PhD Student M/F – TCAT multiscale mechanobiological modelling and clinical evaluation in prosthetic sockets (TWIN-IT WP3+WP5)

Location
ENSAM Paris (70 %)
TIMC Grenoble (15 %)
I2M Bordeaux (15 %)

Recruitment type
Doctoral contract (fixed-term)

Position available from
01/09/2026

Application
https://emploi.cnrs.fr/Offres/Doctorant/UMR5525-YOHPAY-003/Default.aspx

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Application link

https://emploi.cnrs.fr/Offres/Doctorant/UMR5525-YOHPAY-003/Default.aspx

Position environment

The doctoral project is embedded in ***TWIN-IT***, a research programme funded under the French government's France 2030 initiative **(PEPR Digital Health, 2026-2030)**, and addresses a challenge shared by its 8 partners (**ENSAM, CNRS-TIMC, CNRS-LBTI, Mines Paris-PSL, CEA-Leti, Fondation Hopale, Pôle Saint-Hélier, PROTEOR**): ***How can mechanical interfaces (prostheses, orthoses, exoskeletons, cushions) be designed to maximise biomechanical function while protecting the viability of the soft tissues?*** Current tools can estimate interface loads (pressure, shear) or internal strains, but cannot predict injury. The reason is fundamental: biological tissues do not only respond to mechanical loading, they repair, adapt, and undergo inflammatory remodelling.

The central hypothesis of the TWIN-IT project is that ***the mechanisms underlying tissue injuries are predictable, provided they are characterised at the right scale, modelled, and confronted with clinical reality***. If the experimental data confirm this, it will be possible to shift from a reactive approach (the injury has already occurred) to active prevention (it has been anticipated), opening the way for a new generation of devices. The project is structured around five tightly coupled Work Packages (WPs) **(Figure 1 below)**.

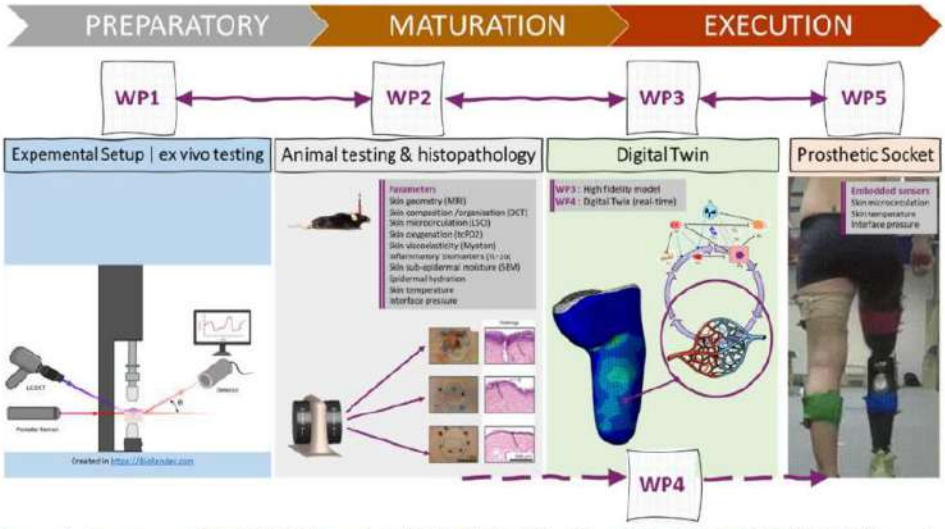

Figure 1: Structure of the TWIN-IT project (PEPR Digital Health, 2025–2029): WP1 (ENSAM): ex vivo platform combining controlled loading, LC-OCT and Raman spectroscopy. WP2 (CNRS-LBTI): extension to the living murine model (inflammation, repair, neurovascular). WP3 (ENSAM–TIMC): high-fidelity model (deformation, O_2, inflammation). WP4 (Mines Paris-PSL): real-time reduction via hybrid ROM-nets. WP5: digital twin in an instrumented prosthetic socket – real-time prediction of tissue risk, evaluated in N=12 transfemoral amputees.

