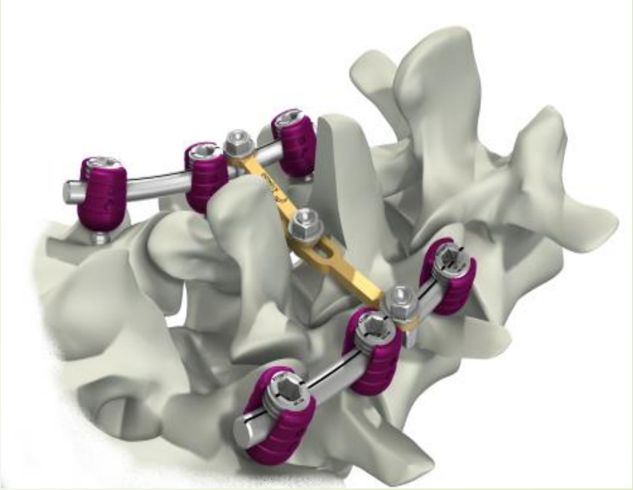
METALLIC BIOMATERIALS



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INTRODUCTION

Physical Properties of Metals:

- Luster (shininess)
- Good conductors of heat and electricity
- High density (heavy for their size)
- High melting point
- Ductile (most metals can be drawn out into thin wires)
- Malleable (most metals can be hammered into thin sheets)

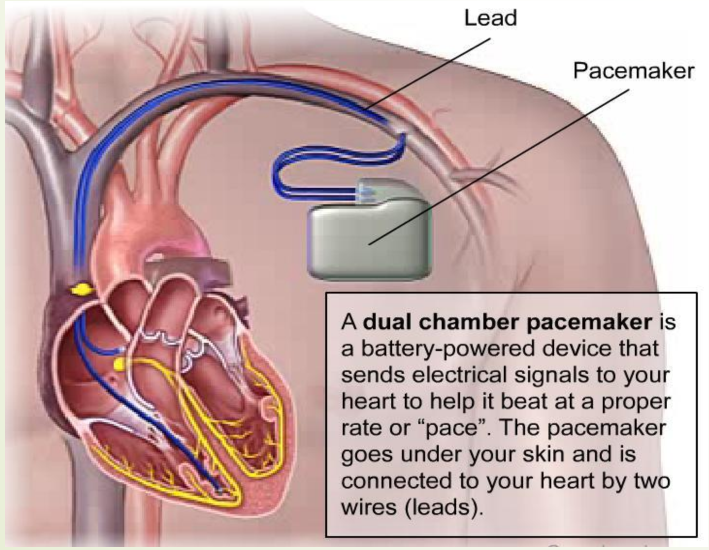
Chemical Properties of Metals:

- Easily lose electrons
- Surface reactive
- Loss of mass (some corrode easily)

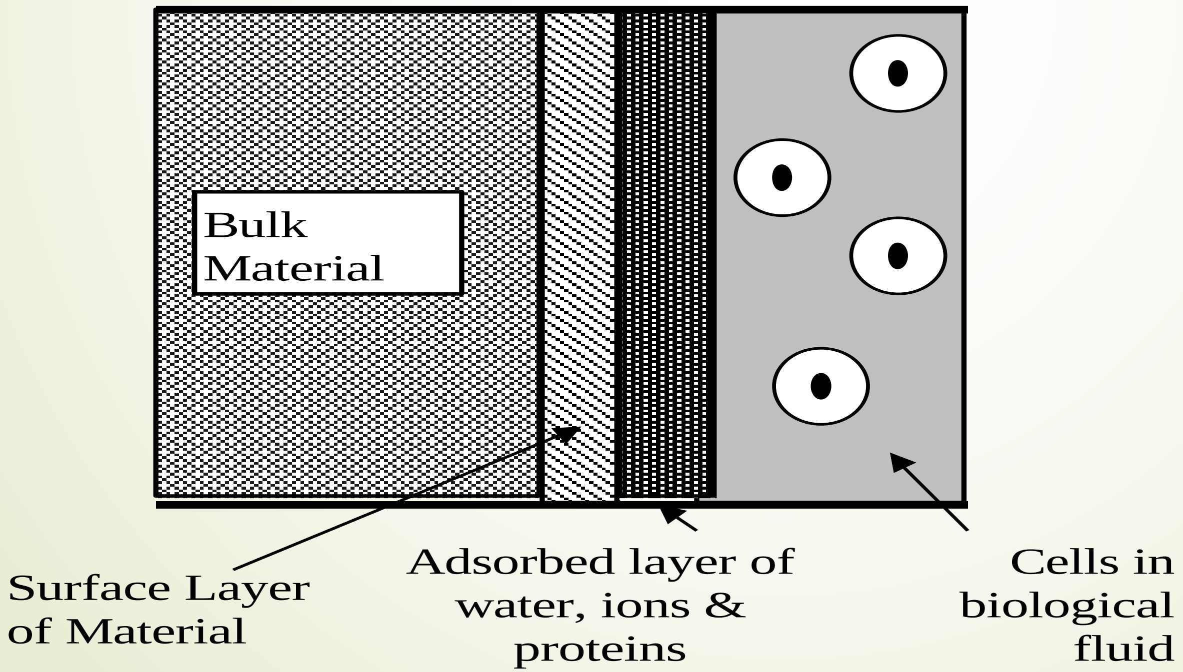
  Corrosion is a gradual wearing away
- Change in mechanical properties

- The high strength and resistance to fracture that this class of material can provide, assuming proper processing, gives reliable long-term implant performance in major load-bearing situations. Coupled with a relative ease of fabrication of both simple and complex shapes using well-established and widely available fabrication techniques (casting, forging, machining), this has promoted metal use in the fields of orthopedics and dentistry primarily, the two areas in which highly loaded devices are most common although similar reasons have led to their use for forming cardiovascular devices (artificial heart valves, blood conduits and other components of heart assist devices, vascular stents), and neurovascular implants (aneurysm clips).

- In addition, the good electrical conductivity of metals favors their use for neuromuscular stimulation devices, the most common example being cardiac pacemakers. These favorable properties (good fracture resistance, electrical conductivity, formability) are related to the metallic interatomic bonding that characterizes this class of material.

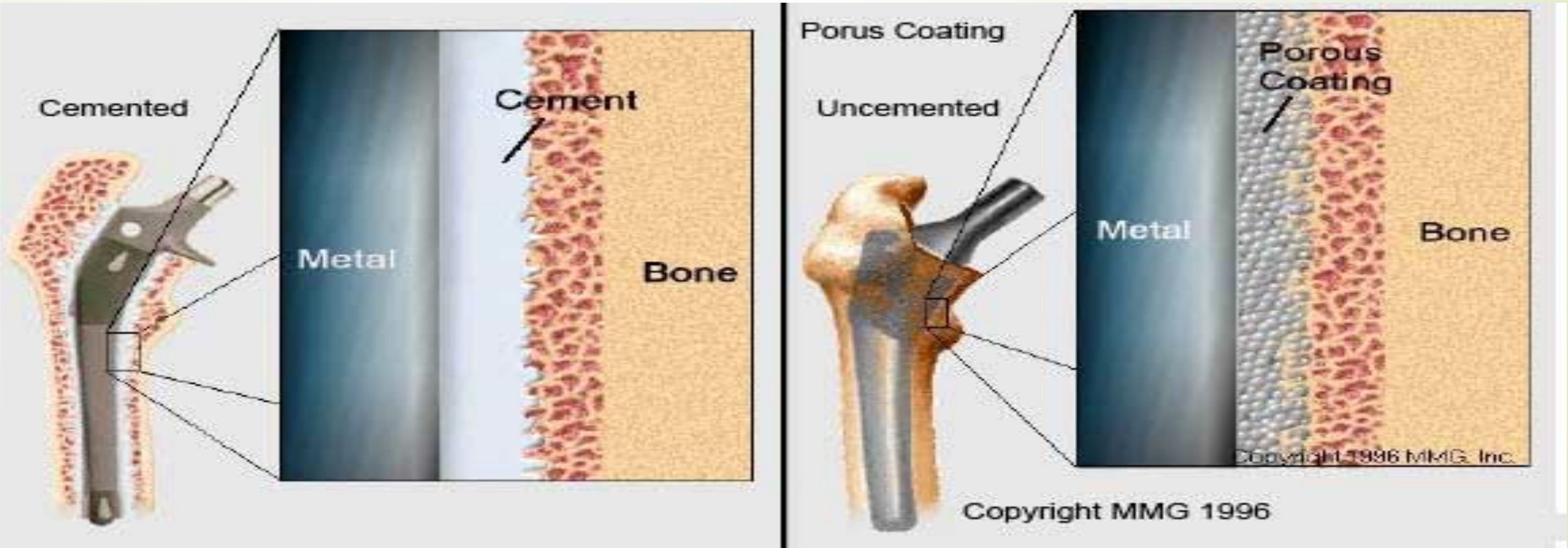


- ***Biocompatibility of metals:***
- In metals, biocompatibility involves the acceptance of an artificial implant by the surrounding tissues and by the body as a whole. The metallic implants do not irritate the surrounding structures, do not incite an excessive inflammatory response, do not stimulate allergic and immunologic reactions, and do not cause cancer. Other functional characteristics that are important for metallic device include adequate mechanical properties such as strength, stiffness, and fatigue properties; and also appropriate density



I. STEEL BIOMATERIALS

- Stainless steel is one of the most frequently used biomaterials for internal fixation device because of a favorable combination of mechanical properties, corrosion resistance, cost effectiveness and easily making a manufacturing. However, Stainless steel is not used as cementless arthroplasty implants due to their low biocompatibility because the stable oxide layer cannot be formed on the surface of stainless steel.

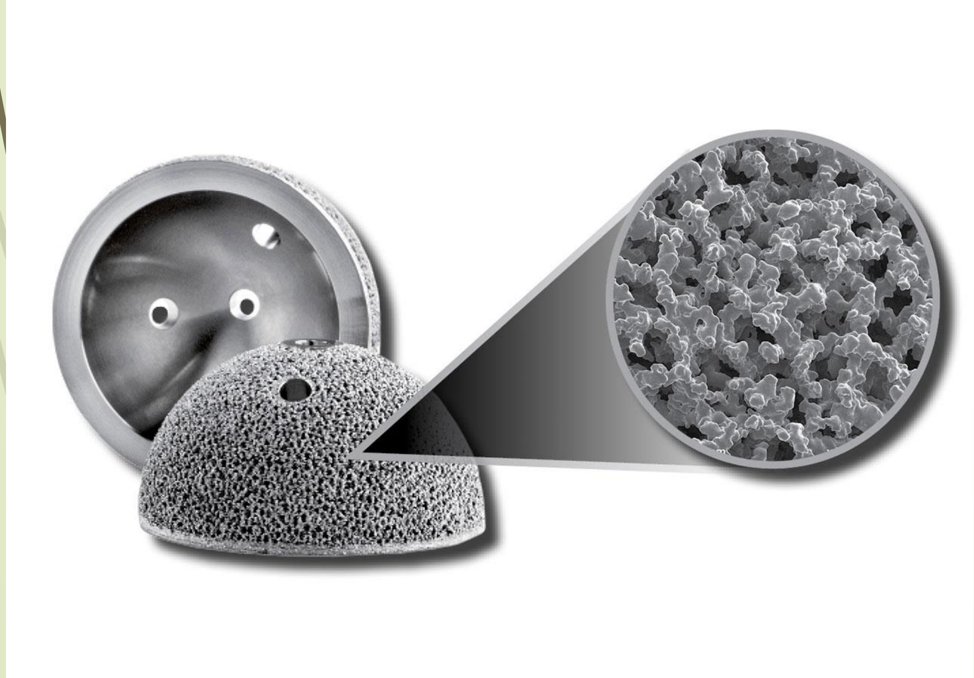


- The corrosion of metallic implant gives adverse effects to the surrounding tissues and to the implant itself. It produces chemical substances that harmful for human organs and deteriorates the mechanical properties of the implant. Therefore, corrosion resistance of a metallic implant is an important aspect of its biocompatibility.

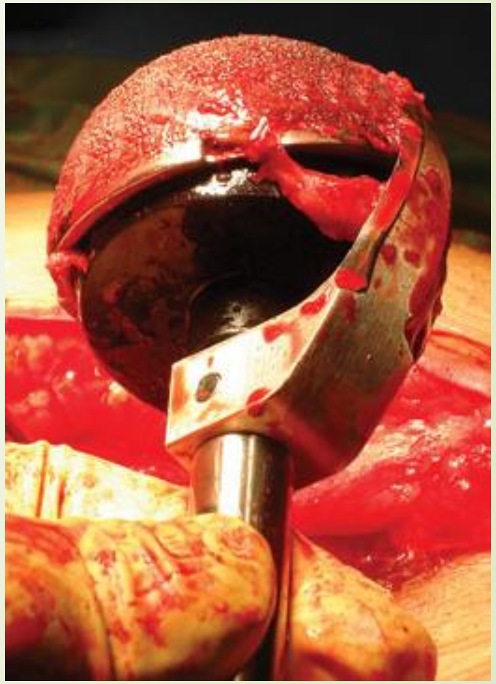
II. 316L STAINLESS STEEL

- 316L stainless steel is considered as one of the attractive metallic materials for biomedical applications due to its mechanical properties, biocompatibility, and corrosion rcsistance. This inatcrial is popular metal for use as acetabula cup (one half of an artificial hip joint) applications.
- Highly porous 316L stainless steel parts were produced by using a powder metallurgy proceses, which includes the selective laser sintering(SLS) and traditional sintering. Porous 316L stainless steel suitable for medical applications was fabricated in the porosity range of 40%-50% (volume fraction) by controlling the SLS parameters and sintering behaviour

- The main advantage of porous materials is their ability to provide biological anchorage for the surrounding bony tissue via the ingrowth of mineralized tissue into the pore space



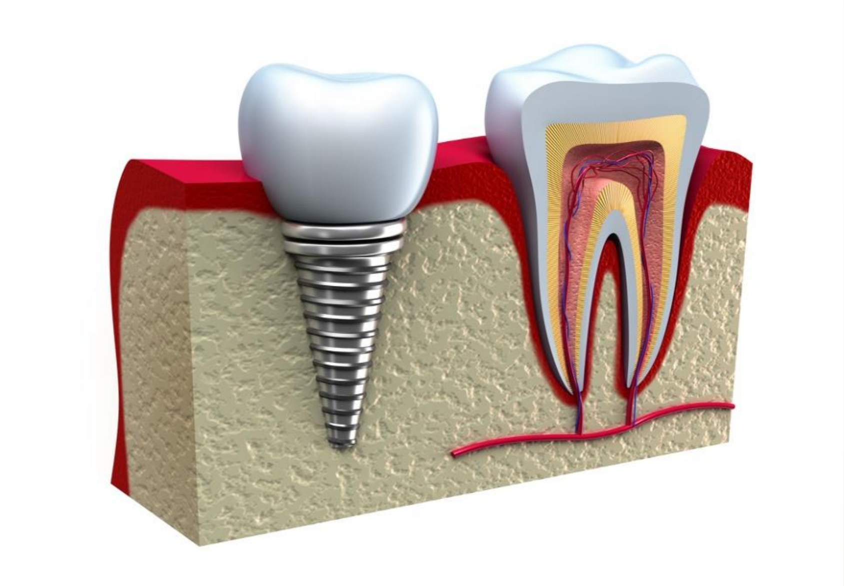
acetabula cups



III. COBALT ALLOYS

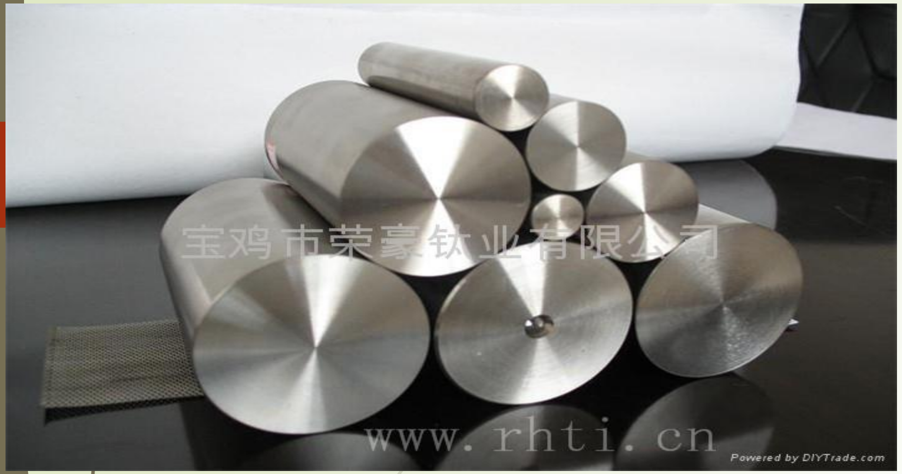
- Cast cobalt-base alloys were originally proposed for surgical implants over 60 years ago. Improvernents in investment casting technology and a better metallurgical understanding of the cast Co-Cr-Mo system provided the technical justification to consider this alloy type for a variety of biomedical applications.
- Co-Cr alloys are most commonly used to make artificial joints including knee and hip joints due to high wear-resistance and biocompatibility.Co-Cr alloys have high corrosion resistance.
- Co-Cr alloy has also been widely used in the manufacture of stent and other surgical implants as Co-Cr alloy demonstrates excellent biocompatibility with blood and soft tissues

- Cobalt-chrome has a very high specific strength and is commonly used in gas turbines, dental implants, and orthopedic implants

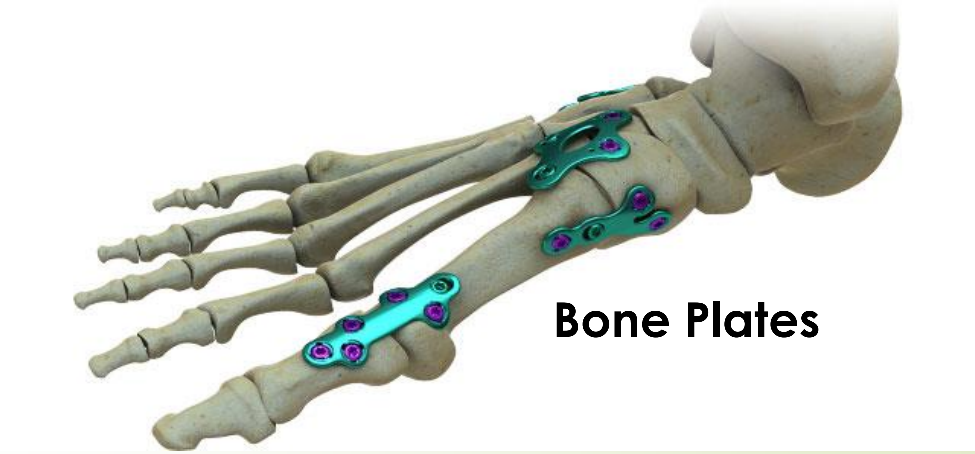


IV. TITANIUM ALLOYS

- Titanium alloys are now the most attractive metallic materials for biomedical applications. In medicine, they are used for implant devices replacing failed hard tissue. Examples include artificial hip joints, artificial knee joints, bone plates, screws for fracture fixation, cardiac valve prostheses, pacemakers, and artificial hearts. Ti-6Al-4V has long been a main medical titanium alloy. However, for permanent implant applications the alloy has a possible toxic effect resulting from released vanadium and aluminum. For this reason, vanadium- and aluminum-free alloys have been introduced for implant applications, based on the Ti-6Al-4V implants. These new alloys include Ti-6Al-7Nb (ASTM F1295), Ti-13Nb-13Zr (ASTM F1713), and Ti-12Mo-6Zr (ASTM F1813).



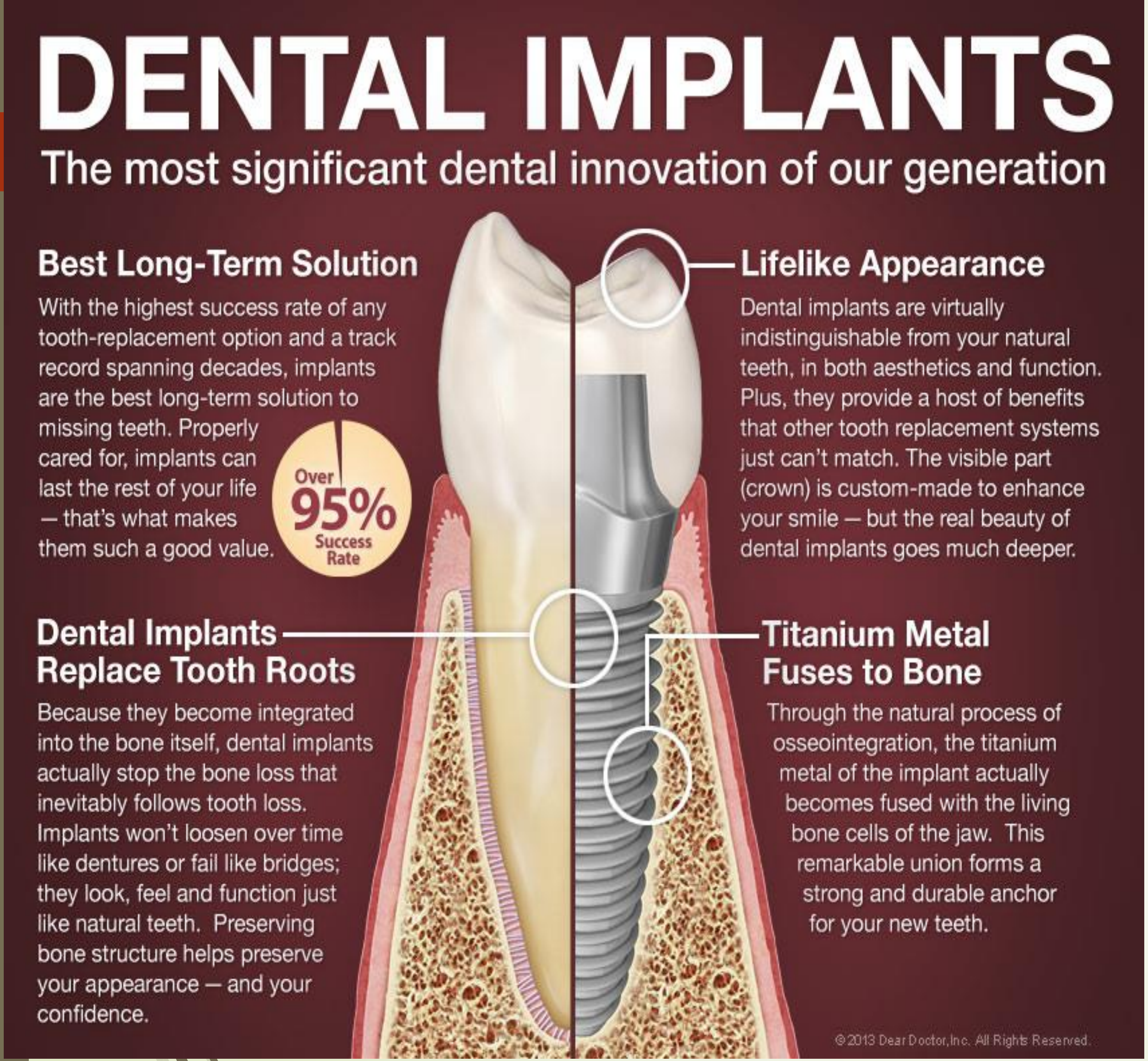
Ti-6Al-4V Alloy Rods



Bone Plates

cardiac valve
prostheses

artificial hearts


DENTAL IMPLANTS
The most significant dental innovation of our generation
Best Long-Term Solution
With the highest success rate of any tooth-replacement option and a track record spanning decades, implants are the best long-term solution to missing teeth. Properly cared for, implants can last the rest of your life — that's what makes them such a good value.
Over 95% Success Rate
Lifelike Appearance
Dental implants are virtually indistinguishable from your natural teeth, in both aesthetics and function. Plus, they provide a host of benefits that other tooth replacement systems just can't match. The visible part (crown) is custom-made to enhance your smile — but the real beauty of dental implants goes much deeper.
Dental Implants Replace Tooth Roots
Because they become integrated into the bone itself, dental implants actually stop the bone loss that inevitably follows tooth loss. Implants won't loosen over time like dentures or fail like bridges; they look, feel and function just like natural teeth. Preserving bone structure helps preserve your appearance — and your confidence.
Titanium Metal Fuses to Bone
Through the natural process of osseointegration, the titanium metal of the implant actually becomes fused with the living bone cells of the jaw. This remarkable union forms a strong and durable anchor for your new teeth.
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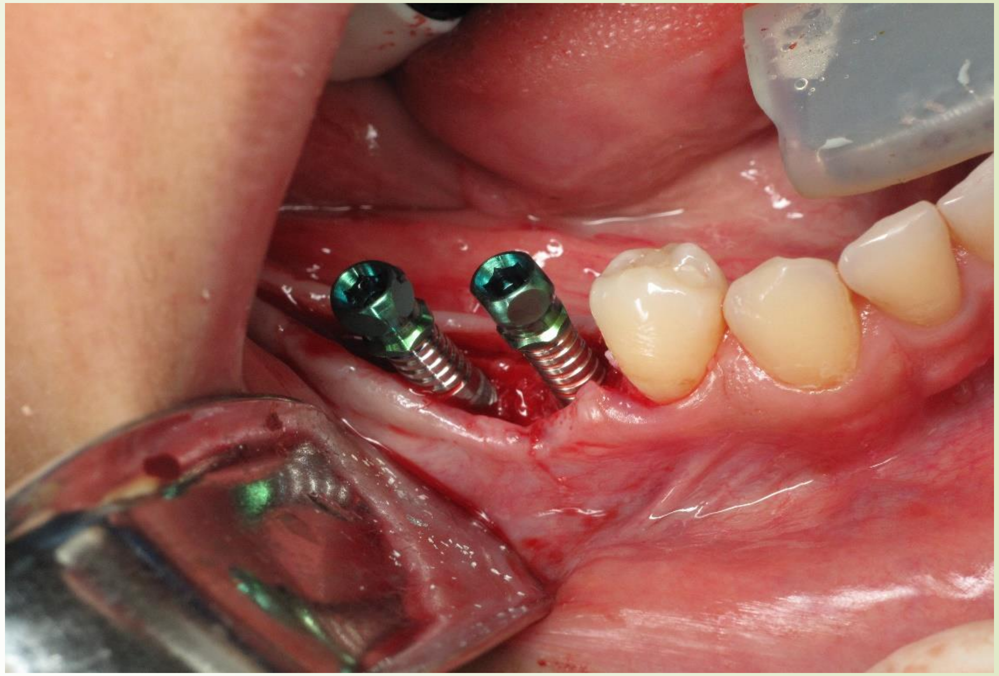


IN VITRO – IN VIVO

In vitro research is generally referred to as the manipulation of organs, tissues, cells, and biomolecules in a controlled, artificial environment. The characterization and analysis of biomolecules and biological systems in the context of intact organisms is known as in vivo research.

