University of Al-Mustaqbal
College of Science
Department of Medical Physics

Biomaterials

Stage : fourth

LEC (1)

Biomaterials Science

BY

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1.1 Introduction

Biomaterials Science is an interdisciplinary field that combines medicine, biology, chemistry, and materials engineering. It focuses on the study and development of materials designed to interact safely with biological systems for medical applications such as diagnosis, treatment, and replacement of tissues or organs. Biomaterials play an important role in modern medicine by improving patient health and quality of life.

1.2 Definition of Biomaterials

A biomaterial is any non-living material engineered to interact with biological systems for a medical purpose, either therapeutic or diagnostic. Over the past five decades, biomaterials science has shown rapid growth with significant industrial and clinical investments.

1.3 Historical Development of Biomaterials (Concise)

1. Early Period

Use of natural materials and simple metals (bone, ivory, gold) for basic repair and replacement, limited by poor sterilization and biological understanding.

2. 20th Century – Medical-Grade Materials

Advances in surgery and sterilization led to the use of metals, ceramics, and polymers with controlled mechanical and chemical properties for implants and medical devices.

3. Shift from Inert to Bio-Responsive Design

Clinical failures (corrosion, wear debris, thrombosis, inflammation) highlighted the importance of material–tissue interactions, especially at the surface.

4. Modern Era – Bioactive and Regenerative Biomaterials

Development of bioactive, biodegradable, and living biomaterials, supported by surface engineering, nanotechnology, tissue engineering, and regenerative medicine.

1.4 Biocompatibility

Biocompatibility refers to the ability of a material to perform its intended function within the body while eliciting an appropriate host response without toxicity or rejection.

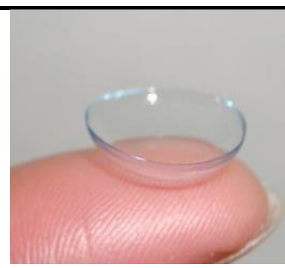
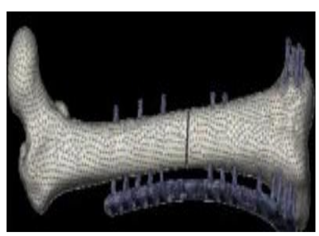
Biocompatibility is not an absolute property; rather, it is a relative and application-specific concept. It depends on several key factors, including the site of implantation, the type of tissue involved, the duration of material–tissue contact, and the intended function of the material.

- A material that is suitable for bone tissue may not be suitable for blood-contacting applications, as it can cause blood clotting (thrombosis).

1.5 Duration of Contact with the Body

The duration of exposure of biomaterials to the human body varies widely, ranging from seconds (e.g., syringe needles) to decades (e.g., hip prostheses and intraocular lenses).

Table 1The following table represents the time scale over which the host is exposed to materials and devices:

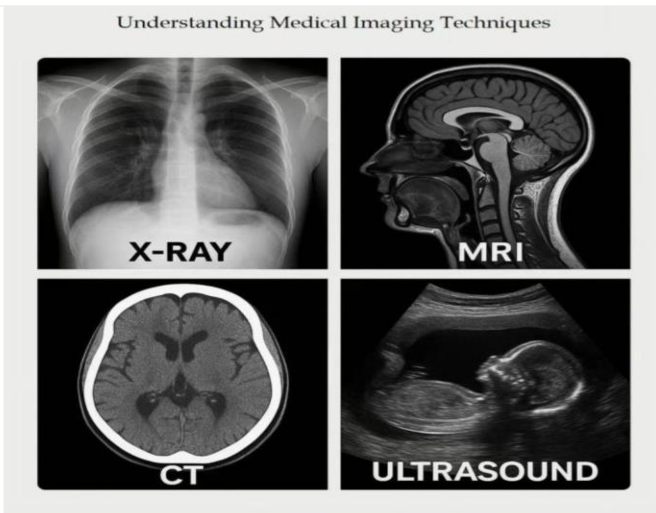
Material	Contact time	
Syringe needle	1-2 s	
Tongue depressor	10 s	
Contact lens	12 hr- 30 days	
Bone screw/plate	3-12 months	

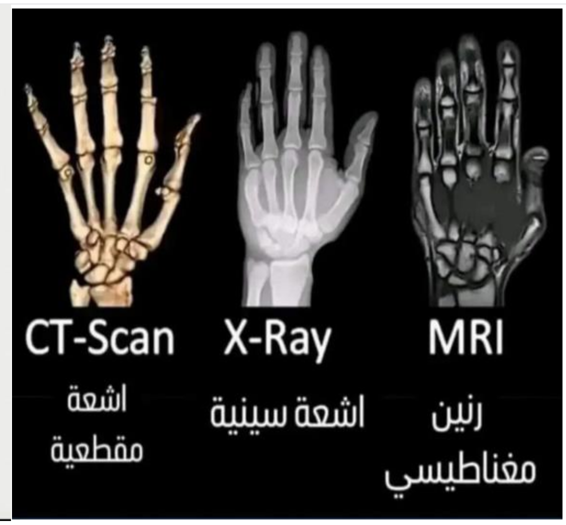
1.6 The Role of Biomaterials in Medical Physics

