

Special Issue “Biomechanics of Soft and Hard Tissues”

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1. Introduction

The field of biomechanics has witnessed a profound evolution over the past decades, increasingly serving as a vital bridge between engineering principles and biological sciences. As biomedical challenges become more complex and patient-specific, the integration of mechanical analysis and modelling with medical research has become indispensable. This Special Issue, “Biomechanics of Soft and Hard Tissues”, hosted by *Applied Sciences*, reflects this interdisciplinary landscape, bringing together novel studies that span experimental testing, constitutive modelling, and advanced fabrication techniques such as additive manufacturing.

Soft and hard biological tissues, while differing significantly in their structure and mechanical behaviour, both play critical roles in maintaining physiological function and structural integrity. From the compliant nature of ligaments and skin to the load-bearing stiffness of bone and dental tissues, these materials respond to mechanical stimuli in highly nonlinear and often hierarchical ways [1–3]. Understanding and replicating these responses remain central goals in biomedical engineering, with implications ranging from injury prevention and prosthetic design to tissue engineering and regenerative medicine [4–6].

In recent years, a discernible trend has emerged in the biomechanics community: the drive to integrate sophisticated experimental methodologies with advanced computational modelling [7,8]. This synergy enables not only more accurate simulations of physiological behaviour but also the development of predictive tools for personalised medicine. At the same time, advances in materials science and fabrication technologies have unlocked new pathways for replicating or replacing biological tissues with unprecedented fidelity [9,10]. Additive manufacturing, in particular, has become a game-changing tool, allowing for the production of anatomically accurate, mechanically tuneable, and biocompatible structures that were previously impossible to fabricate.

This Special Issue captures the state-of-the-art in this rapidly evolving field. The nine original contributions selected for publication reflect the diversity and depth of current research in biomechanics. They explore innovative strategies for mechanical characterisation of tissues and biomaterials, propose new constitutive frameworks for describing nonlinear and anisotropic behaviours, and demonstrate the practical integration of emerging manufacturing methods. The studies also collectively highlight the importance of rigorous validation—whether through in vitro testing, in silico simulations, or comparisons with clinical data.

One of the central themes that emerges from this collection is the necessity of interdisciplinary collaboration. No single field—whether mechanical engineering, materials science, biology, or clinical medicine—can alone address the complexity of the mechanical behaviour of living tissues. The contributions in this Special Issue exemplify collaborative



Received: 8 August 2025

Accepted: 12 August 2025

Published: 12 August 2025

Citation: Berardo, A.; Surace, C. Special Issue “Biomechanics of Soft and Hard Tissues”. *Appl. Sci.* **2025**, *15*, 8902. <https://doi.org/10.3390/app15168902>

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efforts that draw on complementary expertise: combining detailed microstructural analysis with continuum modelling, or merging experimental mechanics with biomedical imaging and design.

This Special Issue also emphasises the growing importance of multiscale and multi-physics approaches. Similarly, the mechanical behaviour of tissues is often governed not only by macroscopic forces but also by microscale architecture, cellular activity, and even molecular interactions. Addressing these phenomena requires new modelling paradigms and experimental protocols, which the articles in this Special Issue begin to explore.

Moreover, the inclusion of additive manufacturing across multiple contributions signals an important direction for the future of biomedical engineering. 3D printing techniques enable not only the fabrication of patient-specific implants and scaffolds but also the realisation of mechanical gradients and anisotropic properties that are characteristic of native tissues. Importantly, the development of bioinspired and biomimetic materials through such technologies holds promise for improving long-term clinical outcomes, particularly when integrated with tailored mechanical and biological cues.

As we consider the broader implications of this Special Issue, several key insights emerge. First, mechanical testing remains a cornerstone of biomechanics yet it must continuously evolve to capture the complex behaviour of biological tissues under physiological and pathological conditions. This requires both methodological innovation and greater standardisation across laboratories and disciplines. Second, constitutive modelling is entering a new phase, where phenomenological laws are increasingly complemented by structurally informed, micro–macro approaches. These developments are enabling more realistic simulations of tissue deformation, growth, and remodelling, with applications ranging from surgical planning to implant optimisation. Third, fabrication techniques are becoming an active design variable, not just a final step in prototyping. The ability to control mechanical properties through layer-by-layer deposition or material blending introduces a new design space in tissue engineering and biomechanics, one that integrates mechanics from the very beginning of the process.

