EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

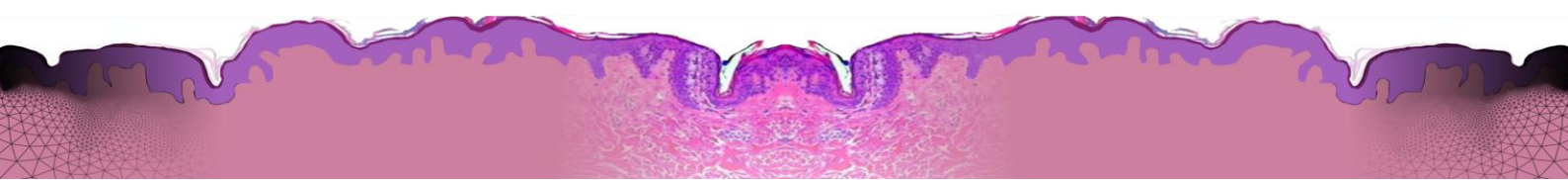
BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

Program

Thursday 9th

09:00	
09:10	
09:20	Welcoming participants
09:30	Opening speech and coffee time
09:40	
09:50	
	Session 1 - Connecting cell and tissue mechanics
10:00	*1-1. Philipp Thurner – Collagen mechanics from the molecular to the mesoscale*
10:10	
10:20	*1-2. Jean-Marc Allain – Multiscale mechanics of human cornea*
10:30	
10:40	*1-3. Cristina Cavinato – Local deformation mechanisms in fibrous soft tissues: A 3D experimental approach*
10:50	
11:00	*1-4. Beatrice Bisighini – Multiscale assessment of the mechanical behaviour of perineal tissues via experimental testing and structural analysis*
11:10	
11:20	*1-5. Edoardo Mazza – On the mechanome of human dermis*
11:30	
11:40	*1-6. Sandra Loerakker – Computational models to understand and advance cardiovascular regeneration*
11:50	
12:00	Lunch break
12:10	
12:20	
12:30	
12:40	
12:50	
13:00	
13:10	
13:20	
13:30	Session 2 - Round table “Measuring More to Understand Less?”
13:40	
13:50	
14:00	
14:10	
14:20	
14:30	Break
	Session 3 - Clinical and industrial applications of soft tissue research
14:40	*3-1. Andreas Wittek – Predictive value of ultrasound strain imaging for AAA rupture risk and wall strength*
14:50	
15:00	*3-2. Christopher Blase – In vivo validation of 4D-US strain imaging based material identification of AAA tissue*
15:10	
15:20	*3-3. Chiara Fontanella – Biomechanics of the human large bowel: experimental testing and constitutive modelling*
15:30	
15:40	*3-4. Alice Berardo – From geometry to function: 3D-printed cellular structures for adipose tissue engineering applications*
15:50	
16:00	Break
16:10	
16:20	
	Session 4 - Innovative experimental techniques of tissue characterisation
16:30	4-1. Stéphane Avril – Full-field 3D strain measurement in soft tissues
16:40	
16:50	4-2. Nathanaël Connesson – In vivo bilayer material young moduli identification using suction only
17:00	
17:10	4-3. Noémie Briot – Addressing initial condition uncertainty in large-deformation testing of soft tissues
17:20	
17:30	4-4. Morgane Evin – Traction tests of ovine and porcine mitral chordae
17:40	
17:50	4-5. Laure-Lise Gras – The bias extension test to measure shear on human iliotibial band samples
18:00	
18:10	



EUROPEAN MECHANICS SOCIETY

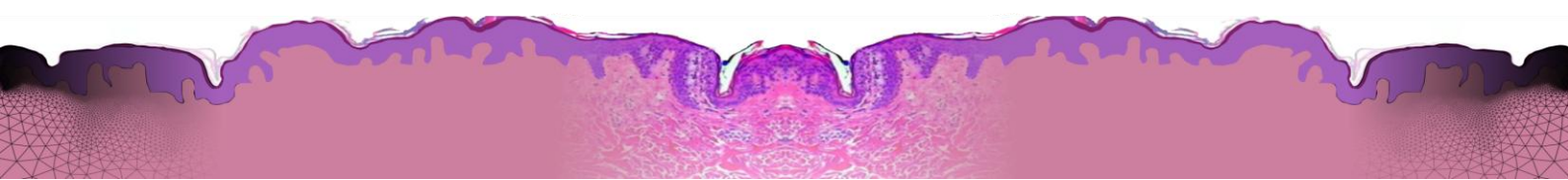
COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

Friday 10th

08:30	Welcoming participants
08:40	
08:50	
	Session 5a - Junior scientists' showcase
09:00	*5-1. Carla Cornillon – The impact of large deformation in brain cancer modeling*
09:10	
09:20	*5-2. Chloé Dupray – Mechanical modelling of the external anal sphincter under tensile loading for birth-injury prediction*
09:30	
09:40	*5-3. Dorian Sweidy – Mechanical characterization and numerical approach of porcine septal myocardium*
09:50	
10:00	*5-4. Arnaud Gisquet – Linking hemodynamics and wall mechanics to model aneurysm growth*
10:10	
10:20	Break
10:30	
10:40	
	Session 5b - Junior scientists' showcase
10:50	*5-5. Ombeline Juteau – Effect of freezing on the mechanical behaviour of whole organ – Application to the swine lung parenchyma*
11:00	
11:10	*5-6. Maeva Lamant – Role of subcutaneaous adipose tissue in pressure ulcer risk: Viscoelastic propertied under uniaxial compression*
11:20	
11:30	*5-7. Kundry Reibel – Effect of geometric heterogeneity on the apparent mechanical anisotropy of atrial appendages*
11:40	
11:50	*5-8. Stella Sublet Vial – Collagen organisation in Porcine Spinal Meninges: A Benchmark of SHG image analysis*
12:00	
12:10	Lunch break
12:20	
12:30	
12:40	
12:50	
13:00	
13:10	
	Session 6 - Advanced constitutive models of soft tissues
13:20	*6-1. Simon Le Floc'h – On the validity of incompressibility and mechanical homeostasis assumptions in cartilage growth models*
13:30	
13:40	*6-2. Sébastien Laporte – Almost incompr(hen)ssible? Careful, not that much!*
13:50	
14:00	*6-3. Thomas Lavigne – Poromechanics to investigate the impact of mechanical loading on human skin micro-circulation*
14:10	
14:20	*6-4. Kevin Linka – Predicting and understanding soft tissue mechanics by data-driven material modeling*
14:30	
14:40	*6-5. Eduard Rohan – Multiscale modelling of perfused soft tissues in wave propagation and transport problems*
14:50	
15:00	*6-6. Mathias Peirlinck – Neural constitutive modelling for soft tissues: Supervised discovery, Bayesian uncertainty and finite element deployment*
15:10	
15:20	Break
15:30	
15:40	
	Session 7 - Current challenges and future directions in soft tissue characterisation
15:50	*7-1. Jérôme Molimard – Experimental study of structural changes in subcutaneous tissue during large volume injection*
16:00	
16:10	*7-2. Baptiste Pierrat – Intramural injection on porcine aorta: Injection rate modulates dissection propagation thresholds*
16:20	
16:30	*7-3. Jérémie Girardot – Discete fiber-network modelling of soft tissue*
16:40	
16:50	*7-4. Simon Le Floc'h – Preliminary results on a model material for characterizing hydro-chemical-mechanical couplings*
17:00	
17:10	*7-5. Dana Solav – In vivo multimodal indentation-based identifiability of soft tissue material parameters*
17:20	
17:30	Closing ceremony
17:40	
17:50	
18:00	



Social events

Welcome Reception

We are delighted to invite all participants to a Welcome Reception on **Wednesday 8th April, starting from 6:00 PM**. The event will take place at **Le Grand Huit**, a vibrant and creative venue located in the heart of Rennes.

Address: Le Grand Huit, 20 rue Pierre Martin, 35000 Rennes.

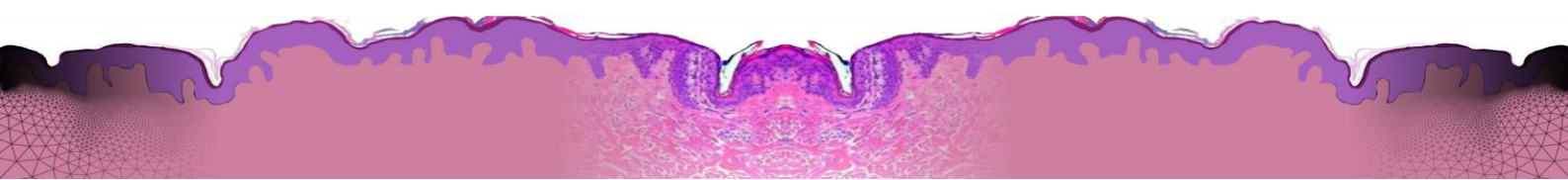
Website: https://legrandhuit-rennes.fr/

Conference Diner

The conference Dinner will be held on **Thursday, 9 April, starting at 7:30 PM**. We are delighted to invite all attendees to **La Taverne de la Marine**, a renowned establishment located in the heart of Rennes. This evening will provide a wonderful opportunity to enjoy local gastronomy in a warm, historic setting.

Adress: La Taverne de la Marine, 2 place de Bretagne, 35000 Rennes.

