BIOMATERIALS

Dr. B. Latha

Dr. Preetha Mary George

Dr. N. S. Shubhashree

www.jpc.in.net

BIOMATERIALS

Authors:
Dr. B. Latha
Dr. Preetha Mary George
Dr. N. S. Shubhashree

First Published November 2023

ISBN: 978-93-91303-82-2

DOI: https://doi.org/10.47715/JPC.B.978-93-91303-82-2

Pages: 222 (Front pages 12 & Inner pages 210)

Price: 375/-

Publisher:
Jupiter Publications Consortium
22/102, Second Street, Virugambakkam
Chennai, Tamil Nadu, India.
Website: www.jpc.in.net
Email: director@jpc.in.net

Printer Details
Magestic Technology Solutions (P) Ltd
Chennai.
www.magesticts.com

Title Verso

Title of the Book:
BIOMATERIALS

Author's Name:
Dr. B. Latha
Dr. Preetha Mary George
Dr. N.S. Shubhashree

Published By:
Jupiter Publications Consortium
Publisher's Address:
22/102, Second Street, Venkatesa Nagar, Virugambakkam
Chennai 600 092. Tamil Nadu, India.

Printer's Details:
Magestic Technology Solutions (P) Ltd.

Edition Details: First Edition

ISBN: 978-93-91303-82-2

COPYRIGHT

Jupiter Publications Consortium
22/102, Second Street, Virugambakkam
Chennai 600 092. Tamil Nadu. India

Printed on acid-free paper
International Standard Book Number (ISBN): 978-93-91303-82-2 (Paperback)
Digital Object Identifier (DOI): https://doi.org/10.47715/JPC.B. 978-93-91303-82-2

Visit the Jupiter Publications Consortium Web site at
http://www.jpc.in.net

DEDICATION

Er. A. C. S. ARUNKUMAR
B.Tech (Hons)., LMISTE., MIET.,(UK)., LMCSI.,
President
Dr. M. G. R. Educational and Research Institute
Chennai, Tamil Nadu, India.

- We take immense pride and heartfelt reverence in dedicating this book to **Er. A C S. Arunkumar, B.Tech (Hons)., LMISTE., MIET.,(UK)., LMCSI.,** who holds the esteemed position of President at our illustrious Dr. M. G. R. Educational and Research Institute, located in the culturally vibrant city of Chennai, Tamil Nadu, India.

Our President's unwavering devotion to cultivating academic excellence and fostering the expansion of knowledge is a testament to his global vision. His educational philosophy not only stimulates us but is a beacon that has helped light the path towards academic and personal growth for countless students, leaving an indelible impact on the landscape of academia.

Our gratitude for our President's leadership is profound, as his guidance persistently propels us to strive for the pinnacle of excellence in all aspects of our pursuits. It is more than an honour; it is a privilege to dedicate this book to such a luminary, a tangible expression of our respect, admiration, and appreciation.

We extend our deepest gratitude to you, sir, for your extraordinary contributions to the field of education and for ceaselessly inspiring us all with your visionary leadership. Like this book, your legacy shall serve as a beacon of inspiration for future generations.

- **Dr. B. Latha**
- **Dr. Preetha Mary George**
- **Dr. N.S. Shubhashree**

PREFACE

In the dynamic and ever-evolving field of biomaterials, the intersection of biology, materials science, and engineering has yielded revolutionary innovations that have profoundly transformed the landscape of medical science. This book, Biomaterials, aims to comprehensively explore biomaterials' current state and future potential in various medical applications.

As we board this journey through the pages, we begin with an "Introduction" that sets the stage for the reader, offering a primer on biomaterials' fundamental concepts and historical context. This foundation paves the way for a deeper dive into "Metals in Biomaterials," where we explore the roles of titanium alloys, stainless steel, and cobalt-chromium alloys, emphasising their unique properties and applications in medical devices.

The narrative then shifts to "Ceramics in Biomaterials," highlighting materials like alumina, zirconia, calcium phosphate, and bioactive glass. These ceramics are examined for their distinct contributions to the biomedical field, particularly in orthopaedics and dentistry.

Our exploration continues with "Polymers in Biomaterials," delving into the world of polyethene, polymethylmethacrylate (PMMA), and polylactic acid (PLLA). This section underscores the versatility of polymers and their growing significance in medical applications, from prosthetics to drug delivery systems.

"Composite Materials in Biomaterials" presents an intriguing blend of materials, discussing polymer-metal and polymer-ceramic composites and showcasing how combining materials can enhance properties to meet specific medical needs.

The focus then shifts to "Biodegradable Materials in Biomaterials," a crucial area that addresses the environmental and physiological impacts of biomaterials, followed by a section on "Surface Modifications and Coatings," which is pivotal in enhancing the performance and biocompatibility of biomaterials.

These chapters provide a detailed look at how biomaterials are revolutionising treatments and improving patient outcomes in these critical areas of healthcare.

As we approach the concluding sections, "Biomaterials in Drug Delivery Systems," "Biomaterials in Tissue Engineering," and "Future Trends in Biomaterials" offer a glimpse into the future, exploring emerging technologies and potential new frontiers in the field.

Finally, "Ethical Considerations and Regulatory Affairs" addresses the critical aspects of ethics and regulation in developing and applying biomaterials, leading to the "Conclusion", which ties together the diverse threads of this intricate knowledge.

Our goal is to provide an informative and inspiring resource, encouraging innovation and collaboration across disciplines to advance the field of biomaterials further. We invite students, researchers, practitioners, and all those fascinated by the potential of biomaterials to join us in exploring these pages.

Happy Reading!

- **Dr. B. Latha**
- **Dr. Preetha Mary George**
- **Dr. N.S. Shubhashree**

ABSTRACT

Biomaterials is a comprehensive exploration of the multifaceted world of biomaterials, intersecting biology, materials science, and engineering. This book delves into the historical context and fundamental concepts of biomaterials, followed by an extensive examination of their applications in various medical fields. It highlights their crucial role in medical devices, starting with metals like titanium alloys, stainless steel, and cobalt-chromium alloys. The discussion progresses to ceramics, such as alumina, zirconia, calcium phosphate, and bioactive glass, emphasising their significance in orthopaedics and dentistry. The versatility of polymers, including polyethene, PMMA, and PLLA, is explored next, illustrating their impact in areas ranging from prosthetics to drug delivery systems. The book also covers composite materials, showcasing the advantages of combining different materials to meet specific medical needs. Attention is given to biodegradable materials and surface modifications, emphasising environmental and physiological considerations. Further, it provides in-depth insights into using biomaterials in orthopaedic surgery, cardiovascular applications, and dental applications, highlighting how these materials are revolutionising treatment approaches and patient care. As the book concludes, it offers a glimpse into future trends in biomaterials, encompassing emerging technologies and potential advancements. It also addresses the ethical considerations and regulatory affairs crucial in developing and applying biomaterials. This book aims to inspire innovation and collaboration, serving as a valuable resource for students, researchers, and practitioners.

Keywords: Biomaterials, Titanium Alloys, Stainless Steel, Cobalt-Chromium Alloys, Alumina, Zirconia, Calcium Phosphate, Bioactive Glass, Polyethylene, PMMA, PLLA, Composite Materials, Biodegradable Materials, Surface Modifications, Orthopedic Surgery, Cardiovascular Applications, Dental Applications, Drug Delivery Systems, Tissue Engineering, Future Trends, Ethical Considerations, Regulatory Affairs.

This Page Intentionally Left Blank

TABLE OF CONTENTS

S. No.	Section	Page Number
1	1.0 Introduction to Biomaterials	1
2	1.1 Need for Biomaterials	3
3	1.2 Biomechanism	3
4	1.3 Classification of Biomaterials	4
5	1.4 Properties of Biomaterials	7
6	1.5 Surface Property	7
7	1.6 Bulk Properties	13
8	1.7 Mechanical Properties	21
9	1.8 Impacts of Biological Fluids on Biomaterials	30
10	2.0 Types of Biomaterials	32
11	2.1 Metallic Implants	32
12	2.2 Stainless Steel	33
13	2.3 Co-based Alloys	35
14	2.4 Titanium and its Alloys	39
15	2.5 Shape Memory Alloys: The Futuristic Implants	43
16	2.6 Nanostructured Metallic Implants: The New Frontier	51
17	2.7 Ceramic Implants: The Pillars of Biostability	56
18	2.8 Biomedical Applications of Polymers	60
19	2.9 Biodegradable Polymers	61
20	2.10 Biopolymers in Controlled Release Systems	67
21	2.11 Synthetic Polymeric Membranes: Biological Applications	73
22	2.12 Composite Implant Biomaterials	80
23	3.0 Surface Characterization	85
24	3.1 Contact Angle and Adhesion	85
25	3.2 Scanning Electron Microscope (SEM)	86
26	3.3 Transmission Electron Microscope	91
27	3.4 Scanning Tunneling Microscopy (STM)	98
28	3.5 Atomic Force Microscopy (AFM)	106
29	3.6 Secondary Ion Mass Spectroscopy (SIMS)	112

30	3.7 Confocal Laser Scanning Microscopy (CLSM)	116
31	4.0 Testing of Biomaterials	126
32	4.1 Biocompatibility Testing	127
33	4.2 Testing of Biomaterials	129
34	4.3 Blood Compatibility Testing	133
35	4.4 Tissue Compatibility Testing	142
36	4.5 Toxicity Testing	143
37	4.6 Sensitization Testing	144
40	4.7 Genotoxicity	145
41	4.8 Carcinogenicity Testing	146
42	4.9 Special Tests	150
43	4.10 Sterilization	151
44	4.11 Autoclave (Pressure Steam Sterilizer)	153
45	4.12 Chemical Method: Gaseous Sterilization with Ethylene Oxide (EO)	156
46	4.13 Radiation Sterilization	158
47	5.0 Biomaterials Applications	162
48	5.1 Metals for Bone and Joint Replacement	162
49	5.2 Stainless Steels in Orthopaedic Prostheses	164
50	5.3 Titanium and Its Alloys in Artificial Hip Joints	166
51	5.4 Porous Metals in Orthopaedic Implants	175
52	5.5 Ceramics	177
53	5.6 Alumina (Bioinert Ceramics)	178
54	5.7 Calcium Phosphate (CaP)	180
55	5.8 Bioactive Glass	182
56	5.9 Polymers	187
57	5.10 Materials for Oral and Maxillofacial Surgery	194
58	5.11 Ophthalmological Biomaterials	199
59	5.12 Intelligent Textiles	204

Unit I:

Introduction to Biomaterials

Biomaterials are specialized materials designed for use in medical applications. Their primary purpose is to replace or repair damaged or diseased body parts in both humans and animals. One of the distinctive features of these materials is their ability to closely interact with living tissues while eliciting minimal adverse reactions. This harmonious interaction is achievable due to the biomaterials' mechanical, physical, and chemical properties, which are tailored to be compatible with the host body. The historical progression of biomaterials is depicted in Figure 1.1. The term "biocompatibility" refers to how well the body accepts and performs with these materials.

