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Physics



Biomaterials

Stage : fourth

LEC (6)

Biomaterials in Medical Imaging

BY

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1. Introduction

Medical imaging is one of the most important technologies used in modern medicine for diagnosing diseases and monitoring the progression of medical conditions without the need for invasive surgical procedures. Medical imaging techniques rely on the interaction of different forms of energy with body tissues, such as X-rays in computed tomography (CT) and strong magnetic fields in magnetic resonance imaging (MRI).

Biomaterials play an essential role in improving the performance of medical imaging systems and ensuring patient safety. Materials used in medical devices, implants, or testing models must possess specific properties that are compatible with the imaging technique being used. These properties include biocompatibility, chemical stability, and the ability to withstand radiation or magnetic fields.

For example, some metals can cause image distortion in CT scans due to their high absorption of X-rays, while magnetic materials can pose serious risks in MRI systems because they may be strongly attracted to the magnetic field. Therefore, biomaterials used in medical imaging applications are carefully selected to balance physical properties and biological safety.

Major applications of biomaterials in medical imaging include CT-compatible materials, MRI-safe materials, containers for contrast agents, and imaging phantoms used for testing and calibrating imaging systems.

2. CT-Compatible Materials

2.1 Concept of Computed Tomography (CT)

Computed Tomography (CT) is a medical imaging technique that uses X-rays to produce detailed cross-sectional images of the human body. When X-rays pass through the body, tissues absorb the radiation to different degrees depending on their density and chemical composition. For instance, bones absorb X-rays more strongly than soft tissues because they contain elements with higher atomic numbers, such as calcium.

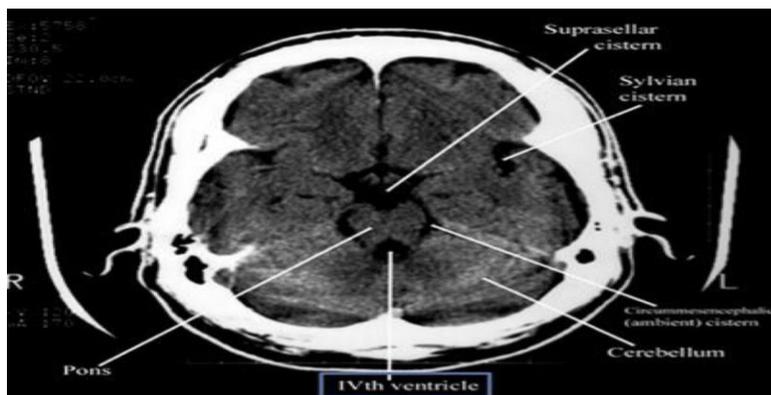


2.2 Properties of CT-Compatible Materials

Materials used in CT environments must possess several important characteristics, including:

- Moderate absorption of X-rays
- Minimal production of image artifacts
- Chemical stability under radiation exposure
- Good biocompatibility with body tissues

These properties allow physicians to obtain clear images without distortions that could affect diagnostic accuracy



2.3 Examples of Materials Used in CT

Medical polymers such as **Polymethyl Methacrylate (PMMA)**¹ are widely used in CT applications because of their relatively low density and their ability to allow X-rays to pass through with minimal interference. For this reason, PMMA is often used in the fabrication of CT testing phantoms, where it simulates the properties of soft tissues and helps researchers evaluate the imaging performance of CT scanners.

In applications requiring simulation of bone tissue, ceramic materials such as **Hydroxyapatite** are commonly used. This material closely resembles the mineral component of natural bone. When incorporated into CT testing models, hydroxyapatite produces X-ray absorption characteristics similar to real bone, enabling accurate calibration of imaging systems.

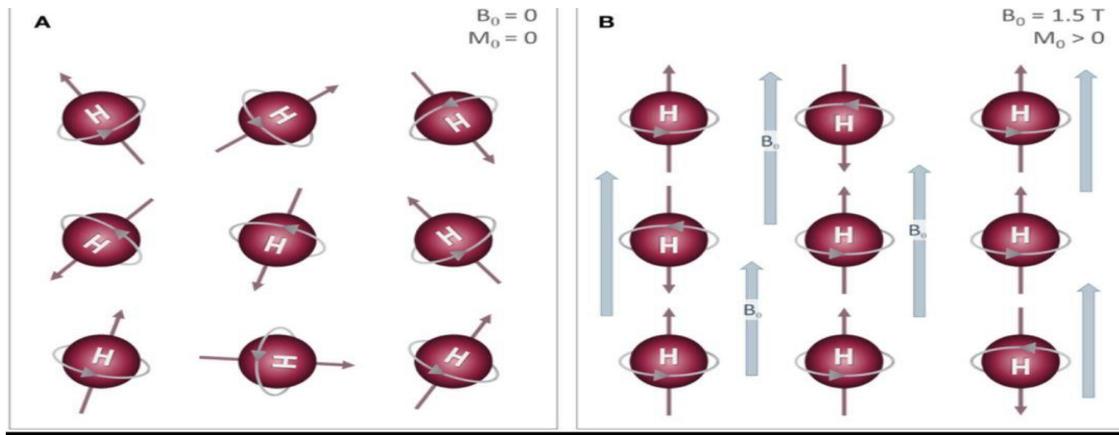
In the case of medical implants such as bone plates or joint prostheses, **titanium alloys** are frequently used instead of stainless steel. Titanium produces fewer artifacts in CT images, allowing physicians to visualize surrounding tissues more clearly during diagnosis.