Website: https://www.lataverne delamarine.com/



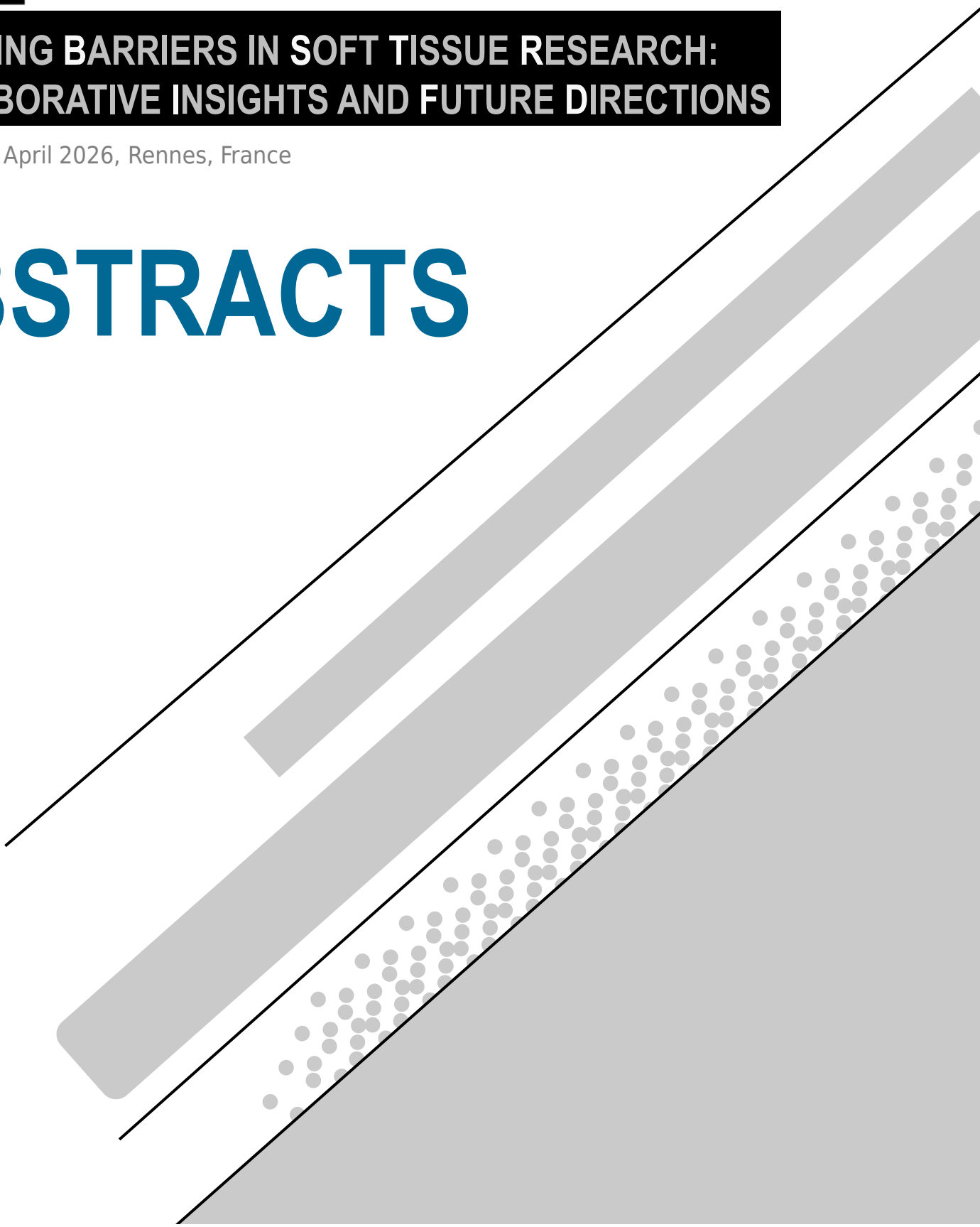
EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

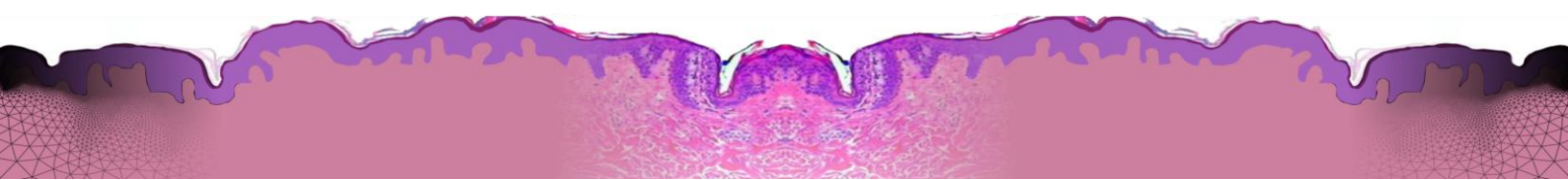
9 April – 10 April 2026, Rennes, France

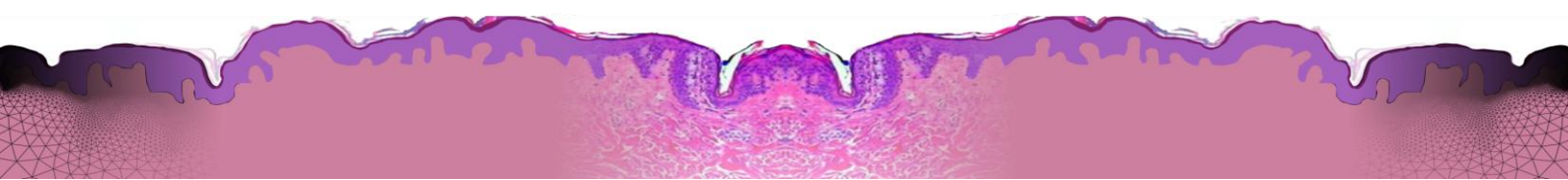
ABSTRACTS



Inria · Rennes Métropole · Région Bretagne · Université de Rennes · société de BIOMECANIQUE

LIST OF ABSTRACTS





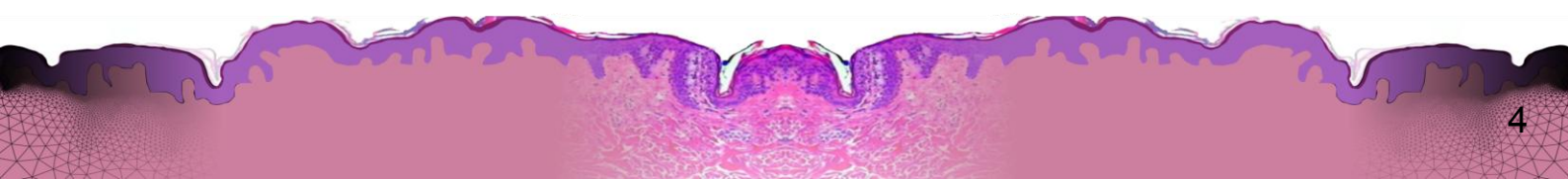
Presentation

Biological soft tissue characterisation is a key research area with broad implications in numerous fields, including the design of biocompatible devices, the development of tissue-mimicking materials, the study of interactions with external devices, and the prevention, diagnosis, and treatment of pathologies and injuries. The complexity of this field stems from the inherently **multiscale** nature of soft tissues, which are structured through a complex hierarchical organisation. These materials also exhibit **multiphysics** interactions, where biological, mechanical, and biochemical processes are tightly coupled.

At the macroscale, these intricate interactions give rise to the diverse mechanical properties of soft tissues, such as **non-linear hyperelasticity, heterogeneity, anisotropy, viscoelasticity, and poroelasticity**. Moreover, soft tissues exhibit dynamic behaviours like **growth**, **remodelling**, and **adaptation** to external loads, further complicating their characterisation. Addressing these challenges requires a multidisciplinary approach integrating complementary expertise in experimental and numerical methodologies. On the **experimental** side, techniques span from *in vitro* mechanical tests to *in vivo* approaches such as indentation, full-field optical methods, and advanced imaging techniques. On the **numerical** side, methods involve **optimisation algorithms, inverse problem-solving, uncertainty quantification, constitutive modelling, and multi-scale simulations**. Given the breadth and complexity of this research, fostering **collaborative synergies** across disciplines is essential.

This colloquium will serve as a **dedicated platform for interdisciplinary exchange**, bringing together experts in biomechanics, materials science, computational modelling, and medical applications. Participants will discuss **innovative experimental designs, cutting-edge numerical techniques, and strategies for integrating multi-scale data**, with an emphasis on bridging theoretical advancements and practical applications. By transcending traditional disciplinary boundaries, this collaborative effort aims to **advance our understanding of soft tissue mechanics** and accelerate progress toward impactful **industrial and clinical applications**.

The ambitious program of this colloquium proposal (detailed below) aims to answer the following questions: How do cellular mechanics influence the macroscopic behaviour of soft tissues? How can experimental data acquisition be improved to provide more accurate, exhaustive and real-time data? What are the most advanced constitutive models describing the complex behaviour of soft tissues? How can advances in soft tissue mechanics be translated into improved clinical treatments and diagnostic tools? What are the major challenges remaining in research, and how can interdisciplinary collaborations be promoted to accelerate progress?



