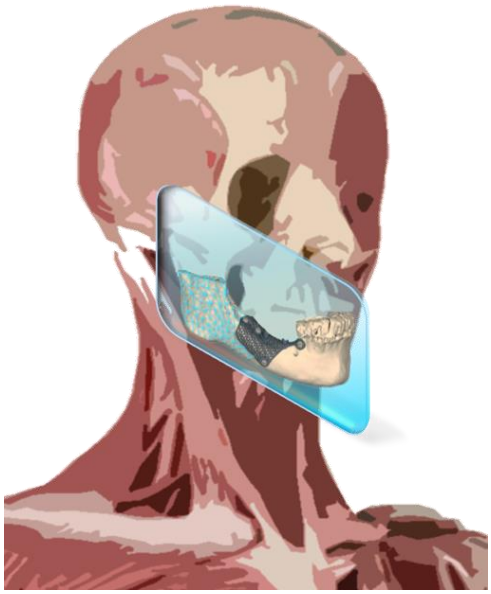
MSc « Biomechanics »
ENIM/University of Lorraine



Aim of the course

The general aim of this course is, for students, to acquire knowledge about the biomechanics of the musculoskeletal system and more specifically about the development of patient-specific medical devices.

General description

The understanding of the biomechanical behavior of the musculoskeletal system and the design of medical devices require diversified knowledge in various fields such as medical sciences (anatomy, cell and tissue biology, medical imaging…), mechanics of materials, finite element simulation, motion analysis of the human body. The Master's degree will provide students all the necessary fundamentals of these domains to allow them to understand a clinical issue and propose realistic and reliable biomechanical solutions.

Studying abroad

The enrolled students will have the possibility to spend the summer semester abroad (in or outside the framework of Erasmus exchanges).

Admission requirements

The students who want to apply to this second-year Masters program will have to be holding a Master 1 level in mechanics or physics.

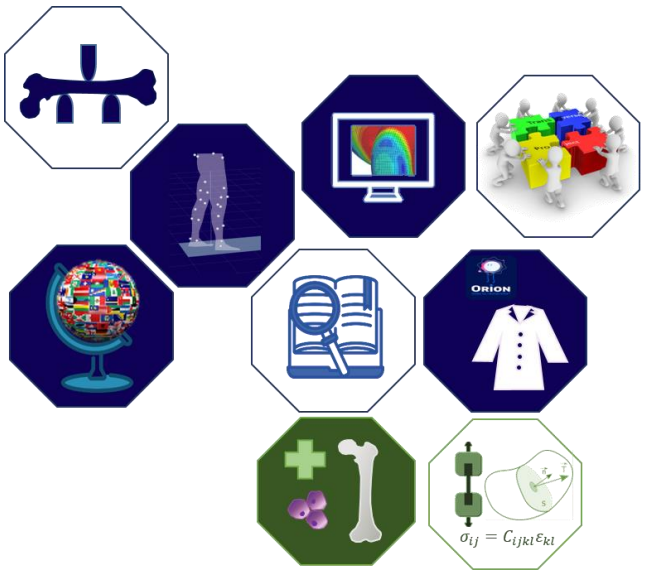
Career opportunities

After this course, the students will have the opportunity to stat a career in public or private sectors as upon graduation they will be able to:

- work in the Research and Development department of biomedical companies
- work in Biomechanics Research laboratories
- carry out a PhD thesis in biomechanics

Curriculum organization

- Winter semester: includes 7 compulsory modules and 1 optional module. Lectures are combined with tutorials, practical work and projects. All classes are given in English (minimum required level : B1+).



1/ Mechanical behaviour of biological tissues
2/ Human movement analysis
3/ Patient-specific FE modeling
4/ Transverse project
5 / Internationalisation
6/ Integrative project
7/ ORION premium laboratory practice

One optional module chosen amongst:
1/ Basic medical knowledge
2/ Fundamentals of solid mechanics
(see the syllabus below for more details)

- Summer semester: Master's Thesis.