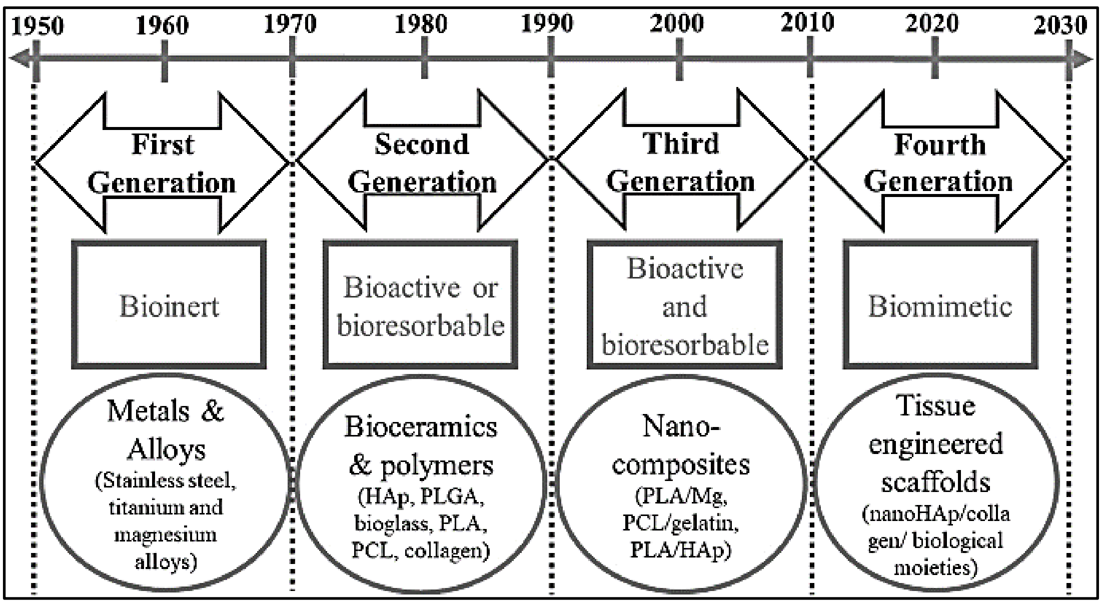


Figure 1.1 Evolutions of Biomaterial

The contemporary space of biomaterials is an interdisciplinary convergence of medicine, biology, physics and chemistry. Additionally, recent advancements in tissue engineering and materials science have further enriched and expanded the scope of this field.

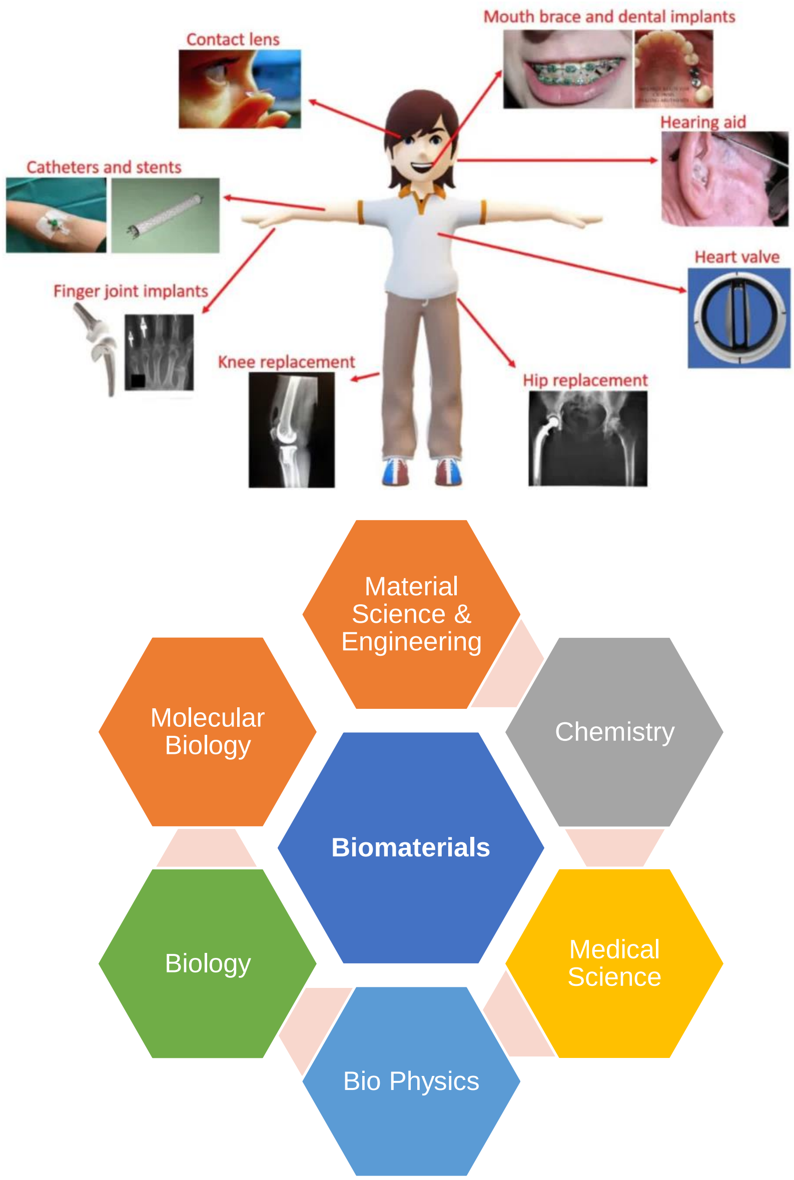


Figure 1.2 Evolutions of Biomaterials

1.1 Need for Biomaterials:

Biomaterials can be derived from a diverse set of substances, including metals, ceramics, plastics, glass, even living cells and tissues. They find significant applications in areas such as tissue engineering, drug delivery, regenerative medicine and chemical biology. These materials are designed to exhibit specific characteristics, like desired shape, stiffness, porosity, biocompatibility and degradation speeds. They are further adapted into various forms - be it molded or machined components, coatings, fibers, films, foams, or textiles - making them suitable for a range of biomedical products and devices. Examples of such applications are heart valves, hip joint replacements, dental implants and contact lenses, as highlighted in Figure 1.2. A notable aspect of these materials is their biodegradability, with certain variants also being bioresorbable.

1.2 Biomechanism When introduced into the body, biomaterials interact with tissues in varied manners, influenced by their inherent material properties. This tissue response to the implant surface is defined as biomechanism. Biomechanisms can be broadly categorized into three types: bioinert, bioresorbable, and bioactive.

Bioinert: Materials like titanium and alumina, referenced in Figure 1.3, are chemically passive within the body. Consequently, they exhibit minimal chemical interaction with the surrounding tissues.

Figure 1.3 Bio inert materials

Bioresorbable: Bioresorbable materials are engineered to gradually degrade and be replaced by native tissues or bones over time. Examples of such materials include tricalcium phosphate, polyacetic polyglycoloic acid and certain polymers.

Bioactive: Bioactive materials are distinctive in their ability to establish a chemical bond with living bone. This results in the creation of a robust mechanical connection between the implant and the bone. The term "bioactive" is derived from this unique characteristic of bonding directly to living bone structures.

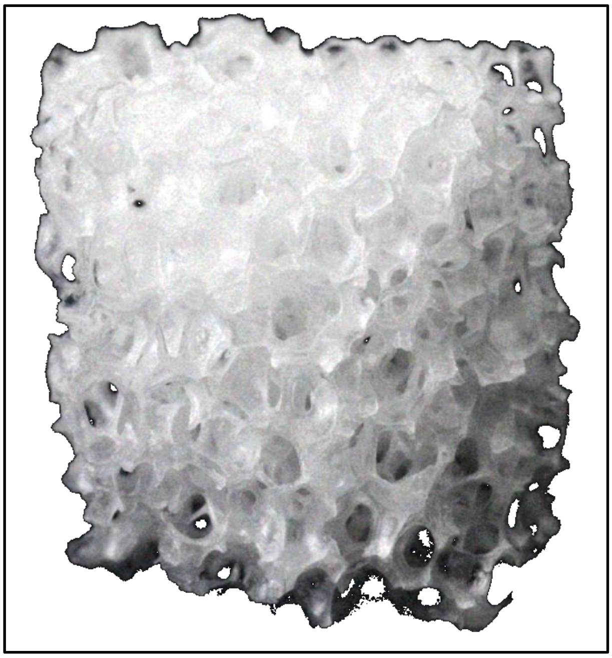


Figure 1.4 Bio Ceramics

Examples: Materials like glass, ceramics and glass-ceramics which are comprised of oxides of silicon, sodium, calcium, and phosphorous are prime examples of bioactive materials. This is further illustrated in figure 1.4.

1.3 Classification of Biomaterials: Biomaterials can be organized into various categories as depicted in Figure 1.5.

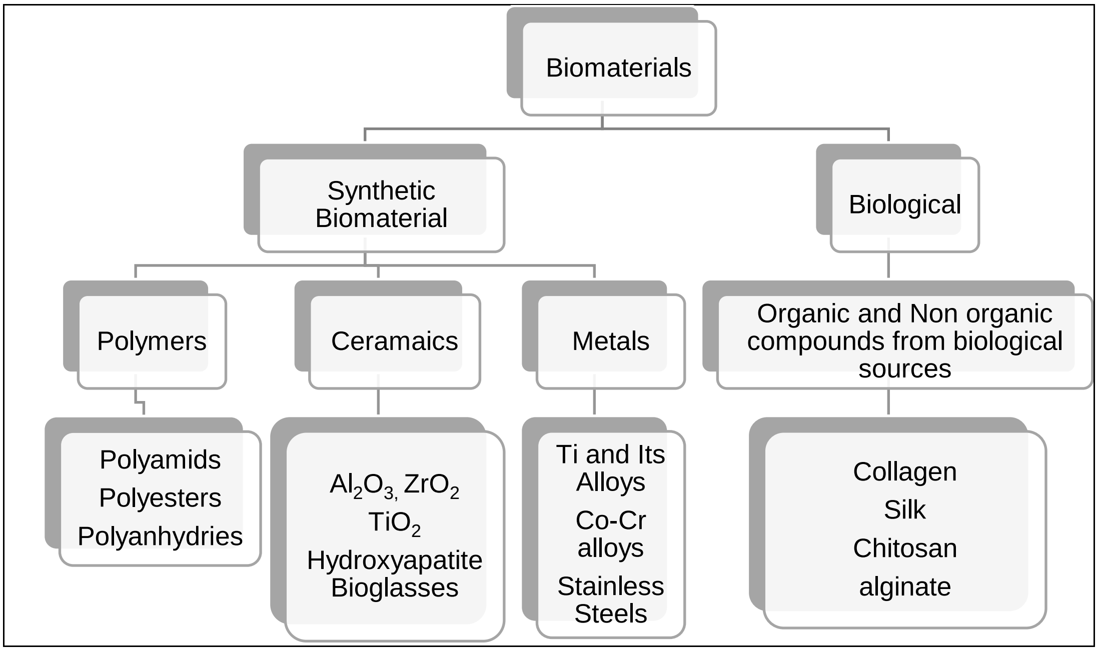


Figure 1.5 Classification of Biomaterials

Metals and Alloys: Metals are inorganic substances and typically exist in combinations of metallic elements such as iron, titanium, aluminum and gold. They may also incorporate minor amounts of non-metallic elements like carbon, nitrogen and oxygen. One method to enhance the strength of metals is through alloying, which combines multiple elements into a single material.

Advantages of metallic biomaterials include:

- High strength
- Ductility
- Toughness
- Abrasion resistance
- Fatigue-resistance
- High elastic modulus
- High electrical conductivity
- Certain metallic materials also possess exceptional magnetic properties.

Examples: Austenitic and Martensitic Stainless Steel are some types of metals used in biomedical applications. Titanium stands out as a preferred choice for medical devices and implants due to its inherent suitability.

Ceramics: Ceramics are inorganic solids made up of metal, non-metal, or metalloid atoms primarily bonded through ionic and covalent forces.

General Properties:

- Typically, crystalline in structure
- High compressive strength
- Effective electric and thermal insulators
- Aesthetically pleasing
- Transparent to light

Ceramics offer certain advantages over metals and alloys, such as specific density, porosity, high elastic modulus, hardness and cost-effectiveness. Their inert nature, coupled with hardness and abrasion resistance, makes them ideal for replacing bones and teeth.

Examples: Ceramics can be compounds formed between metallic and non-metallic elements, like alumina (Al_2O_3), calcium oxide (CaO), and silicon nitride (Si_3N_4).