In vivo experimental research became widespread with the use microorganisms and animal models in genetic manipulation experiments as well as the use of animal models to study drug toxicity in pharmacology.

Both in vitro and in vivo approaches are usually combined to obtain detailed information about structure-function relationships in genes and their protein products, either in cultured cells and test tubes or in the whole organism.

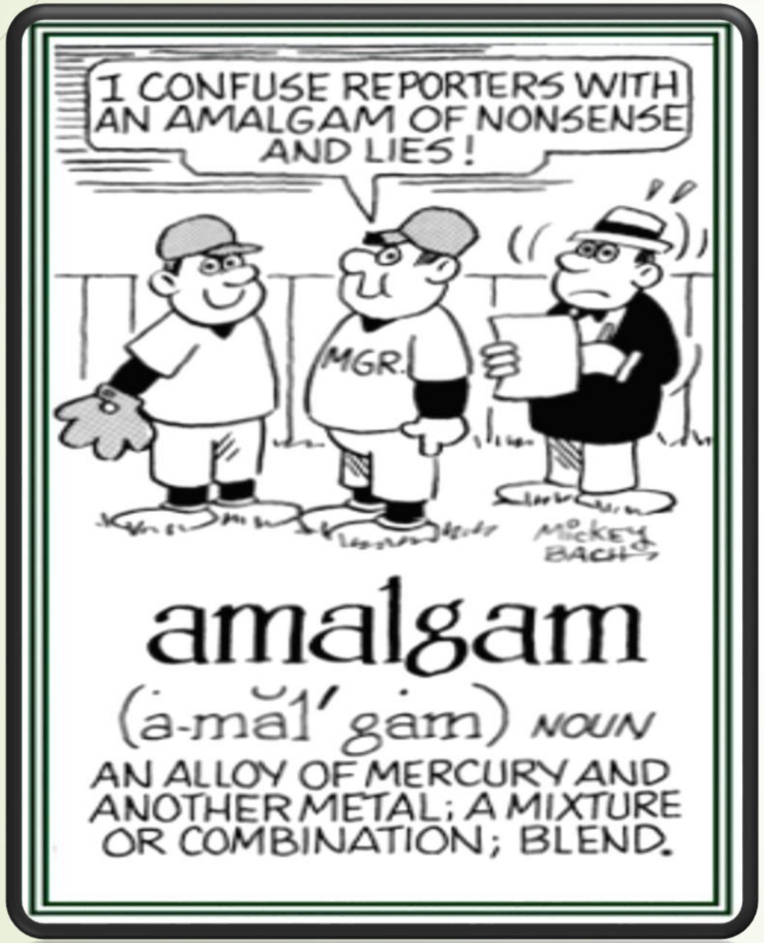
http://science.jrank.org/pages/3541/In-Vitro-in-Vivo.html

MICRO TEST LABORATORIES IN INDUSTRY

In- Vivo Services:
Rabbit Pyrogen
USP Class Testing
Sensitization
Implantation
Sub-Chronic/Chronic
Toxicity
Intracutaneous Reactivity
Irritation Testing
Necropsy Services
Histology Services

In-Vitro Services:
Cytotoxicity
Hemolysis
Complement Activation
PT/PTT Testing
AMES Mutagenicity
Carcinogencity Testing

V. DENTAL AMALGAM

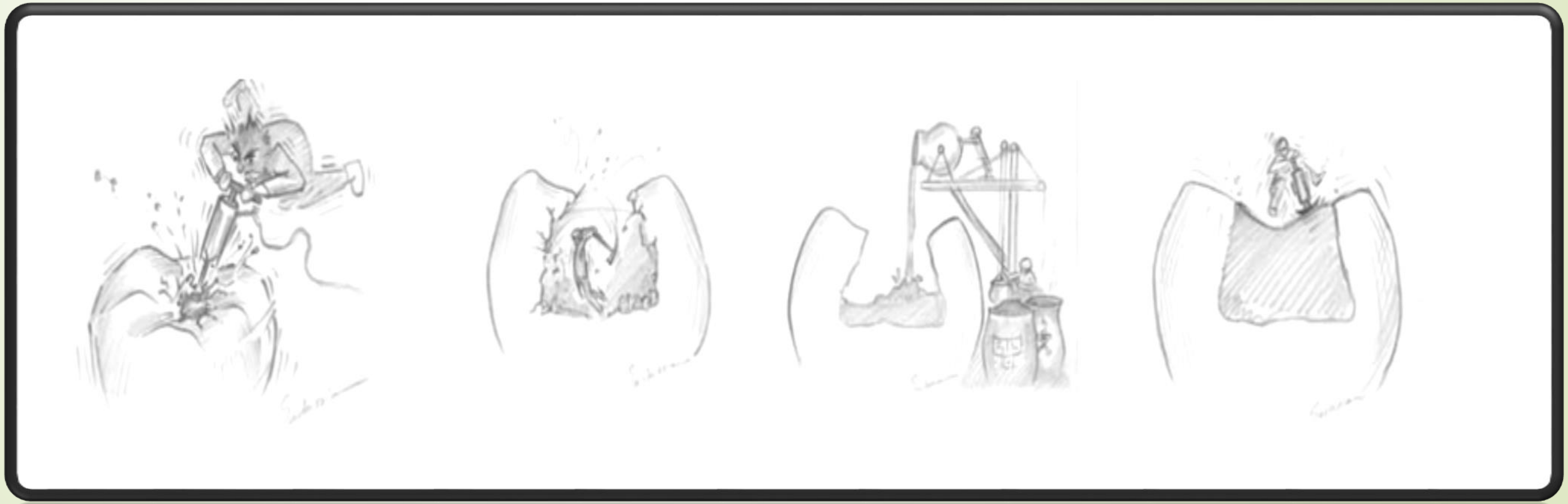


- Dental amalgam is a dental filling material used to fill cavities caused by tooth decay. It has been used for more than 150 years in hundreds of millions of patients around the world.
- Dental amalgam is created by mixing elemental mercury (between 43 percent and 54 percent) and an alloy powder comprised of mainly silver, copper, tin, and zinc. The mercury in amalgam is used to bind the different components together into a hard, workable substance.

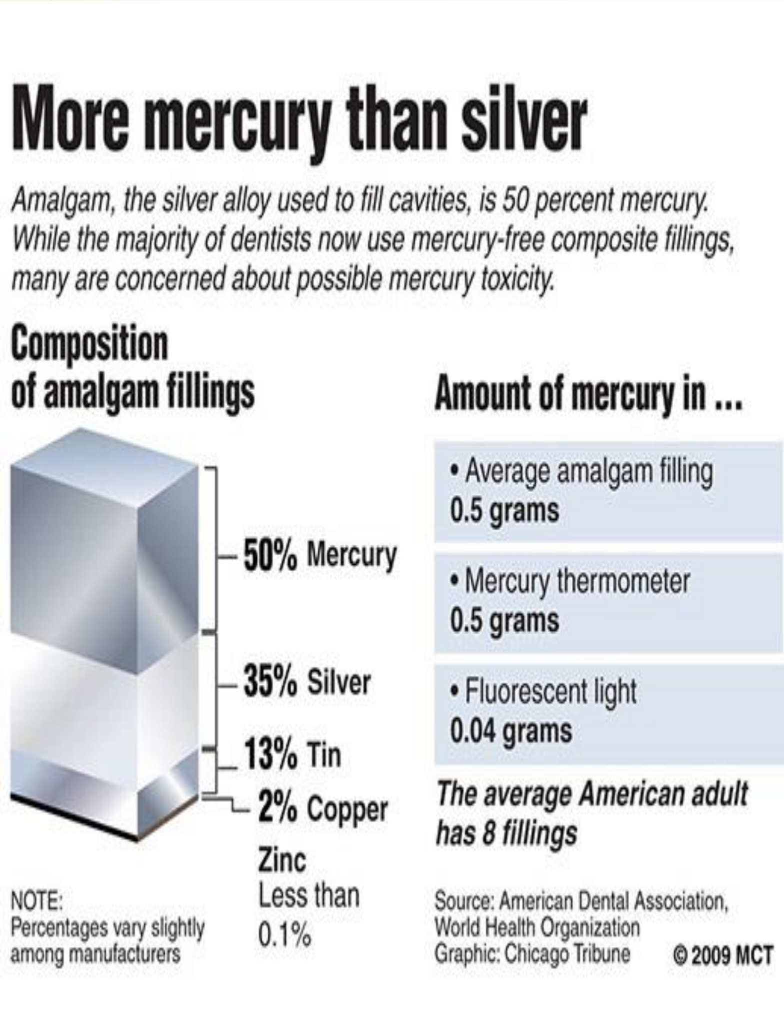
- Dental amalgam fillings are also known as “silver fillings” because of their silver-like appearance. Despite the name, "silver fillings" do contain elemental mercury.

V.I. Properties Of Amalgam As A Dental Restorative

- Before a dentist places amalgam, the tooth cavity is first ground down into a particular form with undercuts. This unnatural gouging of the tooth weakens the cusps and creates internal strains. Second, the dentist packs the amalgam paste into the cavity and then carves it into shape before it hardens completely.



V.II. Why is mercury used in dental amalgam?



- Approximately half of a dental amalgam filling is liquid mercury and the other half is a powdered alloy of silver, tin, and copper. Mercury is used to bind the alloy particles together into a strong, durable, and solid filling. Mercury's unique properties (it is a liquid at room temperature and that bonds well with the alloy powder) make it an important component of dental amalgam that contributes to its durability.
- In its elemental form, mercury can be toxic. This fact has made many people wonder if there are potential health risks associated with the mercury in dental amalgam.

VI. GOLD

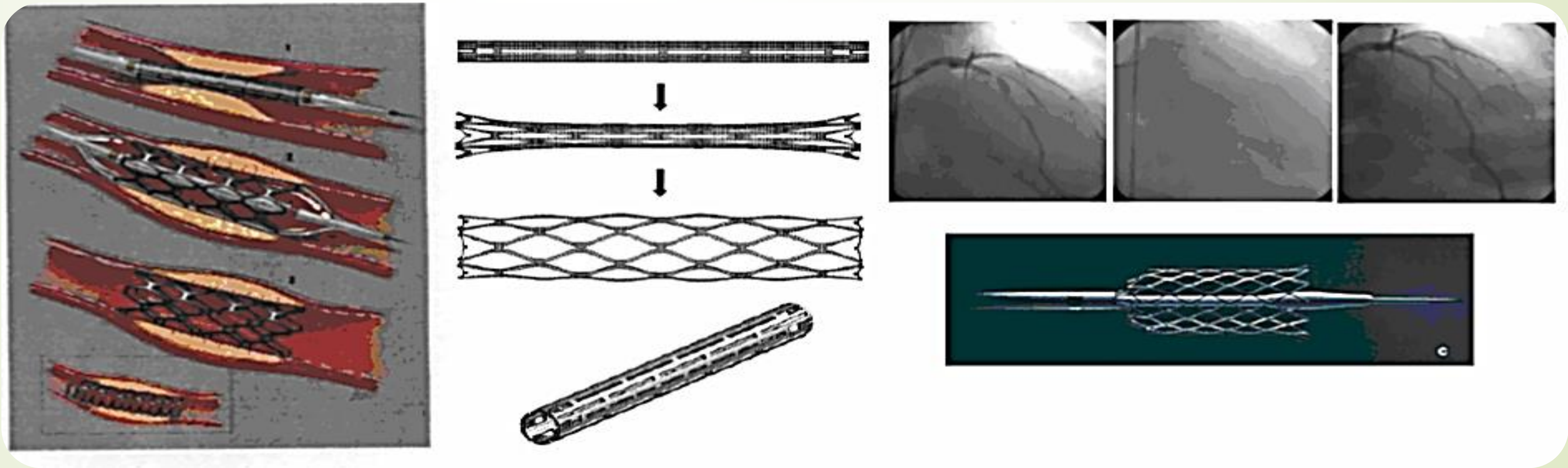
- Gold and gold alloys are useful metals in terms of; stability, corrosion resistance, odontotherapy (because of its long-lasting). Since gold alloys have more mechanic property than pure gold, it is subjucted to casting process. These alloys consist of %75 or more than %75 gold, the ramaining is comprise of noble metals. Copper increases strength. Platin also increases strenght, but if it add more than %4, due to increasing of melting temperature its process gets diffucult.Due to adding small amounts of zinc, melting temperature getting decrease. Soft alloys which have more than %83 gold uses as a packing meterial. Because alloys which have less gold are rigid, they use as lining material.

VII. NICKEL-TITANIUM ALLOYS

- These alloys have the property transformation into their original shape when heated decomposes. This feature is called the shape memory effect. Some biomaterials applications where the shape memory effect is required; dental bridges, connections of blood vessels in the skull, can be listed as muscle and orthopedic prostheses to artificial heart.

VII.I. Applications of Nickel Titanium Alloys

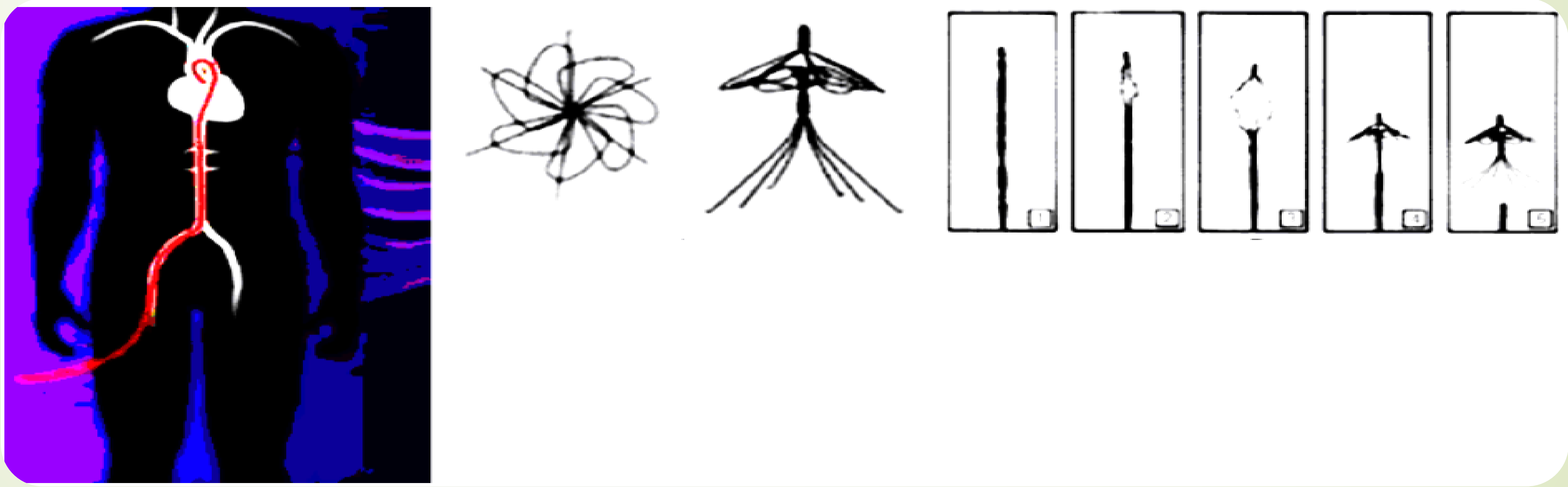
- NiTi alloy stent made from wire before insertion into the blood vessel into a flattened wire. After the stent inserted into a vein, into action with body temperature returned to open the blockage in the arteries clogged vessel to its original shape is provided on-site.



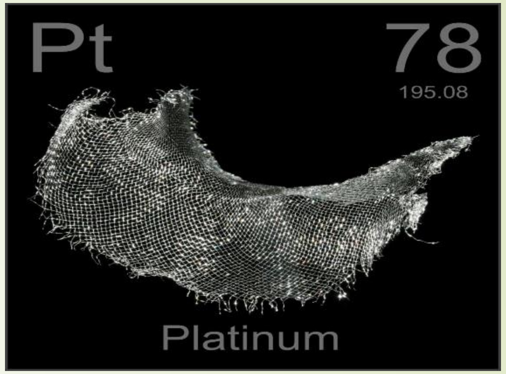
Stents made from SMA uses to solve the problem of blockage in the veins in the figure.

VII.I. Applications of Nickel Titanium Alloys

- Anchor made of NiTi alloy wire prior to insertion into the blood vessel into a flattened wire. These wires are then inserted into a vein to provide returns to its original shape filter function by acting with body temperature and the amount of clot moving through the veins.



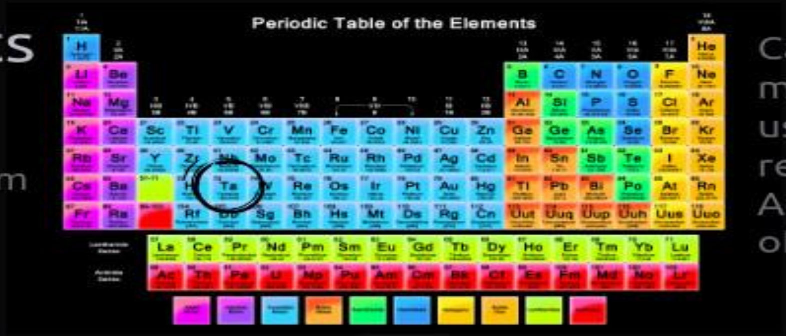
VIII. OTHER METALS



- **Platinum and group of rare metals** have a high corrosion resistance, but poor mechanical properties. These metals, which stimulates the onset of cardiac beats used as electrode at autonomic centers.
- **Tantalum**, which do not have widespread use because of the weakness of the mechanical strength and high density material. The most important application is the use as a suture in plastic surgery.

Physical Facts

Melting pt: 2996 C
Boiling pt: 5458 C
Density: 16.4g/cubic cm
Abundance: 2mg/kg of earth's crust



Can be found naturally in ore of the mineral Tantalite [(Fe, Mn)Ta_2O_6]. Of the use in the U.S., about 20% comes from recycling, and the rest is imported. Australia, Canada, and China are all sources of Tantalum.

Where to Find It

Tantalum

(Symbol: Ta, Atomic Number:73, Atomic Mass: 180.9479)
Belongs is group 5, period 6, class: metal, family: transition

Isotopes

Tantalum has 2 natural isotopes.
Tantalum-180: mass: 179.9, rarest isotope
Tantalum-181: mass: 180.9, stable, may be used for nuclear weapons

What's in the Name?

Uses of Tantalum

Capacitors-military systems, and electronics (can hold energy charge)
Surgical implants- such as skull plates and artificial joints (it is durable and unreactive to body)
Camera lenses
Medical Instruments- dental and surgery tools (because of durability)
Metal Alloys- for tools used in high temperatures (also hard to corrode or break)

Tantalus, a mythological Greek king, is trapped in a pool of water, surrounded by fruit trees which move out of reach if reached for. This inspired the name Tantalum, as it does not react with/ absorb acid, just as Tantalus cannot reach food or water.

Tale of Two Elements

Tantalum was discovered in 1802 in Sweden by Anders Ekenberg. Columbium was discovered one year earlier, and it was often thought tha the two were the same. However, in 1844 and 1866, it was proved that they are truely two individual elements.

Reflection

Tantalum is a significant element. Though we may not recognize it around us, it is used in many everyday items. Electronics, for example , make great use of tantalum. Without electronics, our society would certainly not be as advanced as it is now, and we would slowly go insane. Medical procedures would be less successful and more expensive, as insturments would have to be replaced more often. Tantalum has also helped raise awareness about conflict minerals (coltan, which it has been found in). Many countries rely on this element for money. Life without tantalum would be much different.

Sources: http://education.jlab.org/itselemental/ele073.html http://www.periodni.com/ta.html
http://environmentalchemistry.com/yogi/periodic/Ta.html http://www.chemistryexplained.com/elements/P-T/Tantalum.html
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TESTING PROCEDURES FOR BIOCOMPATIBILITY OF DENTAL MATERIALS

- Many different materials have been used in prosthetic treatment throughout dentistry's long history. Currently, in the development of new materials, biological properties have become markedly important, along with physical and mechanical properties. Biocompatibility has been described as the ability of a material to perform with an appropriate host response in a specific application. Appropriate host response means no adverse reaction of a living system to the presence of such a material. An adverse reaction may be due to the toxicity of a dental material. Therefore toxicity may be regarded as one reason for non biocompatibility of a dental material. Biocompatibility is an important feature of any material designed for use within the body.

- Biocompatibility is the result of interactions between the material, patient and function, and is an ongoing process. Materials' biocompatibility is evaluated with in vitro tests, animal tests and usage tests. In the evaluation of the biologic effects of dental materials, in vitro testing methods using cell cultures have become more common, and several cell culture methods have been developed to assess the cytotoxicity of dental materials. In vitro tests are simpler than animal and usage tests. These tests, performed under repeatable and controllable conditions and presenting comparable results, give information about a material's first usage. Cell or tissue cultures play an important role because they allow a maximum standardization. Future efforts may be directed toward development of materials biocompability for safety application.

THE PROPERTIES OF TITANIUM AND IT'S USAGE IN DENTAL PRACTICE

- The most important reason for their preference in the dental practice of titanium and its alloys is biocompatibility properties. Biocompatibility properties of titanium and its alloys, is due to the superior corrosion resistance. The corrosion resistance and the material formed on the surface is a result of passive oxide layer that protects against electrochemical attack. Under normal conditions of titanium also other criteria that determine the biocompatibility of bone osseointegration is excellent and on a similar manner to hydroxyapatite is to allow the formation of a rich layer of calcium phosphate.