Skills

General Skills

Skill 1 To solve a mechanical problem with its boundary conditions, to propose a model as simple as possible and to conduct a critical analysis of the results.	*Level 4*
Skill 2 To apply the usual concepts of various scientific fields of a technical subdomain to solve a complex problem, including a problem of design or engineering	*Level 3*
Skill 3 To adopt free or commercial software packages, to solve physical problems.	*Level 4*
Skill 4 To develop team-working skills, abilities to work autonomously and together with colleagues for the benefit of the project.	*Level 4*
Skill 5 To know how to communicate in both written and spoken French and English and become a team manager (to plan, organize, create and conduct meetings in an efficient way)	*Level 3*

Biomechanics Subdomain

Skill 9 To analyse the functioning of living organisms and/or human body through a scientific approach: - taking into account the experience of clinicians - using scientific and technical knowledge	*Level 3*
Skill 10 To propose an anatomic and functional restaurative solution adapted to a clinical issue: - taking into account the specificities of a given patient - proposing design solutions adapted to manufacturing processes and techniques used in biomedicine - identifying the risks related to real-condition implementation - taking regulatory aspects into account	*Level 3*

Application platform :

- For students who reside in one of the following countries, the "Etudes en France" (*Studying in France*) procedure is applied (https://www.campusfrance.org/en/application-etudes-en-france-procedure) :

  Algeria, Argentina, Benin, Brazil, Burkina Faso, Burundi Cameroon, Chile, China, Colombia, Comoros, the Republic of the Congo, South Korea, Ivory Coast, Egypt, United States, Gabon, Guinea, Haïti, India, Indonesia, Iran, Japan, Kuwait, Lebanon, Madagascar, Mali, Morocco, Mauritius, Mauritania, Mexico, Niger, Nigeria, Peru, Senegal, Democratic Republic of Congo, Russia, Saudi Arabia, Senegal, Singapore, Taiwan, Tchad, Togo, Tunisia, Turkey and Vietnam.

- For other students : the application must be done through the e-candidat platform of the Université de Lorraine (https://ecandidat.univ-lorraine.fr/)

Annual Application Deadline:

- "Etudes en France" (*Studying in France*) procedure : according to "Etudes en France" calendar
- “E-candidat” : end of May.

Tuition fees:

- EU students : ≈ 300€
- Non-EU students : ≈ 3870€

Contact :

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Module code UE 961 : Mechanical behaviour of biological tissues (56h = 30 lectures + 20h tutorials + 6h practicals) – 5 ECTS

Module coordinator : Dr. Adrien Baldit (adrien.baldit@univ-lorraine.fr)

Description :

Knowledge of the mechanical behavior of biological tissues is required to understand the clinical issues for rehabilitation and design new prosthetic solutions. This module firstly aims to teach students how to model and characterize the mechanical behavior of biological tissues using classical models.
The lectures will progressively talk about the composition and structure of bone and soft tissues to explain and justify the mechanical properties of those tissues (constitutive laws, ranges).
Then experimental methods and issues specific to biological tissues will be studied, focusing on methods for identification of parameters for mechanical and multi-physical models .

The second aim of this module is to give students the tools to develop multi-scale models on the instantaneous and adaptive behavior of biological tissues. In a first step, various micromechanical approaches are studied by focusing on their validity domains and their possibilities of application on biological tissues and substitutes. Secondly,an introduction to adaptive behavior is proposed by describing the mechanisms of growth, adaptation, remodeling and healing.

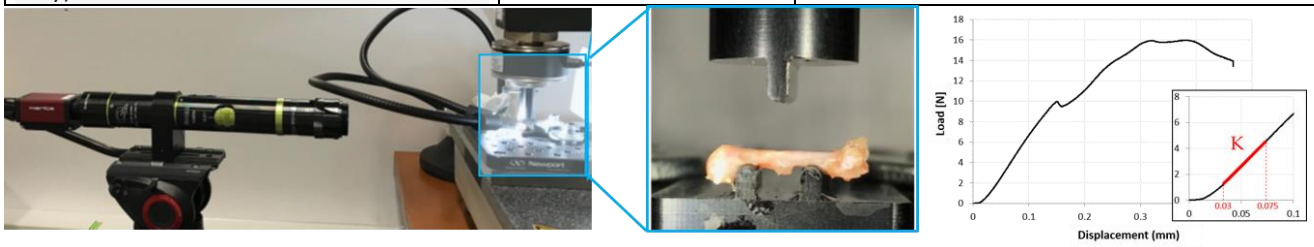
Pre-requisites :