Polymers: Polymers are substances composed of large molecules, known as macromolecules, that are formed from simpler chemical units called monomers. They are the most diverse group of biomaterials and are alike to soft tissues in nature. Their uses span across various medical devices and replacements.

Properties:

- High strength or modulus-to-weight ratios
- Toughness
- Resilience
- Corrosion resistance
- Non-conductivity (both thermal and electrical)
- Varied colors
- Transparency

Polymers can be sourced either synthetically (e.g., polyethylene, polyester, Teflon, epoxy) or naturally (e.g., collagen, silk, wool, DNA, cellulose, and proteins). Synthetic polymers can be further classified based on their degradation rates: biodegradable and non-degradable.

1.4 Properties of Biomaterials:

The choice of biomaterial for a specific application hinge on:

- Surface properties
- Bulk properties
- Mechanical properties

1.5 Surface Property:

The surface of a biomaterial plays a pivotal role in determining the biological response it elicits. The interface between bone and bioactive materials is sometimes referred to as a "bonding zone" or "amorphous zone". Surface properties are paramount since, upon implantation into a human or animal body, the level of interaction the material has with surrounding fluids is largely dictated by these properties.

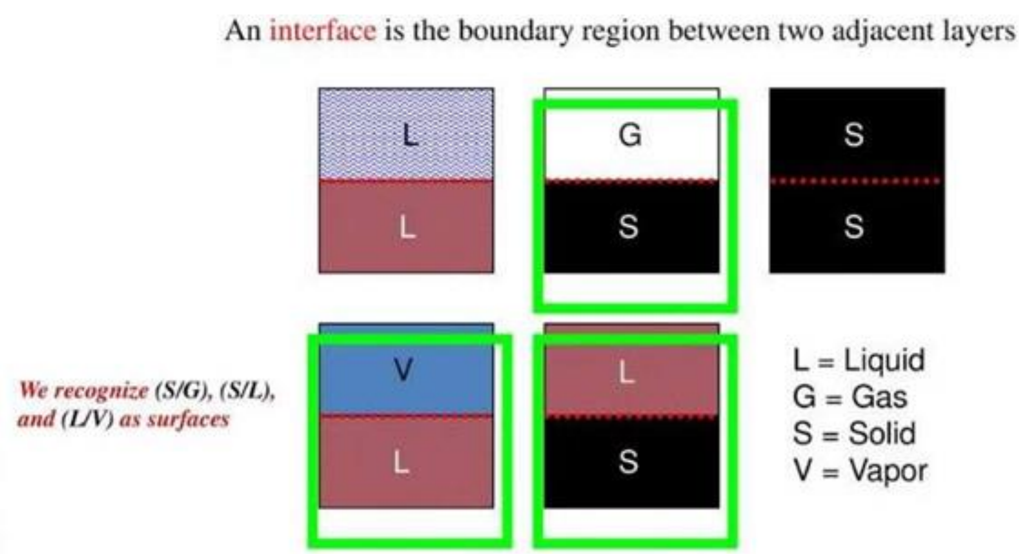


Figure 1.6 Interfaces

Surface Modification of Implants:

By altering the surfaces of implants, several benefits can be realized. These include increased resistance to corrosion, enhanced biocompatibility and improved osseointegration—all while retaining the inherent bulk properties of the implant.

The potential for metal implants to corrode within the body is a significant concern. Corrosion could result in the release of ions into body fluids, which might trigger adverse reactions. Therefore, the design and optimization of the biomaterial surface is of paramount importance. Proper surface design can significantly influence cell-material interactions, which, in turn, can dictate the overall success of biomedical implants and tissue engineering endeavors.

Key surface properties of biomaterials under consideration include:

- Surface energy
- Contact angle
- Surface tension

Surface Energy:

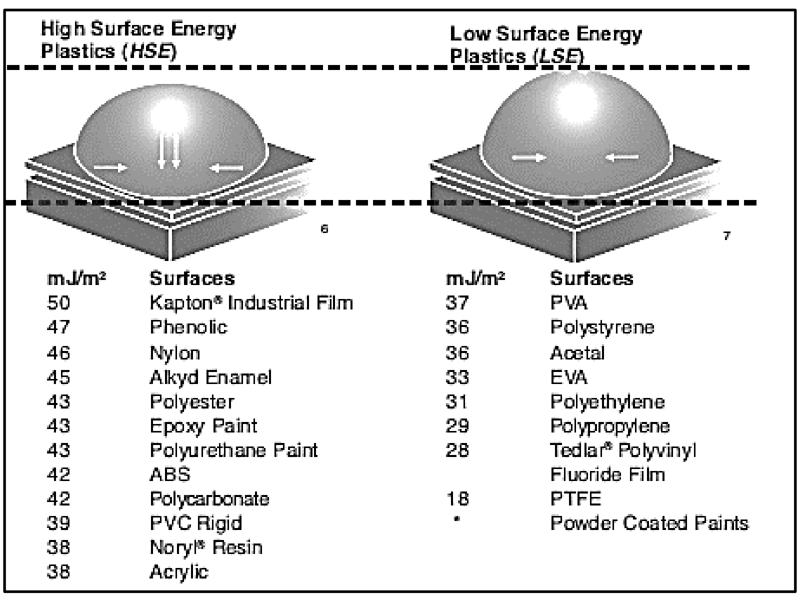


Figure 1.7 Surface Energy

Surface energy is a measure that captures the disruption of intermolecular bonds that take place when a surface is generated. It is alternatively referred to as surface free energy or interfacial free energy, as visualized in Figure 1.6. Due to the asymmetry in force fields at the surface, there's a net pull of surface atoms towards the bulk material. This phenomenon can lead to a relative deficiency of atoms at the surface, placing the surface under tension.
Metals and ceramics typically exhibit surfaces with high surface energies, generally in the range of 102 to 104 ergs/cm^2. On the other hand, most polymers and plastics possess significantly lower surface energies, often less than 100 ergs/cm^2. The surface energy of a material is influenced by the charge and polarity of its outermost functional groups. Figure 1.7 provides a visual representation, contrasting high and low surface energy biomaterials.

Contact Angle:
The contact angle is a critical parameter used to describe the wettability of a solid surface by a liquid. It is defined as the angle formed between a liquid-vapor interface and a solid-liquid interface, as illustrated in Figure 1.8.

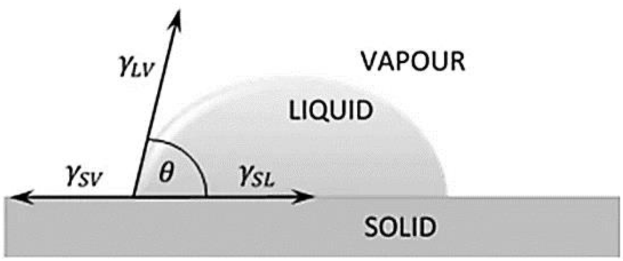


Figure 1.8 Contact Angle

The determination of the contact angle is influenced by the balance between adhesive forces (between the liquid and the solid) and cohesive forces (within the liquid itself). When a liquid drop exhibits a greater inclination to spread across a flat solid surface, it results in a smaller contact angle. Conversely, if the liquid drop tends to bead up and not spread, the contact angle is higher.

In the context of biomaterials, the contact angle can give insights into how a material might interact with body fluids. A lower contact angle (indicating higher wettability) might suggest better integration and interaction of the biomaterial with the surrounding tissues and fluids.

Hydrophobicity and Hydrophilicity in Biomaterials:

The concepts of hydrophobicity and hydrophilicity are fundamental when examining the surface properties of biomaterials, as they influence how materials interact with biological systems, particularly with body fluids.

Hydrophobicity essentially refers to the degree to which a material repels water and it's quantitatively measured using the 'contact angle'. Conversely, hydrophilicity describes a material's affinity for water.

- **Hydrophilic Surface:** If the contact angle is less than 90°, the surface is "wetting" or hydrophilic. A contact angle of 0° indicates complete wetting, meaning the liquid perfectly spreads across the material without forming any distinct droplet.
- **Hydrophobic Surface:** If the contact angle is greater than 90°, the material is non-wetting or hydrophobic with respect to that particular liquid.
- **Superhydrophobic Surface:** Surfaces with a contact angle exceeding 150° are categorized as superhydrophobic, implying an extremely high degree of water repellency.

These surface characteristics are crucial in the design and application of biomaterials. For instance, hydrophilic surfaces might promote cell attachment and proliferation, while hydrophobic surfaces might be used in applications where minimal interaction with surrounding tissues is desired. The distinction between these properties, as demonstrated by varying contact angles, can be visualized in Figure 1.9.

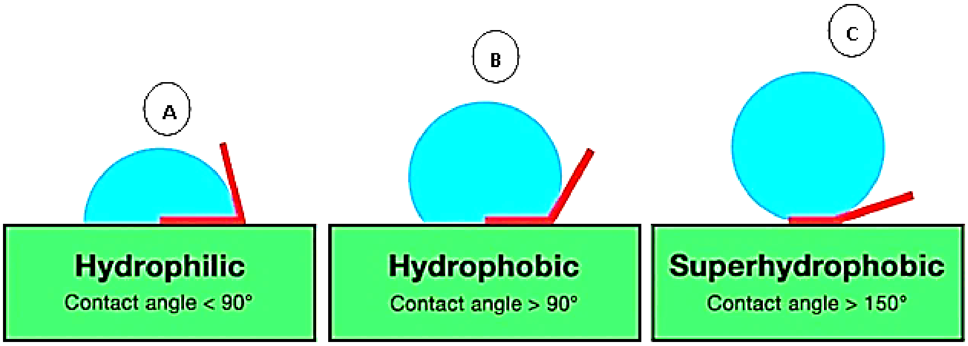


Figure 1.9 Wetting of Surface

Figure 1.9 Interpretation:

In Figure 1.9(A), we observe a fluid that exhibits strong wetting behavior as the droplet spreads across the surface, resulting in a small contact angle. This behavior indicates a hydrophilic or "water-loving" surface. Conversely, Figure 1.9(C) demonstrates a fluid with minimal wetting, where the droplet remains almost spherical, indicating a large contact angle and a hydrophobic or "water-repelling" surface.

Notion: Wetting is defined by a liquid's capability to sustain contact with a solid surface, primarily driven by intermolecular interactions between the liquid and the solid. In essence, the contact angle serves as an inverse indicator of wettability: a smaller contact angle corresponds to better wetting and a larger contact angle indicates poorer wetting.

Surface Tension:

Surface tension can be conceptualized as the cohesive energy at an interface, predominantly resulting from intermolecular forces acting between molecules. This phenomenon is particularly evident at the boundary where a liquid meets another phase (e.g., a gas like air or another liquid).

Figure 1.10 elucidates the distinction between the forces acting on molecules located within the bulk of the liquid versus those at the liquid's surface. Molecules in the bulk are surrounded by other molecules and experience uniform forces from all directions.

Surface Tension and its Impact on Wettability:

The molecules within the bulk of a liquid are in a state of equilibrium because they experience cohesive forces uniformly from all directions. In contrast, the molecules at the liquid surface don't have molecules above them (assuming the liquid is exposed to a gas, like air), so they experience intermolecular forces primarily laterally and inward. This imbalance pulls these surface molecules toward the interior of the liquid. As a result, the liquid attempts to reduce its exposed surface area to the minimum, giving rise to the phenomenon of surface tension. This force creates a "film" on the liquid surface, increasing the resistance to moving an object through the surface, like to a stretched elastic sheet.