COLLAGEN MECHANICS FROM MOLECULAR- TO THE MESOSCALE

Philipp J. Thurner (1), Magdalena Fuchs (1), Andreas Rohatschek (1), Alessandra Carriero (2), Mathis Uelner (1), You-Rong Chiang (1), Marco Röcklinger (1), Christian Hellmich (3), Bruno Zappone (4), Orestis G. Andriotis (1)

1. Institute of Lightweight Design and Structural Biomechanics, TU Wien, Vienna, Austria; 2. City College of New York, NY, USA; 3. Institute for Mechanics of Materials and Structures, TU Wien, Vienna, Austria; 4. Consiglio Nazionale delle Ricerche - Istituto di Nanotecnologia, Rende, Italy

The protein family of collagens make up about 30% of the protein mass in the human body. Collagens provide passive mechanical function to tissues and organs, act as a cell scaffold and translate internal and external loads into feedback for mechanosensory cells. At the level of cell-collagen interactions, collagen fibrils offer direct attachment motifs, hence, fibril mechanics are an important input for mechanotransduction. Collagen fibrils, predominantly, resist tensile loading and at the tissue level provide a wide range of mechanical properties depending on tissue type. In recent years, we have conducted several studies investigating these properties and their alterations due to age and pathology [1-4]. Given the complex hierarchical architecture of tissues and their structure-mechanics interdependence, we have developed a toolbox to assess the mechanics across scales. In this context, we also developed a nanotensile testing device that allows mechanical characterization (ramp, nanoscale dynamic mechanical analysis, creep and stress relaxation) of individual collagen fibrils [5]. Using our toolbox for mechanical testing across the scales enables us to report the impact of pathology, enzymatic and non-enzymatic cross-linking and hydration on collagen fibril and microtissue mechanics. For example, stiffening of collagen fibrils in fibrotic disease [2], upon enzymatic and non-enzymatic cross-linking [3, 6], or upon dehydration [4]. In addition, our data show the nonlinear viscoelastic behaviour of collagen fibrils that remain largely unexplored [4, 7]. Furthermore, highly cross-linked fibrils exhibit failure strains of up to 35% or more [6], which can be explained by disentanglement of collagen molecules during tensile failure. At the molecular level, we recently reported experimental evidence from force spectroscopy experiments conducted on collagen molecules functionally attached to an atomic force microscopy probe [8]. Overall, while collagen fibrils manifest a range of properties and in specific cases high performance, their full mechanical behaviour across tissues remains to be elucidated.

References

1. Andriotis O. A. Et al., J. R. Soc. Interface, 12 (2015) pp. 20150701, https://dx.doi.org/10.1098/rsif.2015.0701.
2. Jones M. G. et al., eLife eLife (2018),7, e36354, https://doi.org/10.7554/eLife.36354
3. Rufin, M. et al., Acta Biomat, 189 (2024), 208-216, https://doi.org/10.1016/j.actbio.2024.08.039.
4. Andriotis O. A. et al., ACS Nano (2018), 12(4), pp. 3671-3680, https://doi.org/10.1021/acsnano.8b00837.
5. Nalbach M. et al., Rev Sci Instrum, 93, 054103 (2022), https://doi:10.1063/5.0072123.
6. Andriotis, O.G. et al., Acta Biomat, 163 (2023) 35-39, https://doi.org/10.1016/j.actbio.2022.12.008.
7. Chiang Y.-R. Et al., MAMS, under review
8. Rohatschek A. Et al. ACS Nano, 2026, https://doi.org/10.1021/acsnano.5c15873

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

MULTISCALE MECHANICS OF HUMAN CORNEA

Qian Wu (1), Chloé Giraudet (2), Jean-Marc Allain (3)

1. Laboratoire de mécanique des solides, CNRS, École polytechnique, Institut Polytechnique de Paris, Palaiseau, France

The cornea is the front part of the eye. It plays an essential role in vision, providing two-thirds of the light focusing. It is therefore important to preserve its shape, which is due to a balance between its mechanical properties and intraocular pressure. Cornea shape is deeply related to its mechanical properties, which is expected to vary laterally and in thickness. Up to now, there has been no measure of the human cornea deformation in volume when pressure is applied. We developed here a volumetric quantification of the deformation of ex-vivo human corneas under inflation [1].
By combining a swelling test with optical volume imaging methods, we observed corneal deformations during inflation test.
Strains in the plane of the cornea is in the expected range, around few percents, with a higher strain in the posterior part of the cornea. This higher deformability is partly due to the presence of a mesostructured, the Voigt striae. These striae are folds of collagen, easy to deform perpendicularly to the striae [2].
Strain in the thickness direction shows very large compression, up to 20%, with a heterogeneity in depth showing 3 regions. These regions are not necessarily associated to the collagen microstructure. However, the variation in the thickness is deeply linked to the water exchange (in *ex-vivo* tests).

References

1. Giraudet C, Wu Q, Allain JM. JMBBM; 169:107078 (2025).
2. Wu Q, Giraudet C, Allain JM, JMBBM; 160:106770 (2024).

LOCAL DEFORMATION MECHANISMS IN FIBROUS SOFT TISSUES: A 3D EXPERIMENTAL APPROACH

Cristina Cavinato (1), Elena Tomaselli (1), Dominique Ambard (1), Jérôme Sohier (2), Simon Le Floc'h (1)

1. LMGC, Univ. Montpellier, CNRS, Montpellier, France; 2. Laboratoire de Biologie Tissulaire et Ingénierie Thérapeutique, Université Claude Bernard Lyon 1, UMR 5305

In fibrous polymeric composites and soft tissues such as vascular tissues, local deformations arising from the composite structure are critical to understanding nonlinear and viscoelastic behaviors. In living tissues, cells further modulate this multiscale response, as their deformation relative to the surrounding matrix shapes their mechanobiological environment [1].
We investigated local deformation in two experimental models: (i) polycaprolactone fibers embedded in a hydrogel and (ii) ex vivo murine thoracic aortas. Composites were subjected to uniaxial tension with 3D optical coherence tomography (OCT), while aortas underwent cyclic extension–distension with synchronized OCT and two-photon microscopy, allowing separation of collagen fibers and nuclei for independent and combined analyses [2]. Local 3D strains were quantified using Digital Volume Correlation with global kinematic constraints and a multiscale pyramidal search [3]. Fiber orientation and waviness were correlated with local strains. Results reveal strain localization and nonlinear transitions detectable only via full-field 3D analysis. Microstructure influences macroscopic response, including local auxetic behavior at low load, which tend to be reduced after preconditioning. Collagen and nuclei display distinct deformation patterns, partly reflecting their spatial localization, and providing insight into how cells sense the mechanical behavior of their surrounding matrix. These findings will inform computational micromechanical models to predict tissue behavior under physiologically relevant loads.

References

1. Holzapfel GA et al., J R Soc Interface, 22 (2025).
2. Weiss D et al., Science Advances., 6(49) (2020).
3. Yang J et al., Exp Mech, 60:1147–1163 (2020).

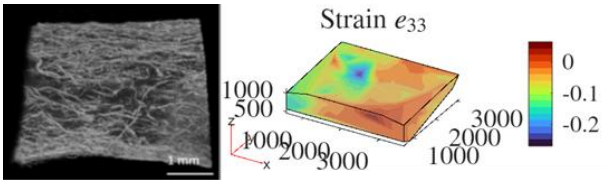


Figure 1 : OCT image of the fibrous composite model with corresponding full-field strain under uniaxial loading.

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

MULTISCALE ASSESSMENT OF THE MECHANICAL BEHAVIOUR OF PERINEAL TISSUES VIA EXPERIMENTAL TESTING AND STRUCTURAL ANALYSIS

Beatrice Bisighini[1], Cristina Cavinato[2], Sarah Iaquinta[2,3], Anne-Sophie Caro[2,3], Baptiste Pierrat[1]

1. SAINBIOSE, Mines Saint-Etienne, INSERM, Saint-Etienne, France

2. LMGC, IMT Mines Alès, Univ Montpellier, CNRS, Alès, France

3. LMGC, Univ Montpellier, CNRS, Montpellier, France

Perineal tears affect the majority of primiparous women during vaginal delivery and may involve multiple tissue layers, leading to long-term functional impairments. Despite their prevalence, the mechanical behaviour of perineal tissues remains insufficiently characterised, limiting the reliability of biomechanical models used to study childbirth-related injuries. This study provides a comprehensive multiscale characterisation of the mechanical behaviour and structural organisation of five perineal tissues using ex vivo porcine samples: skin, vaginal mucosa, anal mucosa, and internal and external anal sphincters.

Uniaxial tensile tests were performed on dog-bone specimens cut along two perpendicular directions to assess anisotropy, except for the external anal sphincter, which was tested along its principal fibre direction. Cyclic loading at increasing strain levels up to rupture was applied to reproduce labour-like loading conditions, with digital image correlation used for accurate strain measurement. Tissue mechanical responses were quantified through inverse identification of hyperelastic parameters using a Veronda–Westmann model. Mechanical testing was complemented by structural analysis across multiple scales. Two-photon excitation microscopy enabled quantitative assessment of collagen fibre organisation at the microscale, while micro-computed tomography provided three-dimensional insights into the architecture of full perineal samples.

Distinct mechanical behaviours were observed among the tissues: vaginal and anal mucosae were the stiffest, skin showed intermediate stiffness, and the sphincters were the most compliant, with marked direction-dependent behaviour in the internal anal sphincter. Structural imaging revealed tissue-specific collagen architectures consistent with these findings, while micro-CT confirmed the anisotropic architecture of the sphincters and highlighted the folded morphology of the anal mucosa and skin.

Overall, this study establishes baseline mechanical and structural markers for perineal tissues, emphasising their anisotropy, variability, and layered complexity. Future investigations will focus on characterising the high-rate, viscoelastic behaviour of these tissues.

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

ON THE MECHANOME OF HUMAN DERMIS

Anastasia Martyts (1), David Sachs (1), Raphael Jakob(1), Kim Busenhart (1), Consanza Giampietro (2),Alexander Ehret (1,2), Edoardo Mazza (1,2)

1. Institute for Mechanical Systems, Department of Mechanical and Process Engineering, ETH Zurich, Zurich, Switzerland

2. EMPA, Swiss Federal Laboratories for Materials Science and Technology, Dübendorf, Switzerland

Deformation is a key determinant of skin physiology and pathology, as evidenced by skin growth during pregnancy and in autologous tissue expansion, or by excessive scar formation in wounds under tension. However, the mechanisms of dermal cell response to deformation are not well understood, especially concerning the influence of skin elongation on the biophysical cell environment, i.e. the dermal mechanome. We developed dedicated multiaxial, time-dependent experimental protocols to characterize the mechanical behavior of human dermis, from cell to tissue length scales. These data were used to inform a multiphase constitutive model which allowed us to quantify the variations of osmotic pressure, hydrostatic pressure, interstitial fluid velocity and electric field induced by skin stretching [1]. These stimuli are related to the liquid phase of the ECM and were shown to affect the behavior of dermal fibroblasts [2].