Biomaterials act as the material interface that connects medical-physics principles (radiation, electromagnetism, ultrasound, mechanics, and heat transfer) to clinical function inside the human body. Their role includes:

1. Compatibility with medical imaging and artifact reduction (Imaging compatibility)

- **MRI:** Selecting materials with suitable magnetic properties to reduce artifacts and ensure safety in high magnetic fields.
- **CT and X ray:** Controlling density/atomic number to reduce streak artifacts / beam hardening and improve visualization of tissues near implants.
- **Ultrasound:** Addressing strong reflections and acoustic shadowing through appropriate material selection and device/geometry design.





2. Controlling radiation interaction and dose effects (Radiation–matter interaction)

- In radiation therapy, metallic or high-density implants can cause dose perturbations (changes in local dose distribution).

Therefore:

- materials and designs should minimize unwanted effects when possible, and
- implants must be properly represented in treatment planning workflows.

3. Enabling sensing and bio-signal transduction (Sensors & transduction)

Biomaterials are used as functional layers in biosensors to convert biochemical/biological changes into measurable electrical/optical signals, while mitigating biofouling (protein/cell buildup on surfaces).

4. Safe delivery of energy (Energy delivery)

- In laser, hyperthermia, or therapeutic ultrasound applications, material properties (thermal conductivity, optical absorption, insulation) influence:
- the efficiency of energy delivery, and
- the safety of surrounding tissues.

5. Mechanical support and biomechanics (Biomechanics)

- In implants (especially bone and joint devices), properties such as stiffness, fatigue resistance, and wear behavior determine:
- stress distribution,
- failure risk, and
- stress shielding when implant stiffness significantly exceeds that of bone.

1.7 Diagnostic Applications of Biomaterials (Diagnostic Applications)

1.7.1 Contrast-related materials and carriers (Contrast agents / carriers)

- Materials (or polymer/particle-based carrier systems) are used to improve image contrast by altering physical signal response (e.g., magnetic effects in MRI or X ray attenuation in CT).
- Biomaterials contribute by improving stability, biocompatibility, lower toxicity, and targeting.

1.7.2 Biosensors

- Examples: glucose sensors, ion/pH sensors, biomarker sensors.
- Polymers/hydrogels immobilize biological recognition elements (enzymes/receptors) and support mass transport while enabling signal generation.
- Key challenge: minimizing signal drift and performance loss due to biofouling.

1.7.3 Radiopaque materials for image-guided interventions (Interventional guidance)

Radiopaque markers/fillers in catheters and guidewires improve visibility under fluoroscopy, enhancing the accuracy and safety of minimally invasive procedures.

1.7.4 Materials for implantable diagnostic devices (Implantable diagnostic devices)

- Packaging and surfaces for implantable sensors (e.g., pressure/oxygen sensors) require:
- high biocompatibility, and
- surface designs that reduce fibrous encapsulation, which may functionally isolate the device.

1.8 Therapeutic Applications of Biomaterials (Therapeutic Applications)

1.8.1 Orthopedic implants (bone and joint implants)

- Metals (Ti, Co–Cr) for load-bearing components + polymers (e.g., UHMWPE) for bearing surfaces + ceramic coatings (hydroxyapatite) to enhance bone bonding.
- Goal: restore mechanical function and reduce loosening/failure long term.

1.8.2 Coronary stents and drug-eluting stents (Stents, drug-eluting stents)

- A metallic scaffold provides mechanical support, while a polymer coating regul ates controlled drug release to reduce restenosis.
- This integrates materials mechanics with mass transport / controlled release principles.

1.8.3 Drug delivery and controlled release systems

- Polymeric or micro/nano carrier systems enable:
- time-controlled release,
- reduced systemic toxicity, and
- improved local drug concentration at the target site.

1.8.4 Tissue engineering scaffolds (Tissue engineering scaffolds)

• Biodegradable polymer scaffolds or polymer–ceramic composites are engineered with appropriate porosity and mechanics to support regeneration, then degrade as new tissue forms.
• Scaffold function: support nutrient transport, cell attachment, and new tissue formation.

1.8.5 Radiation therapy-related materials (Radiation therapy-related)

• Materials used in or around radiation therapy systems (e.g., encapsulation/components of localized sources, fixation devices) typically require:
• dimensional stability,
• corrosion resistance, and
• biocompatibility to minimize tissue irritation.