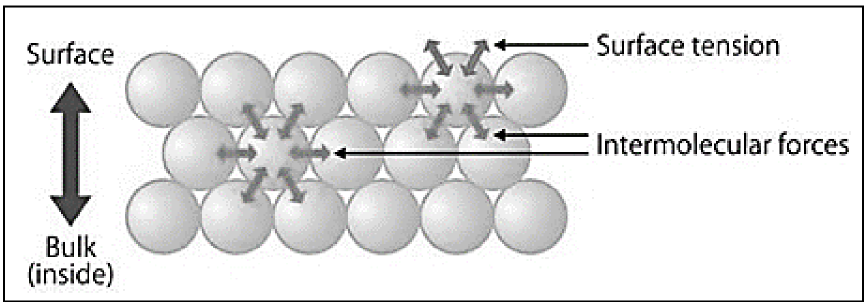


Figure 1.10 Intermolecular forces

Wettability, or the degree to which a liquid maintains contact with a solid, is closely related to surface tension. The surface tension arises from the excess energy at the liquid surface, as surface molecules "search" for other molecules to bond with, given the absence of molecules from the gaseous side. The critical surface tension of a liquid is the specific value below which the liquid will spontaneously spread across a solid surface, completely wetting it.

Figure 1.11 provides a visual representation of the relationship between surface energy and surface tension on a biomaterial surface. The interplay of these forces defines how a biomaterial will interact with liquids, which is crucial for many biomedical applications, such as implantable devices or drug delivery systems.

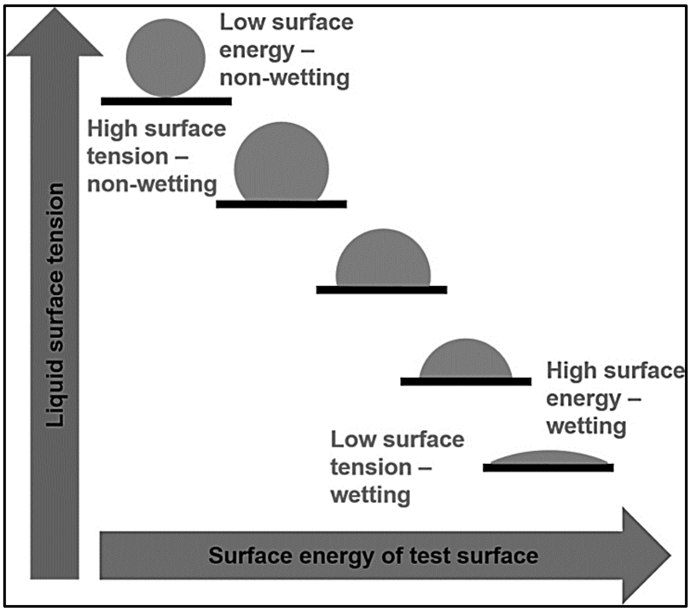


Figure 1.11 Surface energy Vs Surface Tension

Notion: Surface Energy vs. Surface Tension

While we typically refer to the surface tension of liquids, when discussing solids, it's more common to use the term "surface free energy." Although the units differ—surface tension is measured in Newton per meter (N/m) representing the force required to pull a unit length wire, while surface free energy is measured in millijoules per square meter (mJ/m^2) indicating the energy necessary to spread a unit area surface—the underlying values are equivalent.

1.6 Bulk Properties:

The core or bulk of a biomaterial encompasses the intrinsic physical, chemical, and mechanical characteristics that remain consistent throughout the lifespan of an implanted device.

Physical Property:

The inherent physical properties of a material significantly influence its interaction with the biological environment.

When selecting the optimal biomaterial for a medical application, it's essential to evaluate various factors, including:

- **Size:** The dimension of biomaterials is pivotal. There has been extensive research into micro-fabrication techniques and the development and application of nanoparticles.
- **Shape:** The geometry or form of a biomaterial can significantly influence cellular responses. The shape can dictate how cells grow around or adhere to the material.
- **Surface Texture:** This property is fundamental in determining cellular adhesion to the material. A specific texture might promote or hinder cell attachment and proliferation.
- **Atomic and Molecular Bonds:** The type of bonding present in a material inherently dictates its properties. For instance, metallic bonds, illustrated in Figure 1.12, facilitate high electrical and thermal conductivity due to the presence of free electrons that act as a transmission medium.

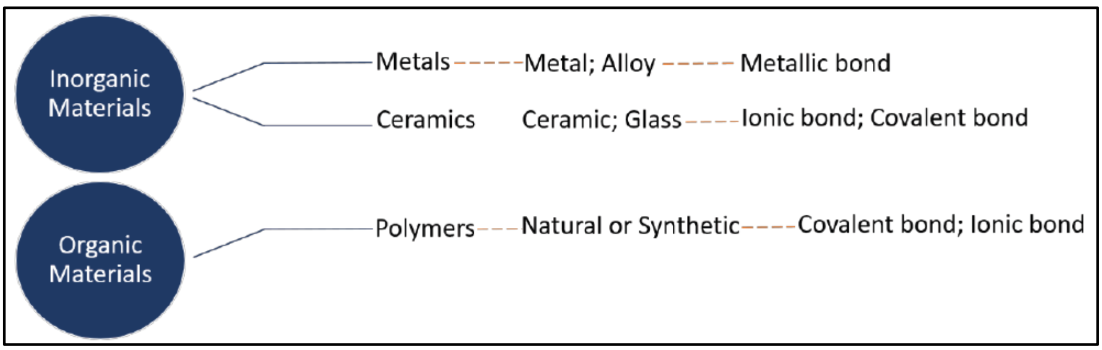


Figure 1.12 Different kinds of biomaterials and chemical bonds associated.

Bonding in Materials and Their Impacts on Properties:

Different types of atomic and molecular bonds confer distinct properties to materials:

- **Ionic Bonds:** In ionic materials, electrons are transferred from one atom to another, resulting in the formation of positive and negative ions. These ions are held together by the electrostatic attraction between them. Due to the tight holding of electrons by the ions, ionic materials are typically insulators of both heat and electricity. The directional nature of the ionic bond, combined with the repulsion between like-charged ions, limits the number of slip planes in these materials. This characteristic contributes to the brittleness of ionic materials.
- **Metallic Bonds:** In metallic bonds, metal atoms release some of their outer electrons, creating a "sea" of freely moving electrons. These delocalized electrons provide metals with their notable electrical and thermal conductivity. Furthermore, the non-specific nature of metal atoms regarding their neighboring atoms allows them to change positions under applied stress, resulting in ductility.
- **Covalent Bonds:** Atoms in covalent compounds share valence electrons, forming a strong bond. Typically, covalent materials exhibit poor electrical and thermal conductivity, similar to ionic materials. This is because the electrons are tightly bound and not free to move as in metals.
- **Secondary Bonds:** Apart from the primary bonds mentioned above, secondary or van der Waals bonds also significantly influence material properties. These include dipole-dipole interactions, hydrogen bonds, and van der Waals interactions. While these bonds are weaker than primary bonds, they play a crucial role in determining the characteristics of many materials, especially organic compounds and polymers.

The relative strengths of different chemical bonds can be deduced from their heat of vaporization. Table 1.1 lists these strengths in terms of bond strength: Ionic>Metallic>Covalent>Hydrogen>van der Waals. This hierarchy is visualized in Figure 1.13. Consequently, the elastic moduli of various biomaterials, which is a measure of their stiffness, can be ordered as:

Ceramic > Metallic > Polymeric.

This sequence reflects the inherent stiffness of ceramics due to strong ionic and covalent bonds, the intermediate stiffness of metals due to metallic bonds, and the flexibility of polymers because of weaker covalent and secondary bonds.

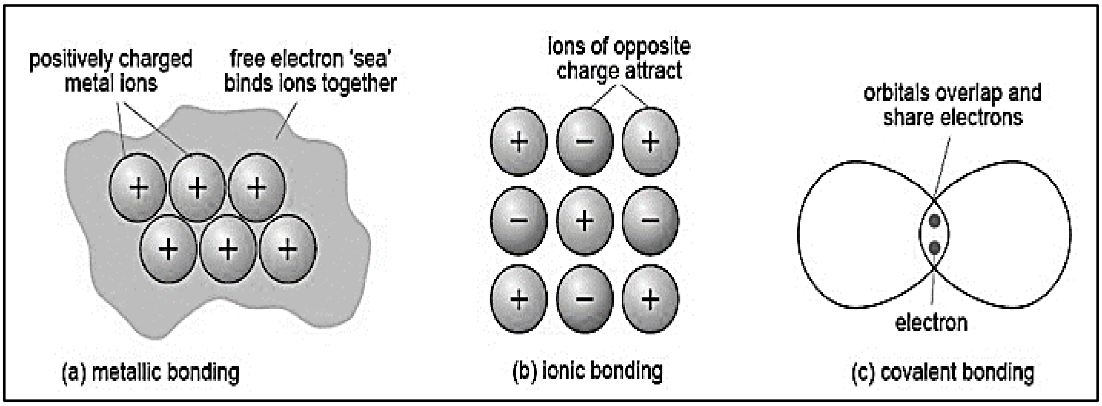


Fig. 1.13 Schematic Representation of Covalent, Ionic and Metallic bonds

Crystal Structure of Solids:

Materials, based on their internal arrangement of atoms or molecules, are categorized into two primary groups: crystalline and amorphous.

- **Crystalline Solids:** In these materials, atoms or molecules are periodically and repetitively arranged in all three spatial directions. As a result of this specific arrangement, their physical properties can differ depending on the direction, making them anisotropic. Examples of crystalline materials include metals like copper, silver, aluminium and tungsten.
- **Amorphous Solids:** These materials lack a consistent, repetitive atomic or molecular arrangement. Instead, their constituents are dispersed randomly, leading to uniform properties in all directions. This uniformity makes them isotropic. Examples of amorphous materials are glass, plastics, and rubber.

Table 1.1: Strength of Different Chemical Bonds Reflected from Their Heat of Vaporization

Bond Type	Substance	Heat of Vaporization (KJ/mol)
Vander Waals	He, N_2	0.14, 13
Hydrogen	Phenol, HF	31, 47
Metallic	Na, Fe	180, 652
Ionic	NaCl, MgO	1062, 1880
Covalent	Diamond, SiO_2	1180, 2810

Crystalline Structures and Unit Cells:

The atomic arrangement in a crystalline solid can be visualized using a three-dimensional space lattice. The basic repeating unit in this lattice, which represents the smallest unit that can depict the entire crystal structure, is known as the unit cell. This unit cell is the foundational building block of a crystal structure.

Figure 1.14 provides a visual representation of a basic cubic unit cell.

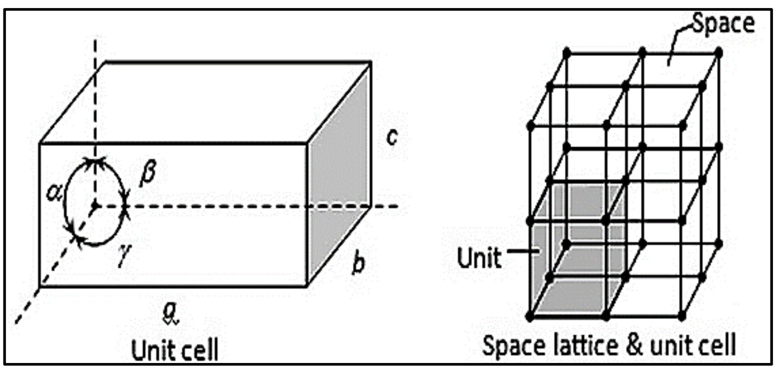


Figure 1.14 Crystal Structure Systems and Space Lattices

Crystalline structures are classified into seven distinct systems based on the lengths of their axes and the angles between these axes, known as interaxial angles. Parallel lines along the three primary edges of these systems are referred to as crystallographic axes. The external appearance of a crystal is termed its habit.

While there are 14 unique space lattices that can represent any crystalline material, the cubic and hexagonal systems are especially prevalent for implant metals and ceramics. These space lattices are tabulated in Table 1.2.