- Biocompatibility studies related to the titanium biomaterial made from a variety of many animal experiments and in vitro tests extend to in vivo studies. The local lymph nodes titanium implant material used and the build-up of corrosion products in the internal organs and have been shown to generate galvanic side effects. However, cases of allergic reactions against titanium has also been reported by some investigators.
- Urban and friends they do in vivo studies in hip / knee replacement bearing on patients, but can be widely distributed in the body of the corrosive product showed that create toxic effects. In vitro studies indicate that the mutagenic and non-toxic titanium.

Materyal	Gerilme Direnci (MPa)	Kalıcı Deformasyon Direnci (MPa)	Uzama (%)	Elastiklik Modülü (GPa)
		α- tip		
Pure Ti grade 1	240	170	24	**102.7**
Pure Ti grade 2	345	275	20	**102.7**
Pure Ti grade 3	450	380	18	**103.4**
Pure Ti grade 4	550	485	15	**104.1**
		α+β tip		
Ti-6Al-4V	895-930	825-869	6-10	**110-114**
Ti-6Al-4V ELI	860-965	795-875	10-15	**101-110**
Ti-6Al-7Nb	900-1050	880-950	8.1-15	**114**
Ti-5Al-2.5V	1020	895	15	**112**
		β tip		
Ti-13Nb-13Zr	973-1037	836-938	10-16	**79-84**
Ti-12Mo-6Zr-2Fe	1060-1100	1000-1060	18-22	**74-85**
Ti-15Mo	874	544	21	**78**
Ti-15Mo-5Zr-3Al	852-1100	838-1060	18-25	**80**
Ti-15Mo-2.8Nb-0.2Si	979-999	945-987	16-18	**83**
Ti-35.3Nb-5.1Ta-7.1Zr	596.7	547.1	19	**55**
Ti-29Nb-13Ta-4.6Zr	911	864	13.2	**80**

Table 1: Mechanical properties of Ti alloys developed for medical applications

Özellik	Co-Cr	Titanyum	Ti-6Al-4V
Density/yoğunluk (g/cm^3)	8,9	4,5	4,5
Döküm sıcaklığı (^0C)	1500	1700	1700
Tensile strength (MPa)	850	520	1000
Elastiklik modülü (GPa)	190-230	110	85-115
Sertlik (VHN)	360-430	200	-
Ductility/esneklik (%)	2-8	20	14

Table 2: Comparison of some characteristics of base metal alloys with Ti

Materyal	Elastiklik modülü (GPa)
Alümina-seramik	380.4
Co-Cr	218.7
Paslanmaz çelik	193.1
Ti-6Al-4V	113.8
CpTi (grade1-4)	103.4
Mine	84.1
Dentin	18.3
Kemik	16.5

Table 3: Elasticity values of teeth, bones, implant materials and dental alloys

- Corrosion resistance, one of the most important properties of metallic biomaterials. Corrosion, distortion of the prosthesis is a serious problem in terms of release of potentially toxic or allergenic fragments from both the denture. Both CPs were both Ti-6Al-4V, as high resistance against corrosion materials, it has a high affinity. High corrosion resistance of titanium, the solid surface consists of approximately 10 nm thick oxide layer (TiO_2) is connected. This oxide layer on the titanium acid attack, protect against chemical and thermal influences. Available oxide layer of air and water, even if the game in any way harm it may occur in the presence again. Permanently damage at the oxide layer depends on the presence of factors that are not very high in the mouth.

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Ceramic Biomaterials (Bioceramics)

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INTRODUCTION

Biomaterials have become a ‘fashionable’ and very active area of research and development in Materials Science and Engineering (MSE) worldwide. Each year witnesses the creation of new journals specialized in this or in related subjects. The reasons for this fascinating area to grow so fast are complex.

However one can name some of the most relevant aspects of Biomaterials Science and Technology that make the field so attractive. First of all, the need to do interdisciplinary work when addressing a specific problem in this area has led many researchers, spanning from public health specialists to the so-called hard sciences investigators, to have fruitful exchanges from areas others than their original field

Second, because biomaterials oblige to study in detail some fundamental problems that are common to many sciences. Many difficulties when preparing or characterizing biomaterials lie in the basic physical-chemical or even mathematical phenomena. Third, and perhaps the main motivation for many private corporations, because biomaterials represent a potential market of several million dollars a year, and any innovation proven to be adequate for a particular problem constitutes a very attractive profit.

The word 'biomaterial' itself is loosely employed for describing a wide variety of materials used for biomedical applications. Arguments still arise on where exactly the boundary lies between an authentic biomaterial and a biomedical device. In fact, many polymeric materials that are utilized as parts of a complicated kidney replacement, for instance, could or could not be regarded as a biomaterial, depending on the working definition of the term.

Nevertheless, calcium-based compounds including carbonates and phosphates are the rising stars of biomaterials, at least in terms of the growing number of articles, patents and designs that are issued annually. The attraction to these particular materials has several aspects of its own, including without a doubt, commercial interests of certain powerful companies. As we shall see in what follows, however, the basic technical reason for the preference for calcium-based compounds lies in the fact that a bone is formed largely by calcium phosphates, among which hydroxyapatite (HAp) has received special attention.

Ceramics

Ceramics are refractory polycrystalline compounds;

- Inorganic
- Hard and brittle
- High compressive strength

Applications:

- Orthopaedic load-bearing coatings
- Dental implants
- Bone graft substitutes
- Bone cements

- The class of ceramics used for repair and replacement of diseased and damaged parts of the musculoskeletal system are referred to as bioceramics.
- Ceramics are refractory polycrystalline compounds ;

✓ Usually inorganic

✓ Highly inert

✓ Hard and brittle

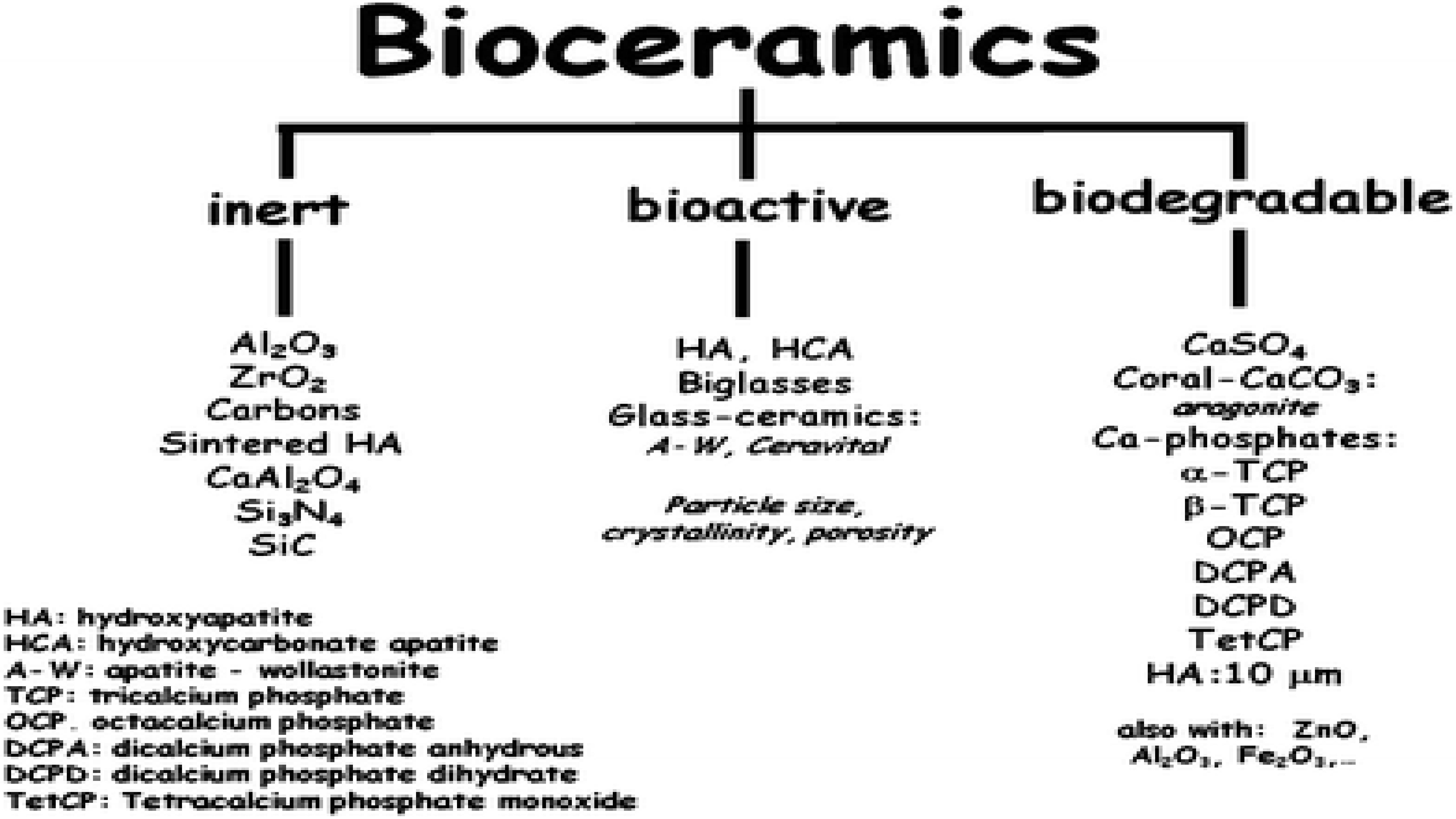
✓ High compressive strength

✓ Generally good electric and thermal insulators

✓ Good aesthetic appearance

Types of Bioceramics

- Bioinert
- Bioactive
- Bioresorbable


Bioceramics
inert
bioactive
biodegradable
Al_2O_3
ZrO_2
Carbons
Sintered HA
$CaAl_2O_4$
Si_3N_4
SiC
HA, HCA
Biglasses
Glass-ceramics:
A-W, Ceravital
Particle size, crystallinity, porosity
$CaSO_4$
Coral-$CaCO_3$:
aragonite
Ca-phosphates:
α-TCP
β-TCP
OCP
DCPA
DCPD
TetCP
HA:10 μm
also with: ZnO, Al_2O_3, Fe_2O_3,..
HA: hydroxyapatite
HCA: hydroxycarbonate apatite
A-W: apatite - wollastonite
TCP: tricalcium phosphate
OCP. octacalcium phosphate
DCPA: dicalcium phosphate anhydrous
DCPD: dicalcium phosphate dihydrate
TetCP: Tetracalcium phosphate monoxide

Bioinert

- Maintain their physical and mechanical properties while in host.
- Resist corrosion and wear.
- Have a reasonable fracture toughness.
- Typically used as structural-support implant such as bone plates, bone screw and femoral heads.

Bioactive

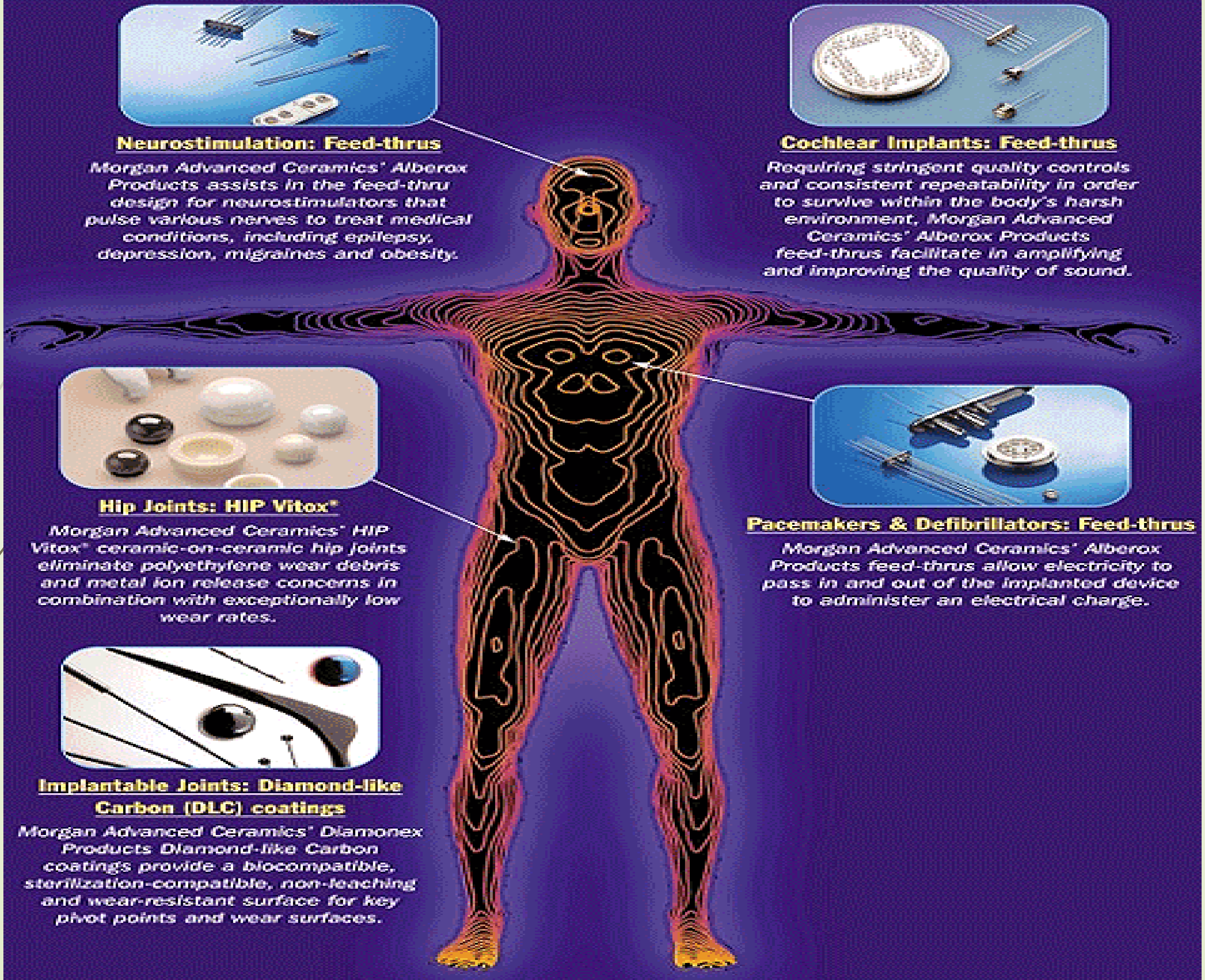
- Direct and strong chemical bond with tissue.
- Fixation of implants in the skeletal system.
- Low mechanical strength and fracture toughness.
- Examples: Glass ceramic , Dense nonporous glasses

Bioresorbable (Biodegradable)

- Chemically broken down by the body and degrade.
- The resorbed material is replaced by endogenous tissue.
- Chemicals produced as the ceramic is resorbed must be able to be processed through the normal metabolic pathways of the body without evoking any deleterious effect.
- Synthesized from chemical (synthetic ceramic) or natural sources (natural ceramic).

Bioceramics

- The class of ceramics used for repair and replacement of diseased and damaged parts of the musculoskeletal system are referred to as bioceramics.


Neurostimulation: Feed-thrus
Morgan Advanced Ceramics' Alberox Products assists in the feed-thru design for neurostimulators that pulse various nerves to treat medical conditions, including epilepsy, depression, migraines and obesity.
Cochlear Implants: Feed-thrus
Requiring stringent quality controls and consistent repeatability in order to survive within the body's harsh environment, Morgan Advanced Ceramics' Alberox Products feed-thrus facilitate in amplifying and improving the quality of sound.
Hip Joints: HIP Vitox®
Morgan Advanced Ceramics' HIP Vitox® ceramic-on-ceramic hip joints eliminate polyethylene wear debris and metal ion release concerns in combination with exceptionally low wear rates.
Pacemakers & Defibrillators: Feed-thrus
Morgan Advanced Ceramics' Alberox Products feed-thrus allow electricity to pass in and out of the implanted device to administer an electrical charge.
Implantable Joints: Diamond-like Carbon (DLC) coatings
Morgan Advanced Ceramics' Diamonex Products Diamond-like Carbon coatings provide a biocompatible, sterilization-compatible, non-leaching and wear-resistant surface for key pivot points and wear surfaces.

- Bioceramics and bioglasses are ceramic materials that are biocompatible.Bioceramics are an important subset of biomaterials. Bioceramics range in biocompatibility from the ceramic oxides, which are inert in the body, to the other extreme of resorbable materials, which are eventually replaced by the body after they have assisted repair. Bioceramics are used in many types of medical procedures. Bioceramics are typically used as rigid materials in surgical implants, though some bioceramics are flexible. The ceramic materials used are not the same as porcelain type ceramic materials. Rather, bioceramics are closely related to either the body's own materials or are extremely durable metal oxides.

OBJECTIVES:

- ✓ To examine chemical/physical properties of ceramics
- ✓ To introduce the use of ceramics as biomaterials
- ✓ To explore concepts and mechanisms of bioactivity

Biocompatibility

- Bioceramics' properties of being anticorrosive, biocompatible, and aesthetic make them quite suitable for medical usage. Zirconia ceramic has bioinertness and noncytotoxicity. Carbon is another alternative with similar mechanical properties to bone, and it also features blood compatibility, no tissue reaction, and non-toxicity to cells. None of the three bioinert ceramics exhibit bonding with the bone. However, bioactivity of bioinert ceramics can be achieved by forming composites with bioactive ceramics. Bioglass and glass ceramics are nontoxic and chemically bond to bone. Glass ceramics elicit osteoinductive properties, while calcium phosphate ceramics also exhibit non-toxicity to tissues and bioresorption.

- The ceramic particulate reinforcement has led to the choice of more materials for implant applications that include ceramic/ceramic, ceramic/polymer, and ceramic/metal composites. Among these composites ceramic/polymer composites have been found to release toxic elements into the surrounding tissues. Metals face corrosion related problems, and ceramic coatings on metallic implants degrade over time during lengthy applications. Ceramic/ceramic composites enjoy superiority due to similarity to bone minerals, exhibiting biocompatibility and a readiness to be shaped. Performance needs must be considered in accordance with the particular site of implantation.

Mechanical Properties of Biomaterials

- Bioceramics are meant to be used in extracorporeal circulation systems (dialysis for example) or engineered bioreactors; however, they're most common as implants. Ceramics show numerous applications as biomaterials due to their physico-chemical properties. They have the advantage of being inert in the human body, and their hardness and resistance to abrasion makes them useful for bones and teeth replacement. Some ceramics also have excellent resistance to friction, making them useful as replacement materials for malfunctioning joints. Properties such as appearance and electrical insulation are also a concern for specific biomedical applications.

TABLE 1.4. Mechanical Properties of Ceramic Biomaterials*

	Young's Modulus, E (GPa)	Compressive Strength, σ_{UCS} (MPa)	Tensile Strength, σ_{UTS} (MPa)
Alumina	380	4500	350
Bioglass-ceramics	22	500	56–83
Calcium phosphates	40–117	510–896	69–193
Pyrolytic carbon	18–28	517	280–560

*Compiled from L.L. Hench. Ceramics, Glasses, and Glass-Ceramics, pp. 73–84 in B.D. Ratner, A.S. Hoffman, F.J. Shoen, and J.E. Lemons (eds), *Biomaterials Science: An Introduction to Materials in Medicine*, Academic Press, San Diego (1996); J.B. Park and R.S. Lakes, *Biomaterials*, Plenum Press, New York (1992); and J. Black, *Biological Performance of Materials*, Marcel Dekker, New York (1992).

Advantages and Disadvantges of Bioceramics

Advantages

- Biocompactible
- Wear Resistant
- Light Weight

Disadvantages

- Low Tensile Strength
- Difficult to Fabricate
- Low Toughness
- Not Resilient

Applications

- Ceramics are now commonly used in the medical fields as dental and bone implants. Surgical cermets are used regularly. Joint replacements are commonly coated with bioceramic materials to reduce wear and inflammatory response. Other examples of medical uses for bioceramics are in pacemakers, kidney dialysis machines, and respirators. The global demand on medical ceramics and ceramic components was about U.S. $9.8 billion in 2010. It was forecast to have an annual growth of 6 to 7 percent in the following years, with world market value predicted to increase to U.S. $15.3 billion by 2015 and reach U.S. $18.5 billion by 2018.

Cermet

Devices	Function	Biomaterial
Artificial total hip, knee, shoulder, elbow, wrist	Reconstruct arthritic or fractured joints	High-density alumina, metal bioglass coatings
Bone plates, screws, wires	Repair fractures	Bioglass-metal fibre composite, Polysulphone-carbon fibre composite
Intramedullary nails	Align fractures	Bioglass-metal fibre composite, Polysulphone-carbon fibre composite
Harrington rods	Correct chronic spinal curvature	Bioglass-metal fibre composite, Polysulphone-carbon fibre composite
Permanently implanted artificial limbs	Replace missing extremities	Bioglass-metal fibre composite, Polysulphone-carbon fibre composite
Vertebrae Spacers and extensors	Correct congenital deformity	Al_2O_3
Spinal fusion	Immobilise vertebrae to protect spinal cord	Bioglass
Alveolar bone replacements, mandibular reconstruction	Restore the alveolar ridge to improve denture fit	Polytetra fluro ethylene (PTFE) - carbon composite, Porous Al_2O_3, Bioglass, dense-apatite
End osseous tooth replacement implants	Replace diseased, damaged or loosened teeth	Al_2O_3, Bioglass, dense hydroxyapatite, vitreous carbon
Orthodontic anchors	Provide posts for stress application required to change deformities	Bioglass-coated Al_2O_3, Bioglass coated vitallium

TABLE 1.3. Ceramics Used in Biomedical Applications

Ceramic	Chemical Formula	Comment
Alumina	Al_2O_3	Bioinert
Zirconia	ZrO_2	
Pyrolytic carbon		
Bioglass	$Na_2OCaOP_2O_3{-}SiO$	Bioactive
Hydroxyapatite (sintered at high temperature)	$Ca_{10}(PO_4)_6(OH)_2$	
Hydroxyapatite (sintered at low temperature)	$Ca_{10}(PO_4)_6(OH)_2$	Biodegradable
Tricalcium phosphate	$Ca_3(PO_4)_2$	

Processing

- Technically, ceramics are composed of raw materials such as powders and natural or synthetic chemical additives, favoring either compaction (hot, cold orisostatic), setting (hydraulic or chemical), or accelerating sintering processes. According to the formulation and shaping process used, bioceramics can vary in density and porosity as cements, ceramic depositions, or ceramic composites.

- A developing material processing technique based on the biomimetic processes aims to imitate natural and biological processes and offer the possibility of making bioceramics at ambient temperature rather than through conventional or hydrothermal processes [GRO 96]. The prospect of using these relatively low processing temperatures opens up possibilities for mineral organic combinations with improved biological properties through the addition of proteins and biologically active molecules (growth factors, antibiotics, anti-tumor agents, etc.). However, these materials have poor mechanical properties which can be improved, partially, by combining them with bonding proteins.

Inert Ceramics: Aluminum Oxides (Alumina)

Applications

In orthopedics:

- ✓ femoral head
- ✓ bone screws and plates
- ✓ porous coatings for femoral stems
- ✓ porous spacers (specifically in revision surgery)
- ✓ knee prosthesis
- ✓ dental: crowns and bridges

Alumina

- Since 1975 alumina ceramic has proven its bioinertness. An alumina ceramic has characteristics of high hardness and high abrasion resistance. The reasons for the excellent wear and friction behavior of Al2O3 are associated with the surface energy and surface smoothness of this ceramic. There is only one thermodynamically stable phase, i.e. Al2O3 that has a hexagonal structure with aluminium ions at the octahedral interstitial sites.

- Abrasion resistance, strength and chemical inertness of alumina have made it to be recognized as a ceramic for dental and bone implants. The biocompatibility of alumina ceramic has been tested by many researchers.The results showed no signs of implant rejection or prolapse of the implanted piece. After a period of four weeks of implantation, fibroblast proliferation and vascular invasion were noted and by eighth week, tissue growth was noted in the pores of the implant.

Alumina matrix composite material

- Advantage:
  - advantage is that it makes material more biocompatible
- Disadvantage:
  - non-adherent fibrous membrane at the interface
  - failure can occur, leading to implant loosening

Inert Ceramics: Zirconia, ZrO_2

- Zirconia is a biomaterial that has a bright future because of its high mechanical strength and fracture toughness. Zirconia ceramics have several advantages over other ceramic materials due to the transformation toughening mechanisms operating in their microstructure that can be manifested in components made out of them. The research on the use of zirconia ceramics as biomaterials commenced about twenty years ago and now zirconia is in clinical use in total hip replacement (THR) but developments are in progress for application in other medical devices.

