient's own cells** for better integration.
🔹 **Bioresorbable Heart Valves** – Polymer-based valves that degrade as new tissue grows.
🔹 **Wireless Pacemakers** – Leadless designs reduce risk of infection & complications.
🔹 **Artificial Hearts with Wireless Power** – Eliminating external power sources for long-term use.

Vascular Graft Materials: Types, Properties, and Applications

Vascular grafts are used to **replace or bypass damaged or diseased blood vessels**. The materials used must be **biocompatible, durable, resistant to thrombosis (clot formation), and capable of integrating with the body's tissues**.

1. Key Properties of Vascular Graft Materials

✓ **Hemocompatibility** – Prevents blood clotting (thrombosis).
✓ **Mechanical Strength** – Withstands blood pressure and pulsatile flow.
✓ **Flexibility & Compliance** – Matches natural blood vessel behavior.
✓ **Biodegradability (For Some Cases)** – Allows tissue regeneration.
✓ **Porosity** – Enables tissue ingrowth and healing.

2. Types of Vascular Grafts & Their Materials

A. Synthetic Vascular Grafts

Used in **large-diameter arteries (≥6 mm)** like the **aorta and femoral arteries**.

🔹 **Materials:**

- **Polytetrafluoroethylene (PTFE, Teflon)** – Non-porous, low thrombogenicity, high durability.
- **Dacron (Polyethylene Terephthalate, PET)** – High strength, good integration.
- **Polyurethane (PU)** – More flexible, good for small-diameter grafts.

🔹 **Examples:**

- **GORE-TEX® Vascular Grafts** (PTFE).
- **Dacron Grafts for Aortic Repair**.

🔹 **Advantages & Disadvantages:**

Material	Advantages	Disadvantages
PTFE (Teflon)	High durability, low thrombosis	Stiff, not ideal for small vessels
Dacron (PET)	Strong, good for high-pressure arteries	Requires pre-clotting, can calcify over time
Polyurethane (PU)	Good elasticity, better for small vessels	Less long-term durability

B. Biodegradable & Bioresorbable Vascular Grafts

Designed for **temporary scaffolding** while natural tissue regenerates.

🔹 **Materials:**

- **Polycaprolactone (PCL)** – Slowly degrades, supports cell growth.
- **Polylactic Acid (PLA)** – Biodegradable, promotes endothelialization.
- **Polyglycolic Acid (PGA)** – Faster degradation, good for small vessels.

🔹 **Examples:**

- **Tissue-engineered biodegradable grafts for pediatric patients**.

🔹 **Advantages & Disadvantages:**

Material	Advantages	Disadvantages
PCL (Polycaprolactone)	Supports tissue growth, slow degradation	Lower mechanical strength
PLA (Polylactic Acid)	Biocompatible, promotes healing	Can degrade too quickly in high-flow vessels
PGA (Polyglycolic Acid)	Fast degradation, useful in small vessels	Less mechanical stability

C. Tissue-Engineered & Biological Vascular Grafts

These grafts use **cells and biomaterials to create living blood vessel substitutes**.

🔹 **Materials:**

- **Decellularized Human/Animal Blood Vessels** – Bovine or porcine arteries.
- **Collagen-Based Scaffolds** – Encourages cell adhesion and growth.
- **Fibrin & Alginate Hydrogels** – Used for cell encapsulation.

🔹 **Examples:**

- **Humacyte's Human Acellular Vessel (HAV)** – Lab-grown human tissue graft.
- **Decellularized Porcine Arteries** – Used for tissue-engineered solutions.

◆ **Advantages & Disadvantages:**

Material	Advantages	Disadvantages
Decellularized Vessels	Natural structure, low rejection	Risk of calcification
Collagen Scaffolds	Biodegradable, supports cell growth	Weak mechanical strength
Fibrin & Hydrogels	Good cell encapsulation	Short lifespan, needs reinforcement

3. Comparison of Vascular Graft Materials

Type	Examples	Best For	Limitations
Synthetic (PTFE, Dacron, PU)	GORE-TEX®, Dacron grafts	Large-diameter arteries	Less flexible, may require pre-clotting
Biodegradable (PCL, PLA, PGA)	Pediatric grafts	Temporary support, small vessels	Mechanical weakness, degradation control needed
Tissue-Engineered (Collagen, Hydrogels, Decellularized Tissue)	Humacyte HAV	Long-term integration, small vessels	Requires advanced manufacturing, costly

4. Future Trends in Vascular Graft Materials

◆ **3D Bioprinting of Blood Vessels** – Using patient-derived cells & biomaterials.
◆ **Nanotechnology-Based Coatings** – Improves hemocompatibility & prevents infections.
◆ **Smart Polymers** – Responsive materials that **change properties in response to stimuli** (e.g., temperature, pH).
◆ **Gene-Activated Grafts** – Coated with growth factors to **stimulate natural blood vessel formation**.