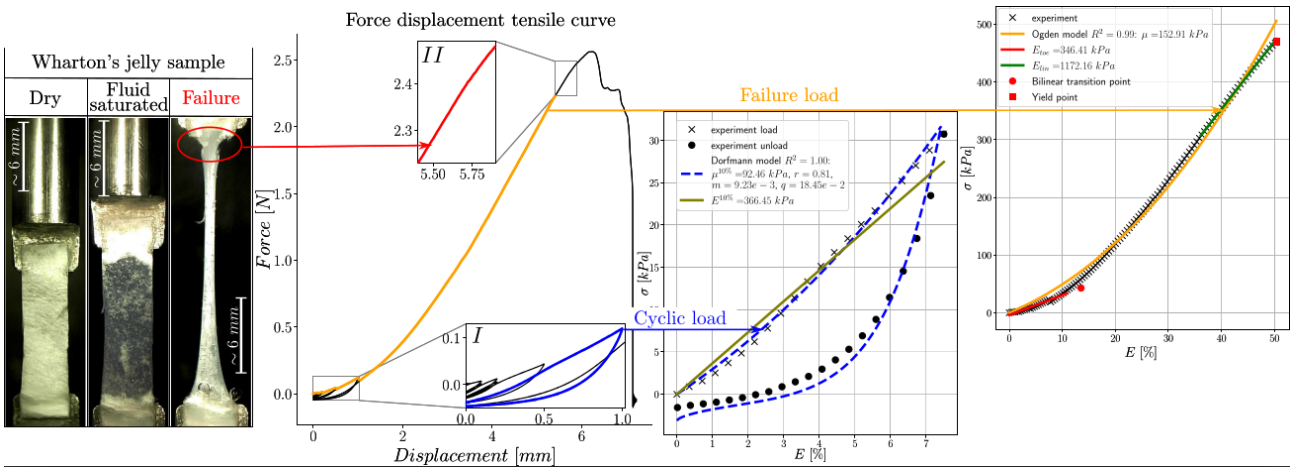
Continuum mechanics for solids: tensor calculus and Einstein notation, theory of elasticity (small strains), isotropic and anisotropic constitutive laws, mechanics of plastic strain, plasticity criteria.
Basic knowledge concerning experimental tests on conventional materials..

Skills and learning outcomes:

Skills	Level	Learning outcomes
Skill 9 To analyse the functioning of living organisms and/or human body through a scientific approach: - taking into account the experience of clinicians - using scientific and technical knowledge	**3**	- To apply the theoretical principles of the continuum mechanics to study biological tissues - To recognize different biological tissues on histological slices or anatomical schemes - To draw the typical behavior observed during experimental tests on biological tissues - To identify parameters for mechanical models
Skill 9 To analyse the functioning of living organisms and/or human body through a scientific approach: - taking into account the experience of clinicians - using scientific and technical knowledge	**2**	- To describe the processes of bone growth and remodeling. - To explain the similarities and differences between the different adaptive processes
Skill 10 To propose an anatomic and functional restauration solution adapted to a clinical issue - taking into account the specificity of a given patient - proposing design solutions adapted to manufacturing processes and techniques in biomedicine	**3**	- To choose a homogenization scheme adapted to the problem and to the validity field of the method - To determine the effective properties of the equivalent medium modeled and their evolution

- identifying the risks related to the implementation in real conditions - taking into account regulatory aspects		
Skill 5 To know how to communicate in both written and spoken French and English and become a team manager (to plan, organize, create and conduct meetings in an efficient way).	**3**	- To link the experimental analysis to the theoretical knowledge through a written report





Baldit et al, 2022.