Table 1.2 Crystal structure systems and space lattices

Sl. No	Crystal System	Axes	Angles (α, β, γ)	Examples
1	Cubic	$a=b=c$	$\alpha=\beta=\gamma=90°$	Fe, Cu, NaCl, NaBr, Diamond
2	Tetragonal	$a=b\neq c$	$\alpha=\beta=\gamma=90°$	Sn (Simple tetragonal)
3	Orthorhombic	$a\neq b\neq c$	$\alpha=\beta=\gamma=90°$	KNO_3 (Simple orthorhombic)
4	Hexagonal	$a=b\neq c$	$\alpha=\beta=90°$, $\gamma=120°$	Graphite (Simple hexagonal)
5	Rhombohedral	$a=b=c$	$\alpha=\beta=\gamma\neq 90°$ (but less than 120°)	α-Fe_2O_3 (Hematite)
6	Monoclinic	$a\neq b\neq c$	$\alpha=\beta=90°\neq\gamma$	$CaSO_4{\cdot}2H_2O$ (Gypsum)
7	Triclinic	$a\neq b\neq c$	$\alpha\neq\beta\neq\gamma\neq 90°$	$KAlSi_3O_8$ (Microcline feldspar)

Within the sphere of solid-state physics and materials science, atomic arrangements play a crucial role in defining the properties of a material. Figure 1.15 illustrates three prominent structures: face-centered cubic (FCC), body-centered cubic (BCC) and hexagonal close-packed (HCP).

Implant materials often comprise multiple elements, leading to complex crystalline structures. The exact configuration of these structures is influenced by the type and spatial occupancy of the constituent atoms.

A pivotal concept in understanding these structures is the "coordination number." This term refers to the count of immediate neighboring atoms surrounding a particular atom in the structure. A higher coordination number typically suggests a denser atomic arrangement.

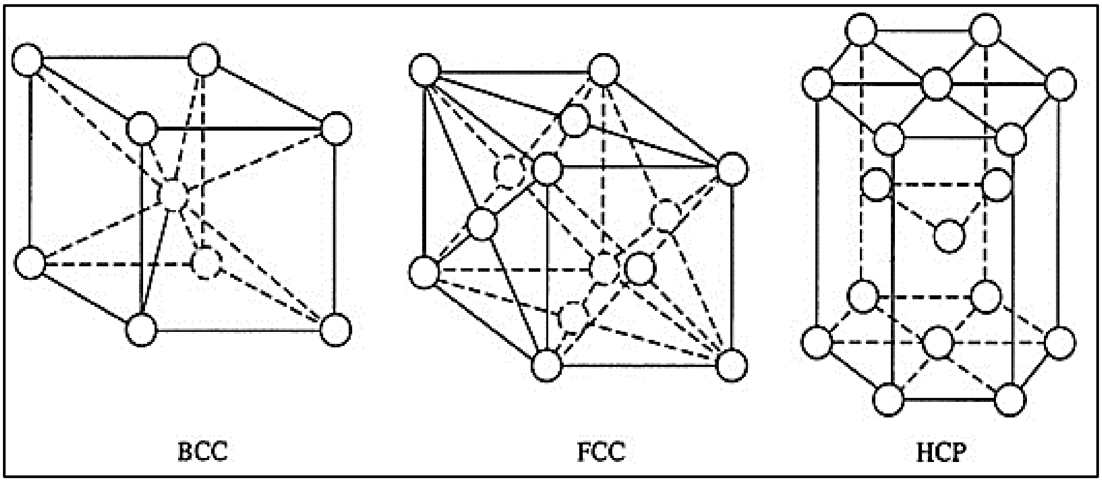


Fig. 1.15 Common Crystal Structures BCC, FCC and HCP

Phase Changes:

Materials undergo phase transitions when they shift from one state of matter to another, typically influenced by variations in temperature or pressure. These changes are typically associated with specific temperatures, such as a substance melting or boiling point.

Allotropy is an interesting phenomenon where certain substances can exist in multiple structural forms or phases within the same state of matter. These variations in structure, induced by temperature, are characterized as allotropic phase transformations. Table 1.3 provides examples of materials that demonstrate different crystal structures due to such phase transitions.

A phase diagram provides a comprehensive view of the relationships between the solid, liquid and gaseous states of a substance, with temperature and pressure as variables.

Table 1.3: Phase Transitions in Various Materials

Material	Structure
Co	HCP (up to 460°C), FCC (beyond 460°C)
Ti	HCP (up to 882.5°C), BCC (beyond 882.5°C)

Chemical Property

When selecting a biomaterial, its essential to consider its chemical attributes, which include reactivity, electronegativity, biodegradability, resistance to corrosion, and its acidic or basic nature.

Reactivity: This refers to how actively the biomaterial interacts with its surrounding environment, especially when implanted within the human body.

Electronegativity: A fundamental concept in chemistry, electronegativity measures an atom's affinity to attract and retain electrons. An atom with high electronegativity tends to pull electrons towards itself, influencing the chemical behavior of the material (see Figure 1.16).

Other factors, such as biodegradability (how quickly the material decomposes under biological conditions) and corrosion resistance (the material's resilience against degradation), also play a crucial role in determining the suitability of a biomaterial for a specific application.

The ability of an atom to attract electrons when the atom is in a compound

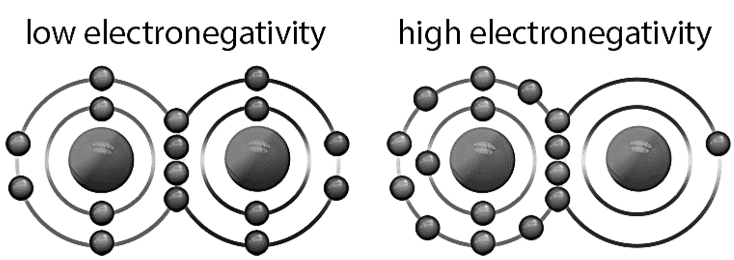


Figure 1.16 Electronegativity

Biodegradability: Biodegradability pertains to a material's capability to break down organically via microbial action. This property is paramount in designed scaffolds used in tissue regeneration. Polymers, due to their diverse range and customizable nature, are frequently utilized for scaffold creation.

Corrosion Resistance: This represents a material's innate capacity to resist degradation and maintain its integrity, especially against factors that might induce the emergence of porosity and fractures.

1.7 Mechanical Properties:

In biomedical applications, especially when components like plates or screws are integrated into bones, mechanical robustness is imperative. The overarching objective is to ensure resilience and stability. The biomedical landscape encompasses materials such as ceramics, alloys and polymers.

The contemporary roster of metals and alloys, spanning from stainless steel to titanium and Co–Cr alloys, ceramics like hydroxyapatite and bioglass and a plethora of polymers, has found pivotal application in load-bearing scenarios. This encompasses dental prosthetics and orthopedic applications.

Despite hydroxyapatite's acclaim as a bioactive and biocompatible material, it's hindered by a relatively low Young’s modulus and a propensity to be brittle. This drives the imperative to craft biomaterials that amalgamate bioactivity with mechanical prowess.

Key mechanical attributes include:

- **Elastic Modulus:** Denoted as the stress-to-strain ratio within the elastic limit, it provides insight into material stiffness under tensile or compressive forces. Visualize its representation in Figures 1.17 and 1.18. The significance in clinical contexts is its mirroring of the deformation characteristics of the tissue it replaces. High-load materials necessitate a potent elastic modulus combined with minimized deflection. It’s noteworthy that as a material's elastic modulus escalates, its fracture resilience tends to decline. Ideally, a biomaterial's elastic modulus should align with that of bone, ensuring balanced load distribution.

In the dominion of biomaterials, matching mechanical properties with the native tissue's properties ensures effective integration and function within the human body.

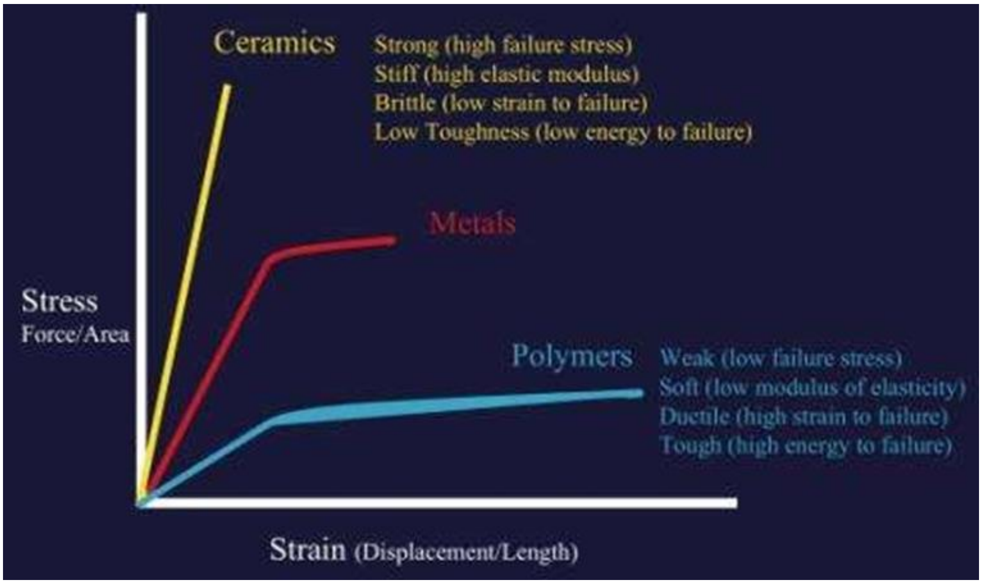


Figure 1.17 Stress Vs Strain

Material Moduli and Bond Strength:

The moduli of materials, such as the Young's modulus or shear modulus, reflect the inherent bond strengths within the material. A direct relationship exists between the bond strength and the modulus: stronger bonds yield higher moduli.

For instance:

- **Materials with Stronger Bonds:** These substances have high moduli, meaning that even when subjected to stress, they undergo minimal deformation or strain. Notable examples include Diamond and Alumina (Al_2O_3).
- **Materials with Weaker Bonds:** These materials are characterized by lower moduli, which means they can deform more easily under the same stress. Examples in this category are polymers and gold.

It's noteworthy that the properties of alloys, which are combinations of different metals, can vary significantly based on their constituents. For instance, the Cobalt-Chromium alloy exhibits a high Young's modulus, making it particularly rigid. In contrast, SS316L, a specific type of stainless steel, has a pronounced shear modulus, indicating its resistance to shape change when subjected to opposing forces.

Notion:

It's essential to comprehend that the inherent bond strengths and the resulting moduli govern a material's behavior under applied forces. This understanding is fundamental in of biomaterials, where materials often need to mimic or complement the mechanical behaviors of biological tissues. Properly matching or tailoring these properties ensures that the biomaterial performs optimally in its intended application.

The relationship between stress and strain is fundamental in understanding the mechanical behavior of materials. Let's delve into the key concepts:

1. **Stress (σ)**: Stress is defined as the force applied per unit area. It provides a measure of the internal resistance a material offers to deformation.
2. **Strain (ε)**: Strain measures the deformation of a material in response to an applied force. It's defined as the change in length divided by the original length.
3. **Young's Modulus (E)**: This is the measure of the stiffness of a material. It is defined as the ratio of tensile stress to tensile strain. It describes the material's response to linear stress.
4. **Shear Modulus (G)**: Also known as the modulus of rigidity, it describes the material's response to shear stress. It's the ratio of shear stress to shear strain.
5. **Bulk Modulus (K)**: This modulus describes the material's response to volumetric stress. It's the ratio of volumetric stress to volumetric strain.
6. **Poisson's Ratio (ν)**: It is the measure of the Poisson effect, which is the phenomenon where materials tend to expand in directions

and can be tinted to match various shades and levels of transparency. PMMA's color and optical properties remain stable in normal intraoral conditions, making it suitable for dental prosthetics. When placed in an aqueous environment, PMMA absorbs minimal water, but this water can significantly affect its mechanical and dimensional properties. The PMMA resins used for prosthetic teeth are similar to those used in denture base construction.

