BIODEGRADABLE MATERIALS FOR MEDICAL APPLICATIONS
INTRODUCTION TO BIOMATERIALS

BIODEGRADABLE MATERIALS
  – SYNTHETIC POLYMERS
  – MAGNESIUM ALLOYS BASED

PRELIMINARY MATHEMATIC MODEL FOR DEGRADATION PROCESS
During the last two decades, significant advances have been made in the development of biocompatible and biodegradable materials for medical applications.

In the biomedical field, the goal is to develop and characterize artificial materials or, in other words, “spare parts” for use in the human body to measure, restore and improve physical functions and enhance survival and quality of life.
What’s a biomaterial?

1980 - *Passive* and *inert* point of view

Any substance or drugs, of synthetic or natural origin, which can be used for any period alone or as part of a system and that increases or replaces any tissue, organ or function of the body

1990 – *Active* point of view

Non-living material used in a medical device and designed to interact with biological systems
Classification of biomaterials

First generation: INERT

Do not trigger any reaction in the host: neither rejected nor recognition
→ “do not bring any good result”

Second generation: BIOACTIVE

Ensure a more stable performance in a long time or for the period you want

Third generation: BIODEGRADABLE

It can be chemically degraded or decomposed by natural effectors (weather, soil bacteria, plants, animals)
Mean features for medical applications

BIOFUNCTIONALITY
Playing a specific function in physical and mechanical terms

BIOCOMPATIBILITY
Concept that refers to a set of properties that a material must have to be used safely in a biological organism
What is a biocompatible material?

1) Synthetic or natural material used in intimate contact with living tissue (it can be implanted, partially implanted or totally external).

2) Biocompatible materials are intended to interface with biological system to EVALUATE, TREAT, AUGMENT or REPLACE any tissue, organ or function of the body.

A biocompatible device must be fabricated from materials that will not elicit an adverse biological response.
Biocompatible material features

1) Absence of **carcinogenicity** (the ability or tendency to produce cancer)

2) Absence of **immunogenicity** (absence of a recognition of an external factor which could create rejection)

3) Absence of **teratogenicity** (ability to cause birth defects)

4) Absence of toxicity
Applications for Medical Devices

1) Total implanted device

2) Partially implanted device

3) Totally externals device

Some examples
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<th>Categories of implantable materials</th>
<th>Composition</th>
<th>Use</th>
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<td>Polymers carbon</td>
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<td>Gore-Tex (PTFE expanded)</td>
<td>Thoracic and abdomen rebuilding</td>
<td>Surgical Suture</td>
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<tr>
<td>Poly-propylene (Marlex, Prolene)</td>
<td>Filling Defect of the soft tissue</td>
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<tr>
<td>Poly-ethylene (Medpore)</td>
<td>Thoracic and abdominal wall reconstruction</td>
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<tr>
<td>Poly-ethylene tereftalato (Dacron, Mersilene)</td>
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<td>Poliuretano</td>
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<td>Polyesters aliphatic (ac. Poly-lactic, poly-glycolic ecc.)</td>
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<tr>
<td>Metilmetacrilato (MMA)</td>
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<td>Not carbon Polymers</td>
<td>Silicon</td>
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<td>Prosthetics for increased facial characteristics</td>
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<td>Ceramics</td>
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<td>Phosphate tricalcium</td>
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<tr>
<td></td>
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<td>reconstruction</td>
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<tr>
<td>Metals</td>
<td>Titanium, stainless steels and cobalt and magnesium alloys</td>
<td>Mini plates and screws</td>
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<td>Orthopedic prosthesis</td>
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<td></td>
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<td>Surgical tools</td>
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</table>
What’s a biodegradable implant?

Once implanted, should maintain its mechanical properties until it is no longer needed and then be absorbed and excreted by the body, leaving no trace.

Biodegradable implants are designed to overcome the disadvantages of permanent metal-based devices.
Problems caused by permanent implants

- Physical irritations
- Chronic inflammatory local reactions
- Thrombogenicity and long term endothelial dysfunction (for cardiovascular applications)
- Inability to adapt to growth
- Not allowed or disadvantageous after surgery
- Stress shielding, corrosion, accumulation of metal in tissues (for internal fixation applications)
- Repeat surgery necessary
Advantages of biodegradable implants

- More physiological repair
- Possibility of tissue growth
- Less invasive repair
- Temporary support during tissue recovery
- Gradual dissolution or absorption by the body afterwards.