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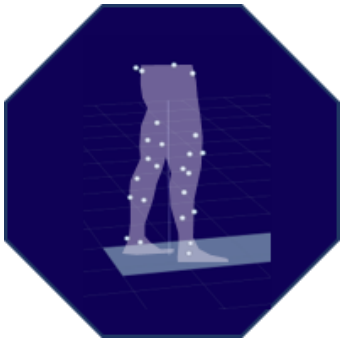
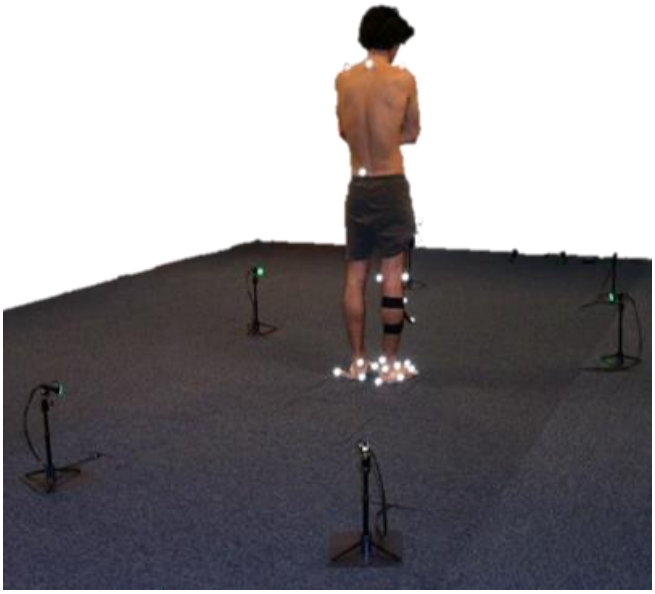


Module code UE 962 : Human movement analysis (42h : 14h lectures + 18h tutorials + 10h practicals) – 4 ECTS

Module coordinator : Dr. Emilie De Brosses (emilie.de-brosses@univ-lorraine.fr)



Description

The motion analysis is involved in scientific advances in various fields such as computer- guided surgeries, sports or robotics. This course aims both to provide fundamental scientific knowledge for the analytical description of the human movements as well as practical skills such as carrying out a motion capture trial and analyze it. An introduction to musculoskeletal modeling and dynamic analysis will be proposed combined with the physiological processes driving muscular contractions. Students will have the possibility to experience sEMG measurements and post-processing.

Prerequisites: Basic knowledge concerning the kinematics of solids - the Newton's laws applied to rigid bodies - Rheological models - Names of the limbs, joints and bony structures - Names of the anatomical directions and planes

Skills and learning outcomes

Skills	Level	Learning outcomes
Skill 2 To apply the usual concepts of various scientific fields of a technical subdomain to solve a complex problem, including a problem of design or engineering	**4**	- To write and solve the equations corresponding to a human motion
Skill 9 To analyse the functioning of living organisms and/or human body through a scientific approach: - taking into account the experience of clinicians - using scientific and technical knowledge	**3**	- To quantify and analyze human motions by choosing the right frame for the clinical interpretation according to the international standards - To use rheological models to describe the mechanical behavior of muscles by taking into account its specificities - To understand and explain the principles of EMG and sEMG measurement
Skill 10 To propose an anatomic and functional restauration solution adapted to a clinical issue - taking into account the specificities of a given patient	**2**	- To develop numerical and analytical models to compute joint loads

- proposing design solutions adapted to manufacturing processes and techniques in biomedicine - identifying the risks related to the implementation in real conditions - taking into account regulatory aspects		
Skill 4 To develop capability to work in a team, with autonomy and also with colleagues for the benefit of the project.	**3**	- To carry out a motion capture trial and analyze the required data.
Skill 5 To know how to communicate in both written and spoken French and English and become a team manager (to plan, organize, create and conduct meetings in an efficient way)	**4**	- To collect, synthetize and communicate scientific information in a short oral presentation

