Multiscale Modelling and Simulation Lab., MSME UMR 8208

Open PhD position

Model-driven approaches for the modeling of soft tissues under impact loading

Context. The skin serves as the body's outermost protective layer and must retain its elasticity, firmness, and tensile strength. Assessing its biomechanical properties is essential for accurate diagnosis, monitoring treatment responses, and improving theragnostic strategies. Since the mechanical behaviour of biological soft tissues is highly dependent to their physiopathological state, clinicians often rely on palpation, a subjective experience-dependent method with limited sensitivity, to detect abnormalities in superficial tissues. To address these limitations, various non-invasive techniques, such as elastography, have been developed to quantitatively evaluate tissue elasticity. However, despite their precision, these imaging techniques remain costly and complex to operate.

A practical, low-cost, and real-time method for non-invasive skin characterization has been proposed by the MSME lab. The approach involves an instrumented small hammer equipped with a piezoelectric force sensor on its impacting surface. By measuring the time-dependent force applied between the hammer and a metallic cylindrical rod in contact with the skin, the system enables the assessment of soft tissue mechanical properties. In this context, we need a detailed understanding of the dynamic behaviour occurring during the measurement procedure of the skin biomechanical properties, which will eventually lead to the development of an effective medical device for the estimation of the skin properties.

Objective. The objective of this work is to develop biomechanical models and associated numerical methodscapable of predicting the dynamic behaviour of the skin-rod coupled system under impact loading, as defined by the experimental protocol. The biomechanical model must accurately describe the high strain-rate deformation behaviour of the skin during impact. Two primary challenges must be addressed: (1) *Constitutive modelling of skin:* The tissue's model must account for its anisotropic, multilayered, and micro-structured nature, as well as its rate-dependent dissipative behaviour; (2) *Contact modelling:* The contact model must incorporate detailed surface geometries and deformations to capture the complexity of friction and adhesion phenomena at the skin-metal interface under dynamic loading.

The project will proceed through the following steps:

1. The derived physical models—both for the skin and the skin–rod contact interface—will be implemented in numerical solvers to address the forward problem.

2. A contact detection algorithm will be developed to effectively handle the irregular interface between the metallic rod and the stratum corneum (the outermost layer of the epidermis).

3. Direct time integration schemes will be employed to efficiently solve the resulting nonlinear coupled system.

4. Model order reduction techniques for finite element simulations of impact problems in the considered multiphysics and strongly heterogeneous medium will be developed.

5. Finally, model-based machine learning approaches will be introduced to enable real-time simulation of this large-scale system.

Required skills. Master (or equivalent) degree in mechanics, applied mathematics, or a similar domain; Good knowledge in mechanics, numerical methods and programming; Interested by biomedical engineering, even no specific skills in this field are expected; Ability to work in a multidisciplinary, creative environment and interact with experts from different areas; Full professional proficiency in both written and spoken English, knowledge of French is advantageous.

Work context. The PhD candidate will work within the Biomechanics team of the Laboratory of Multiscale Modelling and Simulation (MSME, UMR 8208 CNRS) at the University Paris-Est Créteil (located about 10 km from Paris centre). The team is one of the recognized leaders in the research domain. This PhD programme will be part of the project SkinImpact, funded by "Agence National de la Recherche " (ANR) in collaborating with the ENSTA Paris, Hospital Henri Mondor and the start-up Impactell (www.impactell.fr). Strong interaction with experimental scientists (Hospital Henri Mondor), applied mathematicians (ENSTA Paris) as well as biomedical engineers (ImpactTell) will be expected to validate the proposed methods.

The PhD candidate may also have opportunities to participate to national/international conferences and/or benefit visiting doctoral fellowships in universities abroad during her/his PhD program.

Keywords. Biomechanics; Soft tissue, Skin, Impact testing; Finite element, Reduced-order model; Machine learning.

Salary. The net salary will be about 1800 €/month. This salary may be complemented by assisting to some teaching tasks.

Application. Send your CV, motivation letter, last 3 year transcripts and references with contact information to: Vu-Hieu Nguyen : vu-hieu.nguyen@u-pec.fr ; Salah Naili : naili@u-pec.fr