The solid part of the ECM determines the stiffness perceived by cells exerting tractions on their environment. This was investigated using a discrete fiber network (DFN) model. The results showed a large variability of local compliance and only modest impact of global skin stretch [3]. DFN simulations further demonstrated that only a small subset of fibers contributes to global stiffness, while the majority remains unstretched, thus providing limited mechanotransductive cues. Similarly, DFN-based cell representations [4] revealed that cell-substrate interaction is governed by processes at the length scale of individual focal adhesions, which cannot be resolved using a continuum model of the cell cytoskeleton. Altogether, our findings demonstrate that quantitative investigation of the dermal mechanome requires dedicated experimental and computational approaches accounting for the heterogenous and multiphase nature of soft collagenous materials.

References

[1] Sachs D et al, 2024, A quadriphasic mechanical model of the human dermis. Biomech Model Mechanobiol. 23(4):1121-1136.

[2] Martyts A et al., 2026, Quantification of Stretch-Induced Stimuli Altering the Mechanome of Dermal Fibroblasts. J Invest Dermatol.146(1):116-129.e15.

[3] Wahlsten A et al., 2023, Multiscale mechanical analysis of the elastic modulus of skin. Acta Biomater. 170:155-168.

[4] Jakob R et al., 2024, Discrete network models of endothelial cells and their interactions with the substrate. Biomech Model Mechanobiol.;23(3):941-957.

COMPUTATIONAL MODELS TO UNDERSTAND AND ADVANCE CARDIOVASCULAR REGENERATION

Sandra Loerakker (1,2)

1. Department of Biomedical Engineering, Eindhoven University of Technology, The Netherlands;
2. Institute for Complex Molecular Systems, Eindhoven University of Technology, The Netherlands

Regenerative medicine aims to cure diseased tissues by restoring their physiological organization and thus functionality. Cardiovascular tissue engineering is a promising approach in this field, for which biodegradable scaffolds are implanted that should immediately take over the function of the diseased tissue (e.g., blood vessels, heart valves) and gradually transform into living tissue at the site of destination. Despite encouraging results, previous *in vivo* studies have demonstrated largely unpredictable results and unacceptably high failure rates. Computational models can tremendously contribute to unraveling the underlying regenerative mechanisms and identifying scaffold design criteria that ensure robust and successful cardiovascular regeneration.

In this talk, I will give an overview of the experimentally informed computational models that we developed to analyze the growth and remodeling of cardiovascular tissues, with a focus on understanding how mechanobiological processes at the (sub)cellular scale control the macroscopic properties blood vessels and heart valves. Specifically, I will show how we used our models to improve the *in vivo* remodeling of tissue-engineered heart valves [1,2], to understand the role of mechanosensitive Notch signaling in (tissue-engineered) blood vessels [3-7] and heart valves [8], and to predict the combined growth and remodeling of (tissue-engineered) heart valves [9,10].

References

1. Loerakker S et al., J Biomech; 46(11):1792-1800 (2013).
2. Emmert MY et al., Sci Transl Med; 10(440):eaan4587 (2018).
3. Loerakker S et al., PNAS; 115(16):E3682-E3691 (2018).
4. Karakaya C et al., Front Cell Dev Biol; 10:910503 (2022).
5. Van Asten JGM et al., Biomech Model Mechanobiol; 22(5):1569-1588 (2023).
6. Van Asten JGM et al. Ann Biomed Eng; doi:10.1007/s10439-025-03843-7 (2025).
7. Karakaya C et al., *in preparation*.
8. Hoursan H et al., *in preparation*.
9. Middendorp E et al., Biomech Model Mechanobiol; 23(6):1889-1907 (2024).
10. Stolk WR et al., *in preparation*.

ROUND TABLE - “MEASURING MORE TO UNDERSTAND LESS?”

Co-organised by the GDR CNRS Mécabio Santé

This special round table, initiated and coordinated by the CNRS GDR Mecabio and the Euromech 670 Organising Committee, aims to stimulate a collective reflection on current practices in soft tissue biomechanics among all colloquium participants.

Soft tissue mechanics is increasingly characterised by highly sophisticated experiments and ever more complex constitutive models. Yet, fundamental questions remain: Why do we build increasingly complex models when available data remain limited? Do we actually gain clarity or just more parameters? How far should we seek identifiable parameters and minimised uncertainty? Is a model truly validated if only specific quantities are predicted correctly?
Structured as a dynamic and interactive discussion, this session will explore central themes including:

- Model complexity versus scientific necessity
- The quest for identifiability versus physical realism
- Validation and the true scientific value of our models

Rather than seeking a simple consensus, the goal is to expose underlying assumptions, clarify methodological tensions, and encourage constructive debate across communities. This round table aims to create a space where experimentalists, theorists, and modellers can openly challenge each other’s perspectives and collectively discuss how we measure, model, and interpret soft tissue mechanics.

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

PREDICTIVE VALUE OF ULTRASOUND STRAIN IMAGING FOR AAA RUPTURE RISK AND WALL STRENGTH

Andreas Wittek (1), Manuel Schönborn (1, 2), Achim Hegner (1, 2), Wojciech Derwich (3), Kyriakos Oikonomou (3), Armin Huß (1), Antonio J. Gámez (2), Christopher Blase (1, 4)

1. Frankfurt University of Applied Sciences, Germany; 2. University of Cádiz, Spain; 3. Frankfurt University Hospital, Germany; 4. Goethe University, Germany

The clinical assessment of abdominal aortic aneurysm (AAA) rupture risk relies on diameter-based criteria, which are acknowledged to be insufficient in individual cases. Usually, the clinical validation of novel biomarkers for rupture risk or failure strength of the wall requires large-scale prospective clinical studies. This study introduces a validation framework based on patient-specific, experimental ground truth metrics and applies it to evaluate the potential of Wall Motion Indices (WMI) that are derived from time-resolved 3D ultrasound full-field strain imaging (4D-US).
For a cohort of nine AAA patients, a 'worst-case' metric for structural integrity - the Normalized Experimental Rupture Potential (NERP) - was established: In vivo wall tension of the AAA wall was estimated by a finite element analysis based on CT imaging and measured blood pressure. The rupture strength was determined by uniaxial tensile tests on tissue samples that were harvested during open surgery. The NERP was calculated as the ratio of peak wall tension and minimal rupture strength observed in the same patient. For the same patients, non-invasive biomarkers (WMI) were derived from pre-operative 4D-US scans. Finally, a correlation analysis was performed for NERP and rupture strength itself, on the one hand, and WMI on the other.
Several WMI quantifying the distribution and kinematic anisotropy of the heterogeneous strain fields demonstrated strong ($|r| \geq 0.7$) and significant ($p \leq 0.05$) correlations with both the NERP and the rupture strength. The results of this study suggest that WMI are powerful, non-invasive indicators of AAA wall integrity that warrant further investigation.

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

IN VIVO VALIDATION OF 4D-US STRAIN IMAGING BASED MATERIAL IDENTIFICATION OF AAA TISSUE

Christopher Blase (1,2), Achim Hegner (1,3), Wojciech Derwich (4), Kyriakos Oikonomou (4), Armin Huß (1), Antonio J. Gámez (3), Andreas Wittek (1)

1. Frankfurt University of Applied Sciences, Germany; 2. Goethe University, Germany; 3. University of Cádiz, Spain; 4. Frankfurt University Hospital, Germany

Patient-specific biomechanical models are critical for assessing Abdominal Aortic Aneurysm (AAA) rupture risk, yet identifying individual wall material properties in vivo remains a challenge. This study presents a new 4D ultrasound (4D-US) strain imaging approach that identifies nonlinear, anisotropic material parameters using only non-invasive, in vivo data.

Data of two AAA patients (AAA1 and AAA2) were evaluated. Six wall samples (longitudinal and circumferential) were harvested during open surgery and subjected to uniaxial tensile tests to establish a "gold standard" stress-stretch profile. Finite element models were created from 4D-US geometries and blood pressure data. A Differential Evolution (JADE) optimization algorithm was used to iteratively identify parameters for the Holzapfel-Gasser-Ogden (HGO) material equation by minimizing the error between 4D-US measured strains and model-calculated strains.

The 4D-US identification method showed high accuracy when compared to tensile tests: Mean absolute percentage errors (MAPE) ranged from 0.07% to 0.76% (AAA1) and 0.51% to 17.83% (AAA2).

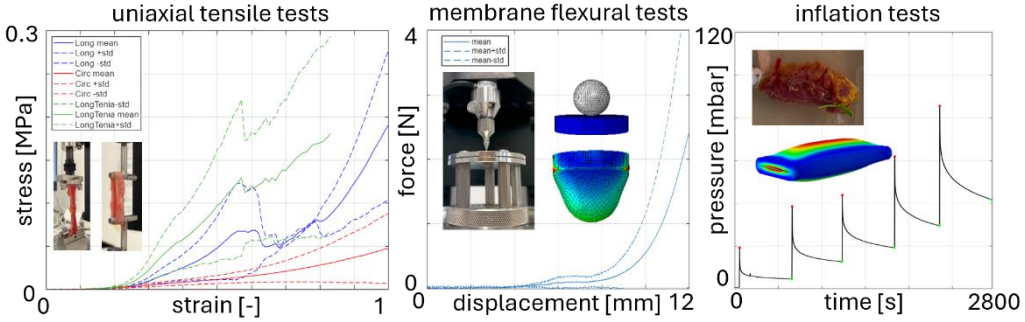
The in vivo 4D-US approach was successfully validated. While AAA2 showed higher variance in individual samples, the 4D-US method’s "global" material identification aligned well with the averaged behavior of the physical specimens. This confirms that 4D-US strain imaging is a robust, non-invasive tool for determining patient-specific tissue properties in clinical settings.