Fabrication:

- Obtained from the mineral zircon
- Addition of MgO, CaO, CeO, or Y_2O_3 stabilize tetragonal crystal structure (e.g. 97 mol%ZrO_2 and 3 mol%Y_2O_3)
- Usually hot-pressed or hot isostatically pressed

Applications:

- Orthopaedics: femoral head, artificial knee, bone screws and plates, favored over UHMWPE due to superior wear resistance
- Dental: crowns and bridges

Zirconia Dental Application

Biodegradable Ceramics; Calcium Phosphates

The inorganic phase of the bone tissue is primarily composed of calcium phosphates. A significant influence in bone tissue regeneration is given to phosphate salts because their physical, chemical and structural properties are very similar to those of bone tissue. During the 1920's these materials were available only as powders and they were used purely as filling materials. It was soon found, however, that they promote the formation of new bone tissue, particularly when the atomic ratio for these salts. Success of calcium phosphates in vivo implants depends on several factors, but very important ones are the Ca/P atomic ratio, the porosity and the crystalline structure.

Uses ;

- ✓ repair material for bone damaged trauma or disease
- ✓ void filling after resection of bone tumours
- ✓ repair and fusion of vertebrae
- ✓ repair of herniated disks
- ✓ repair of maxillofacial and dental defects
- ✓ ocular implants
- ✓ drug-delivery

Bioactive Ceramics: Glass Ceramics

Bioactive: capable of direct chemical bonding with the host biological tissue

Glass:

- an inorganic melt cooled to solid form without crystallization
- an amorphous solid
- possesses short range atomic order ... BRITTLE!

Bioglass

- Bioglasses are interesting versatile class of materials and structurally all silica-based glasses have the same basic building block - SiO_4. Glasses of various compositions can be obtained and they show very different properties. Bioglasses have also found a place in prosthetics. These bioglasses are embedded in a biomaterial support to form prosthetics for hard tissues. Such prosthetics are biocompatible, show excellent mechanical properties and are useful for orthopedic and dental prosthetics.

Tests

- **IN VIVO;**
- Studies that are in vivo are those in which the effects of various biological entities are tested on whole, living organisms usually animals including humans, and plants as opposed to a partial or dead organism, or those done in vitro ("within the glass"), i.e., in a laboratory environment using test tubes, petri dishes etc. Examples of investigations in vivo include: the pathogenesis of disease by comparing the effects of bacterial infection with the effects of purified bacterial toxins; the development of antibiotics, antiviral drugs, and new drugs generally; and new surgical procedures.

- Consequently, animal testing and clinical trials are major elements of in vivo research. In vivo testing is often employed over in vitro because it is better suited for observing the overall effects of an experiment on a living subject. In drug discovery, for example, verification of efficacy in vivo is crucial, because in vitro assays can sometimes yield misleading results with drug candidate molecules that are irrelevant in vivo (e.g., because such molecules cannot reach their site of in vivo action, for example as a result of rapid catabolism in the liver).

In Vitro;

- ***In vitro*** studies are performed with microorganisms, cells or biological molecules outside their normal biological context. Colloquially called "test tube experiments", these studies in biology and its sub-disciplines have traditionally been done in test-tubes, flasks, petri dishes *etc*and since the onset of molecular biology involve techniques such as the so-called omics. Studies that are conducted using components of an organism that have been isolated from their usual biological surroundings permit a more detailed or more convenient analysis than can be done with whole organisms. In contrast, *in vivo* studies are those conducted in animals including humans, and whole plants.

- ***In vitro*** studies are conducted using components of an organism that have been isolated from their usual biological surroundings, such as microorganisms, cells or biological molecules. For example, microrganisms or cells can be studied in artificial culture medium, proteins can be examined in solutions. Colloquially called "test tube experiments", these studies in biology, medicine and its sub-disciplines are traditionally done in test-tubes, flasks, petri dishes *etc*. They now involve the full range of techniques used in molecular biology such as the so-called omics.
- In contrast, studies conducted in living beings (microorganisms, animals, humans, or whole plants) are called *in vivo* .

Future trends

- Bioceramics have been proposes as a possible treatment for cancer. Two methods of treatment have been proposed: hyperthermia and radiotherapy. Hyperthermia treatment involves implanting a bioceramic material that contains a ferrite or other magnetic material. The area is then exposed to an alternating magnetic field, which causes the implant and surrounding area to heat up. Alternatively, the bioceramic materials can be doped with β-emitting materials and implanted into the cancerous area.
- Other trends include engineering bioceramics for specific tasks. Ongoing research involves the chemistry, composition, and micro- and nanostructures of the materials to improve their biocompatibility.

Conclusion

- Bioceramics has evolved to become an integral and vital segment of our modern health-care delivery system.
- In the years to come the composition, microstructure, and molecular surface chemistry of various types of bioceramics will be tailored to match the specific biological and metabolic requirements of tissues or disease states.
- “Molecular-based pharmaceutical" approach should be coupled with the growth of genetic engineering and information processing, resulting in a range of products and applications.

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Polymeric Biomaterials

Presented by: Fahir Mert BOSTANOGL

Baybars SARICA

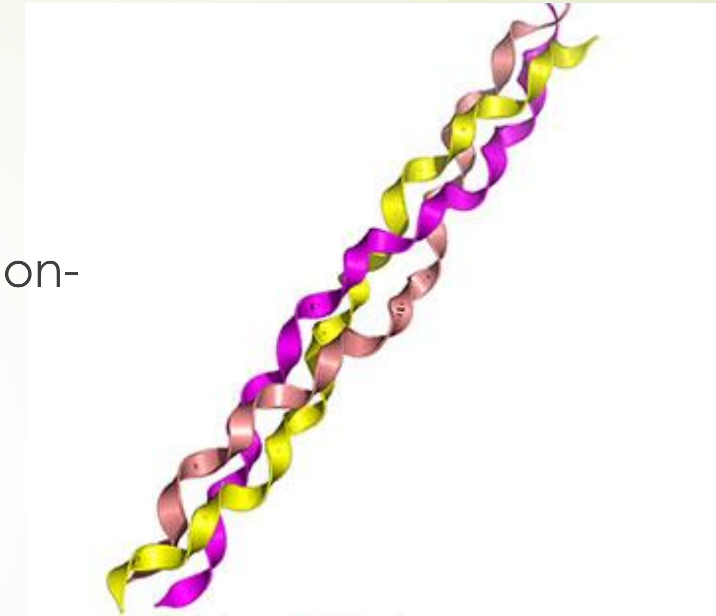
Contents

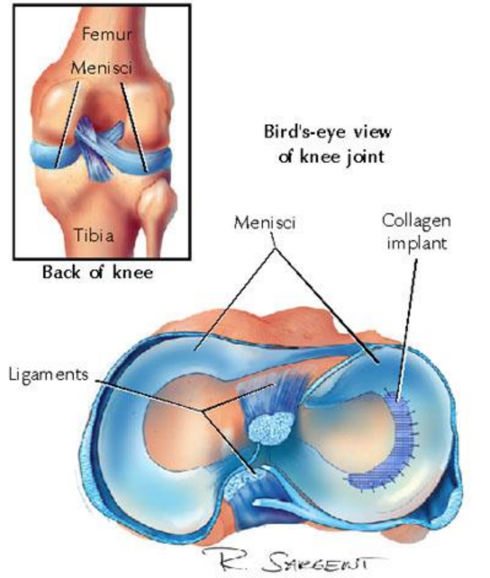
Natural Polymers

- Polymers derived from living creatures
- "Scaffolds" grow cells to replace damaged tissue
  - Desirable properties:
    - Biodegradable
    - Non-toxic
    - Mechanically similar to the replaced tissue
    - Capable of attachment with other molecules
- Natural polymers used as biomaterials
  - Collagen, Chitosan and Alginate

Collagen

- Consist of three intertwined protein chains, helical structure
- Collagen can be desorbed into the body, non-toxic , minimal immune response
- Can be processed into a variety formats
  - Porous sponges, Gels, and Sheets
- Applications
  - Surgery, Drug delivery, Prosthetic implants and tissue-engineering of multiple organs





Chitosan

- Derived from chitin, present in hard exoskeletons of shellfish like shrimp and crab
- Chitosan desirable properties
  - Minimal foreign body reaction
  - Mild processing conditions
  - Controllable mechanical/biodegradation properties
- Applications
  - In the engineering of cartilage, nerve, and live
  - wound dressing and drug delivery devices

Alginate

- A polysaccharide derived from brown seaweed
- Can be processed easily in water, non-toxic, biodegradable, controllable porosity
- Forms a solid gel under mild processing conditions

- Has been explored for use in:
  - Liver, nerve, heart, cartilage & tissue-engineering
- Mechanical weakness: low strength & poor cell adhesion
  - Can be overcome by enhancing with other materials

Synthetic Polymers

- Advantages of Synthetic Polymers
  - Easy manufacturability, processability and not expensive
- The Required Properties
  - Biocompatibility
  - Non toxic
  - Physical Property
  - Manufacturability
- Applications
  - Medical disposable supplies, Prosthetic materials, Dental materials, implants, dressings, polymeric drug delivery, tissue engineering products

Polymerization

- Process of reacting monomer molecules together in a chemical reaction to form three-dimensional networks or polymer chains
  - Addition Polymerization
  - Condensation Polymerization

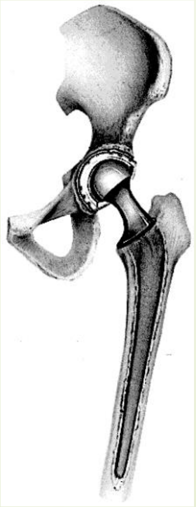
Structural Modification →

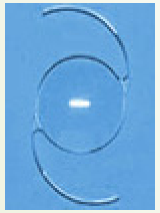
- Molecular Weight
- Cross-linking
- Effect of

Temperature

Synthetic Polymers Used as Biomaterials

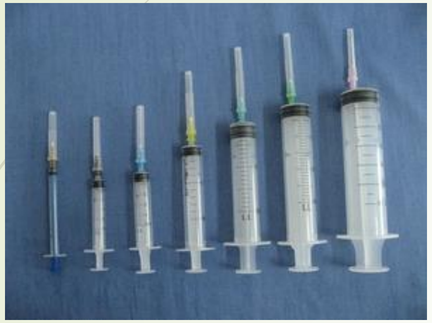
- Polyvinylchloride (PVC)
  - Amorphous & rigid polymer, high melt viscosity
  - Made flexible and soft by the addition of plasticizers
  - For: blood and solution bag, surgical packaging





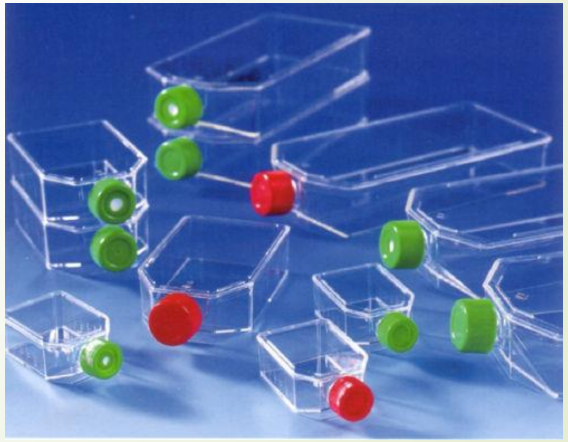
- Polymethyl metacrylate (PMMA)
  - Resistant to inorganic solutions
  - Excellent optical properties
  - For: Blood pump and reservoir, implantable ocular lenses, bone cement

Synthetic Polymers Used as Biomaterials



- Polypropylene (PP)
  - High tensile strength
  - Excellent stress-cracking resistant
  - For: Disposable syringes, blood oxygenerator membrane, artificial vascular grafts

- Polystyrene (PS)
  - Unmodified General Purpose Polystyrene (GPPS)
    - Good transparency, ease of fabrication, thermal stability, relatively high modulus
    - Used in tissue culture flasks, vacuum canisters, filterware.



Biodegradable Polymers

- Advantages on biodegradable polymer
  - Didn’t leave traces of residual in the implantation
  - Regenerate tissue
- Accelerated by greater hydrophilicity, greater reactivity, less crystallinity, greater porosity

- Most widely used
  - Polylactide (PLA), Polyglycolide (PGA), Poly(glycolide-co-lactide) (PGLA)
- Applications
  - Tissue screws, suture anchores, meniscus & cartilage repair
  - Drug-delivery system

Surface Modification

TABLE 3.7 Physical and Chemical Surface Modification Methods for Polymeric Biomaterials

To modify blood compatibility	Octadecyl group attachment to surface
	Silicon containing block copolymer additive
	Plasma fluoropolymer deposition
	Plasma siloxane polymer deposition
	Radiation-grafted hydrogels
	Chemically modified polystyrene for heparin-like activity
To influence cell adhesion and growth	Oxidized polystyrene surface
	Ammonia plasma-treated surface
	Plasma-deposited acetone or methanol film
	Plasma fluoropolymer deposition
To control protein adsorption	Surface with immobilized polyethyelenglycol
	Treated ELISA dish surface
	Affinity chromatography particulates
	Surface cross-linked contact lens
To improve lubricity	Plasma treatment
	Radiation-grafted hydrogels
	Interpenetrating polymeric networks
To improve wear resistance and corrosion resistance	Ion implantation
	Diamond deposition
	Anodization
To alter transport properties	Plasma deposition (methane, fluoropolymer, siloxane)
To modify electrical characteristics	Plasma deposition
	Solvent coatings
	Parylene coatings

Source: Ratner et al. [1996], p. 106.

Surface modification of polystyrene with atomic oxygen radical anions-dissolved solution

The O^- water, generated by bubbling of the O^- (atomic oxygen radical anion) flux into the deionized water.

Surface characterization

The surface hydrophilicity,

surface energy, and

surface roughness

all are increased by the O^- water treatments.

Particularly, it was found that some hydrophilic groups were introduced onto the polystyrene surfaces via the O^- water treatment, **increases the surface hydrophilicity and surface energy.**

The O^- water is also considered as a "clean solution" and easy to be handled at room temperature. Present method may potentially suit to the surface modification of polymers and other heat-sensitive materials.

In Vivo and In vitro Tests

In vivo and in vitro are types of biocompability tests. Biocompability tests are applied on biomaterial before materials implant on people.

In vitro refers to the technique of performing a given procedure in a controlled environment outside of a living organism. Many experiments in cellular biology are conducted outside of organisms or cells.

In vivo refers to experimentation using a whole, living organism as opposed to a partial or dead organism. In vivo testing is often employed over in vitro because it is better suited for observing the overall effects of an experiment on a living subject.

Diferences of In Vitro and In Vivo Test

- In vivo is an experiment or testing that is done inside the living organism or in its natural environment while in vitro is an experiment that is done outside of the living organism, usually in a test tube or Petri dish.

- In vivo testing is more expensive and time consuming than in vitro testing which provides quicker results.

- While most biological experiments are done in vitro, it is less precise than experiments done in vivo because it does not simulate the actual conditions inside the organism.

Composite Biomaterials

- Selim Can Karaüzüm
- Doğacan Yücel
- İlkay Kütüklüler

COMPOSITE

Composites are engineering materials that contain two or more physical and/or chemical distinct, properly arranged or distributed constituent materials that have different physical properties with an interface separating them. Composite materials have a continous bulk phase called the matrix and one or more discontinuous dispersed phases called the reinforcement which usually has superior mechanical or thermal properties to the matrix.

Separately, there is a third phase named as interphase between the matrix and reinforced phases such as coupling agent coated on glass fibers to achieve adhesion of glass particles to the polymer matrix

«A biomaterial is any matter, surface, or construct that interacts with biological systems»

The study of biomaterials is called biomaterials science. It has experienced steady and strong growth over its history, with many companies investing large amounts of money into the development of new products. Biomaterials science encompasses (includes) elements of medicine, biology, chemistry, tissue engineering and materials science.

Biomaterials can be derived either from nature or synthesized in the laboratory. They are often used and/or adapted for a medical application, and thus comprises (oluşturmak) whole or part of a living structure or biomedical device which performs, augments (çoğaltmak), or replaces a natural function.

- The beginning of the 1980's hydroxyapatite/polyethylene composite was the first bioactive composite to be investigated. These biomaterials have as the main aim to help the bone reparation.

Definitions of Biocompatibility

- «The ability of a material to perform with an appropriate host response in a specific application» Williams' definition*.

- **Biocompatibility:** Ability to be in contact with a living system without producing an adverse effect. **IUPAC Recommendations 2012****

Bioactive

- «Qualifier for a substance that provokes any response from a living system. **IUPAC Recommendations 2012**
- *The concept of *bioactivity* does not imply beneficial action only, although the term is often used positively, i.e., to reflect a beneficial action.
- In the study of biomineralization, bioactivity is often meant as the formation of calcium phosphate deposits on the surface of objects placed in simulated body fluid SBF, a buffer solution with ion content similar to blood.

Bioinert

Biologically inert, or bioinert materials are ones which do not initiate a response or interact when introduced to biological tissue. In other words, introducing the material to the body will not cause a reaction with the host. Originally, these materials were used for vascular surgery due to the need for surfaces, which do not cause clotting of the blood.

Realistically, most materials are not completely bioinert and no synthetic material is bioinert. Some examples of bioinert, or very close to bioinert substances are tianium-aluminum-vanadium alloy (used in hip replacements) and diamond.

Important properties of a biodegradable biomaterial

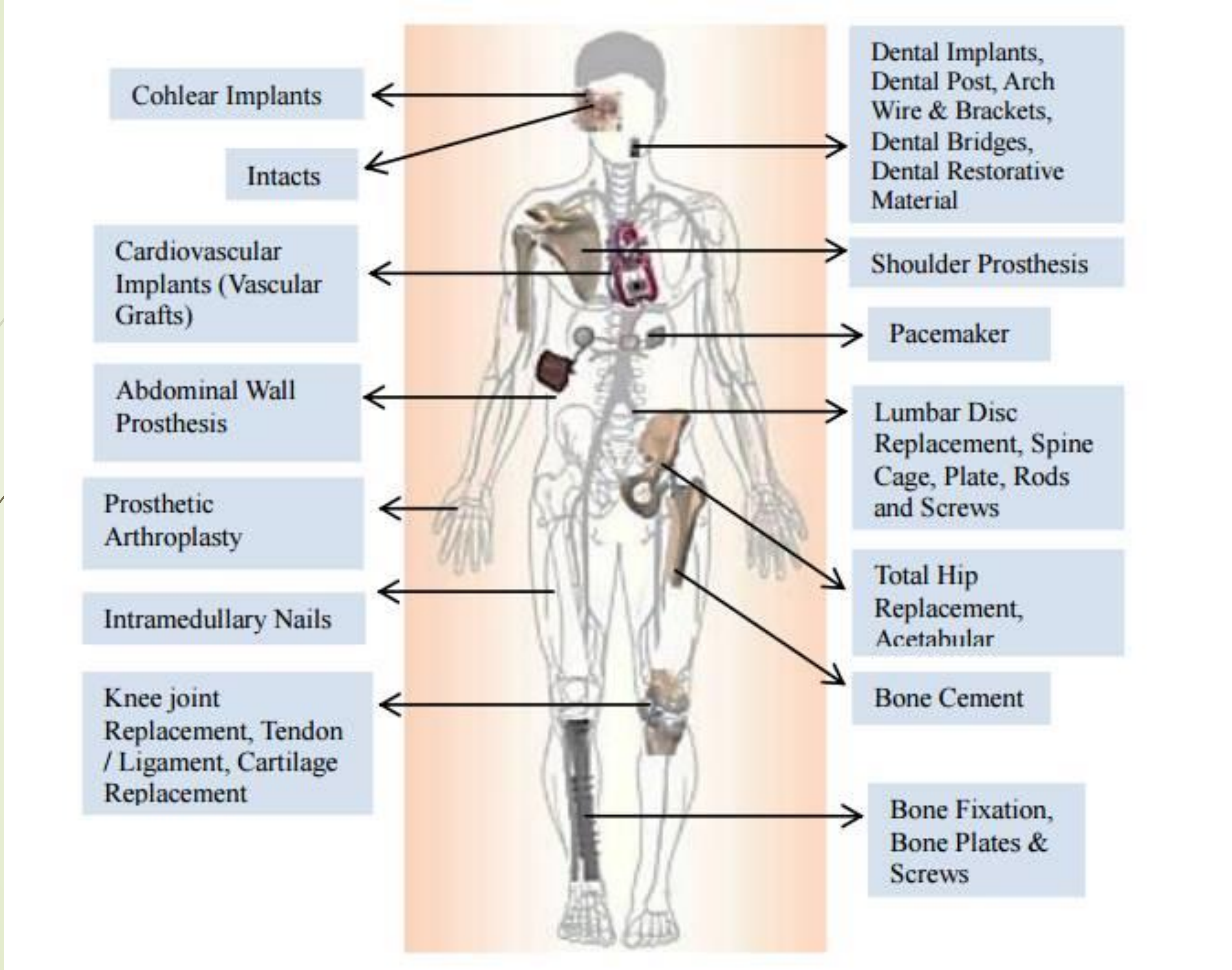
- The material should not evoke a sustained (sürekli) inflammatory or toxic response upon implantation in the body.
- The material should have acceptable shelf life.
- The degradation time of the material should match the healing or regeneration process.
- The material should have appropriate mechanical properties for the indicated application and the variation in mechanical properties with degradation should be compatible with the healing or regeneration process.
- The degradation products should be non-toxic, and able to get metabolized and cleared from the body.

Composite biomaterial

- Biocomposites are composite materials composed of biodegradable matrix and biodegradable natural fibres as reinforcement. The development of biocomposites has attracted great interest due to their environmental benefit and improved performance.

- Biodegradable and bioacti ceramic glass polymer composites for bone tissue engineering applications ar their mechanical properties

Biocomposite		Percentage of Ceramic (wt%)	Porosity (%)	Pore size (μm)	Compressive (C) Tensile (T) Flexural (F) Strength (MPa)	Modulus (MPa)
Ceramic	Polymer					
Non-crystalline CaP	PLGA	28-75	75	>100		65
ß-TCP	Chitosan-Gelatine	10-70	-	322-355	0.32-0.88 (C)	3.94-10.88
ß-TCP	PLGA	30	-	400(macro) 10(micro)	-	-
HA	PLLA PLGA PLGA	50 60-75	85-96 81-91 30-40	100x300 800-1800 110-150	0.39 (C) 0.07-0.22 (C) -	10-14 2-2.75 337-1459
nHA	PA	60	52-70	50-500(macro) 10-50(micro)	13.20-33.90 (C)	0.29-0.85
HA	PCL	25	60-70	450-740		76-84
HA	PLAGA	50-87	-	-	80 (C)	Up to 120
Bio-glass®	PLGA	75	43	89	0.42 (C)	51
	PLLA	20-50	77-80	100(macro) 10(micro)	1.5-3.9 (T)	137-260
	PLGA	0.1-1	-	50-300	-	-
	PDLLA	5-29	94	100(macro) 10-50(micro)	0.07-0.08(F)	0.65-1.2
CaP glass	PDLLA	20-50	93-96.5	80-450	-	0.05-0.2
A/W Phosphate	PLA- PDLLA	40 20-40	93-97 85.5-95.2	98-154	0.017-0.020 (C)	0.075-0.12
Glass	PDLLA	-	-	-		
Human cancellous bone	-	-	-	-	4-12 (C)	100-500


Cohlear Implants
Intacts
Cardiovascular Implants (Vascular Grafts)
Abdominal Wall Prosthesis
Prosthetic Arthroplasty
Intramedullary Nails
Knee joint Replacement, Tendon / Ligament, Cartilage Replacement
Dental Implants, Dental Post, Arch Wire & Brackets, Dental Bridges, Dental Restorative Material
Shoulder Prosthesis
Pacemaker
Lumbar Disc Replacement, Spine Cage, Plate, Rods and Screws
Total Hip Replacement, Acetabular
Bone Cement
Bone Fixation, Bone Plates & Screws

Matrixes

The matrix in a composite is the continuous bulk phase that envelopes the reinforcement phase either completely or partially. It serves several important functions.1 It holds the fibers or particles in place, and in oriented composites, it maintains the preferred direction of fibers. The matrix transfers the applied load to the reinforcement and redistributes the stress. When used with brittle fibers, the matrix helps increase fracture toughness because it is typically of a lower stiffness material and can tolerate greater elongation and shear forces than the reinforcement. The matrix also determines the environmental durability of the composite by resisting chemical, hygroscopic, and thermal stresses and protecting the reinforcement from these stresses. The matrix also greatly influences the processing characteristics of a composite.