Polyurethane Polymers

Polyurethane is a relatively recent addition to the materials used in maxillofacial prosthetics. Fabricating a polyurethane prosthesis involves precise proportioning of three materials, which are then placed in a mold (stone or metal) and allowed to polymerize at room temperature.

Natural Polymers

Natural polymers derived from living organisms are of great interest in the biomaterials field, particularly in tissue engineering. These scaffolds are sought after for their biodegradability, non-toxicity, mechanical similarity to the target tissue, high porosity, support for cell attachment and growth, ease of manufacture, and potential for interaction with other molecules to enhance scaffold-tissue interaction.

Three examples of natural polymers studied for use as biomaterials are:

1. **Collagen**: A protein found in connective tissues, collagen is a well-suited natural polymer for biomaterial applications.
2. **Chitosan**: Derived from chitin, a component of crustacean shells, chitosan is biodegradable and has potential applications in tissue engineering.
3. **Alginate**: Obtained from brown seaweed, alginate is often used in cell encapsulation and drug delivery due to its biocompatibility and ability to form hydrogels.

These natural polymers are advantageous because they naturally align with the requirements for tissue engineering and other biomaterial applications.

Collagen

Collagen is a fundamental protein in mammals, constituting approximately 25% of our protein mass. It plays a crucial role in providing strength to various tissues within the body. The basic unit of collagen is a molecule comprised of three intertwined protein chains, forming a helical structure akin to a spiral staircase. These collagen molecules combine to create collagen fibers of varying lengths, thicknesses, and interweaving patterns. Some collagen molecules form rope-like structures, while others create meshes or networks. There exist at least 15 different types of collagens, each distinguished by its unique structure, function, location, and other characteristics.

In biomedical applications, the most employed collagen type is type I collagen. This type, known as "rope-forming" collagen, is distributed throughout the body, including the skin and bones. Its prevalence and versatility make it a valuable biomaterial for various medical uses.

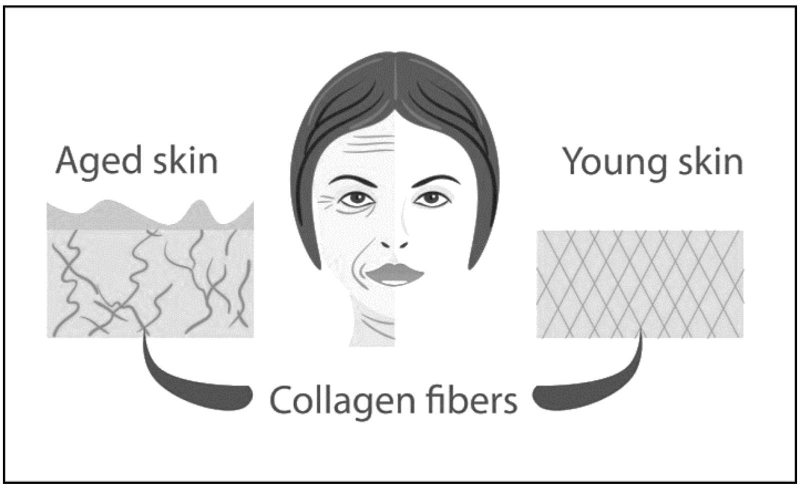


Figure 5. 13 Collagen fibers

Collagen's Diverse Roles and Applications

Collagen serves a multifaceted role in the body, contributing to its structural integrity and supporting various biological functions (see Figure 5.13 and 5.14). Some of the specific functions of collagen include:

- **Assisting Fibroblast Formation:** Collagen plays a crucial role in aiding the formation of fibroblasts in the dermis, which, in turn, promotes the growth of new cells.
- **Participating in Cell Replacement:** Collagen is involved in the replacement of dead skin cells, ensuring the continuous regeneration of skin tissues.
- **Providing Organ Protection:** It forms a protective covering for organs, contributing to their structural integrity and safeguarding against external factors.
- **Enhancing Skin Properties:** Collagen is responsible for imparting structure, strength, and elasticity to the skin, making it essential for skin health and appearance.
- **Facilitating Blood Clotting:** Collagen plays a role in the blood clotting process, contributing to wound healing and injury response.

One of collagen's remarkable features is its ability to be resorbed into the body. It is non-toxic and generally elicits only a minimal immune response. Collagen can be manipulated into various formats, including porous sponges, gels, and sheets. Chemical cross-linking can be applied to strengthen it or alter its degradation rate.

Collagen finds extensive use in a wide array of biomedical applications, ranging from surgeries and cosmetics to drug delivery, bio-prosthetic implants, and tissue engineering for various organs. When cells are grown on collagen, they often closely mimic their behavior within the body. This property makes collagen a promising material for replicating natural tissue function and promoting healing. Furthermore, collagen can be easily combined with other biological or synthetic materials to enhance its mechanical properties or influence cell behavior when used as a substrate for cell growth.

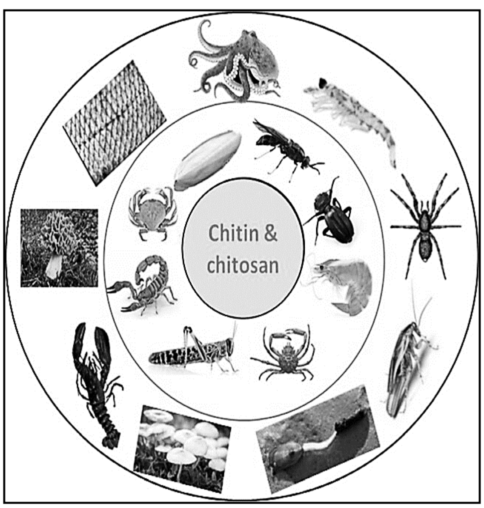
Chitosan: A Natural Biodegradable Polysaccharide

Chitosan is a naturally occurring biodegradable polysaccharide that is derived from marine sources, such as crustacean shells. Extensive research has demonstrated its non-toxic nature through various toxicity tests conducted in both animals and humans (see Figure 5.15).

Chitosan holds significant promise in the field of biomaterials due to its biocompatibility and biodegradability. It has been the subject of investigation for various tissue engineering applications, including:

1. **Cartilage Engineering:** Chitosan has been explored as a material for engineering cartilage tissue. Its biocompatibility and ability to support cell growth make it a potential candidate for regenerating damaged cartilage.
2. **Nerve Tissue Engineering:** Researchers have investigated the use of chitosan in the field of nerve tissue engineering. Chitosan-based scaffolds have shown promise in supporting nerve cell growth and regeneration.
3. **Liver Tissue Engineering:** Chitosan has also been studied for its potential in engineering liver tissues. Its biodegradable and biocompatible properties make it a valuable material for creating scaffolds for liver tissue regeneration.

Chitosan's versatility and natural origin make it an attractive option for various tissue engineering and regenerative medicine applications. Its non-



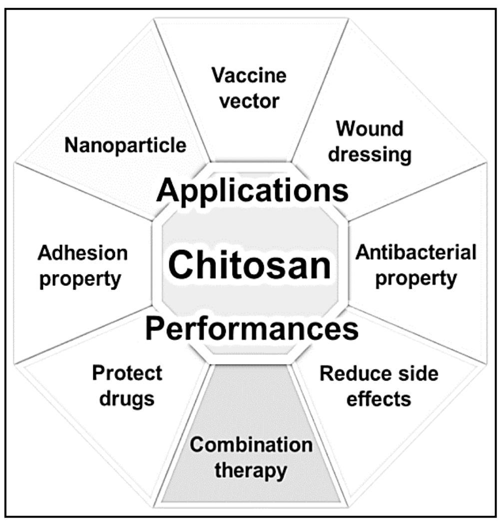


Figure 5. 14 Sources of Chitosan

toxic nature further enhances its suitability for use in biomedical settings, opening up opportunities for innovative solutions in healthcare and regenerative therapies.

Chitosan in Wound Healing and Drug Delivery

Chitosan's applications extend to wound healing and drug delivery. In wound healing, it can aid in tissue regeneration and wound closure. Furthermore, chitosan's properties make it suitable for drug delivery systems, where it can be employed to control the release of therapeutic agents. Chitosan's versatility allows it to serve as a polymer scaffold in tissue engineering, and it can be easily combined with other materials to enhance its strength and cell attachment properties. Researchers have created blends of chitosan with synthetic polymers like poly(vinyl alcohol) and poly(ethylene glycol), as well as natural polymers like collagen, to explore their potential in various biomedical applications.

Alginate: A Hydrophilic Polysaccharide from Seaweed

Alginate, also known as alginic acid or simply alginate, is a hydrophilic and anionic polysaccharide sourced from certain types of brown seaweed (Phaeophyceae) using alkaline extraction methods (see Figure 5.15). Like chitosan, alginate possesses characteristics that make it highly suitable for biomedical applications. It is non-toxic and non-inflammatory, and it has received approvals in some countries for use in wound dressings and food products.

Alginate is water-soluble and can be easily processed in aqueous solutions, making it versatile for various applications. Its potential uses span wound care, tissue engineering, and drug delivery systems. Alginate-based dressings can provide a moist environment for wound healing, and alginate hydrogels have been explored for controlled drug delivery. Alginate's compatibility with biological systems makes it a valuable material for creating innovative solutions in the field of biomaterials.

Figure 5.15 Seaweed

Alginate is a biodegradable material known for its controllable porosity and the ability to be linked to other biologically active molecules. It offers versatility for various biomedical applications. Alginates available on the market come in two main types: fast-setting, with a hardening time of 1–2 minutes, and normal-setting, with a setting time between 2–5 minutes (ref Figure 5.16).

Figure 5. 16 Alginate dental impression

Indeed, the encapsulation of specific cell types within alginate beads (as depicted in Figure 5.17) has been found to improve cell survival and promote growth. Alginate has also been investigated for its potential in tissue engineering applications for the liver, nerve, heart, and cartilage. To enhance its mechanical properties and cell behavior, alginate has been combined with other materials, including natural polymers such as agarose and chitosan.

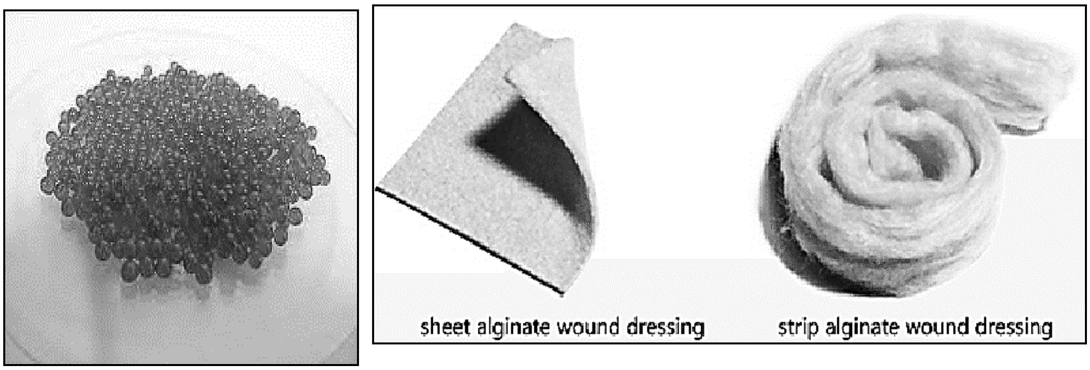


Figure 5. 17 Alginate beads

5.10 Materials for Oral and Maxillofacial Surgery:

Maxillofacial surgery, a dedicated branch of dentistry, focuses on the correction and repositioning of the jaw. This specialized field deals with the bones that comprise the upper part of the jaw, the roof of the mouth, and certain areas of the eye socket and nose. The maxilla, a significant facial bone as depicted in Figure 5.17, plays a critical role in anchoring the upper teeth and supporting the muscles essential for chewing and facial expressions. Maxillofacial surgery serves as a vital link between medicine, dentistry, and oral health. It is a surgical specialty primarily concerned with the diagnosis and treatment of diseases affecting the mouth, jaws, face, and neck.