BIOMECHANICS OF THE HUMAN LARGE BOWEL: EXPERIMENTAL TESTING AND CONSTITUTIVE MODELLING

Chiara Giulia Fontanella (1,2), Ilaria Toniolo (1,2), Elena Stocco (2,3), Veronica Macchi (2,3), Fabrizio Vittadello (4), Giacomo Sarzo (4), Emanuele Luigi Carniel (1,2)

1. Department of Industrial Engineering, University of Padova, Italy; 2. Centre for Mechanics of Biological Materials, University of Padova, Italy; 3. Department of Neuroscience, University of Padova, Italy; 4. Department of Surgery, Oncology and Gastroenterology, Padova University Hospital, Italy

Artificial intestinal sphincters (AISs) could offer bag-free periods for ostomy patients, but their safe design requires a robust understanding of human intestinal biomechanics [1]. An extensive in-vitro mechanical characterisation of surgical intestinal scraps was conducted, combining tests at the tissue level, such as uniaxial tensile and unconfined compression tests, with tests at the structure level, such as membrane flexural and inflation experiments [2]. The tissue response was interpreted using a fibre-reinforced visco-hyperelastic model to capture its anisotropic, nonlinear, and time-dependent behaviour [3]. Material parameters were first identified through analytical fitting, with uniqueness and stability criteria enforced, and were subsequently validated via finite-element analysis. This experimentally grounded and validated framework enables reliable in-silico tools, supporting AISs optimisation while reducing the development of suboptimal prototypes, and the economic and ethical costs associated with animal testing and clinical trials.



References

1. Zewude et al, Ethiop J health Sci, 31: 993–1000, 2021.
2. Massalou et al, J Biomech, 91: 102-108, 2019.
3. Carniel et al, J Biomed Mater Res A 102: 1243-54, 2014.

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

FROM GEOMETRY TO FUNCTION: 3D-PRINTED CELLULAR STRUCTURES FOR ADIPOSE TISSUE ENGINEERING APPLICATIONS

Alice Berardo (1,2), Damiano Coato (1,3), Gianmarco Dolino (1,3), Paolo Gargiulo (3), Emanuele Luigi Carniel (1,2)

1. Department of Industrial Engineering, University of Padova, Italy; 2. Centre for Mechanics of Biological Materials, University of Padova, Italy; 3. Institute of Biomedical and Neural Engineering, Reykjavík University, Menntavegur 1, 102, Reykjavík, Iceland

Architected metamaterials enable the tailoring of mechanical behavior through geometry, offering unique opportunities for the design of soft, tissue-like materials [1,2]. Here, we present adipose-inspired metamaterial architectures based on periodic spherical shell unit cells (Figure 1a), whose compressive response is systematically tuned by varying cell diameter, shell thickness, and spatial orientation [3]. Structures were 3D printed (J850 Digital Anatomy™, Stratasys) and tested through compression tests. The metamaterials exhibit a broad range of mechanical behaviors, from buckling-dominated responses with extended stress plateaus to monotonic, instability-free deformation (Figure 1b-c). Shell thickness primarily controls stiffness and buckling stress, while diameter and orientation regulate instability mechanisms and densification. Finite element simulations and parametric regression models accurately capture deformation modes and quantify the influence of geometric parameters.
Future applications will include the evaluation of additional topologies and multi-material configurations, providing a versatile platform for adipose-like tissue analogues, soft protective systems, and biomechanical modelling applications.

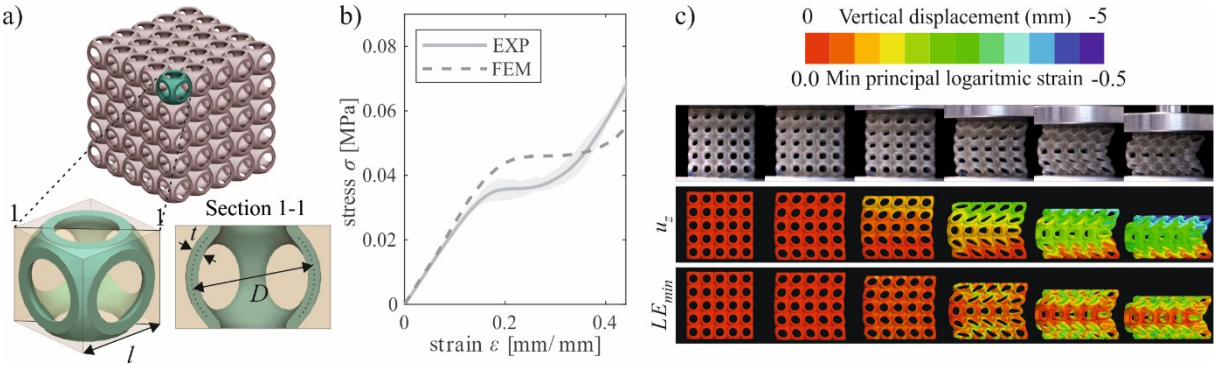


Figure 1. From metamaterial design to experiments and computational analyses.

References

1. Berkane et al, Ann Transl Med, 12, 2024.
2. Wang et al, Mater Today Adv, 13, 2022.
3. Carniel et al, Heliyon 11, 2025.

FULL-FIELD 3D STRAIN MEASUREMENT IN SOFT TISSUES

Stéphane Avril (1)

1. SAINBIOSE U1059, INSERM, Mines Saint-Etienne, France

Due to the complex anisotropic structure of many soft tissues and the nonlinearity of their mechanical response, strain gradients can vary significantly not only at the surface but also through the thickness of the tissue. In this context, a full-field 3D deformation measurement that can penetrate the tissue is required to unravel the non-uniformity. Digital volume correlation (DVC) goes beyond the surface information by using volumetric image data, e.g., 3D image volume consisting of several 2D cross-sectional images.

In the current contribution, we highlight the potential of DVC in combination with optical coherence tomography (OCT) imaging to quantify three-dimensional local strains in different native or tissue-engineered soft tissues during uniaxial and biaxial testing and even to investigate fracture.

One of the interesting results was to measure all the strain components during tensile loading of porcine aortas, enabling to assess their local volume changes with a spatial resolution of approximately 20 µm. Although global volume of the specimen is preserved, local variations were detected, indicated possible interstitial fluid motion inside the specimens during testing. To the best of our knowledge, this was the first time that such a manifestation of poroelastic effects in soft tissue could be quantified thanks to the OCT-DVC method [1]. We were also able to visualize and quantify the intramural strain distributions in the aortic wall under crack propagation [2]. Despite these achievements, low penetration (0.5 mm), time of image acquisition, and possible artefacts caused by local refractive index changes are still limitations of OCT that we are trying to overcome to popularize OCT-DVC for probing the microscale mechanical behaviour of soft tissues and hydrogels and open new perspectives for studying deformation mechanisms in soft matter.

References

1. Santamaría VAA et al. Acta Biomater. 2020;102:127–137 (2020).
2. Lane B et al. Biomechanics of the Aorta. 2024;91–108 (2024).

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

IN-VIVO BILAYER MATERIAL YOUNG MODULI IDENTIFICATION USING SUCTION ONLY

Nathanael Connesson (1), Yohan Payan (1), Pierre-Alain Barraud (1)

1. Univ. Grenoble Alpes, CNRS, UMR 5525, VetAgro Sup, Grenoble INP, TIMC, 38000 Grenoble, France

An original *in vivo* suction system is proposed to estimate soft tissue stiffness, based on volume measurements [1], which enables extreme customisation of the suction aperture shape and diameter. Cyclic (repeatability, no leakage testing) partial vacuum tests are applied under small tissue strains using six suction cups of aperture diameters ranging from 6 to 20 mm. Each test extracts mechanical behaviour information integrated over about one-diameter depth inside the tissue [2].

Experiments are then all compared to their simulated Finite Element (FE) counterparts (bilayer structure, two Neo-Hookean layers) using a single least-squares cost function. An FE database was used to enable real-time identification of three mechanical parameters (the upper-layer thickness and the two materials' Young's moduli). This evaluation also provides patient-specific parameters' indifference regions [3].

The system was evaluated on bilayer-controlled silicone phantoms (3 mm upper-layer), with Young's moduli identified by suction and uniaxial tension presenting a relative difference of less than 10%. Preliminary tests on *in vivo* abdominal tissue provided the skin and underlying adipose tissue Young's moduli at 54±1 kPa and 4.8±0.1 kPa respectively. The skin upper-layer thickness was measured at 2.21±0.033 mm using B-mode ultrasound and was identified at 2.15±0.05 mm using suction data only.

References

1. Elahi SA *et al.*, Journal of Mechanics in Medicine and Biology, 2018, 18(04):1850037
2. Zhao R *et al.*, Acta biomaterialia, 2011,7(3):1220—1227
3. Connesson N et al., Experimental Mechanics, 2023, 63:715–742

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

ADDRESSING INITIAL CONDITION UNCERTAINTY IN LARGE-DEFORMATION TESTING OF SOFT TISSUES

Noémie Briot (1), Nathanaël Connesson (1), Yohan Payan (1) and Grégory Chagnon (1)

1. Univ. Grenoble Alpes, CNRS, UMR 5525, VetAgro Sup, Grenoble INP, TIMC, 38000 Grenoble, France

In the context of experimental research on the mechanical properties of soft tissues under large deformations, classical mechanical testing methods mainly include uniaxial and biaxial tensile tests, compression, and indentation. One of the major methodological challenges associated with these tests lies in the determination of initial conditions, in particular the definition of the reference length L0 and the initial pre-stress state.

To address this issue, a preliminary study was conducted on uniaxial tensile tests performed on porcine fat tissues. This study proposes to use a suction-based device, VLastic [1], to estimate the Young's modulus under small deformation *in situ*, with the aim of recalibrating the equivalent reference length L0 used to analyse the conventional tensile curves.

