UNIT-V

MATERIALS USED IN MEDICINE

5.3 BIOINERT & BIOACTIVE CERAMICS BIOMATERIALS: PROPERTIES, TYPES, AND APPLICATIONS

BIOINERT MATERIALS

Bioinert materials are a class of biomaterials that do not chemically react with the surrounding biological environment. They are used in medical implants where **minimal interaction with body tissues** is required while maintaining **high durability, strength, and corrosion resistance**.

1. Characteristics of Bioinert Materials

✓ **Chemically stable** – Do not degrade or corrode in the body.
✓ **High mechanical strength** – Suitable for load-bearing implants.
✓ **Wear-resistant** – Long-lasting and durable.
✓ **Minimal biological response** – Do not trigger immune reactions.

2. Types of Bioinert Biomaterials

A. Bioinert Metals (Used in High-Strength Implants)

🔹 **Titanium (Ti) and Titanium Alloys (Ti-6Al-4V, Ti-6Al-7Nb)**

- **Excellent biocompatibility, lightweight, and corrosion-resistant**.
- Used in: **Dental implants, hip and knee prostheses, bone plates, screws**.

🔹 **Cobalt-Chromium (Co-Cr) Alloys**

- **Extremely wear-resistant and strong**.
- Used in: **Joint replacements (hip, knee), dental prosthetics, stents**.

🔹 **Stainless Steel (316L Surgical Grade)**

- **Good corrosion resistance and cost-effective**.
- Used in: **Bone screws, fracture fixation plates, temporary implants**.

B. Bioinert Ceramics (Used in Hard Tissue Replacements)

🔹 **Alumina (Al_2O_3) – Aluminum Oxide**

- **Very hard, wear-resistant, and corrosion-resistant**.
- Used in: **Hip prostheses, dental implants, orthopedic bearings**.

🔹 **Zirconia (ZrO_2) – Zirconium Oxide**

- **Higher strength and toughness than alumina**.
- Used in: **Dental crowns, joint prostheses, orthopedic implants**.

C. Bioinert Polymers (Used for Flexible Medical Devices)

🔹 **Polyetheretherketone (PEEK)**

- **Bone-like flexibility, wear-resistant, MRI-compatible**.
- Used in: **Spinal implants, joint replacements, dental prostheses**.

🔹 **Polytetrafluoroethylene (PTFE) – Teflon**

- **Non-stick, biocompatible, and chemical-resistant**.
- Used in: **Vascular grafts, heart valve replacements, joint implants**.

3. Comparison of Bioinert Biomaterials

Material Type	Strength	Wear Resistance	Corrosion Resistance	Uses
Titanium (Ti)	High	Medium	Excellent	Dental implants, bone screws, joint replacements
Cobalt-Chromium (Co-Cr)	Very High	Very High	Excellent	Hip/knee replacements, stents
Stainless Steel (316L)	Medium	Medium	Good	Bone plates, screws, temporary implants
Alumina (Al_2O_3)	Very High	Very High	Excellent	Hip prostheses, dental implants
Zirconia (ZrO_2)	Extremely High	Very High	Excellent	Dental crowns, joint prostheses
PEEK (Polyetheretherketone)	Medium	High	Good	Spinal implants, joint replacements

4. Applications of Bioinert Materials

✓ **Orthopedic Implants** – Joint replacements (hip, knee), bone plates, screws.
✓ **Dental Implants** – Zirconia and titanium crowns, bridges, and prosthetics.
✓ **Cardiovascular Devices** – Heart valves, stents, vascular grafts.
✓ **Spinal Implants** – PEEK and titanium spinal fusion cages.

Bioactive Ceramics: Properties, Types, and Applications

Bioactive ceramics are a class of biomaterials that interact with biological tissues, promoting **bone bonding, tissue regeneration, and healing**. Unlike bioinert materials, bioactive ceramics **stimulate cellular responses and integrate with surrounding tissues** over time.

1. Characteristics of Bioactive Ceramics

✓ **Biocompatible** – Safe for long-term use in the body.
✓ **Osteoconductive** – Supports bone growth and attachment.
✓ **Biointegrative** – Bonds directly to bone or soft tissue.
✓ **Degradable (Some Types)** – Gradually replaced by natural bone.

2. Types of Bioactive Ceramics

A. Calcium Phosphate-Based Ceramics (Mimic Natural Bone)

🔻 **Hydroxyapatite (HA) – $Ca_{10}(PO_4)_6(OH)_2$**

- **Chemically similar to bone mineral**, excellent for osseointegration.
- Used in: **Bone grafts, implant coatings, dental implants, maxillofacial surgery**.

🔻 **Tricalcium Phosphate (TCP) – $Ca_3(PO_4)_2$**

- **More resorbable than HA**, allowing for natural bone remodeling.
- Used in: **Bone graft substitutes, craniofacial reconstruction, orthopedic scaffolds**.

🔻 **Biphasic Calcium Phosphate (BCP) – HA + TCP Mixture**

- **Combines HA's stability with TCP's biodegradability**.
- Used in: **Bone grafts, spinal fusion, dental bone repair**.

B. Silicate-Based Ceramics (Promote Bone Regeneration)

🔻 **Bioglass (Silicate-Based Glass-Ceramic)**

- **Stimulates bone and soft tissue bonding**.
- Used in: **Bone repair, periodontal regeneration, drug delivery**.

🔻 **Glass-Ceramics (e.g., Ceravital, A/W Glass-Ceramics)**

- **Improved mechanical strength & bioactivity**.
- Used in: **Middle ear implants, bone graft substitutes**.

C. Other Bioactive Ceramics

🔻 **Calcium Sulfate ($CaSO_4$) – Plaster of Paris**

- **Highly resorbable, used for temporary bone void filling**.
- Used in: **Bone graft fillers, antibiotic delivery systems**.

🔻 **Strontium-Substituted Hydroxyapatite**

- **Enhances bone cell activity & reduces osteoporosis risk**.

- Used in: **Bone regeneration, dental and orthopedic applications**.

3. Comparison of Bioactive Ceramics

Ceramic Type	Biocompatibility	Bone Integration	Degradability	Uses
Hydroxyapatite (HA)	Excellent	High	Slow	Bone grafts, implant coatings, dental implants
Tricalcium Phosphate (TCP)	High	High	Fast	Bone graft substitutes, scaffolds
Biphasic Calcium Phosphate (BCP)	High	High	Moderate	Bone void fillers, spinal fusion
Bioglass	High	Very High	Moderate	Bone repair, soft tissue healing
Glass-Ceramics	High	High	Moderate	Middle ear implants, orthopedic repairs
Calcium Sulfate ($CaSO_4$)	Moderate	Low	Fast	Temporary bone fillers, antibiotic delivery

4. Applications of Bioactive Ceramics

✓ **Orthopedic Implants** – Bone grafts, spinal fusion, joint replacements.
✓ **Dental Applications** – Tooth fillings, jawbone regeneration, implant coatings.
✓ **Tissue Engineering** – Scaffolds for bone and soft tissue regeneration.
✓ **Drug Delivery** – Slow-release antibiotic or growth factor carriers.