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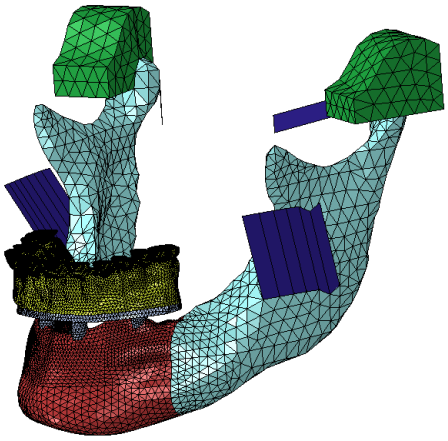
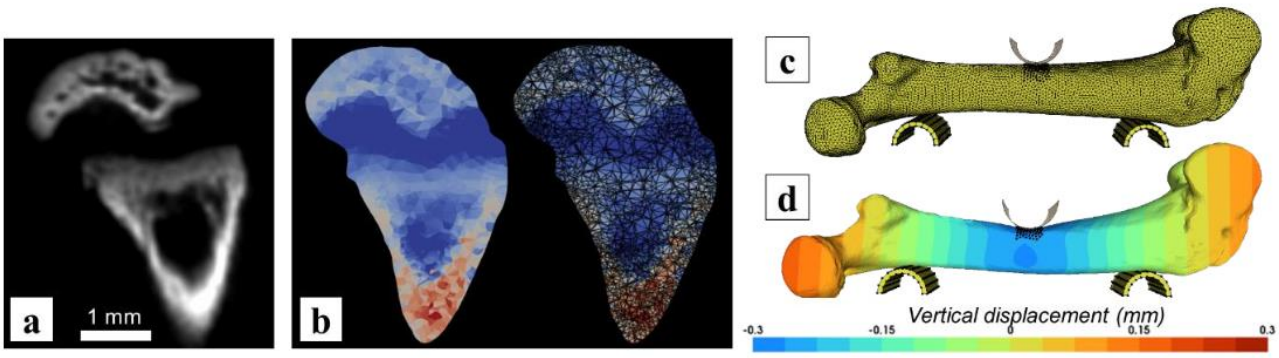
Module code UE 963 : Patient-specific FE modeling (66h = 24h lectures + 10 tutorials + 32h lab) – 6 ECTS

Module coordinator : Pr. Anne-Sophie Bonnet (anne-sophie.bonnet@univ-lorraine.fr)

Description :

The aim of this module is to give the students the theoretical and practical tools to build a patient-specific finite element model from medical imaging data. The module is divided into three parts. The first one will provide a specialized technical training in the field of medical imaging. It will explain the physical principles of different imaging modalities and present the most frequently adopted methods to post-treat images. The second one will provide the theoretical bases of the Finite Element Method. The final part will describe all necessary stages to build a patient-specific FE model from medical imaging data. A great attention will also be given to the analysis of the results provided by the numerical simulations.





C. Laurent et al, 2022.

Pre-requisites :

Basics in wave physics (d'Alembert's equation, one-dimensional wave parameters, stationary waves,…) - Fundamentals of tensor analysis - Bases of Continuum Mechanics - Constitutive laws in elasticity - Mechanics of plastic strain, plasticity criteria -

Skills and learning outcomes:

Skills	Level	Learning outcomes
Skill 2 To apply the usual concepts of various scientific fields of a technical subdomain to solve a complex problem, including a problem of design or engineering	**2**	- To choose a medical imaging modality fitted to a clinical problem by taking into account its advantages and drawbacks
Skill 3 To adopt free or commercial software packages, to solve physical problems.	**3**	- To apply usual post-processing technics on medical images and to compute structural parameters
Skill 9 To analyse the functioning of living organisms and/or human body through a scientific approach: - taking into account the experience of clinicians - using scientific and technical knowledge	3	- To apply appropriate boundary conditions, loadings, interactions between various parts of the model.
Skill 10 To propose an anatomic and functional restauration solution adapted to a clinical issue - taking into account the specificities of a given patient - proposing design solutions adapted to manufacturing processes and techniques in biomedicine - identifying the risks related to the implementation in real conditions - taking into account regulatory aspects	3	- To adapt geometries of anatomic parts obtained after segmentation for importation into FE software - To mesh the parts judiciously (choose of element type, mesh density, mesh concordance and technical application) - To choose and apply suitable constitutive laws - To provide relevant conclusions through the analysis of the results provided by the simulations

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Module code UE 964 : Transverse project (40h practicals) – 4 ECTS

Module coordinator : Dr. Emilie De Brosses (emilie.de-brosses@univ-lorraine.fr)

Description :

The aim of this project is to give the students the opportunity to apply the knowledge developed during the semester to a real clinical or scientific issue through a multidisciplinary project.

Pre-requisites :

Basics in anatomy - Basics in biomaterials - Finite Element modeling - Experimental testing - Manufacturing processes - Imaging methods - Post processing of images.

Skills and learning outcomes:

Skill	Level	Learning outcomes
Skill 9 To analyse the functioning of living organisms and/or human body through a scientific approach: - taking into account the experience of clinicians - using scientific and technical knowledge	3	- To draw the problem to solve and identify the various tasks to achieve
Skill 10 To propose an anatomic and functional restauration solution adapted to a clinical issue - taking into account the specificities of a given patient - proposing design solutions adapted to manufacturing processes and techniques in biomedicine - identifying the risks related to the implementation in real conditions - taking into account regulatory aspects	3	- To conduct a scientific study through experimental testing, computer analysis and/or numerical simulations - To draw conclusions and be critical with respect to the work carried out
Skill 5 To know how to communicate in both written and spoken French and English and become a team manager (to plan, organize, create and conduct meetings in an efficient way)	3	- To present and defend a project through a report and an oral presentation
Skill 4 To develop capability to work in a team, with autonomy and also with colleagues for the benefit of the project.	3	- To build a schedule and manage a project - To work as a team and share tasks

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Module code UE 965 : Internationalisation (30h=20h lectures/ 10h tutorials) –3 ECTS

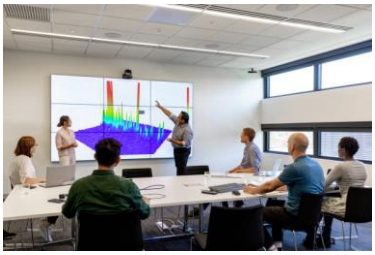
Module coordinator : Pr. Anne-Sophie Bonnet (anne-sophie.bonnet@univ-lorraine.fr)

Description :

The aim of this module is to provide students with guidelines for presenting and discussing scientific work in an international context. The module is composed of two constitutive elements (CE). The first one will give to the students the tools and methods to present scientific concepts and to communicate their work to the scientific community. Seminars and conferences by international scientists will constitute the second CE.

CE1: Scientific communication in English, paper writing, collaboration, lecturing (20h lectures)

CE2: Seminars and conferences (10h tutorials)



Pre-requisites : B1+ level in English

Skills and learning outcomes:

Skill	Level	Learning outcomes
Skill 5 To know how to communicate in both written and spoken French and English and become a team manager (to plan, organize, create and conduct meetings in an efficient way)	2	- to present a scientific work orally or in writing to a scientific audience - to exchange with international scientists

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Module code UE 966 : Integrative project (30 hprj) – 3 ECTS

Module coordinator : Pr. Anne-Sophie Bonnet (anne-sophie.bonnet@univ-lorraine.fr)

Description :

The aim of this module is for the students to review a state-of-the-art on the scientific issues they will have to deal with during their Master's thesis.

Pre-requisites : bibliographic research tools

Skills and learning outcomes:

Skill	Level	Learning outcomes
Skill 5 To know how to communicate in both written and spoken French and English and become a team manager (to plan, organize, create and conduct meetings in an efficient way)	2	– to write a report summarising the literature on a biomechanical issue and complying with the rules for writing a scientific document – to produce an oral summary of the literature on a biomechanical issue

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Module code UE 967 : ORION Premium laboratory practice (30h = 30h practicals) – 3 ECTS

Module coordinator : Dr. Adrien Baldit (adrien.baldit@univ-lorraine.fr)

Description :

This practical sequence is divided into four connected parts starting from ethics to set the framework, it continues with human movement analysis through motion capture as a first session. This human scale measurement technique gives the kinematics of the musculoskeletal system considering bones as rigid bodies. Then the third practice session focuses on trabecular and cortical bone tissues study within the framework of linear elasticity and using various experiments such as dedicated compression tests or x-ray tomography as medical imaging technique and pointing out the anisotropic character of the tissue. Finally, the mechanics of soft biological tissue is observed and analysed through experiments during the last session. Specific workbenches adapted to a universal tensile machine allow capturing the multiphysical response of tissues such as muscles or hydrogels mimicking joint or skin tissue. It requires knowledge on nonlinear hyperelasticity and interest on biphasic media. This set of practicals is aimed at providing to the students a variety of experimental skills in relation with different topics of research in biomechanics. Especially, the students will have the opportunity to use up-to-date and specific experimental devices that are available in the LEM3 lab research platform (Infra+ labelled platform).

Pre-requisites :

Continuum mechanics for solids: Kinematics and dynamics of rigid solid bodies, Theory of elasticity (infinitesimal strains), Isotropic and anisotropic constitutive laws, Basic knowledge concerning experimental tests on conventional materials.

Skills and learning outcomes:

Skills	Level	Learning outcomes
Skill 9 To analyse the functioning of living organisms and/or human body through a scientific approach: - taking into account the experience of clinicians - using scientific and technical knowledge	**3**	- To apply the theoretical principles of the continuum mechanics to study biological tissues - To draw the typical behavior observed during experimental tests on biological tissues - To identify parameters for mechanical models
Skill 9	**1**	- To design a protocol to characterize biological tissues in response to specific hypotheses

To analyse the functioning of living organisms and/or human body through a scientific approach: - taking into account the experience of clinicians - using scientific and technical knowledge		
Skill 10 To propose an anatomic and functional restauration solution adapted to a clinical issue - taking into account the specificities of a given patient - proposing design solutions adapted to manufacturing processes and techniques in biomedicine - identifying the risks related to the implementation in real conditions - taking into account regulatory aspects	**3**	- To choose a homogenization scheme adapted to the problem and to the validity field of the method - To determine the effective properties of the equivalent medium modeled and their evolution
Skill 5 To know how to communicate in both written and spoken French and English and become a team manager (to plan, organize, create and conduct meetings in an efficient way).	**3**	- To link the experimental analysis to the theoretical knowledge through a written report

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Module code UE 968 : Basic medical knowledge (24h lectures) – 2 ECTS

Module coordinator : Dr. Emilie De Brosses (emilie.de-brosses@univ-lorraine.fr)

Description :

This course is aimed at providing both basic medical and biological knowledge for a better understanding of the medical theory and the clinical issues. Basic knowledge in anatomy, in cell and tissue biology as well as bases concerning the biomaterials science will be provided.

Anatomy (10h lectures)

Basics in cell biology, histology and biomaterial science (14h lectures)

Pre-requisites :

Basics in material science

Skills and learning outcomes:

Skills	Level	Learning outcomes
Skill 9 To analyse the functioning of living organisms and/or human body through a scientific approach: - taking into account the experience of clinicians - using scientific and technical knowledge	**2**	- To use the medical vocabulary to describe the anatomy and the functions of the human musculo-skeletal system - To recognize and describe the principal organelles of the human eukaryotic cells - To recognize and describe the different types of human tissues on histologic slices
Skill 10 To propose an anatomic and functional restauration solution adapted to a clinical issue - taking into account the specificities of a given patient - proposing design solutions adapted to manufacturing processes and techniques in biomedicine - identifying the risks related to the implementation in real conditions - taking into account regulatory aspects	**2**	- To choose a biomaterial fitted to a problem by taking into account its chemical, physical and mechanical interactions with cells and tissues. - To list the different steps to fulfill in order to characterize the biocompatibility of a medical device following the regulations

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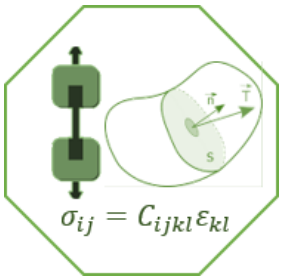

Module code UE 969 : Fundamentals of solid mechanics (24h=14h lectures + 10h tutorials) –2 ECTS

Module coordinator : Dr Cynthia Dreistadt (cynthia.dreistadt@univ-lorraine.fr)

Description :

The aim of this module is to provide basics on solid mechanics. This module is divided into two parts. At first, statics, kinematics and dynamics elementary aspects will be reviewed. Then mechanics of deformable bodies will provide essential concepts of stress and strain followed by the introduction to elastic constitutive law.

Pre-requisites :

Mathematical basics (vector and matrix notations, operations on vectors and matrices, suffix notation, tensor definition), Point Mechanics

Skills and learning outcomes:

Skills	**Level**	**Learning outcomes**
Skill 1 To solve a mechanical problem with its boundary conditions, to propose a model as simple as possible and to conduct a critical analysis of the results.	**2**	- to choose the appropriate model for a given simple mechanical problem - to write and solve the equations corresponding to simple mechanical problems