The results show a significant reduction in the inter-sample dispersion of the tensile curves, suggesting the potential relevance of the proposed approach. However, its applicability is limited to tissues compatible with suction-based measurements. Further studies involving a larger number of specimens will be required to confirm and generalize these findings.

References

1. Connesson, N., Briot, N., Rohan, P. Y., Barraud, P. A., Elahi, S. A., & Payan, Y. (2023). Bilayer stiffness identification of soft tissues by suction. Experimental Mechanics, 63(4), 715-742.

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

TRACTION TESTS OF OVINE AND PORCINE MITRAL CHORDAE

Fedoua El Louali* (1), Julian Manifacier* (1), Yves Godio-Raboutet (1), Morgane Evin (1)

1. Laboratoire de Biomécanique Appliquée UMRT24, Université Gustave Eiffel, Université Aix-Marseille, France;

Previous studies showed that the stiffness of the chordae can be different and depends on the type of chordae, more specifically it depends on the insertion site of each chordae [1], [2].

Two fresh pig (3 to 4-month-old landrace pig - 32-34 kg, C-013-15- 022; Ethical committee CEEA 14) heart (185 g – 139 g) and two frozen pigs (3 to 4-month-old landrace pig - 32 kg) hearts (138 g - 290 g) tissues have been used. With a needle holder system, an Acumen 3 (MTS Solutions, Eden Prairie, MN, USA) and a uni-axial load cell (Kistler, Winterthur, Switzerland) with 5 N range and ≈ –105 pC/N sensitivity (9217A) 45 chordae tendineae have been studied. The test protocol begins with 25 cycles of preconditioning, consisting of a triangular loading-unloading cycle with a strain rate of 20 % per second. The maximum strain limit is set to 20 % of the initial gauge length, which is measured after applying a pre-tension to the sample. Two protocols are used : 1) the sample is stretched with a strain rate of 20 %.s^{-1} until rupture , 2) The sample is then stretched with a strain rate of %.s^{-1} until 20 % strain, followed by a return to 0 % strain. This cycle is repeated two more times, with strain rates of 30%.$s^{-1}$and 40 %.s^{-1}, respectively, until 20 % strain is reached in each case. To analyse the various loads applied to the tissue, an approximation of the stress-strain curve is made using a bilinear model with optimization of the root mean square error (RMSE). A morphological analysis of the chordae including bifurcation number, thickness and insertion within the mitral valve is provided.

Among the 231 cords studied, 84 are basal, with 17 being anterior and 67 being posterior, 118 are marginal, with 52 being anterior and 66 being posterior, and 29 are struts. Comparison with the 10th cycle shows a continuous evolution of the cord elasticity modulus during preconditioning. The 5% difference with the 10th cycle begins as early as the 7th cycle of preconditioning.

The stiffness is found to be higher in basal vs struct and marginal samples for both ovine and porcine samples (521 MPa for basal, 84.1 and 48.45 MPa for respectively struts and marginal chordae) in anterior leaflets. In posterior leaflet, basal and marginal chordae presented similar stiffness (44.8 and 48 MPa). In the ovine samples, the struts and marginal chordae exhibit similar high average moduli, suggesting comparable mechanical properties. In contrast, the anterior basal chordae have a higher modulus, indicating a greater stiffness in this specific subgroup.

Mechanical behaviour of the mitral chordae depends on location of insertion of the chordae, potentially explaining mitral valve regurgitation mechanism.

References

[1] K. Zuo, T. Pham, K. Li, C. Martin, Z. He, and W. Sun, “Characterization of biomechanical properties of aged human and ovine mitral valve chordae tendineae,” *J. Mech. Behav. Biomed. Mater.*, vol. 62, pp. 607–618, Sep. 2016, doi: 10.1016/j.jmbbm.2016.05.034.

[2] A. G. Wilcox, K. G. Buchan, and D. M. Espino, “Frequency and diameter dependent viscoelastic properties of mitral valve chordae tendineae,” *J. Mech. Behav. Biomed. Mater.*, vol. 30, pp. 186–195, Feb. 2014, doi: 10.1016/j.jmbbm.2013.11.013.

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

THE BIAS EXTENSION TEST TO MEASURE SHEAR ON HUMAN ILITIOTIBIAL BAND SAMPLES

Laure-Lise Gras (1), Julien Colmars (2), Karine Bruyère-Garnier (2)

1. Univ Lyon, Univ Gustave Eiffel, Univ Claude Bernard Lyon 1, LBMC UMR_T 9406, F-69622 Lyon, France;
2. INSA Lyon, CNRS, LaMCoS, UMR5259, 69621 Villeurbanne, France

The iliotibial band (ITB) is a connective tissue that contributes to hip and knee joint stability. It is mainly composed of two or three layers of oriented collagen fibers. Shear has been identified as a key strain mechanism during passive leg movement [1]. However, few studies have investigated ITB shear behavior using planar tension tests [2,3]. To analyze and model the results of such tests, fiber networks are generally assumed to be orthogonal, which is not the case for the ITB. To address this limitation, this study proposes the bias extension test as an alternative method to characterize ITB shear behavior.
Seventeen rectangular ITB samples from five subjects were tested using a bias extension protocol, with loading applied along the bisector of the angle between the two fiber networks. Samples were stretched at 25 $mm \cdot min^{-1}$ until failure. Elastic moduli, shear angle variations, and fiber elongations were measured.
The initial angle between fiber networks ranged from 43° to 83°. An average elastic modulus of 24 MPa was obtained. The maximum shear angle variation in the central region ranged from 20° to 40°, while both fiber networks exhibited elongations of at least 5%, indicating the coexistence of shear and tensile deformation.
Bias extension tests are commonly used to assess shear properties of fabric composites under the assumption of inextensible fibers. This assumption does not hold for the ITB, but bias extension testing appears promising for investigating its shear behavior, provided that modeling approaches account for both shear and tensile mechanisms.

References

1. Sednieva et al., Front. Bioeng. Biotechnol. 8:750. doi: 10.3389/fbioe.2020.00750 (2020).
2. Ruiz-Alejos et al., Strain. 52:436–445. doi: 10.1111/str. (2016).
3. Aparicil-Gil et al., Front. Bioeng. Biotechnol. 13:1494793. doi: 10.3389/fbioe.2025.1494793(2025).

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

THE IMPACT OF LARGE DEFORMATION IN BRAIN CANCER MODELING

Carla Cornillon (1, 2), Giuseppe Sciumé (1, 2, 3), Pierre-Yves Rohan (4), and Mejdi Azaiez (1, 2)

1. Université de Bordeaux, CNRS, Bordeaux INP, Institut de Mécanique et d'Ingénierie (I2M), UMR 5295 F-33400 Talence, France; 2. Arts et Métiers Institute of Technology, CNRS, Bordeaux INP, Institut de Mécanique et d'Ingénierie (I2M), UMR 5295, F-33400 Talence, France; 3. Institut Universitaire de France, France; 4. Arts et Métiers Institute of Technology, Université Sorbonne Paris Nord IBHGC – Institut de Biomécanique Humaine Georges Charpak, HESAM Université, F-75013 Paris, France

Glioblastoma is an aggressive form of brain cancer with limited treatment options and poor prognosis [1]. Regions of the brain impacted by tumor growth undergo changes such as elevated solid stresses, increased interstitial fluid pressure, and altered tissue architecture, which can affect the transport of nutrients and drugs [2]. Computational modeling using porous mechanics is a tool for investigating the solid-fluid interactions which govern transport processes and their sensitivity to microenvironmental changes. This study presents a simplified poromechanical model [3] of brain tissue that incorporates finite strain theory to examine the effects of large deformations induced by tumor growth on drug transport mechanisms and parameters. The framework models brain tissue as a multiphase continuum, representing interstitial fluid and cells as a single fluid phase within a deformable extracellular matrix. The large deformation framework is compared to a linearized model and demonstrates higher solid displacements and increased fluid pressure. The updated formulation for large deformations keeps the model in the current configuration of the system, which provides a feasible framework for implementing processes and mechanisms associated with longer time-scale of tumor growth and progression.

References

1. A. C. Tan et al., CA: A Cancer Journal for Clinicians; 70:299–312, (2020).
2. Nia Hadi T et al., Science (New York, N.Y.); 370,6516:eaaz0868 (2020).
3. G, Sciumè, Acta Mech; 232:1445–1478 (2021).

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

MECHANICAL MODELLING OF THE EXTERNAL ANAL SPHINCTER UNDER TENSILE LOADING FOR BIRTH-INJURY PREDICTION

Chloé Dupray (1, 2), Sabine Cantournet (2), Pierre Kerfriden (2), Sarah Iaquinta (1), Anne-Sophie Caro (1)

1. Centre des matériaux, Mines Paris – PSL, 78000 Versailles, France ; 2. LMGC, Univ Montpellier, IMT Mines Ales, CNRS, Ales, France ;

Vaginal delivery frequently induces large deformations of the perineal tissues, which may result in severe obstetric injuries involving the external anal sphincter (EAS). From a mechanical standpoint, the EAS undergoes complex loading paths combining large strains, anisotropy, and time-dependent effects, which remain insufficiently characterized.

This work presents the development of a thermodynamically consistent constitutive model describing the tensile behavior of the EAS up to failure. Mechanical tensile tests combined with microscopic observations are conducted on porcine tissues to characterize fiber organization and to support the development of an anisotropic hyper-viscoelastic model with stress-softening behavior [1]. Current efforts focus on parameter identification and on assessing the model's ability to reproduce nonlinear and history-dependent tissue behavior.

By linking macroscopic mechanical behavior to microstructural characteristics [2], this approach aims to improve the understanding of EAS injury mechanisms and to identify mechanically based indicators relevant for predictive biomechanical biomarkers.

