1SC2291 – Biomaterials for bone tissue engineering

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Language of instruction: FRANCAIS
Campus: CAMPUS DE PARIS - SACLAY
Workload (HEE): 40
On-site hours (HPE): 27,00

Description

Biomaterials for bone tissue engineering is one of the 4 courses (EI) that ends the Engineering Challenge Term (ST2) **Bioengineering: Produce, Protect, Repair**. This course illustrates how bioengineering may contribute to **Repair** human body.

A public health issue
The excellent healing capacity of the bones, combined with immobilization of the limb, is sufficient to repair most fractures. However, in some clinical cases, such as serious traumatic injuries with bone loss or extensive resections of bone tumor, the spontaneous healing process can be very slow or even completely ineffective. For these difficult cases, a bone graft is mandatory. However, for extensive or multiple bone reconstructions, the available volume of bone material for autologous graft may be insufficient. In this context, INSERM is developing an alternative therapy for which bone flaps are replaced by a synthetic microporous biomaterial.

A quicker way to get biomaterials with optimized properties
The development of a biomaterial to its clinical application is long and costly. In order to accelerate this process, INSERM's LVTS laboratory and CentraleSupélec's LMPS and LGPM laboratories are implementing a new strategy that breaks with the traditional empirical approach. This innovative strategy relies on bioreactor engineering, multiphysics modelling and numerical simulation. Bioreactors make it possible to study in vitro the repair of a bone defect. Numerical simulation makes it possible to examine more systematically the influence of the microgeometry of the biomaterial on this repair. Both tools should help to pre-optimize the properties and the microarchitecture of the biomaterial before moving on to in vivo testing.

Multiphysics modelling of the bioreactor
The course focuses on the modelling of cell proliferation within the biomaterial. In the bioreactor, the biomaterial is perfused by a liquid that (i) provides the nutrients and oxygen needed by the cells, (ii) eliminates the

waste they produce and (iii) exerts a shear stress on the cells that stimulates their proliferation and/or differentiation. The course will address different aspects of the multiphysics modelling: (i) the characterization and the geometric representation of the microporous biomaterial, (ii) the hydrodynamics within the pores, (iii) the transport of the chemical species (oxygen and glucose), (iv) the cell proliferation and (v) the coupling between the biomaterial morphology, the hydrodynamics, the solute transport and the cell proliferation.

Quarter number
ST2

Prerequisites (in terms of CS courses)
No prerequisite

Syllabus

- Presentation of the project
  - What is tissue engineering ?
  - Bioreactors: an overview
  - Focus on the bioreactor of the project
- Comprehensive analysis of the problem
  - Different time and space scales
  - The relevant scale to describe cell proliferation within a bioreactor
  - Break down of the problem into smaller parts
  - Bibliographical review
  - Data research
- Description of the biomaterial
  a. Analysis of 3D images of the biomaterial
  b. Characterization of its porous structure
- Experimentation
  - Initiation to cell culture
  - Determination of proliferation kinetics under static conditions
- Pore-scale modelling
  - Hydrodynamics
  - Solute transfer
  - Cell proliferation
- Modelling at the bioreactor scale
  - PNM approach, Pore Network Model
  - Permeability calculation
- Numerical implementation
  - Algorithms
  - Validation of the model on test configurations
- Parametric study

- Adjustment of microgeometry and operating conditions
- Optimization of the cellularization

Class components (lecture, labs, etc.)

Biomaterials for bone tissue engineering is a course dedicated to **Problem solving**. Students will confront the multiphysics and multi-scale aspects of bioengineering problems. They will apply the concepts introduced in the basic courses of the **ST2 Bioengineering** and in the mathematics and computer science courses of the common core.

The course is scheduled over 5 consecutive days. It begins with a half-day project launch (Monday morning). During the week, the students work in groups of 4 and are supervised by a team of researchers from LGPM and LMPS laboratories. Each group addresses the different aspects of the modelling approach and confront reality through a cell culture training (in pairs).

Updates will be held daily: sharing of information, methodological input, additional courses. The week ends with a debriefing session on Friday afternoon in the presence of D. Letourneur (CNRS senior scientist) director of the LVTS laboratory (INSERM).

Grading

The EI final mark depends on : individual assiduity, group involvement, relevance of the model, numerical implementation, code quality, oral presentation, report.

The skills C1 and C7 are validated if the EI final mark is greater than or equal to 14/20.

The skill C4 is assessed by the jury (including the client) using a rating scale between 1 and 4. C4 is validated for a rating of 3 and more.

The skill C8 is assessed by the supervisors.

Course support, bibliography

Presentation slides, scientific articles and a start guide to cell culture will be provided during the course.

Resources

- Teaching staff: H. Duval (Professor, CS, MEP Department, LGPM), B. Taidi (PR, CS, MEP Department, LGPM), B. David (CNRS Associate scientist, LMPS)
- Maximum enrolment: 28
- Software, number of licenses required: Imagej (Public Domain)
- Equipement, specific classrooms (department and room capacity): biology preparation room (MSSMat), 14 students at the same time

Learning outcomes covered on the course

At the end of the course, the students will be able to:

1. identify the different time and space scales taking place in a given process ;
2. select the most appropriate scale to solve a given problem;
3. identify and keep the predominant phenomena;
4. reduce the dimensionality and the complexity of a problem;
5. establish a multiphysics model by aggregating knowledge from different scientific fields (biology, transport phenomena, biochemical engineering, materials science, image analysis);
6. perform cultivation to estimate the proliferation kinetics of a cell line ;
7. write a program to implement a mathematical model;
8. keep a critical eye on a model and its limitations.
9. provide a comprehensive presentation of a modelling approach.

Description of the skills acquired at the end of the course

C1 : Analyze, design, and implement complex systems made up of scientific, technological, social, and economic dimensions
C4: Create value for companies and clients
C7 : Strengthen the Art of Persuasion
C8 : Lead a team, manage a project