1.8.6 Thermal, laser, and therapeutic ultrasound applications (Energy-based therapies)

• Probe/catheter materials and coatings can improve:
• heat transfer control,
• absorption/insulation properties, and
• protection of surrounding tissues during energy delivery.

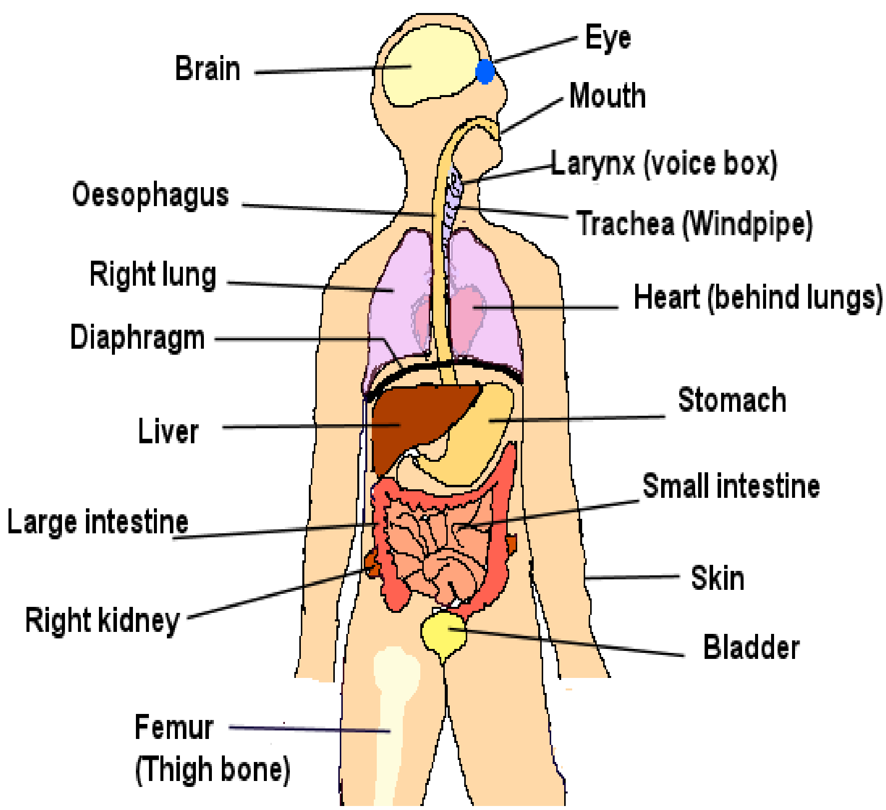
1.9 Applications of Biomaterials According to Purpose

- **Replacement of diseased and damaged part:** Artificial hip joint, kidney dialysis machine
- **Assistance in healing:** Sutures and fixation devices.
- **Functional improvement:** Cardiac pacemakers.
- **Correct cosmetic problem:** chin augmentation, orthodontic.
- **Diagnosis:** Probes and catheters.
- **Treatment:** Catheters and drainage devices.

1.10 Applications of Biomaterials According to Organ

Organ	Example
Heart	Pacemaker, artificial heart valve, totally artificial heart
Lung	Oxy-generator machine
Eye	Contact lens, intraocular lens
Ear	Artificial stapes, cochlea implant
Bone	Fixation plates
Kidney	Kidney dialysis machine
Bladder	Catheters and stent

Organ of human body ;



1.11 Selection Criteria for Biomaterials

A biomaterial used for implant should possess some important properties in order to long-term usage in the body without rejection. The design and selection of biomaterials depend on different properties which are:

1. **Host Response:** is defined as the response of the host organism (local or systemic) to the implanted material or device.
2. **Toxicology :** A biomaterial should not be toxic, unless it is specifically engineered for such requirements (for example, a "smart bomb" drug delivery system thatz
3. targets cancer cells and destroys them). Since the nontoxic requirement is the norm, toxicology for biomaterials has evolved into a sophisticated science. It deals with the substances that migrate out of biomaterials. For example, for polymers, many low-molecular-weight "leachable" exhibit some level of physiologic activity and cell toxicity.
4. **Biodegradability**: It is simply a phenomenon that natural and synthetic biomaterials are capable of decomposing in the body conditions without leaving any harmful substances behind.
5. **Bio functionality:** the bio functionality is playing a specific function in physical and mechanical terms. The material must satisfy its design requirements in service:
   - *Load transmission and stress distribution (e.g. bone replacement).*
   - *Articulation to allow movement (e.g. artificial knee joint).*
   - *Control of blood and fluid flow (e.g. artificial heart).*
   - *Space filling (e.g. cosmetic surgery).*
   - *Electrical stimuli (e.g. pacemaker).*
   - *Light transmission (e.g. implanted lenses).*
   - *Sound transmission (e.g. cochlear implant).*

The following figure represents all Biomaterials in human body: