IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

Project Title:	**Modelling of Mechanics of Sliding in Biological Soft Tissues**	
Project Number	**IMURA1006**	
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Research Clusters:

Highlight which of the Academy's CLUSTERS this project will address? *(Please nominate JUST **one**. For more information, see www.iitbmonash.org)*	
1	*Material Science/Engineering (including Nano, Metallurgy)*
2	*Energy, Green Chem, Chemistry, Catalysis, Reaction Eng*
3	*Math, CFD, Modelling, Manufacturing*
4	*CSE, IT, Optimisation, Data, Sensors, Systems, Signal Processing, Control*
5	*Earth Sciences and Civil Engineering (Geo, Water, Climate)*
6	*Bio, Stem Cells, Bio Chem, Pharma, Food*
7	*Semi-Conductors, Optics, Photonics, Networks, Telecomm, Power Eng*
8	*HSS, Design, Management*

Research Themes:

Highlight which of the Academy's Theme(s) this project will address? *(Feel free to nominate more than one. For more information, see www.iitbmonash.org)*	
1	*Advanced computational engineering, simulation and manufacture*
2	*Infrastructure Engineering*
3	*Clean Energy*
4	*Water*
5	*Nanotechnology*
6	*Biotechnology and Stem Cell Research*
7	*Humanities and social sciences*
8	Design

The research problem

The contact and sliding of tissues is ever present in many physical and biological contexts. A remarkable example is diarthrodial joint, present all over the human body, which allows for a wide range of functional motion [1]. The soft tissues comprise of articular cartilage, soft connective tissue, and bones. All these components are deformable porous structures interacting through lubricated friction and sustain large compression and shear forces during normal muscle activity [2].

Our ability to investigate the failure of these soft tissues under extreme conditions is of utmost importance for developing health and wellbeing interventions wherever such tissues are involved. Experimental investigation has obvious and serious limitations, and consequently, computational models play a critical role in revealing fundamental mechanisms, which are out of reach for in-vivo studies. For this purpose, this project will focus on developing accurate, robust and reliable mixed finite element models to investigate the mechanics of sliding in biological soft tissues.

This project will advance the state-of-the-art in investigating a range of applications in biomechanics, including cartilage-on-cartilage interactions that are of importance, for instance:

- Walking and shock response [2]
- Large-deformation and strain-dependent permeability in common joint loadings [1]
- Mass transport and drug delivery through arterial walls under the presence of pulsating flow [3]
- Formation of myocardial edema [4,6]
- Progressive compaction of collagen layers in the eye, which lead to the formation of glaucoma.

References

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2. Ateshian GA, Maas S, Weiss JA. *Finite element algorithm for frictionless contact of porous permeable media under finite deformation and sliding*. Journal of Biomechanical Engineering. 2010;132(6).
3. Zakerzadeh R, Zunino P. *A computational framework for fluid–porous structure interaction with large structural deformation*. Meccanica. 2019;54(1):101–121.
4. Freitas Reis R, Weber Dos Santos R, Martins Rocha B, Lobosco M. *On the mathematical modeling of inflammatory edema formation*, Computers and Mathematics with Applications, 78 (2019), pp. 2994–3006.
5. Borregales Reveron MA, Kumar K, Nordbotten JM, Radu FA. *Iterative solvers for Biot model under small and large deformations*. Computational Geosciences, in press (2021), pp. 1–13.
6. Chapelle D, Gerbeau JF, Sainte-Marie J, Vignon-Clementel IE. *A poroelastic model valid in large strains with applications to perfusion in cardiac modeling*, Computational Mechanics, 46 (2010), pp. 91–101.
7. Farrell PE, Gatica LF, Lamichhane BP, Oyarzua R, Ruiz-Baier R. *Mixed Kirchhoff stress - displacement - pressure formulations for incompressible hyperelasticity*, Computer Methods in Applied Mechanics and Engineering, 374 (2021), p. e113562.

Project aims

1) Construct suitable models for the contact dynamics of soft tissue. Using asymptotic analysis, study the properties of the coupled multiphysics problems in different contexts, and state the main research questions coming from (at least one of) the applicative problems.
2) Design and implement mixed finite element formulations for coupled large-strain poromechanics. This step involves getting acquainted with aspects of numerical techniques and programming languages such as Python and C++.
3) Perform the numerical analysis (stability, solvability, convergence) of the mixed schemes, addressing also more theoretical questions.
4) Use the tools developed in points 1-2 to investigate models for cartilage-on-cartilage interactions that are of importance to persisting challenges in health and wellbeing.

Expected outcomes

The overall aim will be to improve the current understanding of sliding of soft tissues applicable in diverse contexts.

- A novel framework for the theoretical modelling and design of numerical methods
- Models will be validated against benchmark data and experimental observations
- Computational codes and preprints of our scientific reports will be made publicly available in online repositories

How will the project address the Goals of the above Themes?

Specific applications of the formalisms outlined above include growth and proliferation of embryonic cells, macroscopic interaction between cardiac muscle deformation and perfusion, articular cartilage characterization, design and testing of smart materials. The outcomes of this project will contribute to fill the gap between techniques currently employed by practitioners and the sound foundation of novel models and numerical methods. Being a highly visible subject, it is expected that the project will attract several collaborations from which the IITB-Monash Research Academy will benefit. We also foresee the possibility of building new engagements with the biomedical industrial sector. All these items have a clear relevance to the goal "Advanced computational engineering, simulation and manufacture".

Capabilities and Degrees Required

List the ideal set of capabilities that a student should have for this project. Feel free to be as specific or as general as you like. These capabilities will be input into the online application form and students who opt for this project will be required to show that they can demonstrate these capabilities.

Degree: MSc/MTech in Engineering (Mechanical or Materials Science, Civil, Aerospace, Engineering Physics) or MSc/MTech in Mathematics related fields (Applied Mathematics or Mathematics)

Capabilities:
Continuum Mechanics – Essential
Mechanical Engineering – Preferred
Civil Engineering - Preferred
Numerical methods – Preferred
Scientific computing – Preferred

Potential Collaborators

Please visit the IITB website www.iitb.ac.in OR Monash Website www.monash.edu to highlight some potential collaborators that would be best suited for the area of research you are intending to float.

Prasenjit Basu, Department of Civil Engineering, IIT Bombay. Works on Computational Geomechanics.
Mark Flegg, Monash Mathematics. Works on Mathematical Biology.