Note: these implants may act a new biomedical tool satisfying requirement of compatibility and integration.
More used materials

- **Synthetic polymers:**
  - Poly-lactic acid (PLA) and its isomers and copolymers
  - Poly-glycolic acid (PGA)
  - Poly-caprolactone (PCL)
  - Poly(dioxanone)
  - Poly-lactide-co-glycolide.

- **Magnesium alloys based:**
  - Mg, Zn, Li, Al, Ca and rare earths are the main elements used.
Synthetic Polymers

General criteria of selection for medical applications

- Mechanical properties and time of degradation must match application needs

*Ideal polymer:*
- must be sufficiently strong until surrounding tissue has healed
- does not invoke inflammatory or toxic response
- to be metabolized in the body after fulfilling its purpose, leaving no trace
- to be easily processable into the final product form
- must demonstrates acceptable shelf life
- to be easily sterilized
### Synthetic Polymers

#### Wound management
- Sutures
- Clips
- Adhesives
- Surgical meshes

#### Orthopedic devices
- Pins (spilli)
- Rods (barre)
- Screws (viti)
- Tacks (chiodini)
- Ligaments

#### Tissue engineering

#### Dental applications
- Guided tissue regeneration
- Membrane
- Void filler following tooth extraction

#### Cardiovascular applications
- Stents

#### Intestinal applications
- Anastomosis rings

#### Drug delivery system
- Covering of permanent implants

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Mean applications
Synthetic Polymers

Main advantages

- Good biocompatibility
- Possibility of changing in composition and in physical-mechanical properties
- Low coefficients of friction
- Easy processing and workability
- Ability to change surface chemically and physically
- Ability to immobilize cells or biomolecules within them or on the surface (Drug Eluting Stent)
Main disadvantages

- Presence of substances that may be issued in the body [monomers (*toxic*), catalysts, additives] after degradation
- Ease of water and biomolecules absorption from surrounding
- Low mechanical properties
- In some cases, difficult sterilization

*Note*: the final properties of a device depends both intrinsic molecular structure of the polymer and chemical and mechanical processes which it is undergone.
Polymers degradation (bulk erosion)

Implanted materials subject to degradation processes

Saline solution in human body as an excellent electrolyte that facilitates hydrolysis mechanisms

Most polymers used in medical devices allows the spread of water within molecular structure and can therefore result in processes hydrolysis
Magnesium Alloys Based

- Orthopedic devices
  - Pins
  - Rods
  - Screws
  - Tacks (chiodini)

- Cardiovascular applications
  - Stents
Magnesium Alloys Based

Main advantages

- High biocompatibility (Mg is present into the body and then recognized as a not foreign element)
- Alloy’s elements are dissolved into human body during the degradation process → Not toxic risk
- Not visible by X-ray and not seen by CT or MRI → Do not cause any artifacts.
Magnesium Alloys Based

Main disadvantages

- Too high corrosion rate (*Es: Mg stents corrode quickly both in vivo than in vitro after ~ 1 month)*.

- Degradation occurs before the end of healing process

  *How to adjust this??*

  By alloy and surface treatment

  or

  By mechanical pre-processing to affect biocorrosion resistance
Metal degradation

- Biodegradability expressed in terms of corrosion.
- Very slow process, "ideally" should not influence device mechanical properties until tissue healings not over.
- Biocompatibility is reduced from ion accumulation released from metal.
- Rate of corrosion and mechanisms vary with applied "shear-stress".
Polymers VS Metals

Considerations in the selection

- Strength
- Overall time and rate of degradation/corrosion (a very high degradation rate can be associated with inflammations)
- Biocompatibility
- Lack of toxicity
Polymers VS Metals

Orthopedic applications (screws, tacks...)

- Metal alloys present greatest load bearing, with similar results to non biodegradable metals (stainless steel).
- Polymers present lower load bearing. Appropriate pre-processing may improve their mechanical characteristics.
Polymers VS Metals

Vascular applications (stents...)

- Magnesium alloys degrade too fast in biological environment and they dissolve in the body, not permitting the correct vascular remodeling. Mg is an element that exists naturally into the body, then it is good tolerated.

- Polymers degrade slower than magnesium alloys. Fundamental to care about degradation product concentration, which may be toxic.
Non-linear viscoelastic model

As the material degrades and softens, the applied stresses lead to greater deformations that lead to greater increases in degradation.