Fibers

A great majority of materials is stronger and stiffer in the fibrous form than in any other form. This explains the emphasis on using fibers in composite materials design, particularly in structural applications, where they are the principal load-carrying component. Fibers have a very high aspect ratio of length to diameter compared with particles and whiskers, and the smaller the diameter, the greater is the strength of the fiber due to a reduction in surface flaws. Many properties of a composite are determined by the length, orientation, and volume fraction of fibers of a given type.

Particles

Particles can be added to a matrix to improve mechanical properties such as toughness and hardness. Other properties, such as dimensional stability, electrical insulation, and thermal conductivity, can also be controlled effectively by particles, especially when added to polymer matrices.

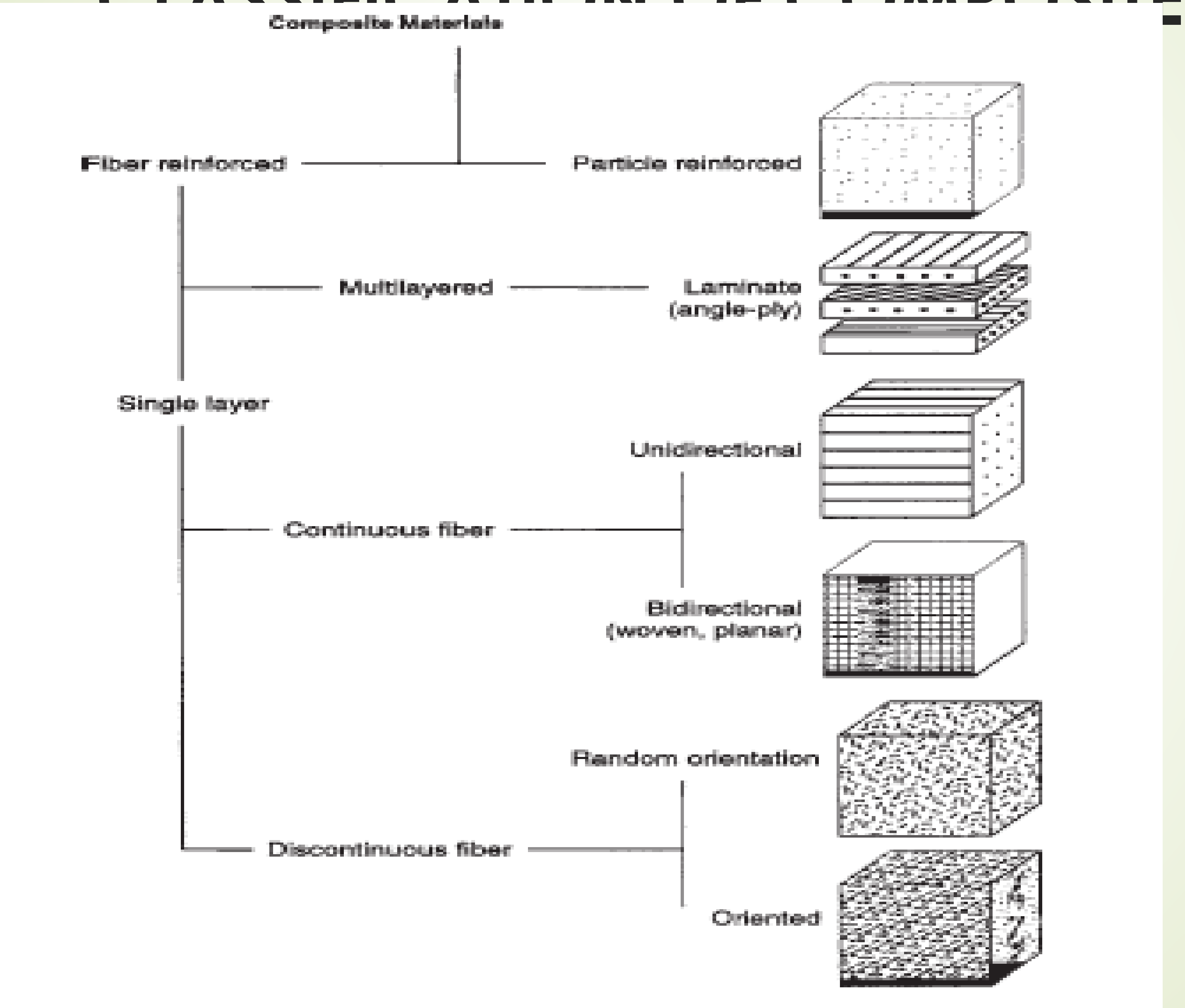
Particulate reinforcement is randomly distributed in a matrix, resulting in isotropic composites. Particles can either strengthen or weaken a matrix depending on its shape, stiffness, and bonding strength with the matrix. Spherical particles are less effective than platelet- or flakelike particles in adding stiffness. Hard particles in a low-modulus polymer increase stiffness, whereas compliant particles such as silicone rubber, when added to a stiff polymer matrix, result in a softer composite. Fillers are nonreinforcing particles such as carbon black and glass microspheres that are added more for economic and not performance purposes.

Common matrices, fibers, particles in biomaterials

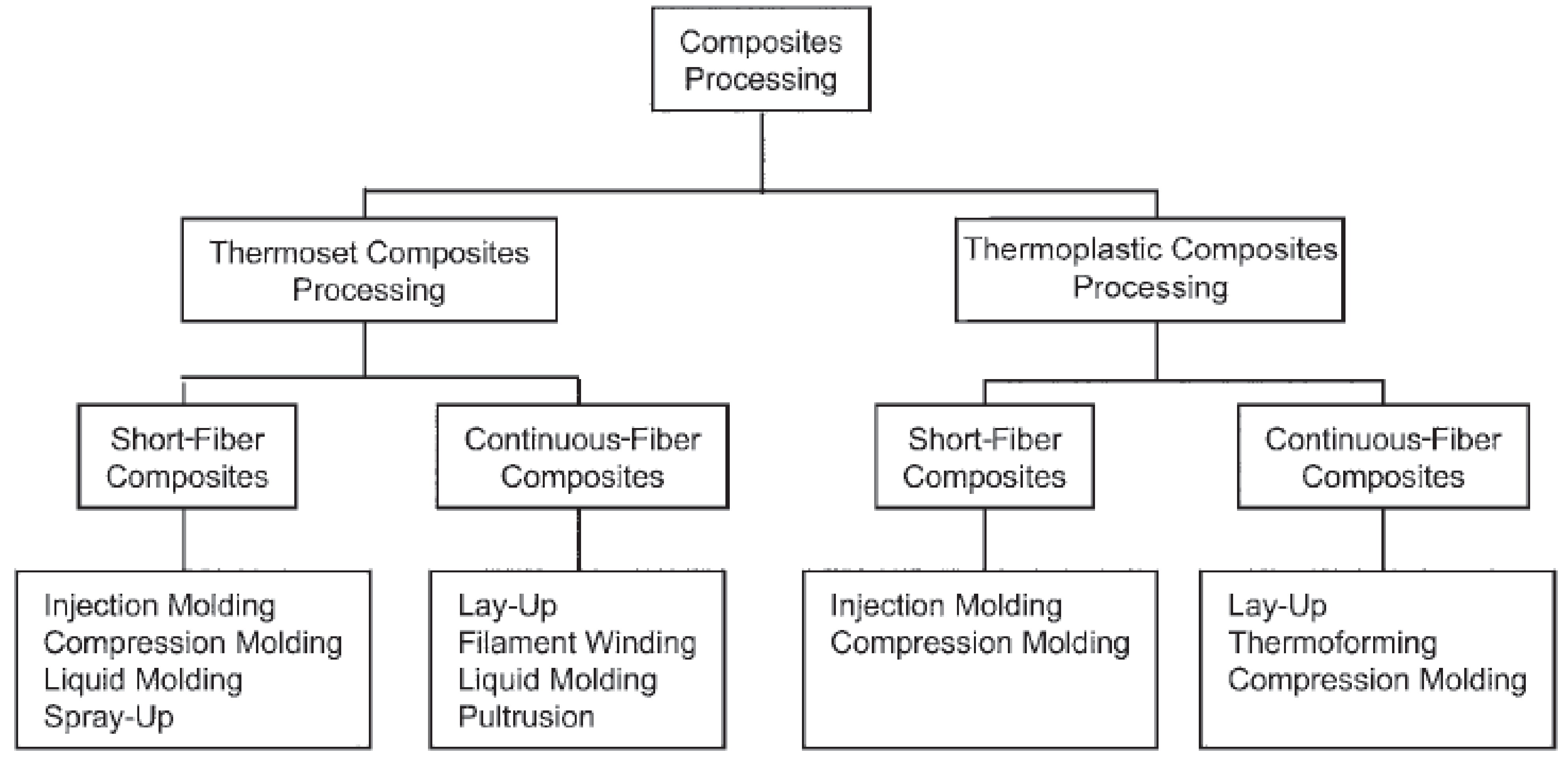
TABLE 12.1 Constituents of Biomedical Composites

Matrix	Fibers	Particles
Thermosets	*Polymers*	*Inorganic*
Epoxy	Aromatic polyamides (aramids)	Glass
Polyacrylates	UHMWPE	Alumina
Polymethacrylates	Polyesters	*Organic*
Polyesters	Polyolefins	Polyacrylate
Silicones	PTFE	Polymethacrylate
Thermoplastics	*Resorbable polymers*	
Polyolefins (PP, PE)	Polylactide, and its copolymers with polyglyocolide	
UHMWPE	Collagen	
Polycarbonate	Silk	
Polysulfones	*Inorganic*	
Poly(ether ketones)	Carbon	
Polyesters	Glass	
Inorganic	Hydroxyapatite	
Hydroxyapatite	Tricalcium phosphate	
Glass ceramics		
Calcium carbonate ceramics		
Calcium phosphate ceramics		
Carbon		
Steel		
Titanium		
Resorbable polymers		
Polylactide, polyglycolide and their copolymers		
Polydioxanone		
Poly(hydroxy butyrate)		
Alginate		
Chitosan		
Collagen		

CLASSİFİCATİON OF COMPOSİTE MATERİALS



Fabrication Process



The Helical Filament

- Helical filament process, a low viscosity resin impregnated fiber yarn in the bath is obtained by continuously rotating on a shaft and still passed. The layers are wound until the desired thickness is obtained at constant or varying angles to the material. It is then dried. This production method is the most suitable method for the production of the material of the cylindrical tube. Lured here in the ability to be controlled from the fibers in a good way 65% high fiber containing structures can be produced.

Pultrusion

- Profile of a composite material can be produced by drawing method. A liquid thermosetting resin bath and are in the process of empowering a continuous heated passes from the mold withdrawn from on November. The fibers as light passes from the bath is saturated with the resin. Creates a product with constant cross-sectional area in patterns. The thermosetting resin allows the shape of the heated mold to dry and cross-sectional area determines. In this process, thermoplastic composites can be produced. Here a mold is accompanied by cooler system.

Extrusion

- The machine basically consists of a screw rotating within a heated casing extraction. The output of the bucket are combined in a mold. The cross sectional geometry of the component is based on the desired mold cavity. Were mixed with the matrix and reinforcement fibers of feeding. In the structure of the pellets from a hopper at the end of the bucket is fed. Mixed feed is heated to plasticize and extruded. The product extruded, cooled and cut to the desired size. This process is limited to the powder having a uniform cross-sectional area and or short fiber amplifier. Investment costs are high. Typical builders content is 10-30% by volume.

Injection Moulding

- Direct injection moulding of the polymer matrix and reinforcement at a temperature controlled to feed a cylindrical bucket containing plastic is heated for the purpose of plasticizing. The inside of the bucket rotating with the help of screws in the mold material through a nozzle with the help of the editor, distributor, doors and gaps passes through. Solidifying the polymer or cross-connected, depending on the mold is opened and the injected part is taken from. This process is very common in the production of thermoset composites and thermoplastic composites in a manner used in the production of less prevalence . Rotating the screw in the hive in a harsh manner will lead to reductions in the length of the reinforcement. Thus, this process is limited to reinforcement and 10 to 30 per cent by volume of dust or a short in the range of a booster includes. However, this process with the help of complex parts with mass production can be performed in a very precise fashion.

Compression moulding

- This process (prepregs) layer molding compounds (smc), bulk molding compounds (BMC) or indirect amplifier stack glass thermoplastic (GMT), such as pre-impregnated composites are used in construction. Here are made using male and female molds. Pre-weighed material is placed into the mold, the mold is closed after appropriate temperature and pressure with the help of a hot press is applied. The mold cavities it forces the applied pressure and temperature to facilitate the polymerization to run out of material so that it can be secured to the composite material. Contains short and randomly distributed fibers prepreg and easily flows into the mold. In this process, the composite materials obtained to the plates is restricted. This method is simple and flat shaped materials used in the construction of laminates. Thermoset and thermoplastic composites, and compression molding is a method suitable for the production of.

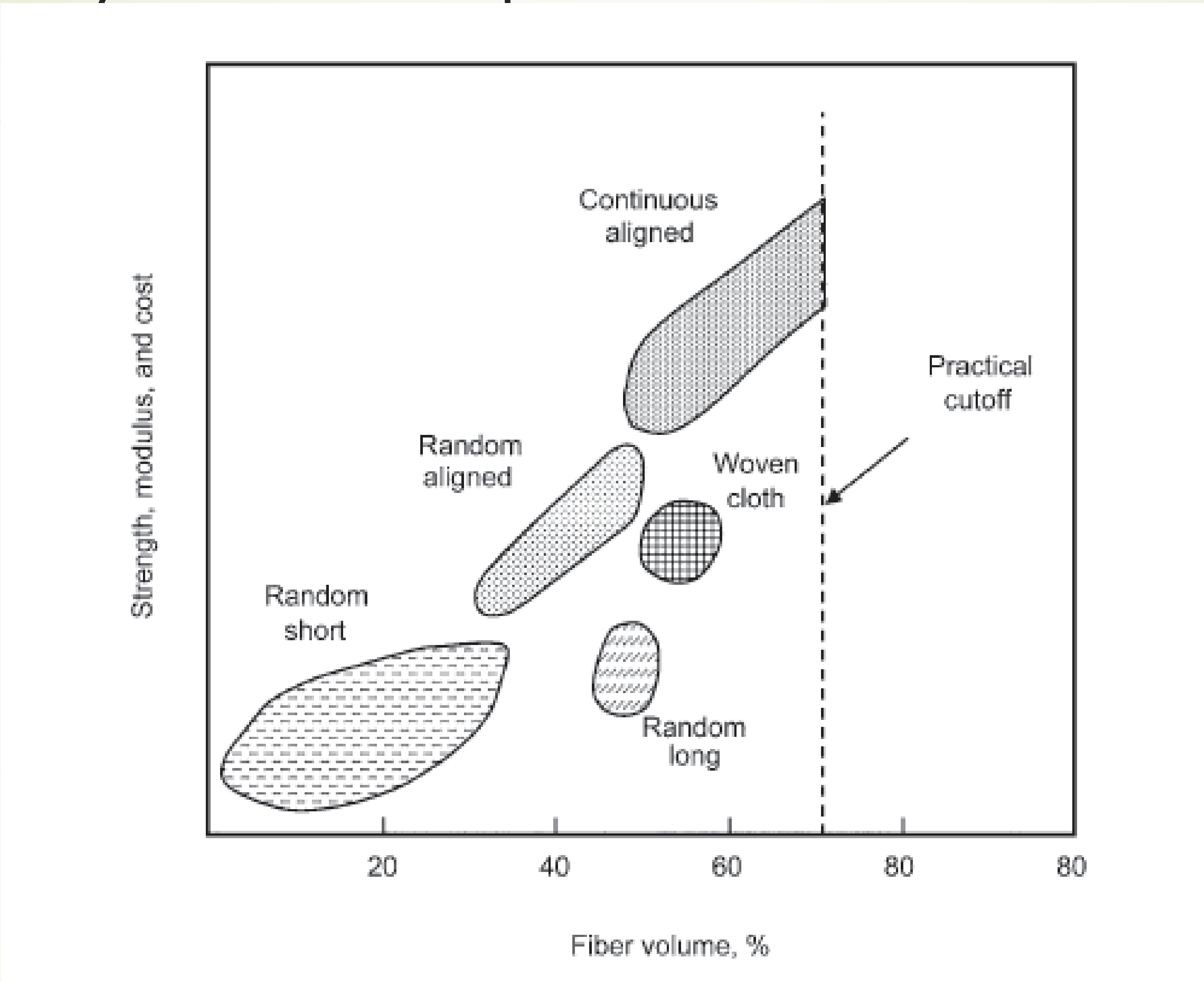
Microtest Laboraties of Biomaterials

- **In- Vivo Services:**
- **Rabbit Pyrogen**
- **USP Class Testing**
- **Sensitization**
- **Implantation**
- **Sub-Chronic/Chronic Toxicity**
- **Intracutaneous Reactivity**
- **Irritation Testing**
- **Necropsy Services**
- **Histology Services**

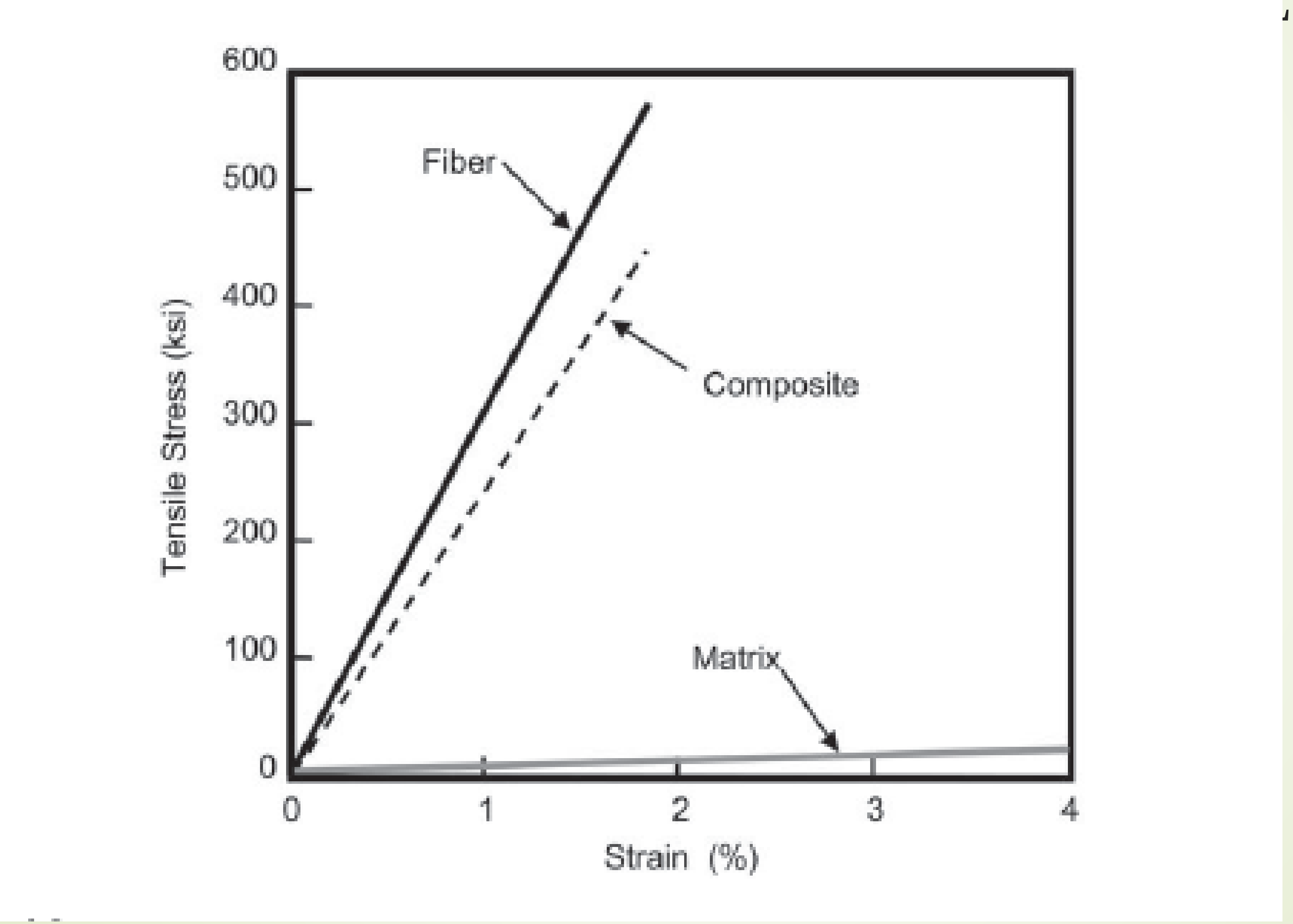
In-Vitro Services

- Cytotoxicity
- Hemolysis
- Complement Activation
- PT/PTT Testing
- AMES Mutagenicity
- Carcinogencity Testing

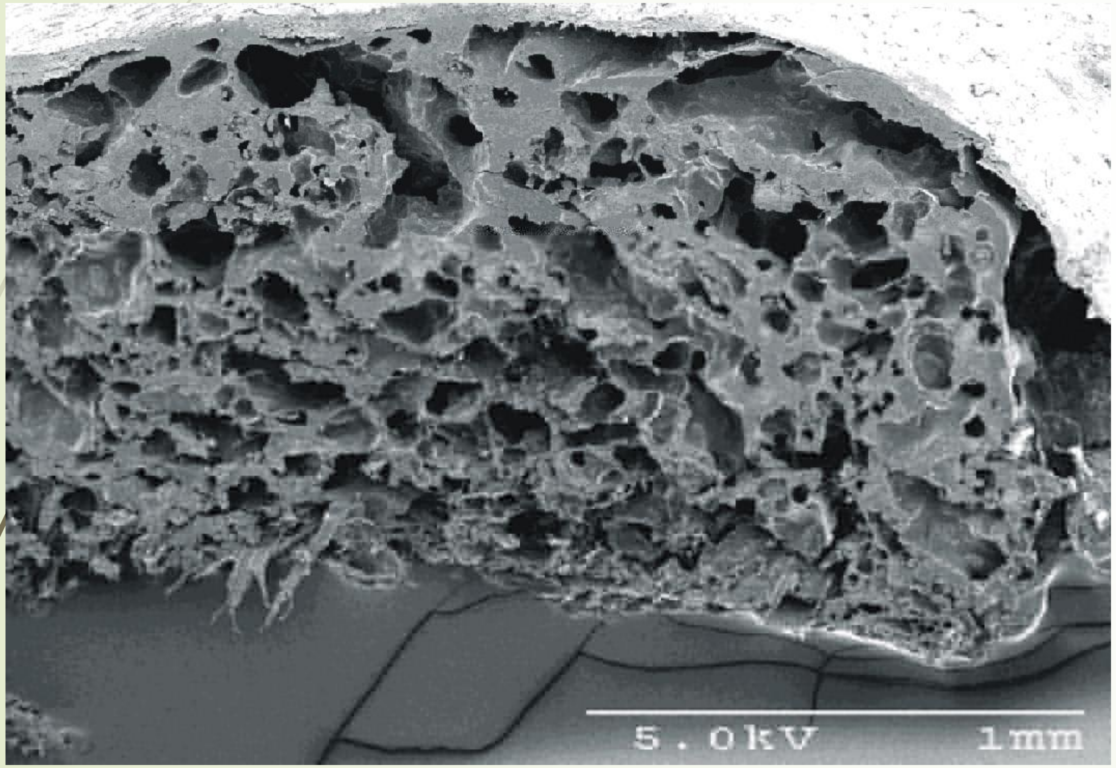
Influence Of Reinforcement Type And Quantity On Composite Performance

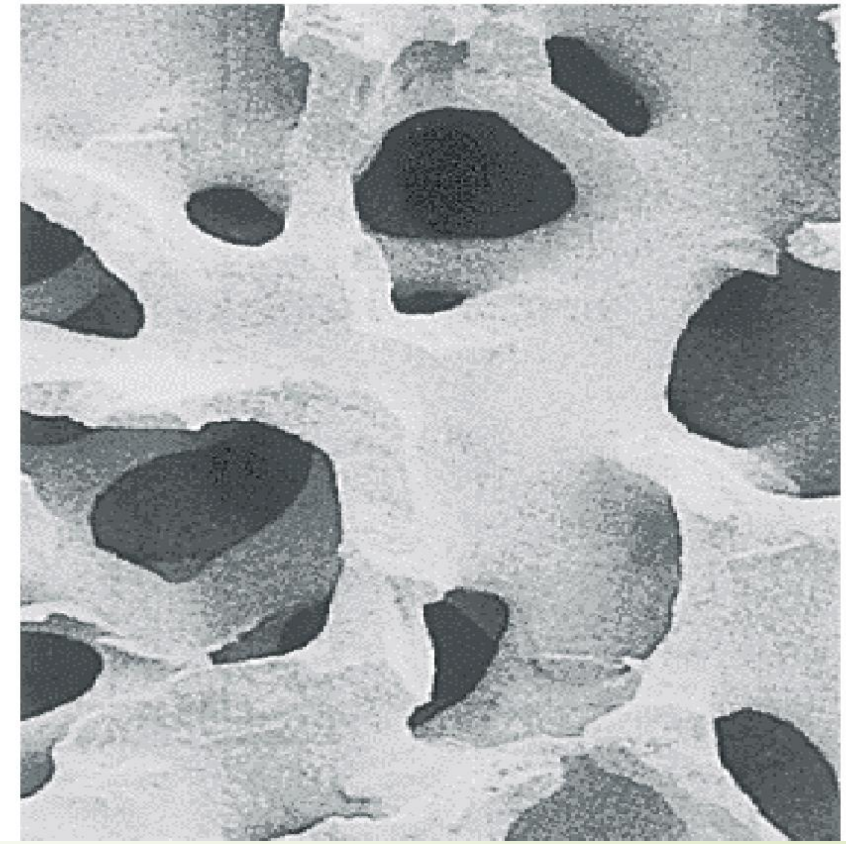


COMPARISON OF TENSILE PROPERTIES OF FIBER MATRIX AND COMPOSITE



SEM displaying the cross section of a composite disk, which had been seeded with cultured bone marrow stromal cells.





