IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

Project Title:	**Interface conditions for elasticity-diffusion and application to the electromechanics of heart and torso**
Project Number	**IMURA0995**

Monash Main Supervisor (Name, Email, Phone)	Ricardo Ruiz Baier, ricardo.ruizbaier@monash.edu	*Full name, Email*
Monash Co-supervisor(s) (Name, Email, Phone)		
Monash Head of Dept/Centre (Name, Email)	Warwick Tucker, warwick.tucker@monash.edu	*Full name, email*
Monash Department:	Mathematics	
Monash ADGR (Name, Email)	Peter Betts, peter.betts@monash.edu	*Full name, email*
IITB Main Supervisor (Name, Email, Phone)	Amit Singh, amit.k.singh@iitb.ac.in	*Full name, Email*
IITB Co-supervisor(s) (Name, Email, Phone)		*Full name, Email*
IITB Head of Dept (Name, Email, Phone)	Sreedhara Sheshadri, head.me@iitb.ac.in	*Full name, email*
IITB Department:	Mechanical Engineering	

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

In this project, we address the mathematical and computational modelling of novel mechanisms revealing nonlinear interactions between chemical, electrical, and mechanical effects in deformable tissue, with special emphasis on cardiac tissue. In particular, we will advance models for the coupling of the bidomain equations describing the propagation of electric potential through the heart and interfacing the torso; together with the interaction with the large deformations exhibited by the active contraction of the myocardial muscle in contact with the surrounding structure, represented by an interface finite elasticity problem. Such a model has the potential to contribute in the understanding of the electromechanical properties of both heart and torso, and phenomena of this kind do occur in many medical procedures, including the very common conduction of electrocardiograms (ECGs). We also plan to study the effect of growth and decay of cardiac musle tissues on these phenomena by decomposing the deformation gradient tensor into elastic, active and growth parts, an approach based on finite strain plasticity which is widely used now a days. This study will help understand Athlete's heart syndrome and similar other heart diseases in which the heart grows abnormally.

The main modelling task consists in setting up appropriate lubricated friction or frictionless transmission conditions for the contact between two hyperelastic materials. Secondly, we will address the specification to cardiac tissue and investigate the effects of including simplified pericardial sac models. The first numerical analysis task consists in employing a primal-mixed finite element method to numerically solve the coupled system. By primal-mixed we mean that, the hyperelasticity equations are set in a mixed form (that is, the associated formulation possesses a saddle-point structure involving additional unknowns, as for instance, the stress), whereas the formulation of the bidomain equations assumes its classical form. Such a structure of the governing equations is motivated by the need of recovering stress without postprocessing them from a (typically low-order) discrete displacement (which usually leads o insufficiently reliable approximations).

Next we aim at combining a perfusion model for of the left ventricle using a poroelasticity-based description at finite strains regime, with a specialised model for electrical conduction on porous tissues. The expected results are the reproduction of flow impediment and wall thickening phenomena, which are extremely difficult to recover with isolated linear poroelastic models or thermodynamically inconsistent formulations.

Such models are inherently complex, multiscale and multiphysics requiring a high computational demand to obtain simulation results in realistic physical domain. Additional aims of the project will involve algorithm implementation, testing computational efficiency, validation, and verification of results against experimental data. Up to now we have advanced in getting a reasonably complete model and a sophisticated numerical method for capturing thermal, chemical, electric, and mechanical properties of the cardiac tissue; however, a number of extensions remain unexplored, and one of the goals will be to work towards establishing new paradigms for the multiscale representation of consistent coupling conditions that currently constitute an open problem in the field.

In general terms, the research problem involves modelling of biomechanics (setting of adequate transmission conditions between the heart and the surrounding tissue, assessing the effects of the electromechanical coupling in the outcome of ECGs and introducing growth or decay deformation tensor), numerical analysis (studying convergence and stability properties of the finite element approximations), and scientific computing (implementation using open-source libraries and the development of efficient solvers for the solution of the arising algebraic systems). The project will allow the student to learn (or to refine their expertise in) biomechanics, theory of saddle-point problems, implementation of large scale solvers, and finite element methods.

Project aims

1. Developing models for the nonlinear coupling of the bidomain equations describing the propagation of electric potential through the heart and interfacing the torso, together with the interaction with the large deformations exhibited by the active contraction of the myocardial muscle in contact with the surrounding structure.
2. Coming up with appropriate, frictionless transmission conditions for the contact between two hyperelastic materials.
3. Addressing the specification to cardiac tissue and investigating the effects of introducing simplified pericardial sac models and the effects of introducing growth and decay models. This will involve employing a primal-mixed finite element method to numerically solve the coupled system.
4. Combining a perfusion model for of the left ventricle using a poroelasticity-based description at finite strains regime, with a specialised model for electrical conduction on porous tissues.
5. Implementing algorithm with open-source codes and developing efficient linear algebraic solvers for our models. This also includes testing computational efficiency and validating and verifying the numerical results against experimental data. This will also involve studying convergence and stability properties of the finite element approximations.

Expected outcomes

- A novel framework for the theoretical modelling and numerical analysis of a class of coupled systems of PDEs arising from continuum mechanics
- Robust and efficient discretisations will be advanced and their capabilities will be fully tested
- Results 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?

The existing models capture the thermal, chemical, electric, and mechanical properties of the cardiac tissue but multiscale representation of consistent coupling conditions still remains a largely open field for which we aim to establish new paradigms. The outcomes of this project will contribute to study the interface conditions of elasticity and diffusion where the heart and the torso meet. 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” and “Biotechnology”.

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 in Mathematics, Msc/M.Tech. in Engineering, or Msc/M.Tech. in Computer Science

Capabilities:
Continuum mechanics
Partial differential equations
Numerical methods
Scientific computing

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.

Tanmay K. Bhandakkar, IITB Mechanical Engineering. He has worked on calcium kinetics in neuron in the past.