COURSE DESCRIPTION
ARTIFICIAL ORGANS AND PROSTHESES

SSD: BIOINGEGNERIA INDUSTRIALE (ING-IND/34)

DEGREE PROGRAMME: BIOINGEGNERIA INDUSTRIALE (P16)
ACADEMIC YEAR 2024/2025

COURSE DESCRIPTION

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GENERAL INFORMATION ABOUT THE COURSE

INTEGRATED COURSE: NOT APPLICABLE
MODULE: NOT APPLICABLE
TEACHING LANGUAGE: INGLESE
CHANNEL: FG A-Z
YEAR OF THE DEGREE PROGRAMME: II
PERIOD IN WHICH THE COURSE IS DELIVERED: SEMESTER II
CFU: 6

REQUIRED PRELIMINARY COURSES

No prerequisites

PREREQUISITES

The course requires the basic knowledge of vector and tensor algebra, mathematical analysis and chemistry. Knowledge of biomaterials and mechanics, even if not specifically required, might be helpful

LEARNING GOALS

The course aims to illustrate some examples of prosthetic systems (both temporaty and permanent) and artificial organs, mostly used in the clinical field. The goal is to provide students with information on the types of biomaterials used, manufacturing technologies, operating principles, in vivo performance, limits and potential developments of implantable and non-implantable medical devices. Part of the course is devoted to the physiology and mechanics of tissues and organs, thus providing the fundamental criteria for the design of potential substitutes.

The properties of classes of materials or combinations of these and their applications in the biomedical field are then illustrated, providing an overview of the advantages and disadvantages associated with the use of specific materials in specific contexts. In addition, students are also provided with the fundamentals of continuum mechanics and modeling as valid tools for designing devices and predicting the mechanical response of prosthetic systems under specific operating conditions.

EXPECTED LEARNING OUTCOMES (DUBLIN DESCRIPTORS)

Knowledge and understanding

At the end of the course the student knows the chemical/physical characteristics of classes of materials and combination thereof; knows the possible applications of specific classes of materials due to their characteristics; knows the main manufacturing techniques of prostheses and medical devices; knows the main methods of chemical and physical functionalization of material surfaces. Knows the mechanical stresses to which implants are subjected in vivo; knows the most commonly used implants/devices in the orthopedic, cardiovascular and soft tissue reconstruction fields; knows the fundamentals of continuum mechanics and some of its applications in the biomedical field; he/she is aware of the interactions between tissues and implants and of the possible reactions that can develop under particular operating conditions.

Applying knowledge and understanding

The student is able to identify the most suitable materials or classes of materials to perform specific biomechanical or biological functions in vivo; is able to identify the most effective manufacturing technologies for making prostheses or biomedical devices; is able to formulate and solve continuum mechanics problems to estimate loads and deformations due to specific boundary conditions.

COURSE CONTENT/SYLLABUS

Polymeric biomaterials:
Polymer classification and polymerization reactions; polymer architecture; physical state of aggregation. Amorphous, crystalline and semi-crystalline polymers. Thermoplastic and thermosetting polymers. Elastomers. Mechanical properties of polymers; static properties, viscoelasticity; manufacturing technologies: molding, extrusion blow molding, injection molding. Polymeric fibers. Biocompatibility and haemocompatibility; mechanisms of biodegradation; Polyesters, polyamides, polyolefins; polysiloxanes, polyacrylates. Fluorinated Polymers. Hydrogels. Adhesives for skin wounds. Applications in the cardiovascular; ophthalmic; orthopedic sectors.
Metallic materials:
Metallic bond, lattices, sliding planes; defects and dislocations. Processing technologies of metallic materials. Metal alloys: steels (austenitic, ferritic and martensitic), special steels; cobalt alloys and titanium alloys. Notes on corrosion of metals. Methods for the prevention of corrosion. Surface, thermal and chemical-physical treatments. Examples of alloy applications in orthopedics and maxillofacial surgery.

Biomaterials of natural origin:

Polysaccharides: Cellulose, alginate, agarose, chitin and chitosan. Methods of extraction, purification and chemical modifications. Biomedical applications of polysaccharide-based materials. Protein-based materials: Collagen and elastin. Types of collagen. Thermo-mechanical properties of collagen. Structure and mechanical characteristics of elastin. Technologies of extraction, purification and manipulation of natural biopolymers. Biomedical applications of collagen and elastin. Hyaluronic acid. Rheological properties of hyaluronic acid. Application of hyaluronic acid in the biomedical field.

Outline of biomechanics of natural tissues:

Mechanical response of collagenous tissues. Collagen-based hydrogels. Mechanical properties of elastin; chemical manipulation of elastin. The amorphous matrix (proteoglycans and hyaluronic acid). Viscoelasticity, creep and stress relaxation of connective tissues. Preconditioning of natural fabrics.