3. MRI-Safe Materials

3.1 Principle of Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI) operates using a strong magnetic field combined with radiofrequency waves to visualize the distribution of hydrogen atoms within body tissues. When the human body is exposed to a strong magnetic field, the hydrogen nuclei align in a specific direction. When radiofrequency pulses are applied, these nuclei change their alignment and emit signals that are detected and processed to generate detailed images of internal organs.

¹البولي مثيل ميثاكريلات (PMMA)



3.2 Requirements for MRI-Safe Materials

Due to the extremely strong magnetic field used in MRI systems, materials employed in medical devices or implants must satisfy several requirements:

- They must be non-ferromagnetic
- They should not distort the magnetic field
- They must resist heating caused by radiofrequency energy
- They must exhibit good biocompatibility

3.3 Examples of Materials Used in MRI Environments

Medical polymers such as **Silicone** and **Polyurethane** (بولي يوريثان) are commonly used in devices that may be present in MRI environments. These materials do not interact with the magnetic field and therefore do not produce significant imaging artifacts. As a result, they are frequently used in the manufacture of medical catheters and tubing that may remain inside the patient during MRI examinations.

Certain non-magnetic metals can also be safely used in MRI environments.

Titanium is a common example, as it possesses excellent mechanical strength, outstanding biocompatibility, and very weak magnetic susceptibility. For this reason, many modern orthopedic implants, including hip replacements and bone fixation plates, are manufactured from titanium alloys so that patients can safely undergo MRI scans without major image distortion.

4. Contrast Agent Containers(حملات مواد التباين)

4.1 Concept of Contrast Agents

In many medical imaging procedures, the natural differences between tissues may not be sufficient to produce clear images. Therefore, substances known as **contrast agents** are administered to enhance the visibility of specific structures within the body.

These agents increase the contrast between different tissues by altering the absorption of radiation or the magnetic signal detected by the imaging system.

4.2 Examples of Contrast Agents

In CT imaging, contrast agents commonly contain **iodine**, an element with a high atomic number that strongly absorbs X-rays. This property allows blood vessels and certain organs to appear more clearly in CT images.

In MRI examinations, contrast agents often contain **gadolinium**, a paramagnetic element that enhances the magnetic signal from tissues, thereby improving image clarity and diagnostic accuracy.

4.3 Materials Used in Contrast Agent Containers

Because contrast agents may contain chemically active compounds, they must be stored in containers made from materials that do not react with them. **Medical glass vials** are frequently used for this purpose because glass is chemically inert and does not interact with most pharmaceutical compounds.

In addition, certain polymers such as **Polypropylene**(البولي بروبيلين) and **Polyethylene** (البولي اثيلين) are commonly used to manufacture syringes and plastic containers for contrast agents. These polymers are lightweight, resistant to breakage, and capable of withstanding sterilization processes commonly used in hospital environments.

5. Imaging Phantoms

5.1 Definition of Imaging Phantoms

An **Imaging Phantom** is an artificial model designed to simulate the physical and sometimes biological properties of human tissues. These models are widely used for testing, calibrating, and validating medical imaging systems before they are used on patients. They also serve as valuable tools for training physicians and medical students in imaging techniques.

5.2 Materials Used in Imaging Phantoms

When simulating soft tissues, gel-based materials such as **Agar** or **Gelatin** are often used. These materials contain high water content, which closely resembles the composition of many biological tissues. When used in MRI phantoms, agar or gelatin can produce signals similar to those generated by real human tissues.

For simulating muscle or adipose tissue, polymeric materials such as **Silicone** or **Polyvinyl Alcohol (PVA)** are commonly used. These materials can be engineered to achieve mechanical and density properties similar to those found in natural tissues.

More advanced phantoms may incorporate multiple materials to replicate complex anatomical structures. For example, a polymer matrix may be combined with **Hydroxyapatite particles** to simulate bone structures. When such phantoms are used in CT imaging tests, they allow researchers to evaluate the scanner's ability to distinguish bone from surrounding tissues.

Specialized phantoms are also designed to simulate the human brain for MRI calibration, while vascular phantoms are used to train physicians in catheterization procedures and to test vascular imaging techniques.