Despite advancements in surgical and restorative techniques, the materials utilized in maxillofacial prosthetics are still far from meeting the ideal criteria. An ideal material for maxillofacial prosthetics should possess several key characteristics: affordability, biocompatibility, strength, stability, and skin-like color and texture. Moreover, it should resist tearing and endure moderate thermal and chemical challenges. Unfortunately, there is currently no single material that fulfills all of these requirements. Below, you'll find a brief overview of various maxillofacial materials:

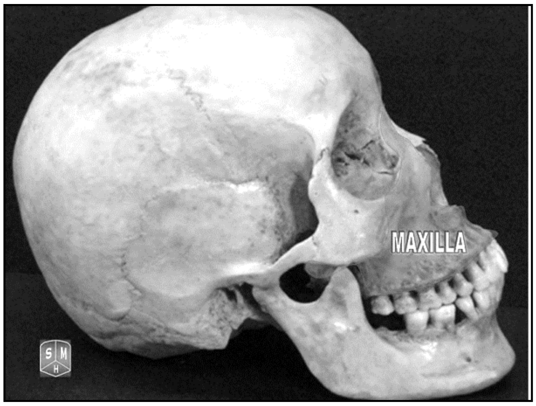


Figure 5.17 Maxilla Bone

Latexes: Latexes are soft and cost-effective materials that have been used to create lifelike prostheses. However, they have significant drawbacks, including weakness, rapid degradation, color instability, and the potential to cause allergic reactions. A more recent development is a synthetic latex composed of butyl acrylate, methyl methacrylate, and methyl methacrylamide. While this material is nearly transparent, its applications are limited.

Vinyl Plastisols: Vinyl plastisols are plasticized vinyl resins occasionally used in maxillofacial applications. These materials are thick liquids consisting of small vinyl particles dispersed in a plasticizer. Colorants can be added to match individual skin tones. Unfortunately, vinyl plastisols tend to harden over time due to plasticizer loss, and they are susceptible to the adverse effects of ultraviolet (UV) light. Consequently, their use in maxillofacial prosthetics is restricted.

Silicone Rubbers: Various types of polymers are employed in maxillofacial prosthesis manufacturing, but silicone elastomers are the most used polymers in maxillofacial prosthodontics due to their favorable properties. There are both heat-vulcanizing and room temperature vulcanizing silicone options available. Each type has its own set of advantages and disadvantages. Room temperature vulcanizing silicones are single-paste systems but tend to be less robust and generally monochromatic. Heat-vulcanizing silicone is a semi-solid material that requires milling, packing under pressure, and a 30-minute heat treatment cycle at 180°C. Heat-vulcanizing silicone offers superior strength and color stability compared to room temperature vulcanizing silicone (Figure 5.18).

Figure 5. 18 Silicone rubber nose prosthesis

Botox and dermal fillers are popular non-surgical cosmetic treatments used to enhance facial contours and correct mild facial asymmetries. They offer effective solutions for various aesthetic concerns, including:

1. **Uneven Brows:** Botox can be strategically injected into the muscles that cause one brow to be lower than the other. By relaxing these muscles, Botox can help lift the lower brow, achieving a more symmetrical appearance.
2. **Asymmetrical Cheeks:** Dermal fillers, such as hyaluronic acid-based fillers, can be used to add volume to one cheek to balance out asymmetry. By carefully injecting filler to restore volume, the cheeks can appear more symmetrical.
3. **Crooked Smile:** Botox can also be employed to address a crooked smile. If one side of the mouth lifts more than the other when smiling,

Botox can be administered to the overactive muscle, reducing its pull and helping to achieve a more even smile.

These treatments are minimally invasive, and their effects are generally temporary. They offer a quick and relatively painless way to enhance facial symmetry and improve overall facial aesthetics without the need for surgery.

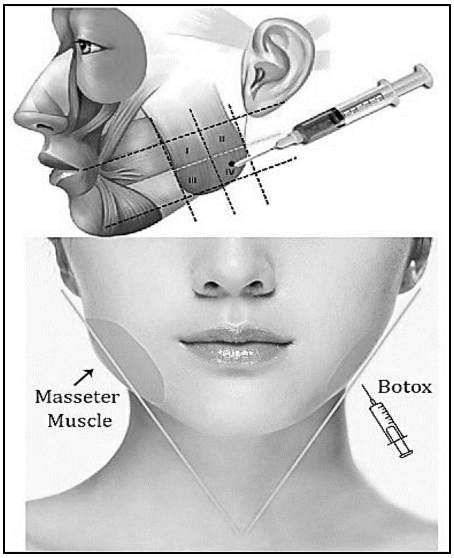


Figure 5.19 Facial Injections

Dermal Fillers: Dermal fillers are a popular cosmetic treatment used to add volume to specific areas of the face and restore facial balance (ref Figure 5.19). These fillers can be composed of various substances, both naturally occurring and synthetic. Some common compounds used in dermal fillers include:

- **Hyaluronic Acid (HA):** HA is a naturally occurring substance found in our skin and is essential for maintaining skin hydration and volume.
- **Calcium Hydroxylapatite:** This filler contains a mineral that is a major component of bone, providing a stable and long-lasting solution for facial volume enhancement.
- **Poly-L-Lactic Acid (PLLA):** PLLA is a biodegradable synthetic material that stimulates collagen production, resulting in gradual and natural-looking improvements in facial volume.

Botox: Botox is a versatile injectable treatment used to address various aesthetic concerns. It can be employed to reduce the prominence of a patient's jaw, raise a low-sitting eyebrow, and even correct nasal asymmetries (ref Figure 5.20). Botox is derived from a toxin produced by the bacterium Clostridium botulinum, which, in large amounts, can cause botulism, a life-threatening type of food poisoning. However, when used in small, controlled doses, Botox has several medical and cosmetic applications, including temporarily smoothing facial wrinkles and enhancing one's appearance.

Both dermal fillers and Botox injections are popular choices for individuals seeking non-surgical solutions to address facial asymmetry and improve their overall facial aesthetics. These treatments offer quick results with minimal downtime, making them attractive options for many patients. It's essential to consult with a qualified medical professional to determine the most suitable treatment plan based on individual needs and goals.

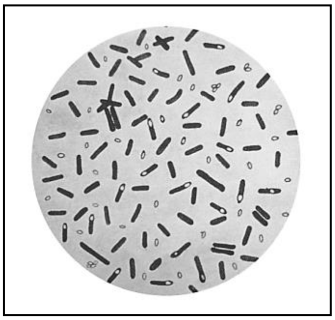


Figure 5.20 Clostridium Botulinum

Bone Plate and Screws: In the field of maxillofacial surgery, bone plates and screws play a crucial role in osteosynthesis procedures. These implants can be manufactured from either pure commercial titanium or titanium alloys, which offer specific mechanical properties ideal for this purpose. Bone plates are designed with characteristics such as lower elasticity, better deformability, and lower hardness, enabling precise adaptation to anatomical contours. In contrast, screws are engineered to possess higher elasticity, tensile strength, and lower deformability.

Maxillofacial surgery offers a range of bone plate systems, including compression and non-compression mini plates. Additionally, microplate systems are indicated for specific fractures, such as nasoethmoidal, infraorbital, and frontal sinus wall fractures.

Dental Implants: Dental implants, which are widely used in restorative dentistry, are primarily made from titanium due to its remarkable properties. Titanium's ability to osteointegrate with bone tissue is essential for dental implants, allowing them to withstand the masticatory forces transmitted through dental prostheses.

The success of titanium dental implants is attributed to several factors. Titanium possesses molecular binding sites that promote the absorption of proteoglycans in the presence of an oxide layer formed on its surface. This oxide layer serves as a substrate for biological and cellular adhesions, facilitating direct bone cell ingrowth onto the implant surface, without the formation of intervening connective tissue.

Another crucial aspect of osteointegration is the minimal adsorption of platelets on the titanium surface, which prevents clot formation responsible for fibrous tissue development. To enhance the success rate and bone anchorage, the implant's surface area is increased through processes such as plasma spraying with titanium particles or hydroxyapatite (HA) coating. HA becomes ionized and condenses onto the metallic implant surface, forming partially amorphous and partially crystalline ceramic coatings.

Plasma-coated implants, including titanium plasma spray (TPS) implants, increase the surface area by six times and improve the bone strength of the surface coating by 33%. This results in a more extensive implant-bone interface and superior osseointegration. It's worth noting that titanium implants are often imported, as they may not be readily available from indigenous sources, contributing to their higher cost.

5.11 Ophthalmological Biomaterials: In ophthalmology, biomaterials are employed to restore and maintain eye functions. Various biomaterials used in this field include viscoelastic solutions, intraocular lenses, contact lenses, eye shields, artificial tears, vitreous replacements, and materials for the correction of corneal curvature, such as LASIK laser surgery, and scleral buckling materials.

Contact lenses serve multiple purposes, from correcting refractive errors to enhancing eye appearance, and are particularly useful in managing conditions like chronic corneal ulcers, recurrent erosions, pain in bulbous keratopathy (corneal edema), and entropion.

In therapeutic applications, contact lenses are often referred to as "bandage lenses" because they serve as a protective covering for the cornea, aiding in the healing process and providing relief in various ocular surface disorders.

Desirable Properties of Contact Lenses:

Contact lenses are a popular vision correction option, and their effectiveness and comfort are influenced by various properties and characteristics. Here are some of the desirable properties of contact lenses:

1. High Oxygen Permeability: Contact lenses should have high oxygen permeability, which allows an adequate amount of oxygen to reach the cornea. This property is crucial for maintaining the health and respiration of the corneal cells, ensuring that they receive the oxygen they need to function properly.

2. Good Wetting Ability: Contact lenses should exhibit good wetting ability, meaning they readily attract and retain moisture from tears. This property helps keep the lens surface moist and comfortable for the wearer.

3. Resistance to Deposits: Contact lenses should be resistant to the deposition of various substances on their surface, including proteins, mucous, lipids, microorganisms, and other foreign substances. This resistance helps maintain the cleanliness of the lens and reduces the risk of irritation or infection.

4. Material Variety: Contact lenses can be made from different materials, each with its own advantages. These materials include:

- **Rigid (Gas Permeable) Lenses:** These lenses provide excellent optical clarity and are durable. They are known for maintaining their shape on the eye and are often used for specific vision correction needs.
- **Elastomer Lenses:** These are soft and flexible lenses that conform to the shape of the eye. They are comfortable to wear and provide good initial comfort.
- **Hydrogel Lenses:** Hydrogel lenses are soft and have a high water content. They are known for their comfort and are suitable for daily wear.

5. Thin and Flexible: Contact lenses should be thin and flexible enough to conform to the curvature of the eye comfortably. Thin lenses are less likely to interfere with blinking and are more comfortable for the wearer.

Elastomeric Contact Lenses:

Elastomeric contact lenses are a type of soft contact lens made from flexible and elastic materials. These lenses are known for their comfort and ability to conform to the shape of the eye. Here are some common materials used for elastomeric contact lenses:

1. Silicone Rubber Lenses:

- **Composition:** Silicone rubber lenses are typically made of cross-linked poly-methyl-phenyl-vinyl silicones.
- **Oxygen Permeability:** They have the highest oxygen permeability ($O2$ permeability) of all contact lens materials. High oxygen permeability allows for better oxygen transmission to the cornea, promoting eye health.
- **Hydrophobic Nature:** One drawback of silicone rubber lenses is their hydrophobic (water-repelling) nature, which can lead to ocular intolerance. They may not interact well with the aqueous (water-based) environment of the eye.