Despite the remarkable advances represented in this Special Issue, challenges remain. Experimental reproducibility, model validation, and clinical translation all require continued attention. Likewise, ethical and regulatory considerations must be addressed as personalised and mechanically tailored solutions move closer to clinical deployment. These challenges, however, should not deter innovation; rather, they should encourage closer cooperation between researchers, clinicians, and industry stakeholders.

2. Overview of Contributions

The contributions collected in this reprint converge on a common objective: to deepen our understanding of the biomechanical behaviour of soft and hard tissues through a combination of experimental methods, computational modelling, and engineering innovation. Although diverse in focus, the articles form a cohesive narrative that highlights three key research threads: mechanical characterisation of biological tissues, modelling and simulation for physiological understanding and clinical insight, and the development of biomimetic or engineered solutions for tissue repair and regeneration.

A first group of papers is centred on the mechanical characterisation of biological tissues, offering valuable data and insights into the structural and functional complexity of human anatomy. Berardo et al. [contribution 4] conduct a unique case study analysing multiple soft tissues from the same human male donor within the lower urinary tract, providing comparative mechanical data essential for pelvic modelling. Similarly, Peña-Trabalon et al. [contribution 3] assess surrogate models for meniscal root repair by comparing porcine and aged human tissues, contributing critical guidance for translational orthopaedic biomechan-

ics. Sahinis and Kellis [contribution 8] use ultrasound imaging to explore the relationship between hamstring muscle and aponeurosis thickness, advancing our understanding of muscle–tendon interactions relevant to both sports science and rehabilitation.

The second thematic thread involves computational modelling and physiological simulation, where biomechanical methods are used to investigate complex biological functions and pathologies. Rădulescu et al. [contribution 1] propose a novel radiographic–stochastic model (URCOTEBS) to describe the complementary states of health and disease in the D-organ and middle-ear mucosa, combining imaging data with probabilistic modelling to support diagnostic applications. Minniti et al. [contribution 9] simulate blood flow in the aorta and right coronary artery through computational fluid dynamics, providing insights into vascular behaviour under both physiological and pathological conditions. Yamin et al. [contribution 7] perform a biomechanical stress analysis on the ankle joint under varying inclinations, contributing to the understanding of joint loading during posture and movement.

A third group of contributions focuses on biomimetic design and regenerative approaches, integrating biomechanics with fabrication technologies. Dolino et al. [contribution 2] present a synthetic 3D-printed cartilage scaffold for the human knee, combining microstructural design, finite element modelling, and mechanical testing to develop a biomimetic solution for joint repair. Belgio et al. [contribution 6] explore 3D bioprinting to recreate the extracellular microenvironment necessary for retinal regeneration, demonstrating how mechanical cues can be engineered to support cell function. Finally, Burgio et al. [contribution 5] offer a comprehensive review of mechanical stapling devices used in soft tissue repair, assessing commercially available solutions and providing a foundation for future improvements in surgical device design.

3. Concluding Remarks

The studies published in this Special Issue reflect the wide scope and interdisciplinary depth of current biomechanical research. Together, these studies embody the interdisciplinary nature of modern biomechanics. They demonstrate how experimental, computational, and engineering approaches can be successfully integrated to investigate biological complexity, support clinical decision-making, and design therapeutic solutions. Whether through characterising native tissue properties, simulating physiological processes, or engineering replacements, each contribution reinforces the importance of biomechanics at the interface of medicine, biology, and technology.

In summary, they illustrate the essential role of biomechanics in addressing challenges at the interface of engineering, biology, and medicine. We hope that this collection will serve as a valuable reference and inspire new collaborations in the rapidly evolving field of tissue biomechanics.

Author Contributions: Conceptualisation, A.B. and C.S.; methodology, A.B. and C.S.; investigation, A.B.; data curation, C.S.; writing—original draft preparation, A.B.; writing—review and editing, C.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: We extend our sincere gratitude to the contributing authors and peer reviewers for their dedication and scholarly excellence. We also thank the *Applied Sciences* Editorial Office for their support throughout the publication process.

Conflicts of Interest: The authors declare no conflicts of interest.

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