Politecnico di Torino

CIVIL AND ENVIRONMENTAL ENGINEERING

Ammin/UniTrento/DISEG - Structural Mechanics of Soft Tissues and Biopolymer-Based Systems for Load-Bearing and Repair Applications

Funded By	UNIVERSITA' STUDI TRENTO [P.iva/CF:00340520220] Politecnico di TORINO [P.iva/CF:00518460019] Dipartimento DISEG
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Context of the research activity	This PhD thesis investigates the structural mechanics of soft biological tissues and biopolymer-based systems for load-bearing and repair applications. Experimental characterisation and advanced nonlinear constitutive modelling are employed to capture tissue microstructure, time-dependent behaviour, and degradation effects. The work supports the development of high-fidelity in-silico models and digital twins for medical device design and performance evaluation.
	The research activity is situated at the intersection of structural mechanics and biomedical engineering, with a specific focus on the mechanical behaviour of soft biological tissues and biopolymer-based systems employed in load-bearing and tissue repair applications. Soft tissues such as tendons, ligaments, and abdominal wall muscles exhibit complex mechanical responses governed by their highly specialised microstructures and time-dependent behaviour. An accurate understanding and modelling of these characteristics are essential for improving clinical outcomes and advancing the design of innovative medical devices. The primary objective of this research is to develop reliable and high-fidelity in-silico models capable of describing the nonlinear, anisotropic, and time-dependent mechanical behaviour of soft tissues and biodegradable polymers under physiological and non-physiological loading conditions. To achieve this goal, the research integrates experimental mechanical characterisation with advanced constitutive modelling within the framework of nonlinear continuum mechanics. Experimental activities are conducted to obtain mechanical data from both biological tissues and commercially available biopolymers used in medical device manufacturing. These tests are designed to capture elastic, viscous, and inelastic responses, as well as the influence of microstructural features such as fibre orientation and distribution. The experimental results form the basis for the formulation, calibration, and validation of constitutive laws that

Objectives	accurately represent tissue- and material-specific behaviour. A key focus of the research is the development of fibre-reinforced constitutive formulations to model tendons and ligaments, accounting for their intrinsic hierarchical microstructure and characteristic nonlinear response. Different modelling strategies are explored to describe viscous effects, ranging from linear to nonlinear viscosity, enabling the assessment of their impact on mechanical behaviour and predictive capability. In parallel, constitutive models for biopolymers are developed and extended to capture viscoplasticity, damage, and degradation phenomena relevant to bioresorbable medical devices. Another central objective is the application of the developed constitutive models to the creation of digital twins for soft tissues and tissue–device systems. These digital twins are implemented within numerical simulation frameworks, such as finite element analysis, to evaluate the performance, safety, and reliability of innovative medical devices designed for tendon and abdominal wall repair. The simulations support the assessment of device –tissue interaction, load transfer mechanisms, and the mechanical environment experienced during healing. From a translational perspective, the research aims to address specific clinical needs identified by surgeons, particularly in the context of tendon injuries and abdominal hernia repair. By providing validated computational tools, the research supports preclinical evaluation, optimises device design, and contributes to reducing postoperative complications, recurrence rates, and recovery times. Moreover, the adoption of advanced in-silico modelling aligns with regulatory requirements and promotes the reduction of animal testing in accordance with the 3Rs principle. Overall, the research activity seeks to advance the state of the art in constitutive modelling and computational biomechanics, fostering a mechanistic understanding of soft tissue behaviour and enabling the development of safer, more effective biopolymer-based medical devices for load-bearing and repair applications. ---

Skills and competencies for the development of the activity	Technical and Experimental Skills • Mechanical testing of soft tissues and biomaterials • Sample preparation and handling of biological tissues • Biomechanical instrumentation and sensors Computational and Modelling Skills • Nonlinear continuum mechanics and constitutive modelling of biological tissues • Finite Element Analysis (FEA)