Introduction to non-linear mechanics:

Kinematics, configuration and motion, spatial description and material, Strain gradient tensor, strain tensors (Green-Lagrange and Euler-Almansi tensors). Rotation and stretch tensors. Transformation of volumes, transformation of areas (Nanson formula). Examples of deformations of continuum in rectangular, polar and cylindrical coordinates. Push forward and pull back operations. Stress states, traction vectors and stress tensors (Piola-Kirchhoff tensors and Cauchy tensors), examples of stress states; conservation of mass, momentum balance. Material objectivity, change of observer and objective tensor fields, superimposed rigid motions. Hyperelasticity, constitutive equations, isotropic and incompressible materials, strain energy function for neo-Hookian and Mooney-Rivlin materials. Incompressible hyperelastic isotropic materials, experimental methods for the determination of material constants. Application examples of the strain energy functions for Neo-Hookian and Mooney-Rivlin materials. Incompressible hyperelastic isotropic materials. Application examples: foams. Modeling of the response of polyurethanes, silicone elastomers. Modeling of the mechanical response of brain tissue and liver tissue to compressive and shear deformations. Exercises, deformation modeling of materials of interest in the biomedical field (uniaxial traction, simple and confined compression, torsion, shear, pure shear, equibiaxial extension).

Biomedical balloons:

definitions of performance parameters; design criteria; manufacturing materials and technologies. Forms and applications of biomedical balloons. Low pressure-high compliance and high-pressure-low compliance balloons. Drug-releasing flasks. Occlusive balloons. Special applications of biomedical balloons. Expansion modeling using continuum mechanics. Modeling of the expansion of spherical and cylindrical balloons (bound or not) by continuum mechanics.

Anisotropy:

Symmetry groups. Transversely isotropic materials; anisotropic materials reinforced with two families of fibers. Example: abdominal wall reinforcement systems, multilayered composite systems, modeling of anisotropic foil.

Tendons and ligament replacements:

Introduction to the anatomy and mechanical characteristics of the natural tissues, properties of

conventional non-resorbable polymeric grafts. The 'augmentation' systems (LAD). The 'bridge' systems (Leeds-Keio). Analysis of explanted grafts, mechanisms of failure. Composite ligaments: structure-property relationship. Design of a composite ligament, modeling of a tensile ligament.
Vascular prostheses:
Introduction to the anatomy and mechanical characteristics of natural vessels, properties of conventional PET and PTFE grafts: materials, structures and manufacturing technologies. Hemocompatibility of polyesters and fluorinated polymers. Hemodynamic considerations. The problem of neointima hyperplasia: mechanical and fluid dynamics considerations. Innovative elastomeric prostheses. Design of a composite vascular prosthesis. Manufacturing technologies of axial-symmetrical composites. Modeling of the mechanical response of a tubular composite prosthesis subject to pressurization.
Heart Valve Prostheses:
notes on the anatomy and physiology of valves. Valvular pathologies. Design of artificial valves, natural valves and mechanical valves: functional and mechanical characteristics. Porcine and bovine valves. Ball and cage valves, disc valves, oscillating disc valves, two hemidisc valves. The Transcatheter Aortic Valve Replacement Technique. Biomechanics, haemodynamic aspects, materials, hemo- and bio-compatibility.
Ventricular Assist Devices and Artificial Hearts:
Introduction to the anatomy and physiology of the heart, blood circulation, cardiac biomechanics, possible treatments, artificial ventricle, materials and properties, types of pumps used for VADs, construction and functional characteristics. Artificial heart, design criteria, alternative volumetric pumps, power systems, models currently used, differences and characteristics.
Hip replacement:
Introduction to the anatomy and biomechanics of the hip joint, design criteria, selection of materials and their mechanical characteristics; design and fabrication of the acetabulum, bone stem integration, cemented and non-cemented prostheses, bone cements characteristics and properties, surface treatments of prostheses; notes on the cell-stem interaction of the prosthesis.
Bone fixation devices: nails, screws plates, buttresses, IMN
Oxygenators: membrane xygenators, hollow fibre oxygenators. Materials, construction and assembly. Analysis on the performance.

READINGS/BIBLIOGRAPHY

Teaching materials
Lessons slides; handouts with exercises carried out in the classroom;
Recommended texts:
Biomaterials part: CM.Agrawal, JL.Ong, MR.Appleford. "Introduction to Biomaterials Basic Theory with Engineering Applications". Cambridge University Press; ; JY.Wong, JD.Bronzino, DR.Peterson "Biomaterials Principles and Practice" CRC Press;
Mechanical part: J.Bonet, RD.Wood "Nonlinear Continuum Mechanics for Finite Element Analysis" Cambridge Press; GA.Holzapfel "Nonlinear Solid Mechanics: A Continuum Approach for Enineering: A Continuum Approach for Engineering" Wiley.

TEACHING METHODS OF THE COURSE (OR MODULE)

Lectures, classroom exercises, quizzes using the Kahoot platform, sections dedicated to "hands-on" on medical devices.

EXAMINATION/EVALUATION CRITERIA

a) Exam type

☐ Written

☑ Oral

☐ Project discussion

☐ Other

In case of a written exam, questions refer to

☐ Multiple choice answers

☐ Open answers

☐ Numerical exercises

b) Evaluation pattern

Students are required to prepare a short presentation regarding either an in-depth analysis of topics covered in the course, or on innovative devices.
Afterwards, questions are asked about the programme, which may also include the solution of an exercise (e.g. sizing of an endoprosthetic device), the analysis of the chemical-physical characteristics of biomaterials, the discussion of applications or known problems of devices.
The evaluation is based on 40% on the paper (presentation) and 60% on the rest of the program.