- Carbon fiber, has a silky texture which is a very durable material

  Carbon fiber is five times lighter than steel

  Carbon fiber is three times more tough than steel.

Karbon-Fiber Ayak Protezleri

Polysulfone , has a high tensile stress , compression and friction resistance can protect

Resist to acid, base and salt solutions

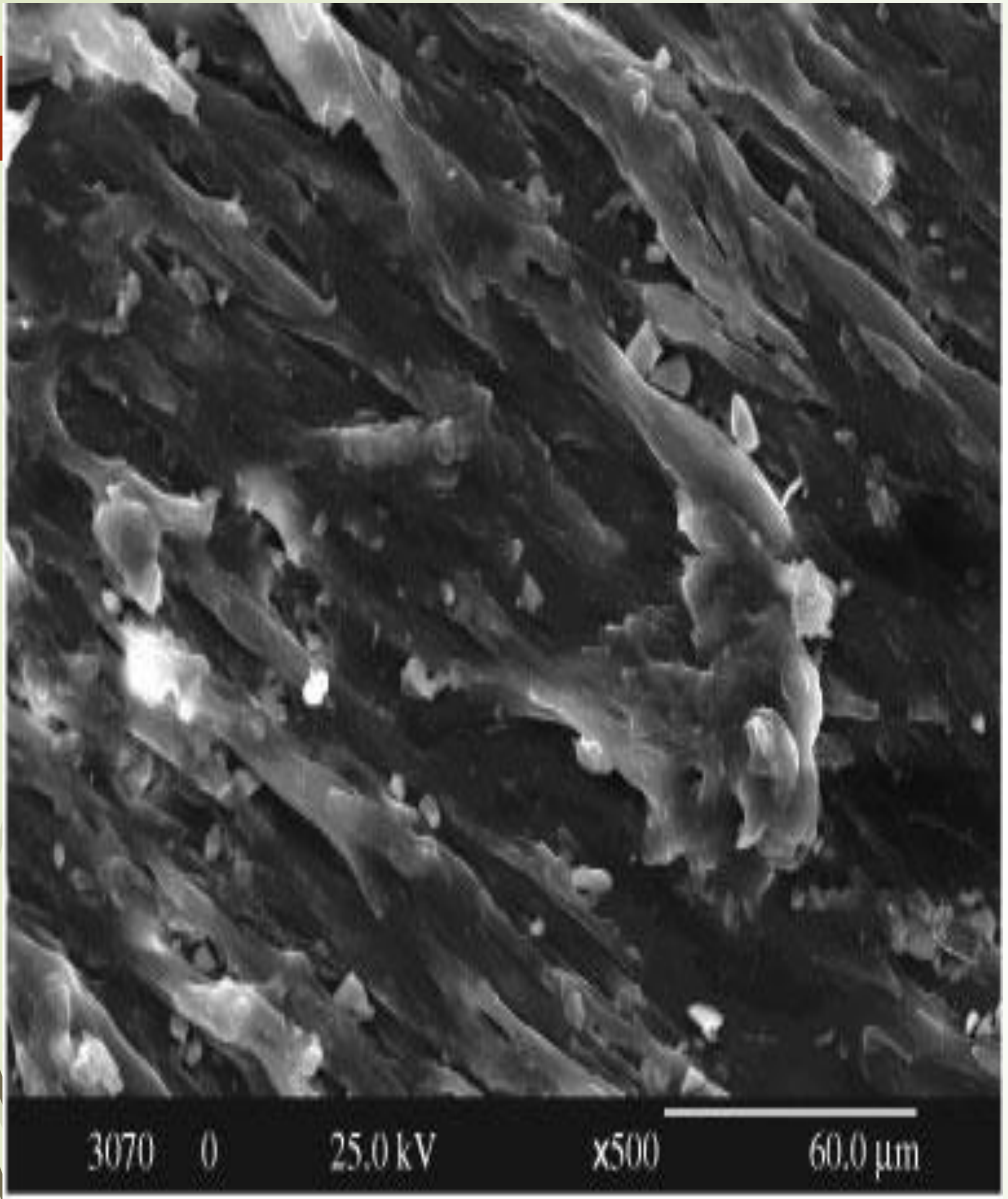


Figure 1. SEM image of composite bioactive glass/PHB 30/70 as prepared.

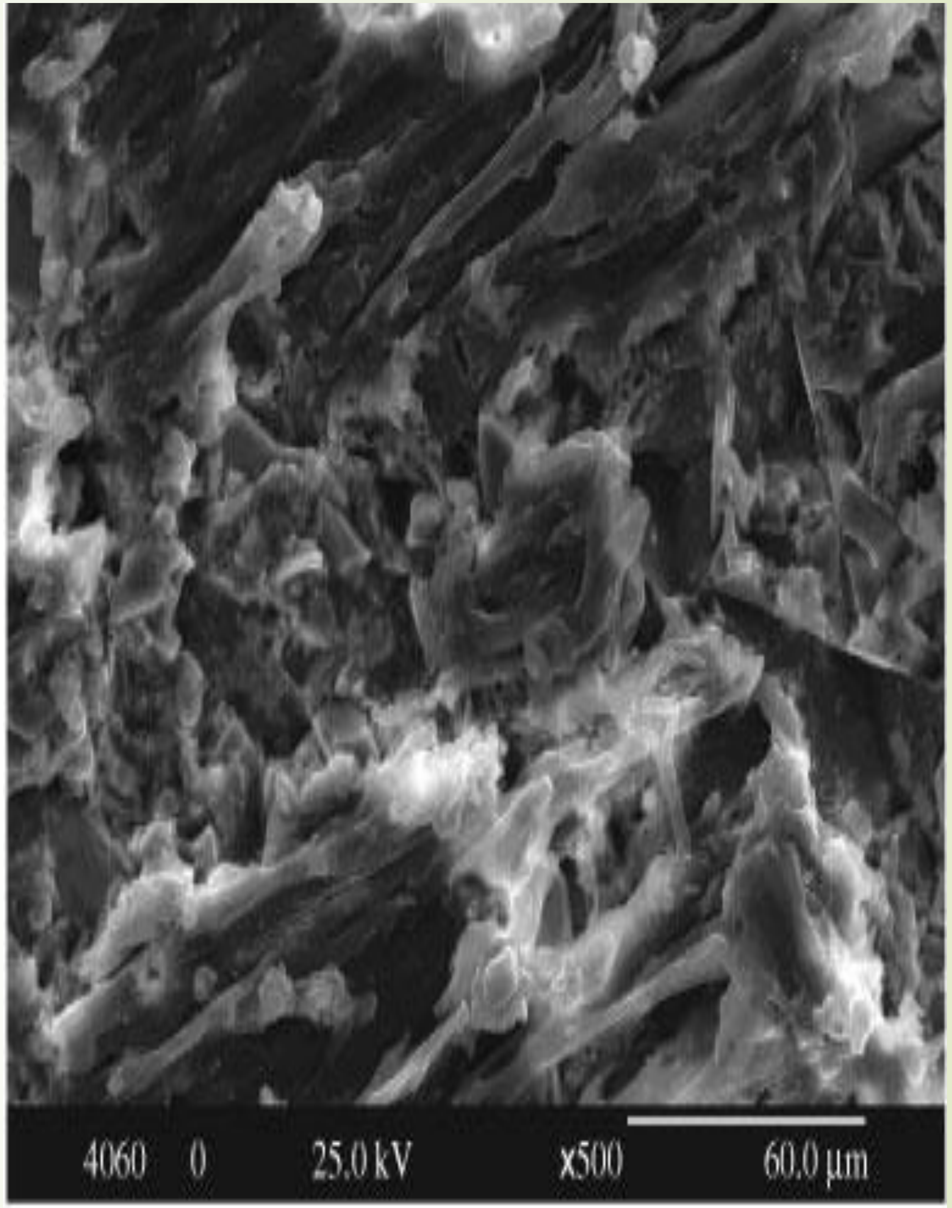


Figure 2. SEM image of composite bioactive glass/PHB 40/60 as prepared.

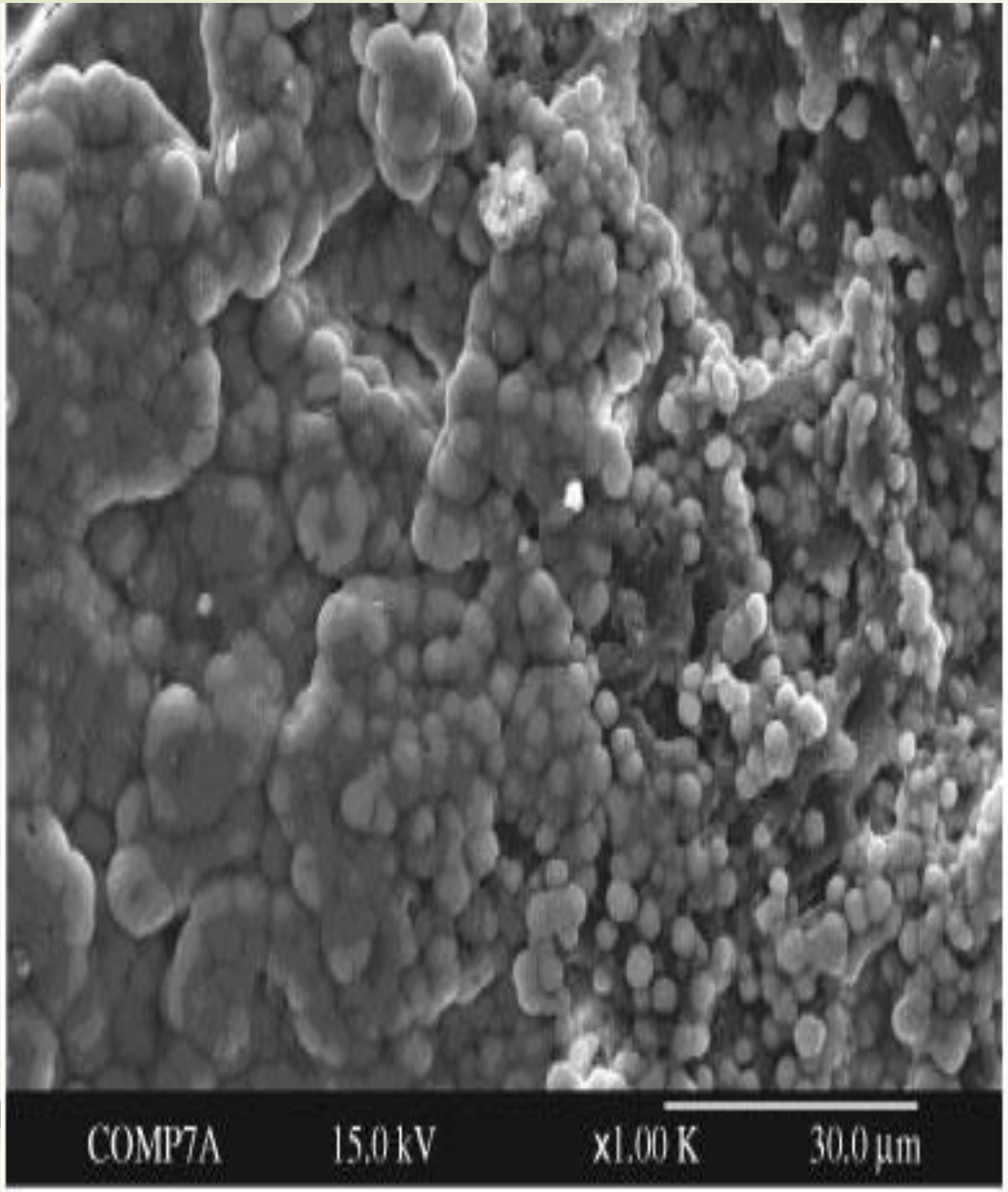


Figure 3. SEM image of composite bioactive glass/PHB 30/70 after 7 days of immersion in SBF.

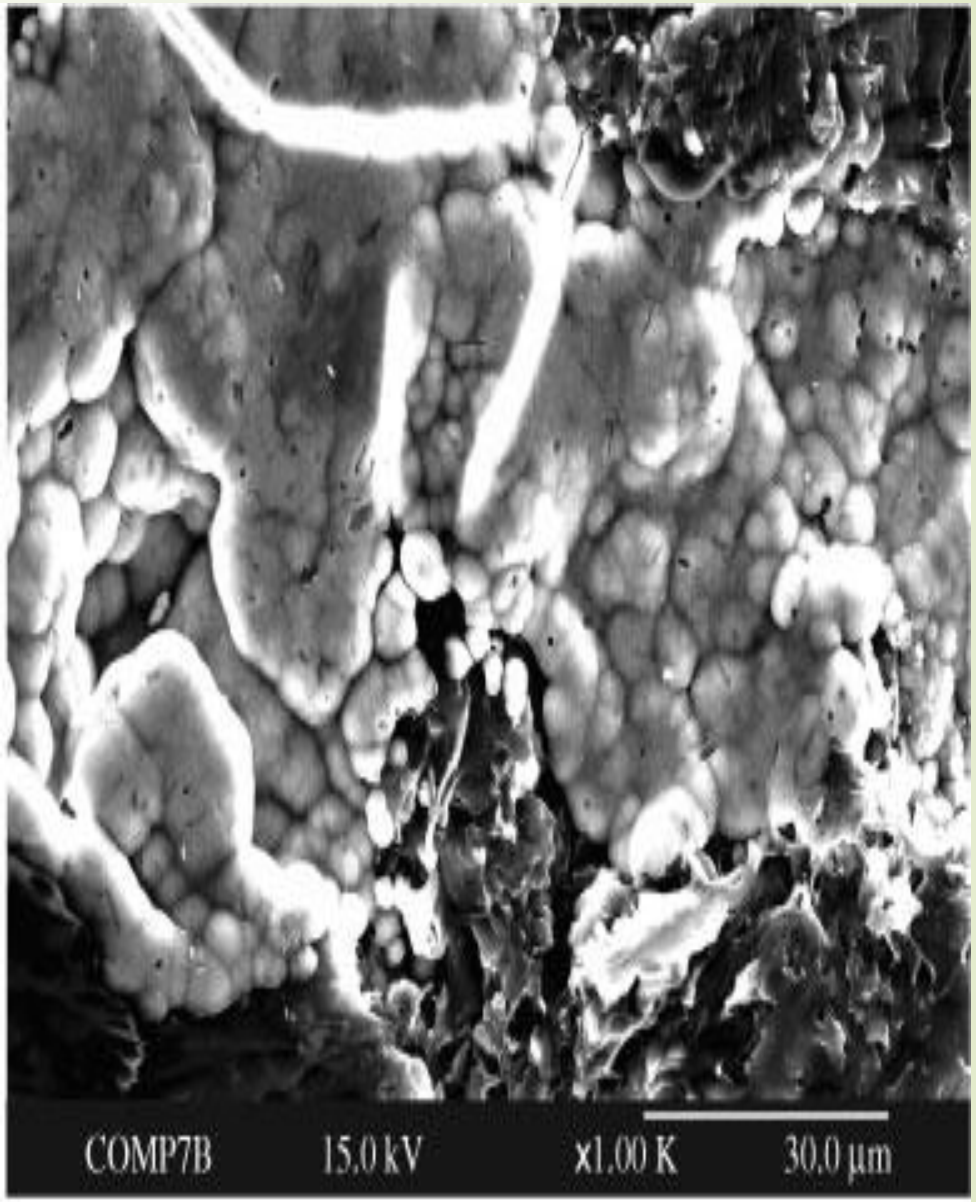


Figure 4. SEM image of composite bioactive glass/PHB 40/60 after 7 days of immersion in SBF.

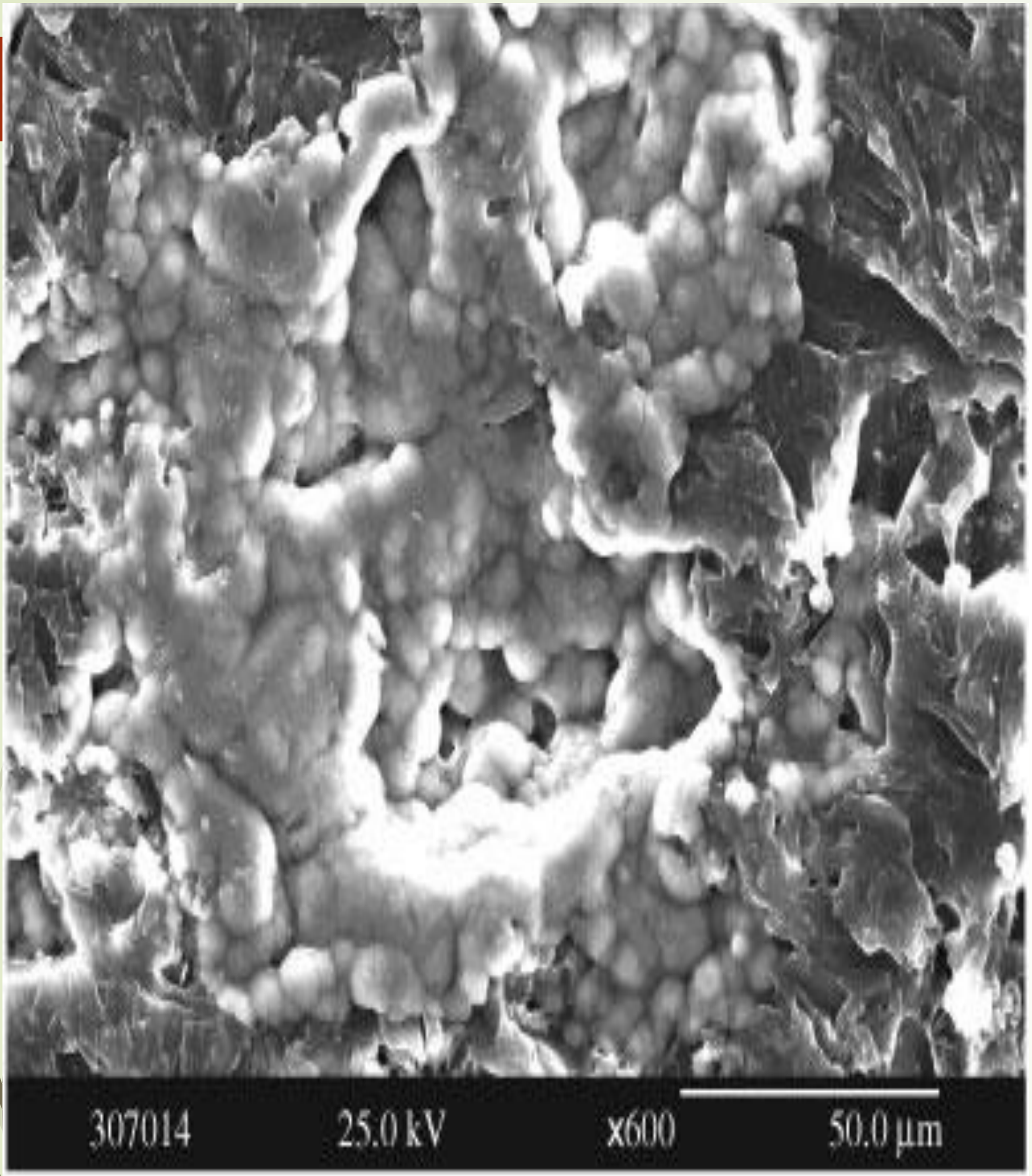


Figure 5. SEM image of composite bioactive glass/PHB 30/70 after 14 days of immersion in SBF.

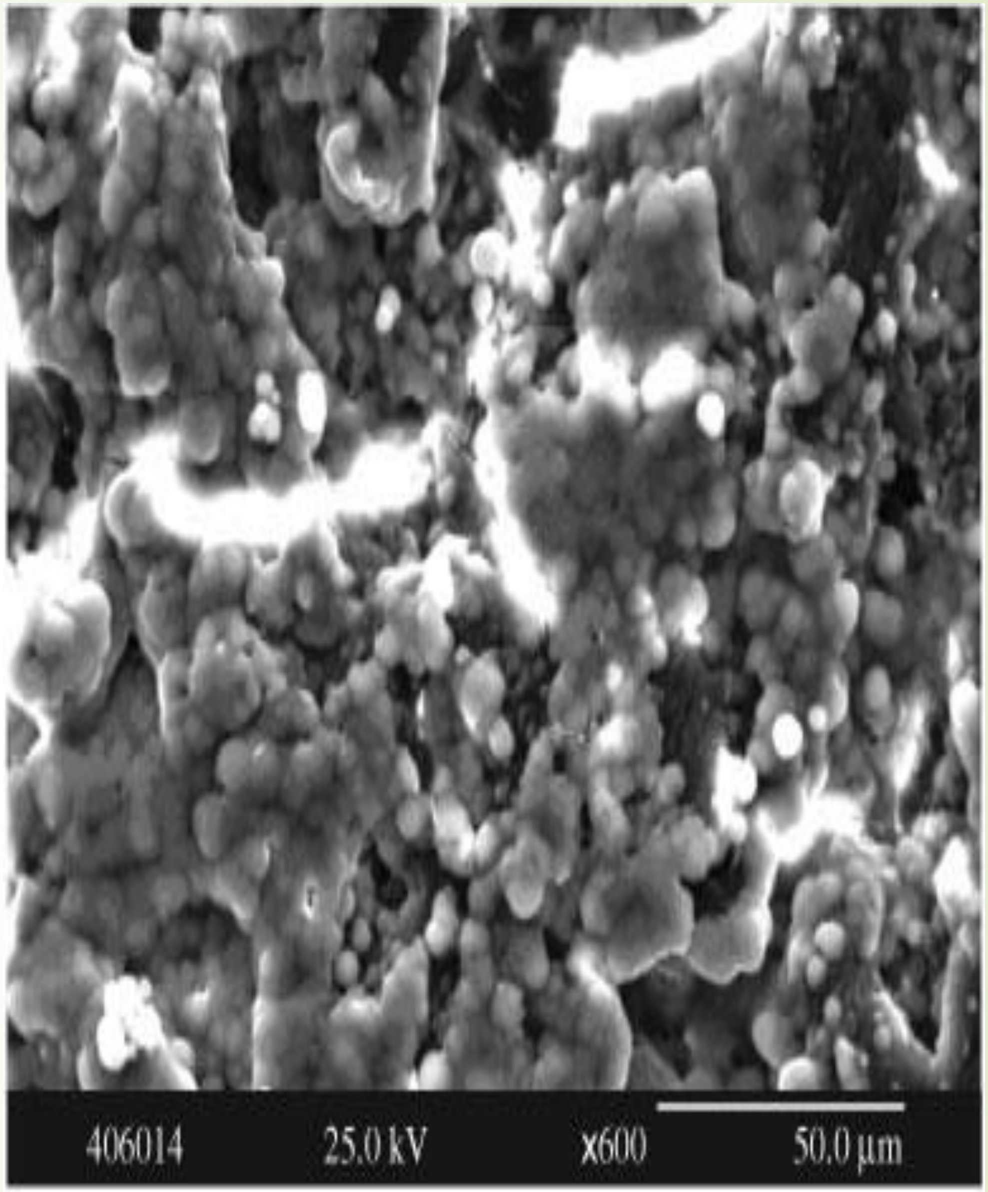


Figure 6. SEM image of composite bioactive glass/PHB 40/60 after 14 days of immersion in SBF.