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WP1 (ENSAM) aims to study the simultaneous mechano-biochemical response of tissue under controlled mechanical loading *ex vivo*, through the construction and use of a platform combining controlled loading, LC-OCT imaging and Raman spectroscopy. **WP2** (CNRS-LBTI) aims to extend this approach to living tissue in a murine model *in vivo*, in order to study the coupling with biology and, in particular, the impact of inflammation, repair and neurovascular regulation. **WP3** (ENSAM–TIMC) uses these data to build a high-fidelity model coupling tissue deformation, oxygen transport and inflammatory cascades. **WP4** (Mines Paris-PSL) aims to enable real-time computation by exploiting model reduction methods (hybrid ROM-nets, machine learning). **WP5** aims to deploy a digital twin platform linking, **in real time**, the measurements from embedded sensors in the socket to estimates of tissue viability via the ROM of the high-fidelity model developed in WP3–WP4. Embedded sensors will measure interface pressure, skin microcirculation and temperature; ***the digital twin will predict in real time the unmeasured quantities (internal deformation, local hypoxia, damage risk) and assess the transition between repair and irreversible injury. This two-way link between the physical and digital systems will not only enable monitoring but also real-world intervention: alerting the patient or clinician, adapting the device, modifying the wearing protocol - all before the injury appears.*** This approach will be evaluated under real clinical conditions in a cohort of N=12 transfemoral amputees.

The methods developed in TWIN-IT are directly transferable to all situations where a mechanical interface loads biological tissue over a sustained period. The anticipated impacts extend to clinicians (an early decision-support tool, seeing the injury before it appears), rehabilitation professionals (personalisation of interfaces based on the patient's tissue profile), learned societies (mechanistic criteria to revise prevention guidelines currently based on empirical thresholds), and institutions (a design framework grounded in active tissue protection).

Main missions and activities

Within the scope of your role, you will be responsible for the following missions and activities:

- **WP3: Task 3.1**: : Implement in FEniCSx a two-compartment model (interstitial fluid + blood) grounded in the **TCAT framework** (**Thermodynamically Constrained Averaging Theory**), a multiphase modelling approach for biological porous media developed over several years in collaboration with Giuseppe Sciumè (I2M, Bordeaux), and whose foundations were established in the PhD work of Stéphane Urcun (2022), Thomas Lavigne (2025) and Carla Cornillon (ongoing). This model will be calibrated on data collected in WP1 and WP2 and extended to include O_2 transport (reaction-diffusion coupled to Darcy flow), hypoxic cell death and IL-1α release (ODE kinetics).
- **WP3: Task 3.3** : Conduct a Sobol sensitivity analysis to identify the 5 dominant model parameters and establish the personalised damage threshold envelope
- **WP5: Task 5.1** : Build personalised FE models for N=12 transfemoral amputees; optimise sensor placement based on the WP3 Sobol analysis
- **WP5: Task 5.2** : Coordinate and carry out **clinical data collection** (N=12 participants, instrumented protocol: F-Socket, laser Doppler, tcPO2, temperature) at the **Fondation Hopale** and **Pôle Saint-Hélier sites**, in collaboration with CEA (instrumentation)

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- **WP5: Task 5.3** : Evaluate the WP3 digital twin predictions against physiological measurements (tcPO2, microcirculation); refine via Bayesian inference on patient-specific parameters; evaluate the WP4 ROM-net (Mines Paris-PSL) on residual limb geometries
- **Contribute to TWIN-IT deliverables** : open-source code library deposition, scientific publications, biannual reports

Regular travel expected: Paris–Grenoble (monthly), clinical sites (~4/year), consortium meetings (~2/year) and scientific conferences

Candidate profile

Qualifications and professional experience:

Holder of a Master's degree (5 years of higher education) in computational mechanics, applied mathematics, biomedical engineering or a related discipline, you have experience in finite element modelling, poromechanical modelling and mechanical characterisation.

Knowledge and technical skills:

- Proficiency with mechanical testing systems (compression, tension, biaxial) and force-displacement data acquisition
- Skills in mechanical design (CAD, prototyping)
- Python programming (numpy, scipy, scikit-learn, matplotlib) for spectral and mechanical data analysis
- Knowledge of soft tissue biomechanics (viscoelastic, hyperelastic, poroelastic behaviours)
- Knowledge of porous media mechanics and multiphase models; interest in mechano-biochemical coupling
- Knowledge of reaction-diffusion models or biochemical kinetics (O2 transport, inflammatory signalling)
- Ability to build personalised FE models and communicate results to a clinical audience

Soft skills:

- Mobility and adaptability for a co-supervised PhD with regular Paris–Grenoble travel and visits to clinical sites
- Ability to bridge computational modelling (WP3, Paris/Grenoble) and real-world clinical evaluation (WP5, Berck-sur-Mer, Rennes) within a coherent translational approach
- Autonomy, scientific rigour and curiosity for multiscale mechanobiology and pressure ulcer prevention
- Excellent English (working language) and French; ability to communicate technical results to a non-specialist clinical audience