References

1. Caro, A.-S.; Chrysochoos, A.; Iaquinta, S.; Chagnon, G. Modeling of Nonlinear Viscoelasticity and Stress Softening in Soft Tissues. *European Journal of Mechanics - A/Solids* **2026**, *115*, 105818. https://doi.org/10.1016/j.euromechsol.2025.105818.
2. Shafik, Ahmed. A New Concept of the Anatomy of the Anal Sphincter Mechanism and the Physiology of Defecation. https://doi.org/10.1016/0002-9610(86)90087-5.

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

MECHANICAL CHARACTERIZATION AND NUMERICAL APPROACH OF PORCINE SEPTAL MYOCARDIUM

Fedoua El Louali* (1), Dorian Sweidy* (1), Alain Lalande (2), Morgane Evin (1)

1. Laboratoire de Biomécanique Appliquée UMRT24, Université Gustave Eiffel, Université Aix-Marseille, France; 2. Université de Bourgogne, France;

Mechanical characterization of the septal myocardium could partially explain the contractile behaviour of the left ventricle. It has been poorly described comparatively between part of the myocardium while left ventricular strain has been shown to significantly vary within the muscular mid ventricle.
Three porcine hearts were used to collect samples per wall (left ventricle (LV) wall, septal wall, right ventricle (RV) wall) depending of the size of the wall and resulting in 26 samples. Biaxial tensile tests were performed with 10 pre-conditioning cycles after preload of 0.1 N and traction test with identic condition on both axis at a strain rate of 2 $\%.s^{-1}$, 10 $\%.s^{-1}$ and $20\%.s^{-1}$ until rupture. The impact of the thickness was assessed numerically using FEBio with fibre based models [2].
The stress-strain curve analysis shows a lower maximum stress in the LV walls with 33.5±19.2 MPa (compared to 125±58.1 and 90.5±3.1 MPa in the RV and septal walls respectively). There was significant correlation between linear elasticity of the two axes in RV and septal wall but not in the left ventricular wall, indicating a high level of anisotropy of LV wall. Using Humphrey model [1], comparison of the apical septal and basal septal segments shows a significant difference, indicating the possibility of a difference in the adaptive and remodeling behavior of the myocardium at this level.
Myocardial tissue has been shown to be nonlinear, anisotropic, viscoelastic, and history-dependent under large deformation. However, we detected some differences between walls in their viscoelastic behavior, but also within the same wall between the apical and basal segments. The limitation of our tests remains the passive character of the myocardium.

References

1. J. D. Humphrey, R. K. Strumpf, and F. C. Yin, Am. J. Physiol., vol. 259, no. 1 Pt 2, pp. H101-108(1990)
2. T. C. Gasser, R. W. Ogden, and G. A. Holzapfel, J. R. Soc. Interface, vol. 3, no. 6, pp. 15–35, (2006).

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

Linking Hemodynamics and Wall Mechanics to Model Aneurysm Growth

Arnaud Gisquet (1), Farid Bakir (1), Mathieu Specklin (2) Pierre-Yves Rohan (3)

1. Arts et Métiers Institute of Technology Université Sorbonne Paris Nord, LIFSE Laboratoire d'Ingénierie des fluides Systèmes Energétiques Paris, France; 2. CNAM Conservatoire National des Arts et Metiers, LIFSE LIFSE Laboratoire d'Ingénierie des fluides Systèmes Energétiques Paris, France; 3. Arts et Métiers Institute of Technology Université Sorbonne Paris Nord, IBHGC Institut de Biomécanique Humaine Georges Charpak Paris, France

An aneurysm is a permanent and irreversible localized dilatation of an artery. Abdominal aortic aneurysm (AAA) is amongst the most prevalent and life-threatening forms, as rupture is associated with extremely high mortality. Current clinical decision-making for surgical intervention mainly relies on a diameter threshold (>5cm) based on population-level statistics. [1]. However, this criterion fails to account for patient-specific mechanical and hemodynamic factors, and a significant number of aneurysms rupture below this threshold. Identifying more reliable, physics-based indicators of. aneurysm growth and rupture therefore remain a major scientific challenge. In this context, a physiomarker was recently proposed by [2]. based on blood–wall fluttering instability, it aims to link aneurysm growth to the coupled mechanics of the arterial wall and hemodynamic While this marker has been tested for short time range, its relevance for longer-term aneurysm evolution has not yet been assessed. In this work, we first investigate the applicability of this physiomarker using a dedicated experimental test bench based on 3D-printed aneurysm models. The setup enables controlled hemodynamic loading and mechanical characterization of the wall material, including the identification of the Young's modulus through combined experimental–numerical comparisons. We then analyse the relationship between the temporal evolution of wall strain and the physiomarker over medium time scales (on the order of hours). The results suggest a correlation between strain evolution at medium time range (~hours) and the proposed physiomarker, supporting its potential relevance beyond short-term dynamics. However, while neglecting the biological processes simplifies experimental investigation, it also limits the ability to predict aneurysm growth over clinically relevant time scales. To overcome this limitation, the perspective of this work is to develop a numerical growth model incorporating fluid–structure interactions and biologically driven wall remodelling. Such a model would enable the integration of mechanical and biological effects, paving the way toward more realistic, patient-specific predictions of aneurysm growth and rupture risk.

References:

[1]: Natzi Sakalihasan, Jean-Baptiste Michel, Athanasios Katsargyris, Helena Kuivaniemi, Jean-Olivier Defraigne, Alain Nchimi, Janet Powell, Koichi Yoshimura, and Rebecka Hultgren. Abdominal aortic aneurysms. Nature Reviews Disease Primers, 4, 12 2018.

[2]: Tom Y Zhao, Ethan M I Johnson, Guy Elisha, Sourav Halder, Ben C Smith, Bradley D Allen, Michael Markl, and Neelesh A Patankar. Blood-wall fluttering instability as a physiomarker of the progression of thoracic aortic aneurysms. Nat. Biomed. Eng., 7(12):1614–1626, December 2023

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

EFFECT OF FREEZING ON THE MECHANICAL BEHAVIOUR OF WHOLE ORGAN – APPLICATION TO SWINE LUNG PARENCHYMA

Ombeline Juteau (1,2), Aline Bel-Brunon (2), Catherine Masson (1), Karine Bruyère-Garnier (2), Claire Bruna-Rosso (1)

1. Univ Gustave Eiffel, Aix-Marseille Univ, LBA UMR_T24, F-13015 Marseille, France;
2. Univ Gustave Eiffel, Univ Claude Bernard Lyon 1, LBMC UMR_T9406, F-69622 Lyon, France

Lung parenchyma is a soft tissue whose complexity lies particularly in its multiscale nature. Its mechanical behaviour is greatly affected when diseased [1]. To characterize these mechanical changes, inflation tests and tensile tests are performed on healthy and pathological lungs [2].
As in many ex-vivo experimental studies, biological tissues need to be preserved between the sacrifice of the animal and the day the tests are carried out. While several studies investigated the impact of conservation on soft biological tissues, they principally focus on membranes [3,4], or small samples already prepared before freezing.
For inflation tests, whole lungs have to be kept intact to preserve airtightness. This raises the question of whether freezing a whole organ has a significant impact on its mechanical behaviour.
That is why in the current study the influence of freezing is studied on porcine lungs withdrawn just after sacrifice and frozen whole, at -20 and -80°C. Cyclic tensile tests are performed on samples cut after thawing to study the conservation temperature influence on common mechanical properties such as tangent moduli.
Preliminary experiments show a slightly stiffer tissue after freezing at -80°C compared to -20°C, even though this tendency is not yet significant. Further tests will confirm or infirm this tendency and compare it with fresh samples.

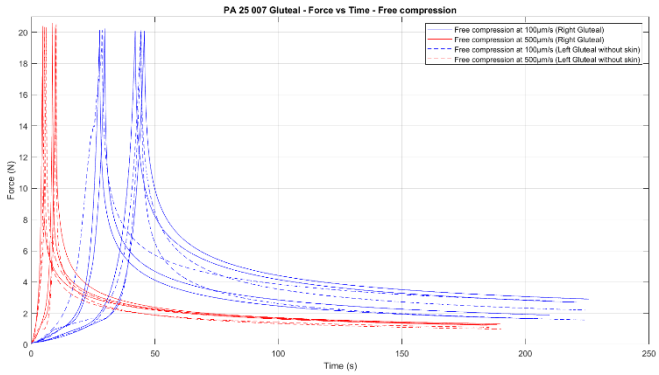
References

[1] M. Cressoni *et al.*, “Lung Inhomogeneity in Patients with Acute Respiratory Distress Syndrome,” *Am. J. Respir. Crit. Care Med.*, vol. 189, no. 2, pp. 149–158, Jan. 2014, doi: 10.1164/rccm.201308-1567OC.
[2] O. Juteau, A. Bel-Brunon, K. Bruyère-Garnier, C. Masson, and C. Bruna-Rosso, “Experimental set-up for the mechanical characterization of lung under inflation,” *Multidiscip. Biomech. J.*, vol. 2, pp. 147–149, Oct. 2025, doi: 10.46298/mbj.16207.
[3] A. S. Caro-Bretelle *et al.*, “Effect of sample preservation on stress softening and permanent set of porcine skin,” *J. Biomech.*, vol. 48, no. 12, pp. 3135–3141, Sep. 2015, doi: 10.1016/j.jbiomech.2015.07.014.
[4] B. Pillet, P. Badel, and B. Pierrat, “Effects of cryo-preservation on skeletal muscle tissues mechanical behavior under tensile and peeling tests until rupture,” *J. Mech. Behav. Biomed. Mater.*, vol. 132, p. 105273, Aug. 2022, doi: 10.1016/j.jmbbm.2022.105273.