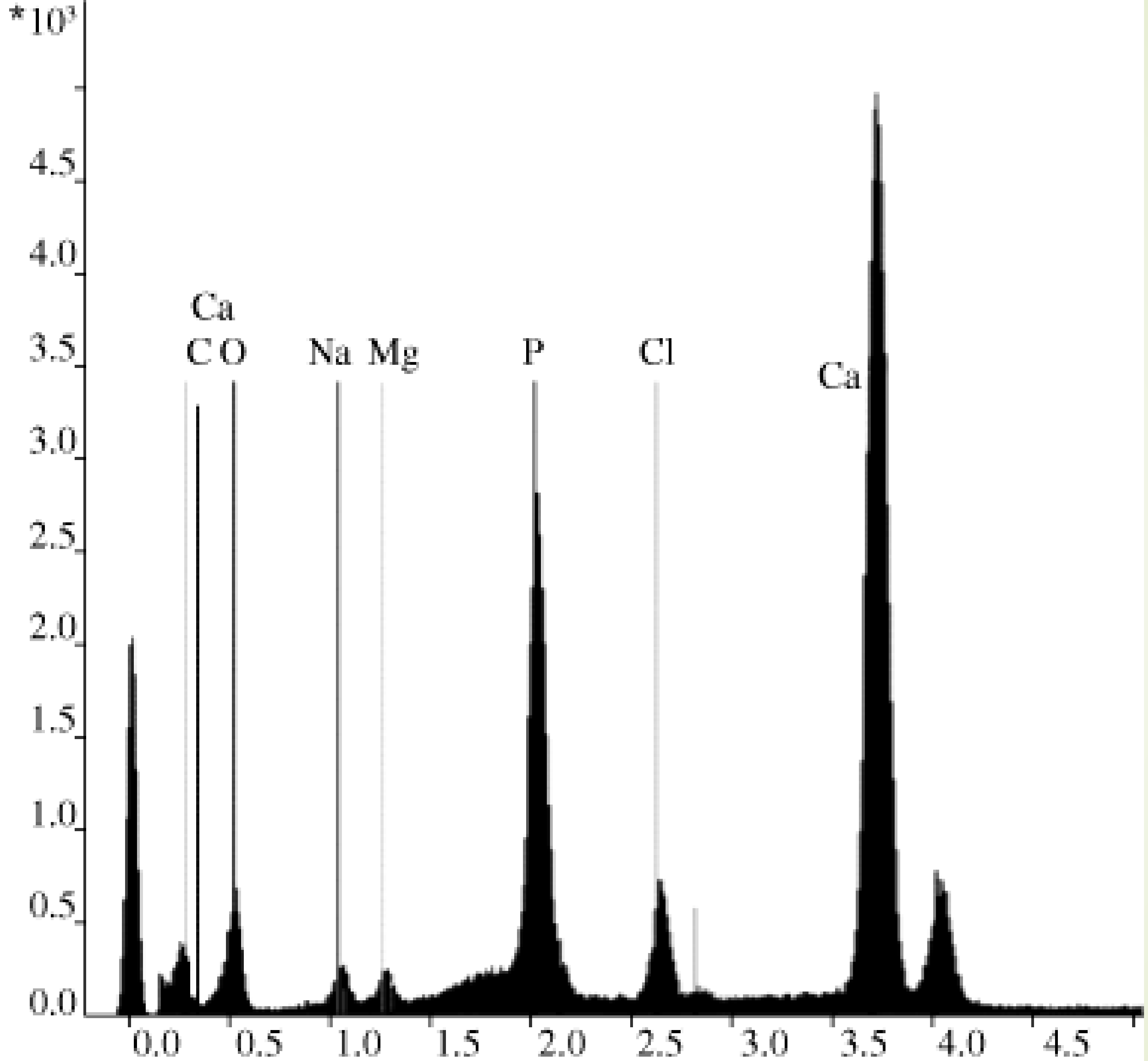


Figure 8. EDS spectrogram of bioactive glass/PHB 30/70 after 7 days.

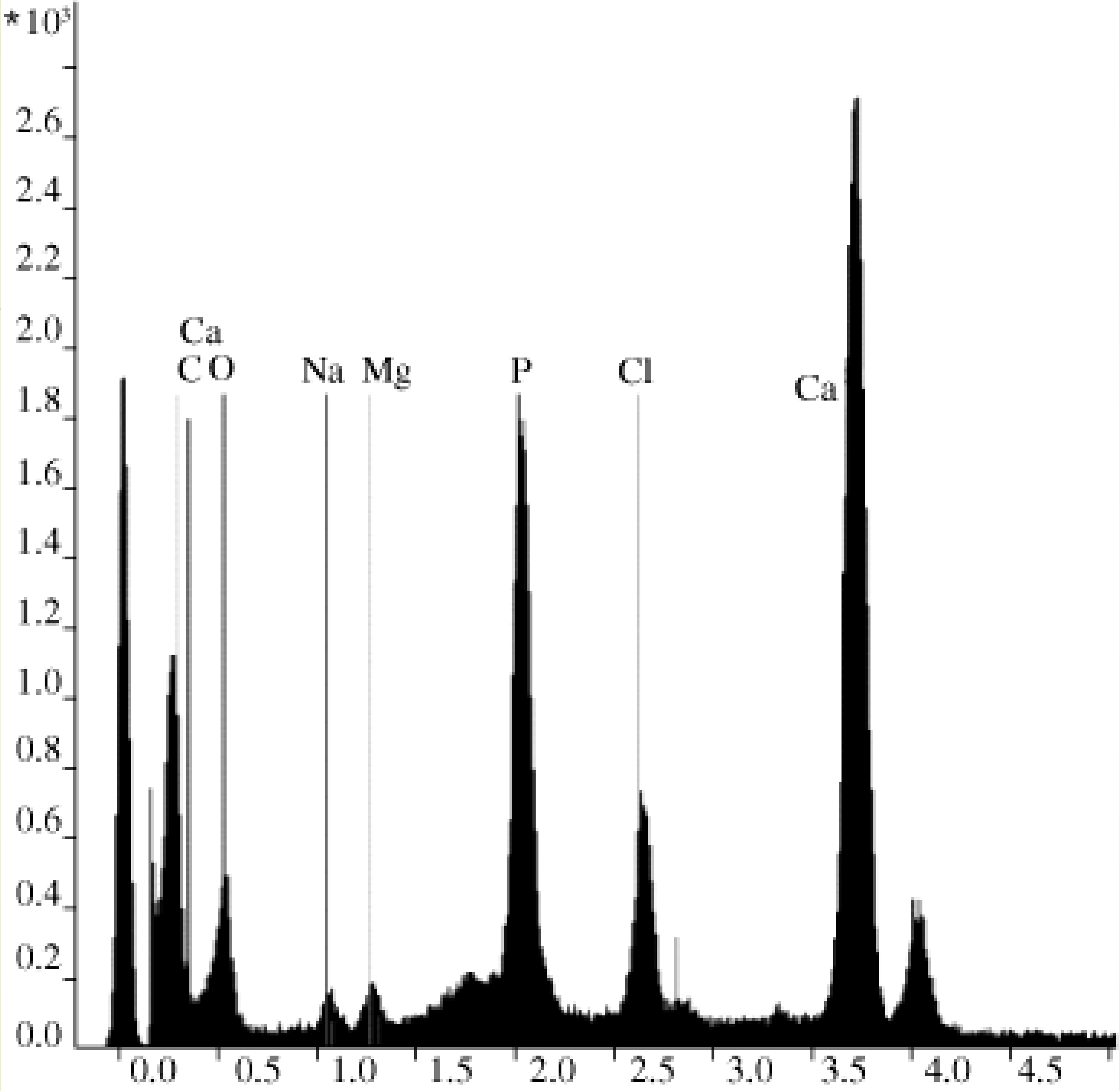


Figure 9. EDS spectrogram of bioactive glass/PHB 30/70 after 7 days.

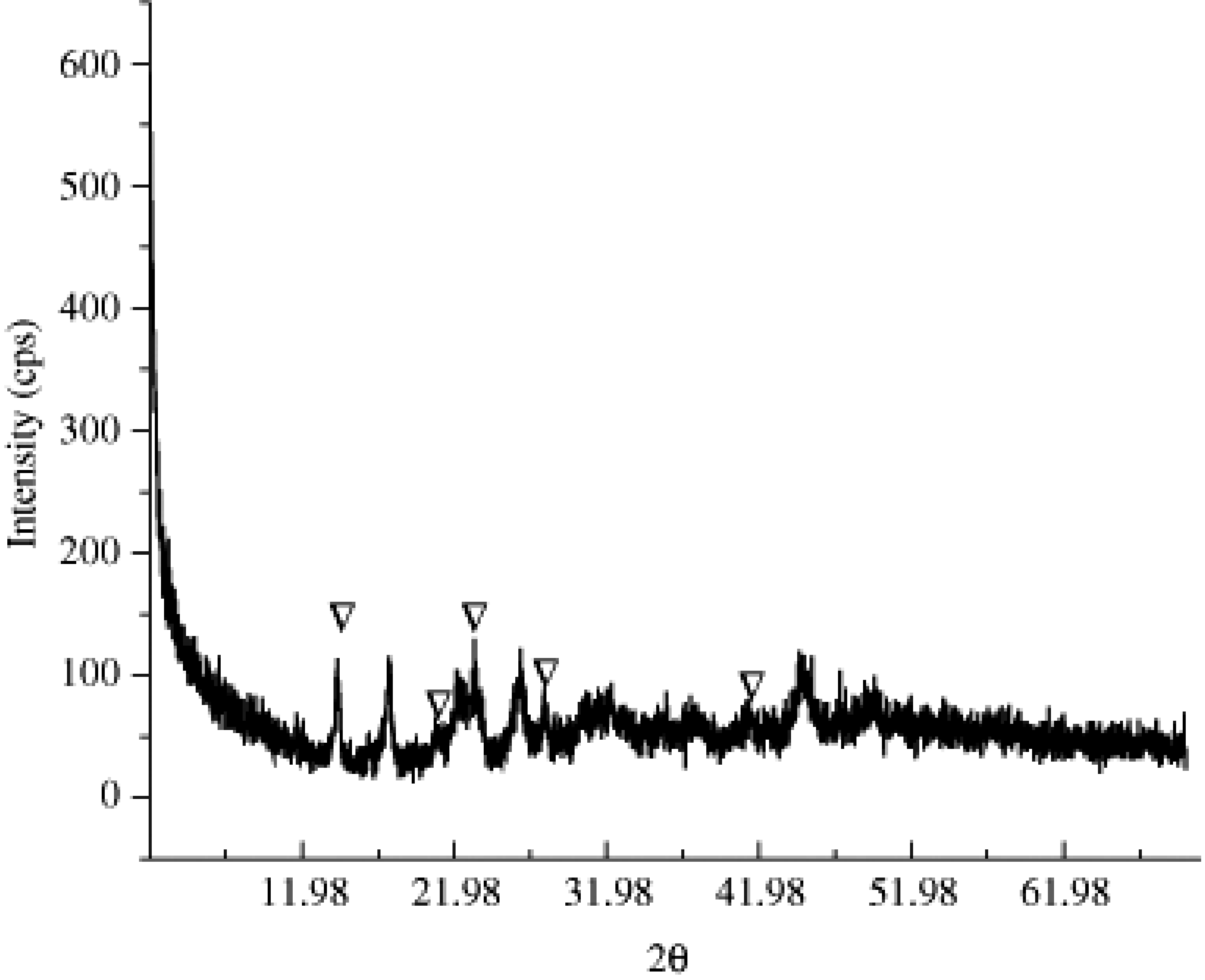


Figure 10. XRD spectrum of bioactive glass/PHB 30/70 after 7 days of immersion in SBF (∇ Calcium Hydrogen Phosphate).

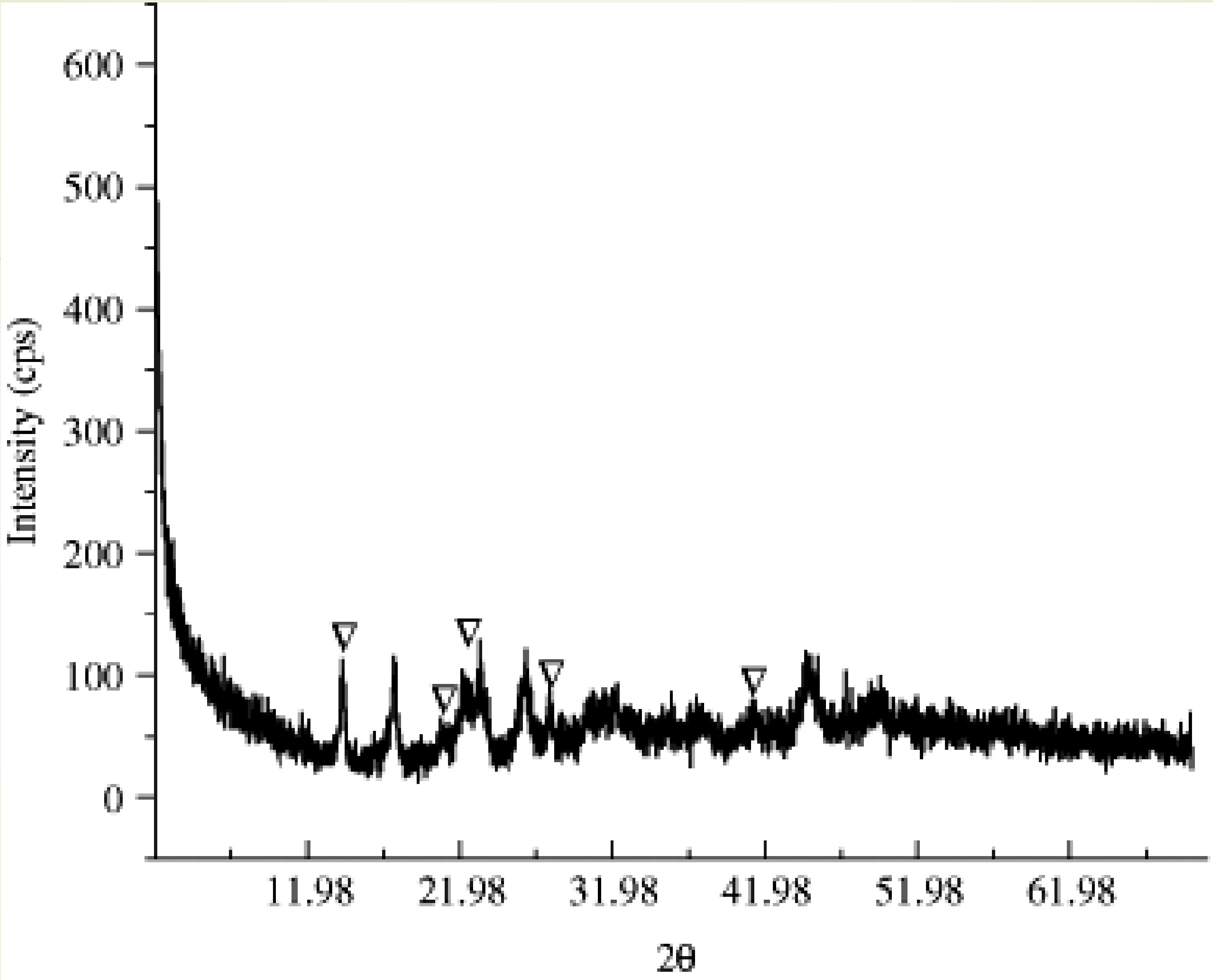


Figure 11. XRD spectrum of bioactive glass/PHB 40/60 after 7 days of immersion in SBF (∇ Calcium Hydrogen Phosphate).

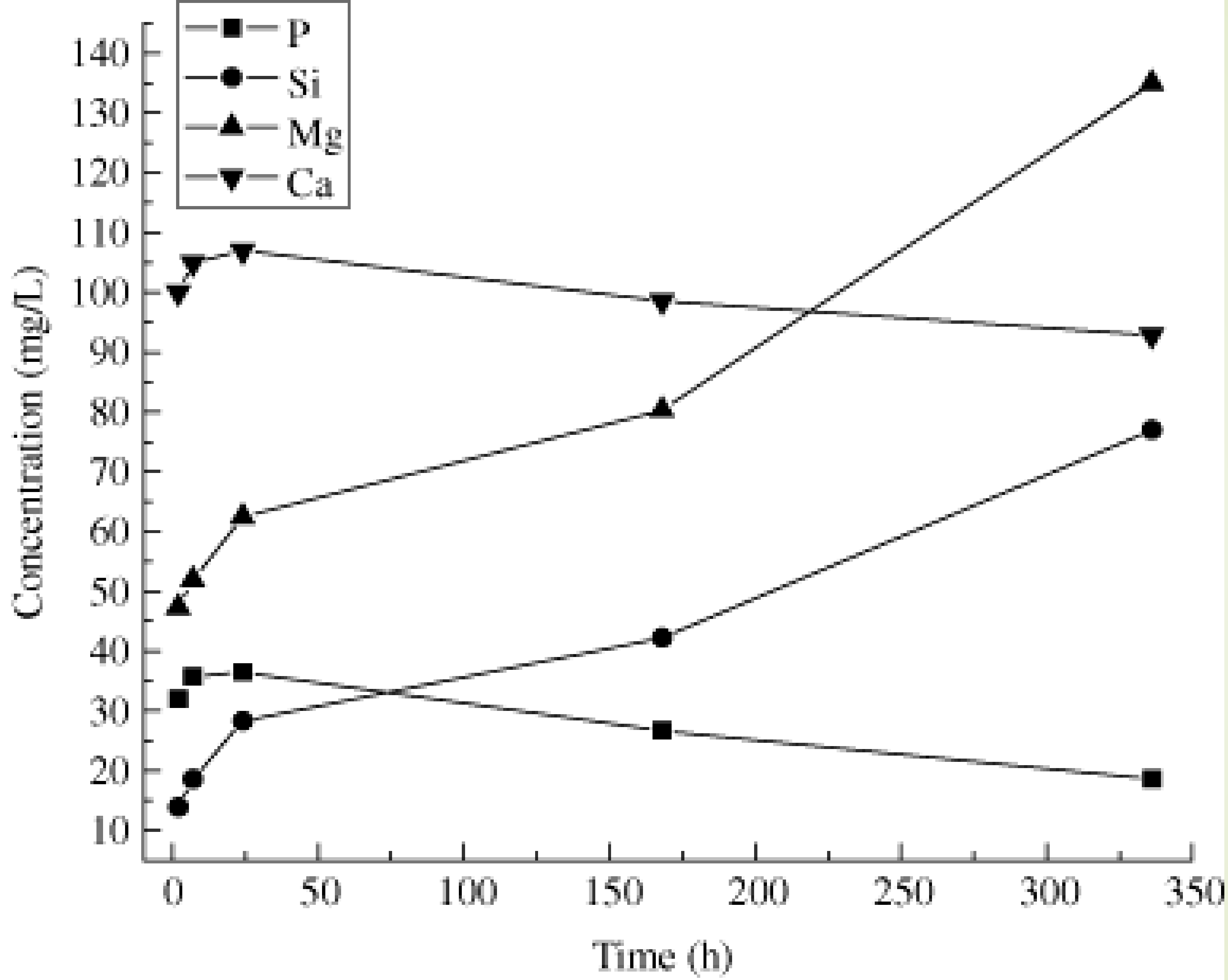


Figure 12. ICP results of solution that soaks bioactive glass/PHB 30/70.

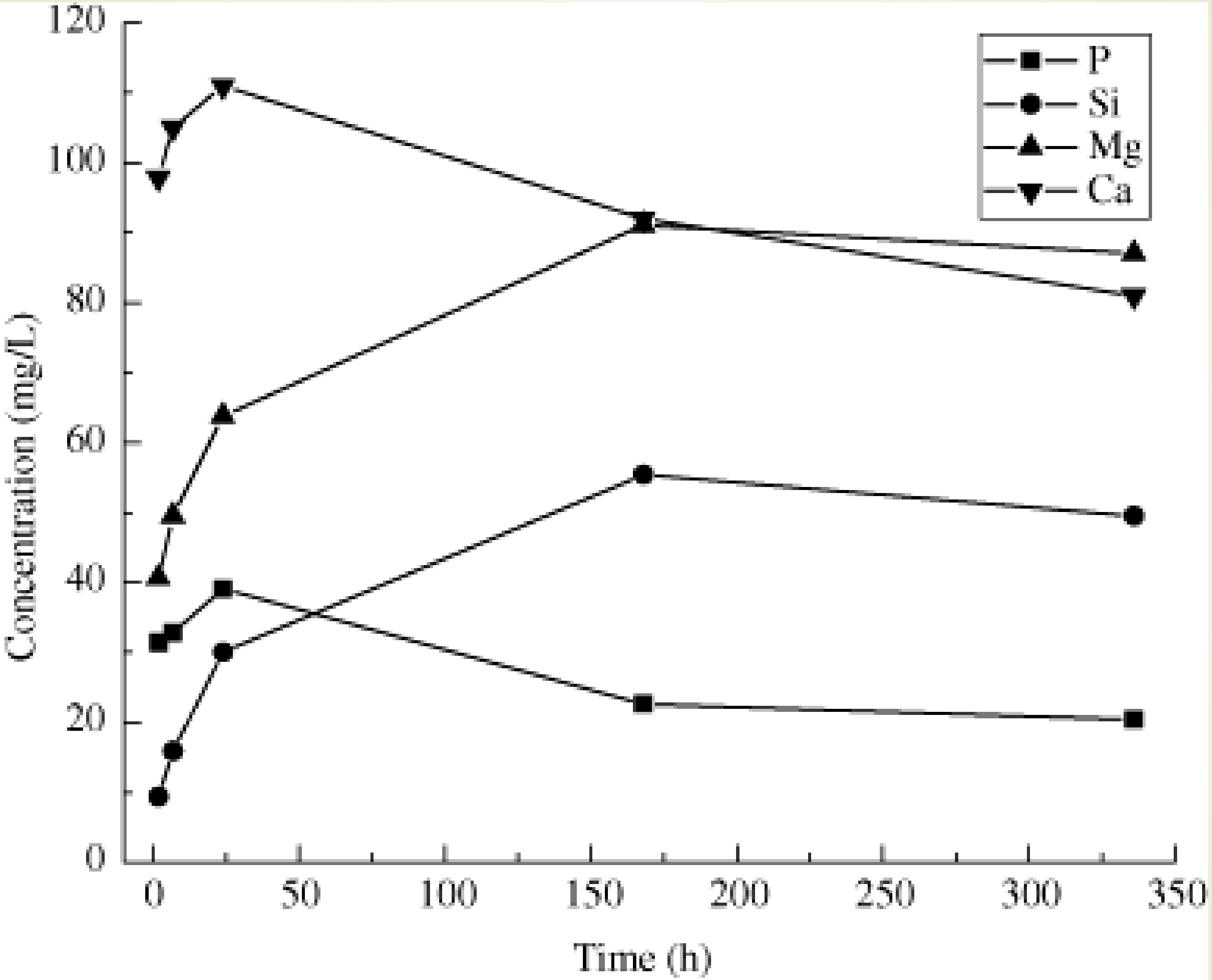


Figure 13. ICP results of solution that soaks bioactive glass/PHB 40/60.

