Internship offer
M2 Musculo-Skeletal system, Locomotion, Exercise (MuSkLE)

Title of the Internship: Finite element modelling of the behaviour of spastic muscles

Laboratory (name, n°, website): Laboratory of biomechanics an impact mechanics (LBMC, UMR_T9406), https://lbmc.univ-gustave-eiffel.fr/en/

Research team (name, website): « Maintaining good health » theme, https://lbmc.univ-gustave-eiffel.fr/en/recherche-1/translate-to-english-themes-de-recherches/translate-to-english-maintenir-le-corps-en-bonne-sante

Supervisor to contact (name, email address): Zeinab AWADA, zeinab.awada@univ-lyon1.fr

Project description including a short introduction, aim/objectives and methods/approach to be used

Spasticity is a common and clinically relevant consequence of central nervous system disorders, such as multiple sclerosis, cerebral palsy, spinal cord injury, stroke, and traumatic brain injury. It is classically defined as a velocity-dependent increase in muscle tone due to abnormal sensorimotor integration, leading to excessive resistance to passive joint motion. Beyond its neurological origin, spasticity significantly impairs mobility, postural control, and balance, and restricts daily activities such as sit-to-stand transfers, dressing, and personal hygiene.

Recent studies indicate that spasticity cannot be explained solely by reflex hyperexcitability. It rather results from a coupled neuro-musculoskeletal adaptation involving structural and functional remodeling of muscle tissue, including:

- Altered muscle microstructure
- Changes in intrinsic mechanical properties
- Intramuscular fibrosis and increased connective tissue content
- Remodeling of fascicular architecture
- Increased passive stiffness
- Strong spatial heterogeneity of mechanical behavior

These mutli-scale alterations jointly drive the abnormal mechanical response of spastic muscle under passive and active loading.

Experimental techniques such as shear wave elastography and myotonometry have enabled in vivo characterization of muscle mechanics. However, computational biomechanical models remain essential to bridge the gap between clinical observations, experimental measurements, and the underlying mechanical mechanisms governing internal stress distributions and strain fields. In spasticity, where neuromuscular interactions are complex and only partially accessible, numerical modeling constitutes one of the few frameworks capable of providing a coherent, mechanistically grounded and testable interpretation of the observed phenomena. It is also highly relevant for clinical applications such as rehabilitation, botulinum toxin injections, and surgical planning.

Despite this need, relatively few models explicitly describe spastic muscle mechanics. Most rely on simplified homogeneous hyperelastic formulations, neglecting key features such as nonlinear viscoelasticity, structural heterogeneity, anisotropy, poro-mechanical effects, and tissue remodeling.

The objective is therefore to develop a theoretical and numerical model capable of predicting the mechanical behavior of spastic muscle. This model will integrate, in a coupled framework, the physiological origin of spasticity, tissue structural alterations, activation dynamics, and muscle anisotropy.

The internship will include:

- A critical review of the state of the art in spastic muscle biomechanics
- The initial development of a constitutive model based on a hyperelastic formulation coupled with an equation describing the onset or origin of spasticity.

This work will serve as a foundation for a future PhD focused on multiscale, mechanistically informed modeling of spastic muscle mechanics.

References:

- Saadat F., Son J., Rymer W. Z., Lee S. S. M., 2018. Frequency Dependence of Shear Wave Velocity in Stroke-Affected Muscles During Isometric Contraction- Preliminary Data. Annu Int Conf IEEE Eng Med Biol Soc., 2292-2295. https://doi: 10.1109/EMBC.2018.8512857.
- Belghith K., Aghaei A., Maktouf W., Zidi M., 2025. Assessment of Stress Distributions in a Skeletal Muscle Affected by Post-Stroke Spastic Myopathy, Innovation and Research in BioMedical engineering, 46 (6). https://doi.org/10.1016/j.irbm.2025.100918.
- Raghavan P., 2025. Muscle physiology in spasticity and muscle stiffness. Toxicon, 259:108350. https://doi: 10.1016/j.toxicon.2025.108350.
- González G., Marsden J., Besinis A., Borja P., Gunn H., 2026. Modeling spasticity: a systematic review. Prog Biomed Eng (Bristol), 16;8(2). https://doi: 10.1088/2516-1091/ae3aed.

Skills required: Solid continuum mechanics, Geometrical nonlinearity, Finite Element Modeling