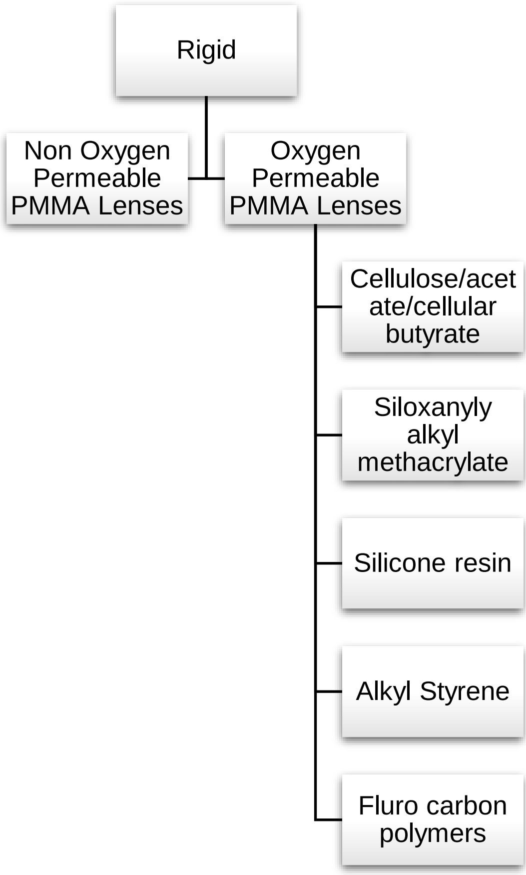


Figure 5.21 Classification of contact lens

2. Acrylic Rubber Lenses:

- **Composition:** Acrylic rubber lenses are made of cross-linked co-polymers of n-butyl acrylate with n-butyl methacrylate.
- **Oxygen Permeability:** While they may not have the highest oxygen permeability, acrylic rubber lenses still provide good oxygen transmission to the cornea.
- **Compatibility:** Acrylic rubber lenses are generally more compatible with the tear film and ocular environment compared to some silicone rubber lenses.

3. Hydrogel Lenses (Soft Contact Lenses):

Hydrogel lenses are a type of soft contact lens known for their comfort and flexibility. They are made from hydrophilic (water-loving) materials that allow them to retain moisture and provide a comfortable fit. Hydrogel lenses come in various water content levels, and here are some key details about them:

i. Low Water Content Hydrogel Lenses:

- **Composition:** These lenses are made from cross-linked 2-hydroxymethyl methacrylate polymer.
- **Inhibition of Contaminants:** They contain methacrylic acid, which serves to inhibit the growth of fungi, bacteria, protein deposits, and the mucous layer on the lens surface.
- **Hydration and Reactivity:** The water content of these lenses determines their hydration level and reactivity to various contaminants. Lower water content lenses may be less prone to dehydration but may require more care to prevent protein and lipid buildup.

ii. Medium and High-Water Content Hydrogel Lenses:

- **Composition:** These lenses consist of co-polymers of vinyl pyrrolidone with 2-hydroxyethyl methacrylate or methyl methacrylate.
- **Hydration:** Medium and high-water content hydrogel lenses provide increased moisture to the eye, which can enhance comfort and wearability. They are designed to mimic the natural moisture content of the eye's cornea.

Eye Shields: Eye shields are thin, clear, and pliable collagen films typically 0.0127-0.77mm thick. They are shaped like a spherical shell with a diameter of 14.5mm and a base curvature of 9mm. These shields are used to alleviate discomfort and serve as a means to prolong the delivery of antibacterial, antifungal, antiviral, and anti-inflammatory agents to the eye.

Eye shields are employed in the treatment of conditions such as corneal abrasions, erosions, epithelial defects, cataract extraction, penetrating keratoplasty, and other inflammatory eye diseases. Once applied to the eye, these shields gradually absorb fluid from the ocular surface and begin to dissolve. They are typically made from materials such as hydrogels, polyvinyl alcohol, silicone rubber, and collagen.

Artificial Tears: Artificial tears are used to alleviate symptoms of dry eye syndrome (keratoconjunctivitis sicca), characterized by reduced tear formation and ocular discomfort. These tears serve as substitutes for natural tears and can help hydrate the eye's surface. Commonly used ingredients in artificial tears include methyl cellulose, polyvinyl alcohol, hyaluronic acid, and chondroitin sulfate.

Vitreous Implants: Eye implants, including vitreous implants, are used to restore the functionality of various components of the eye, such as the cornea, lens, and vitreous humor. These biomaterials encompass a range of products, including viscoelastic solutions, intraocular lenses, contact lenses, eye shields, artificial tears, vitreous replacements, materials for correcting corneal curvature, and scleral buckling materials. These implants are essential in ophthalmology for maintaining and improving eye vision.

Ophthalmic biomaterials play a crucial role in various eye-related medical treatments, and they are continually advancing through tissue engineering and regenerative medicine approaches.

5.12 Intelligent Textiles:

The textile industry has evolved to include "Smart textiles," which are fabrics woven with embedded technology. These textiles can react to their environment and provide data. Smart textiles represent a significant segment of technical textiles. Examples of passive smart textiles include UV-protective clothing, conductive fibers, plasma-treated clothing, and waterproof fabrics. In contrast, active smart textiles can sense environmental stimuli and respond to them, often incorporating both sensor and actuator functions.

Medical Implants Made by Smart Textiles: Smart textiles have made significant contributions to the field of medical implants, including:

- **Artificial knees**
- **Artificial eye lenses**
- **Artificial tendons**
- **Artificial skin**
- **Artificial hearts**
- **Artificial kidneys and lungs**
- **Artificial hips**
- **Artificial heart valves**

These medical implants benefit from the capabilities of smart textiles to sense and react to various stimuli.

Medical Applications of Intelligent Textiles: Medical textiles have a wide range of applications in the healthcare industry, covering areas such as wound care, disease management, preventive clothing, bandages, and hospital hygiene. They play a crucial role in providing first aid, facilitating wound treatment, and maintaining the right conditions during medical care. Additionally, medical textiles help protect healthcare workers from infections and infectious diseases.

Wound Care: Modern wound care involves various fabric manufacturing techniques, including knitting, weaving, braiding, crocheting, composites, and non-woven technologies. Emerging medical textiles offer advanced wound treatment products. These wound care fibers and dressings are designed to be non-toxic, non-allergenic, absorbent, hemostatic, biocompatible, and breathable. Materials such as chitosan, alginate, collagen, and carbon fibers provide advantages over traditional wound care materials. Wound care materials also encompass foams, hydrogels, films, hydrocolloids, and matrices for tissue engineering.

Tissue Engineering: Textile technologies are finding applications in the field of tissue engineering. The physical and chemical properties of fibers, pore size, and fabric strength all play roles in how textile technologies can be applied in tissue engineering. Textile technologies can create fibrous structures tailored to various tissue engineering applications. Tissue engineering involves assembling scaffolds, cells, and biologically active molecules to create functional tissues, and textile-based techniques are being explored for this purpose.

Biomedical Scaffolds:

Hydrogel fibers are utilized in the creation of scaffolds for cell development and drug release in biomedical applications.

Antimicrobial Dressings:

Chitosan exhibits antimicrobial properties and can inhibit the growth of bacteria and fungi. Chitosan-based wound dressings are employed for medical purposes. Hemcon dressings, containing Chitosan, are used by combat medics to treat wounds due to their hemostatic properties. Chitosan hemostatic agents are formed when Chitosan is combined with organic acids like lactic acid or succinic acid. When the bandage comes into contact with blood, it becomes adhesive and seals the wound, stopping blood flow.

Surgical Suture Thread:

Surgical sutures are composed of textile-based materials. Suture materials are categorized into absorbable and non-absorbable threads, further divided into synthetic and natural fibers.

Bandages:

Bandages are fabric pieces used for covering, dressing, and binding wounds. They are made from various textile materials. Bandages secure dressings or splints in place and can also provide support and compression to specific body parts.

Compression Bandages:

Compression bandages are employed in the treatment of lymphatic or venous diseases, such as deep vein thrombosis. These bandages can be either inelastic or elastic.

Antimicrobial Textiles: Antimicrobial textiles are textile materials (including fibers, yarns, and fabrics) treated with antimicrobial agents. These treated textiles are designed to kill bacteria or inhibit the growth of microorganisms. Examples of such products include wipes, gowns, and odorless clothing.

Antimicrobial scrubs, worn by healthcare professionals, are treated with antibacterial chemicals to prevent the spread of harmful microorganisms between staff and patients in healthcare settings.

Antiviral Textiles:

Antiviral textiles are an extension of antimicrobial surfaces and are designed to combat viruses. One example is Polyhexamethylene Biguanide (PHMB) treated Chief Value Cotton (CVC) fabric, which has been shown to kill 94% of

Figure 5.23 Applications of Smart Textiles

coronaviruses within two hours. This makes it suitable for use in personal protective equipment (PPE) kits for healthcare workers.

Chitosan, a natural polymer known for its biocompatibility, lack of allergenicity, biodegradability, and non-toxicity, also possesses antiviral properties. Chitosan-based compounds have demonstrated effectiveness against severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), and cotton fabrics treated with copper, chitosan, and citric acid sustain their antiviral properties through five to ten home laundry cycles.

Figure 5.24 Surgical gowns

Medical Gowns:

Medical gowns are an essential component of personal protective equipment (PPE) for healthcare professionals. They play a crucial role in infection control, protecting wearers from becoming ill or getting infected when they come into contact with potentially contagious or hazardous liquids and solids. In healthcare settings, various types of gowns are used for different purposes, including:

1. **Operating Room Gowns:** These gowns are worn during surgical procedures to maintain a sterile environment and prevent the transfer of microorganisms between the surgical team and the patient.
2. **Surgical Gowns:** Like operating room gowns, surgical gowns are designed to be sterile and are used by surgeons and their teams during surgical procedures.
3. **Isolation Gowns:** Isolation gowns are used to protect healthcare workers from infectious agents when caring for patients with contagious diseases. They are typically used in isolation units.

4. **Nonsurgical Gowns:** These gowns are worn in non-surgical healthcare settings and provide protection against splashes and exposure to potentially harmful substances.
5. **Procedural Gowns:** Procedural gowns are used during various medical procedures, such as diagnostic tests and minor surgical procedures.

Medical gowns are typically constructed from impermeable materials or densely woven, water-resistant fabrics to ensure their effectiveness in preventing the penetration of liquids and microorganisms.

Biomaterials have revolutionized various fields of healthcare and medicine by offering innovative solutions to complex challenges. These versatile materials, ranging from metals and ceramics to polymers and textiles, have opened doors to advancements in orthopaedics, dentistry, tissue engineering, ophthalmology, and infection control. From enhancing bone growth and repairing tissue defects to providing safer medical implants and protective garments, biomaterials have become indispensable in modern healthcare.

The key to biomaterials' success lies in their ability to seamlessly integrate with the human body, promoting healing, reducing infection risks, and improving overall patient outcomes. Whether it's the bioactive properties of ceramics, the versatility of polymers, or the antimicrobial capabilities of textiles, biomaterials continue to drive innovation, making healthcare safer, more efficient, and more patient centric.

As researchers and engineers continue to explore new frontiers in biomaterials science, we can expect even more remarkable applications and breakthroughs in the future. These advancements will not only transform medical treatments and procedures but also enhance the quality of life for countless individuals worldwide. In this ever-evolving journey of discovery, biomaterials are proving to be a vital cornerstone of modern medicine and a testament to the power of interdisciplinary collaboration in the pursuit of better health and well-being.

This Page Intentionally Left Blank