COATING FOR METALLIC BIOMATERIALS

Deniz HAVA & Alican PARLAK

INTRODUCTION

- The main reason for coating of metallic biomaterials is to modify biological response of the host tissue in the peri-implant region.

COATING OF METALLIC BIOMATERIALS

- Surface coating of metallic biomaterials have been developed as a means of sheathing a metal in a coating that is more acceptable to the human body.
- The coating process must be consistent with the substrate to be coated, and an attempt should be made to keep the substrate intact during the coating process.
- The coating process must not introduce impurities on the surface, which may affect the interface properties.

Calcium Phosphate Coatings

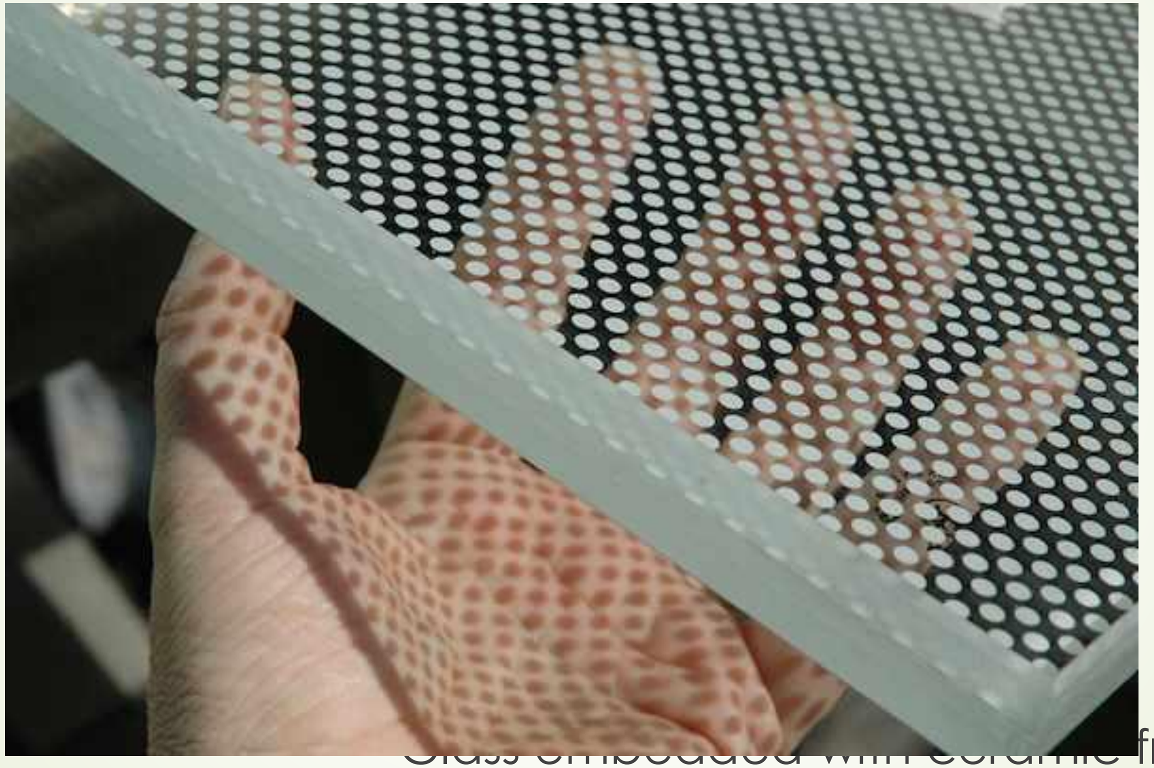
- The most important objective of suface modification of metallic biomaterials for hard-tissue engineering is the improvement of bone conductivity, through formation of bioctive layer
- Given that ≈ 70 wt. % of the bone material is i mineral similar to nonstoichiometric hydroxyapatite (HA; Ca5(PO4)3(OH).
- The most common CaP phases are HA, brushite (DCPD; CaHPO4• 2(H2O)), and tricacium phosphate (TCP; $Ca_3(PO_4)_2$).

Calcium Phosphate Glass-Ceramic Coatings

- Another important class in bioactive coating family is glass ceramics, such as Bioglass and Cerabone.
- Glass ceramics contain both a glass phase and a tough ceramic microstructure that reinforces the material.
- Glass ceramics ar generally composed of CaO, SiO_2, and P_2O_5.
- There kinds of methods are usually used to apply the glasses as coating ;

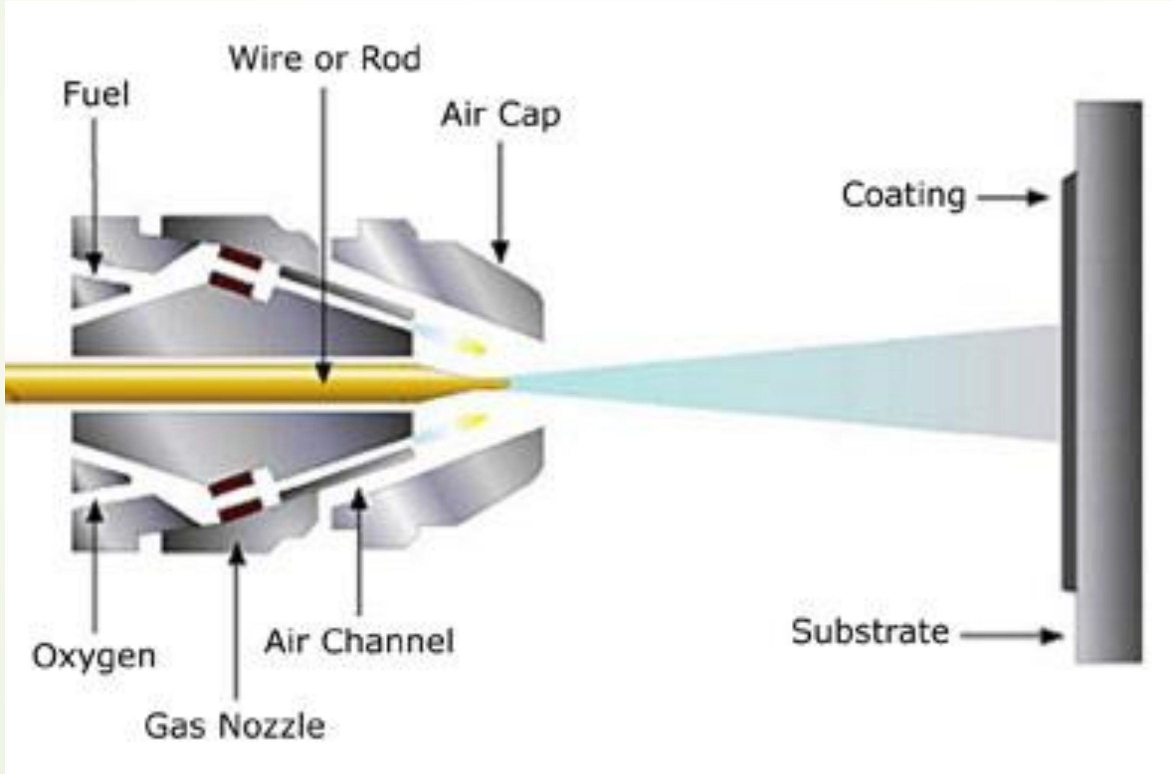
1. Enameling or glazing using glass frits
2. Flame spray coating
3. Rapid-immersion coating

Calcium Phosphate Glass-Ceramic Coatings



Glass embedded with ceramic frit

Calcium Phosphate Glass-Ceramic Coatings



Composite Coatings

- Composite coatings are emerging area of surface modification of metallic biomaterials in which a functional surface layer with the required physical, mechanical, or biological proporties covers a bulk biomaterial.
- Various combinations such as ceramic/ceramic and ceramic/polymer have been proposed recently.

Composite Coatings

- The corporation/immobilization of biomolecules into calcium phosphate has received a considerable interst in the coating of metallic biomaterials.
- To increase the Ti ability to bond with bone, a mixture of titanium dioxide (TiO_2) and CaP was fabricated and deposited as a coating.
- Therefore, CaP/ TiO_2 coatings can be expected to combine the advantages of TiO_2 with those of CaP.

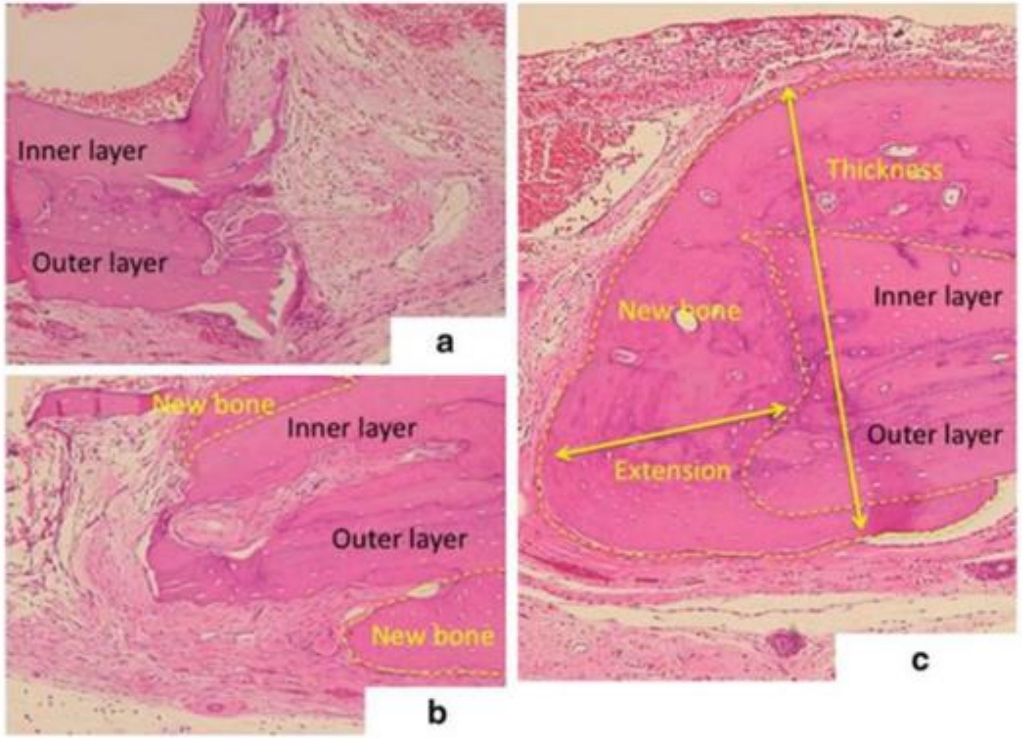


Fig. 6.8 Bone formation around burr hole plugs coated with the CaP (**a**), D-CaP (**b**), and DF-CaP (**c**) layers 8 weeks after the implantation in a rat cranial bone defect model (Reprinted from Zhang et al. [109], Copyright 2011 Zhang, W., Tsurushima, H., Oyane, A., Yazaki, Y., Sogo, Y., Ito, A., et al.; licensee BioMed Central Ltd.)

Oxide Coatings

- Typically used metallic biomaterials, such as surgical stainless steel, cobalt-chromium-based alloys, titanium and titanium-based alloys, have a strong tendency to spontaneously form a very fine and stable oxide layer on its surface in the reaction with atmospheric oxygen.
- The native oxide layers are only few nanometers thick act as a highly protective surface barrier between the bulk metal and aggressive biological environment, conferring biocompatibility to the metallic surfaces.
- The corrosion resistance is known to increase with increasing thickness of TiO_2 coating.

Oxide Coatings

- Several coating methods have been used to deposit TiO_2 on the surface of metallic biomaterials such as;

  - ✓ Dip-coating
  - ✓ Plasma spraying
  - ✓ Microsphere precipitation

TiO_2 coatings between the HA and titanium have been used to improve the bonding strength of the HA layer and the Ti substrate.

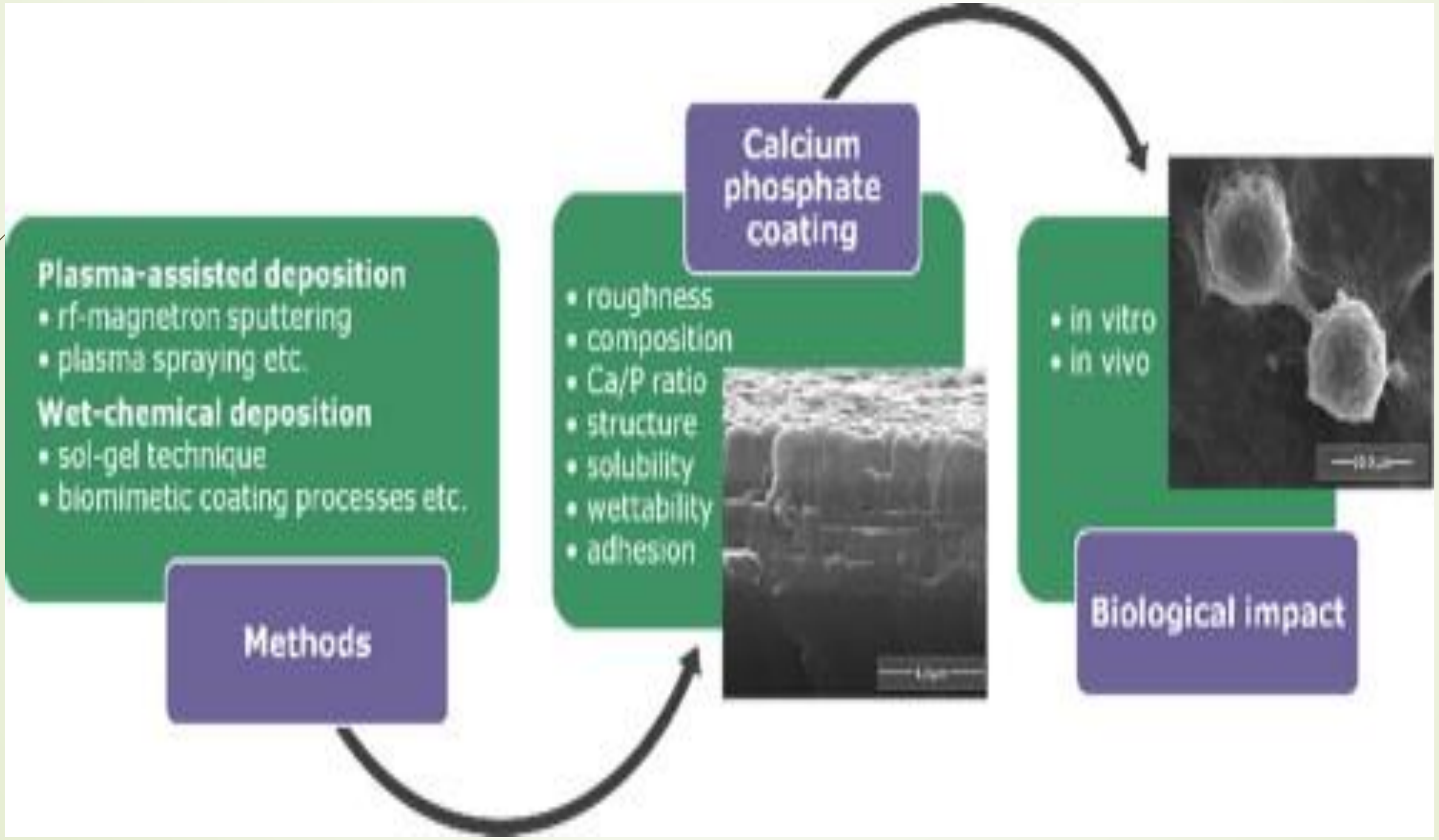
Other Coatings

- ***Carbon Layer Coating:***
- Thin carbon layers in the form of nanocrystalline diamond or diamond-like carbon(DLC) make matallic surface generally more compatible and more resistant to biofilm.
- In orthopedic surgery, the use of diamond coating on metallic biomaterials reduces generation of macrophages and improve the wearability of devices.

Other Coatings

- *Layer-by-Layer Method:*
- The layar-by-layer (LbL) method consist of alternately depositing polyelectrolytes that self-assemble and self-organize on the surface of material , leading to formation of polyelectrolyte multilayer (PEM) films.
- This technique is based on the consecutive adsorption of polyanions and polycations via electrostatic interaction.

CaP Coating



Plasma-assisted deposition
• rf-magnetron sputtering
• plasma spraying etc.
Wet-chemical deposition
• sol-gel technique
• biomimetic coating processes etc.
Methods
Calcium phosphate coating
• roughness
• composition
• Ca/P ratio
• structure
• solubility
• wettability
• adhesion
• in vitro
• in vivo
Biological impact

CaP Coating

- In recent decades, biomaterials research has focused on the improvement of implant design features in an attempt to accelerate bone healing at early implantation times. The implant surface is the first part of an implant that interacts with the host; therefore, surface modifications are essential to enhancing the biocompatible and osteoconductive properties of different medical devices. Coating an artificial material with a thin layer of calcium phosphate (CaP) has also proven to be an effective approach to providing the base material with good biocompatibility and good osteoconductivity.

CaP Coating

- Many factors, including materials, design geometry, surgical technique and patient use, may influence the outcome of an implant . Therefore, the first goal of this survey was to reveal the most recent advances in the application of CaP-based coatings in *in vitro*and *in vivo* studies.

Requirements

- The critical quality specifications for CaP coatings include thickness, phase composition, crystallinity, Ca/P ratio, microstructure, surface roughness, porosity, implant type and surface texture, which influence the resulting mechanical properties of the implant, such as cohesive and bond strength, tensile strength, shear strength, Young's modulus, residual stress and fatigue life.

3. Methodology for the preparation of CaP-based coatings
3.1. Physical deposition techniques

- Thermal spray processes, for example atmospheric plasma spraying (APS), vacuum plasma spraying, suspension plasma spraying, liquid plasma spraying (LPS), high-velocity suspension flame spraying, high velocity oxy-fuel, gas tunnel type plasma spraying, detonation gun spraying, were later elaborated to fabricate bioactive CaP-based coatings

3.2. Wet-chemical techniques

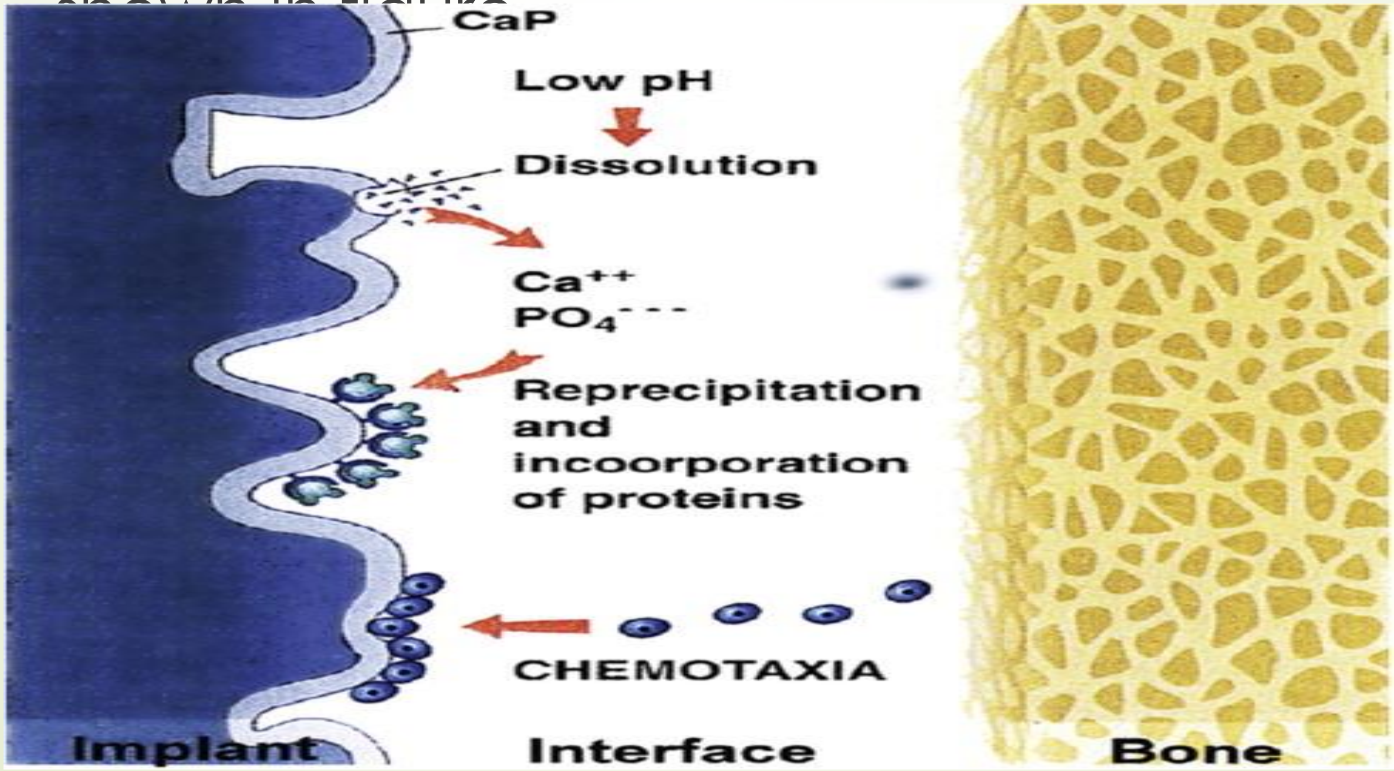
- These processes are based on the surface modification of the base material with CaP seeds and/or functional groups that are effective for the induction of CaP nucleation. The surface-modified material is then immersed in a supersaturated CaP solution, such as simulated body fluid (SBF) with ion concentrations, pH and temperature approximately equal to those of human blood plasma. As a result of this immersion step, a dense and uniform CaP layer, which is typically composed of low-crystalline apatite, is formed on the surface.

In Vitro Investigation of CaP Coatings

- *In vitro* investigations play a crucial role in the biological assessment of new biomaterials and allow the estimation of several aspects of both cell interactions with artificial materials and the behaviour of implants in a biological environment. Consequently, *in vitro* studies partly mimic some aspects of the cell function and signalling activated after the implantation of a foreign material *in vivo*

Cont.

- Schematically, the processes occurring at the interface of biomaterials after implantation into a living system are shown in figure



In Vitro Studuies

- A study of the *in vitro* growth of human bone-derived cells on surfaces that were plasma sprayed with CaP revealed low cell growth on the coated surfaces compared with plastic .It was suggested that the dissolution and precipitation of CaP coatings might prevent human bone-derived cells from attaching to the surface during the first 2 weeks of *in vitro* culture

Cont.

- In another study involving the culture of preosteoblasts,cell density was found to be highest on tissue culture plastic after 14 days.
- In this case, an increase in the concentration of phosphate ions in the culture medium due to dissolution of the coating was hypothesized as a possible reason for the reduced proliferation obtained compared with the plastic control.

In vivo animal studies

- *In vivo* animal studies provide the most accurate data prior to clinical trials.
- Different animal models, such as dog,rabbit,sheep,mini-pig and rat have been used. However, due to their similar body weight to humans, adult sheep and goats have some advantages. Moreover, due to the similarities between the dimensions of human bones and those of sheep and goats, these models allow direct placement of original implant prostheses without recourse to reduce the size.

Cont.

- The *in vivo* testing of an implant should demonstrate stability in a biological environment for up to 1 month, which corresponds to the initial healing phase.At early implantation times (typically 2–12 weeks), most animal studies have demonstrated that CaP-based thin films deposited on Ti and Ti6Al4 V implants result in higher bone–implant shear strength compared with non-coated implants.

Cont.

- In a beagle model, an MAO-deposited CaP coating exhibited significant effects after 4, 8 and 12 weeks under non-weight-bearing conditions.Sol–gel-derived CaP coatings implanted transversely across the tibiae of 17 New Zealand rabbits significantly increased the rate of bone ingrowth into the porous region of the Ti surface after 2 weeks of healing. The apposition of new bone tissue directly onto HA coatings after 12 weeks of implantation in the canine femora was observed

Conclusions

- This review summarizes some of the latest achievements in the field of CaP-based coating fabrication. A majority of the studies shows that CaP coatings exert a significantly beneficial effect both *in vitro* and *in vivo* compared with uncoated implants.
- In conclusion, further investigations are necessary to reveal the relative influences of implant design, surgical procedure and coating characteristics (thickness, structure, topography, porosity, wettability, etc.) on the long-term clinical effects of CaP coatings.