ROLE OF SUBCUTANEOUS ADIPOSE TISSUE IN PRESSURE ULCER RISK: VISCOELASTIC PROPERTIES UNDER UNIAXIAL COMPRESSION

Maeva Lamant (1), Sharon Sonenblum (2), Dominique Sigaudo-Roussel (3), Bérengère Fromy (3), Claudio Vergari (1), Nathalie Maurel (1), Amadou Diop (1), Maud Creze (1), Pierre-Yves Rohan (1)

1. Arts et Métiers Institute of Technology Université Sorbonne Paris Nord, IBHGC - Institut de Biomécanique Humaine Georges Charpak, HESAM Université, F-75013, Paris, France; 2. Nell Hodgson Woodruff School of Nursing, Emory University, Atlanta, GA, USA; 3. CNRS, University of Claude Bernard Lyon 1, UMR 5305, LBTI, Lyon 69367, France.



Pressure ulcers (PUs) are localized injuries to the skin and underlying tissue, primarily affecting individuals with reduced mobility. Most biomechanical research to date has focused on muscle deformation and internal tissue strain, yet increasing evidence suggests that subcutaneous adipose tissue (SAT) also plays a critical role in PU development [1]. This study aims to better understand the mechanical behavior of SAT through unconfined and confined compression tests on human skin samples (N=3) from the gluteal and abdominal areas (N=142) at two speeds (100µm/s and 500µm/s). The first part of the test was modelled as hyperelastic (Ogden), while the second part involved determining viscoelastic parameters. All samples demonstrated marked viscoelastic behavior, with observable stress-relaxation. The mechanical properties were similar between gluteal and adominal adipose tissue. These results support prior findings that SAT exhibits time-dependent mechanical behavior and highlight the importance of testing fresh, anatomically relevant samples.

References

[1] S. E. Sonenblum, S. H. Sprigle, J. M. Cathcart, et R. J. Winder, « 3D anatomy and deformation of the seated buttocks », *J. Tissue Viability*, vol. 24, nº 2, p. 51-61, mai 2015, doi: 10.1016/j.jtv.2015.03.003.

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

EFFECT OF GEOMETRIC HETEROGENEITY ON THE APPARENT MECHANICAL ANISOTROPY OF ATRIAL APPENDAGES.

Kundry Reibel (1), Baptiste Pierrat (1), Nicolas Curt (1), Claudia Cino (2), Stéphane Avril (1), Fanette Chassagne (1)

1. Mines Saint-Etienne, INSERM, U1059 Sainbiose, 42023 Saint-Etienne, France; 2. Department of Engineering, Università degli Studi di Palermo, Viale delle Scienze Ed.8, Palermo 90128, Italy;

The mechanical behavior of atrial appendage tissue remains poorly understood, partly due to its highly trabeculated macro-structure, which induces strong spatial variability in thickness. This study investigates how this geometric heterogeneity influences the apparent anisotropy observed in mechanical testing.

Porcine atrial appendages (n = 80) were dissected into paired longitudinal and transverse specimens and tested under uniaxial loading. Sample thickness was first measured using calipers and then characterized using high-resolution 3D scans, to generate full-field thickness maps. Mechanical behavior was described using an isotropic Veronda–Westmann constitutive law, implemented through both an analytical direct model based on mean thickness and an inverse finite-element (FE) model incorporating scanned geometry. The mechanical responses and constitutive parameters identified in the longitudinal and transverse directions were compared using a statistical approach. The predictive response of the simplified vs geometrically accurate model were evaluated.

Thickness maps revealed pronounced intra- and inter-sample variability, with caliper measurements underestimating mean thickness by ∼25%. While longitudinal material parameters consistently overpredicted the transverse response, FE-based predictions significantly reduced errors compared to the analytical approach, demonstrating the importance of geometry in capturing mechanical behavior. However, remaining discrepancies indicate that macro-structure alone cannot fully explain the observed anisotropy.

Overall, this study demonstrates that geometric heterogeneity plays a major role in atrial appendage mechanics but must be complemented by meso- and microstructural considerations, such as fiber organization, to achieve accurate constitutive modeling.

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

COLLAGEN ORGANISATION IN PORCINE SPINAL MENINGES: A BENCHMARK OF SHG IMAGE ANALYSIS

Stella Sublet-Vial (1), Sarah Iaquinta (2,3), Cristina Cavinato (2), Morgane Evin (1)

1. Univ Gustave Eiffel, Aix-Marseille Univ, LBA UMR_T24, F-13015 Marseille, France;
2. Univ Montpellier, LMGC, Montpellier, France ; 3. Mines d'Alès, Alès, France

Collagen fibers and their organization in biological soft tissues influence their elasticity, resistance and mechanical behavior. Meningeal tissues (pia mater and dura mater and arachnoïdal complex) are composed of dense, anisotropic, highly interlaced, cross-linked, and fragmented collagen fibers which can be described with fiber density, orientation distribution, anisotropy, waviness, length, and diameter [1]. This provides essential information on tissue architecture to link microstructural organization to tissue-scale mechanical behavior. Second Harmonic Generation (SHG) microscopy enables label-free visualization of fibrillar collagen despite signal noise and heterogeneity and was used to image stretched meningeal tissues. The objective of this work was to develop a robust image-processing pipeline for automated fiber identification and network characterization in SHG datasets exploring a wide range of image processing, segmentation, filtering, and tracking methods.

The investigated approaches included local step-wise tracking, graph-based shortest path optimization (Dijkstra), sub-Riemannian geodesic methods, Sequential Monte Carlo probabilistic tracking, structure tensor analysis, Hessian-based vessel enhancement filtering, and multi-scale directional transforms. Evaluation of each method relied on noise robustness, stability at intersections, sensitivity to gaps, pixel-wise exploration costs, geometric consistency of the fibers, and continuity preservation.

A hybrid pipeline tailored to the acquired SHG data was finally designed. The approach combines multi-scale steerable filtering for orientation-selective enhancement [2] with Frangi-based vesselness filtering to reinforce elongated curvilinear structures while suppressing background noise [3]. This dual enhancement improves directional coherence, stabilizes tracking across crossings, and preserves geometric continuity in densely packed regions.

By benchmarking methods to reliably quantified collagen microstructural organization in stretched meningeal tissues, we proved the feasibility of the collagen organization characterization, confirming the necessity of a hybrid approach and of an adaptable rather than a one only method.

References

1. Rezakhaniha, R., Agianniotis, A., Schrauwen, J. T. C., Griffa, A., Sage, D., Bouten, C. V. C., van de Vosse, F. N., Unser, M., & Stergiopulos, N. (2012). Experimental investigation of collagen waviness and orientation in the arterial adventitia using confocal laser scanning microscopy. Biomechanics and Modeling in Mechanobiology, 11(3–4), 461–473. https://doi.org/10.1007/s10237-011-0325-z

2. Püspöki, Zsuzsanna, et al. "Transforms and Operators for Directional Bioimage Analysis: A Survey." *Focus on Bio-Image Informatics*, edited by Winnok H. De Vos et al., vol. 219, Springer International Publishing, 2016, pp. 69–93. Advances in Anatomy, Embryology and Cell Biology. DOI.org (Crossref), https://doi.org/10.1007/978-3-319-28549-8_3.

3. Frangi, A. F., Niessen, W. J., Vincken, K. L., & Viergever, M. A. (1998). Multiscale vessel enhancement filtering. In W. M. Wells, A. Colchester, & S. Delp (Eds.), *Medical Image Computing and Computer-Assisted Intervention—MICCAI'98* (Vol. 1496, pp. 130–137). Springer Berlin Heidelberg. https://doi.org/10.1007/BFb00561953. Caiazzo A et al., ICCS 2009 conference: Springer; 2009. p. 705-14

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

ON THE VALIDITY OF INCOMPRESSIBILITY AND MECHANICAL HOMEOSTASIS ASSUMPTIONS IN CARTILAGE GROWTH MODELS

Noémie Petitjean (1), Romain Gayraud (2), Cristina Cavinato (2), Patrick Cañadas (2), Pascale Royer (2), Danièle Noël (3), Simon Le Floc'h (2)

1. LBMC, Univ. Gustave Eiffel, CNRS, Lyon, France; 2. LMGC, Univ. Montpellier, CNRS, Montpellier, France; 3 IRMB, Univ Montpellier, Inserm, Montpellier, France

We present new experimental results on cartilage microspheres subjected to controlled mechanical loading, and discuss their implications for growth and remodelling models of soft tissues. Two main findings are obtained: (i) the tissue exhibits a compressible behaviour, and may have a transition from nearly-incompressible to compressible behaviour during its development [1]; (ii) cyclic low-amplitude strains (<1%) significantly enhance chondrogenic gene expression (GaGs, type IIb collagen), whereas static deformations do not [2]. These observations are placed in the context of classical growth and remodelling frameworks relying on the multiplicative decomposition of the deformation gradient [3], [4], volumetric incompressibility, and mechanical homeostasis [5-7]. Our results challenge two fundamental assumptions: (a) incompressibility, commonly imposed for soft tissues both at the constitutive level and in mass balance equations; and (b) time-scale separation between fast dynamic loading and slow growth adaptation, which is not clearly supported by our data. We conclude that accounting for material compressibility and non-trivial mechanotransductive time-scales may be necessary to extend current growth laws to cartilage tissues. Perspectives on how to revise existing models are briefly discussed.

References

1. PhD Thesis of Noémie Petitjean. theses.fr/2020MONTT047
2. Petitjean, et al. Stem Cell Research & Therapy 14
3. Rodriguez et al., J. Biomech. 1994
4. Taber, Biomech. Model. Mechanobiol., 1995
5. Humphrey, *Cardiovascular Solid Mechanics*, 2002
6. Kuhl & Menzel, *J Mech Phys Solids*, 2012
7. Holzapfel et al., J. R. Soc. Interface, 22(222):20240361 (2025)

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

ALMOST INCOMPRE(HEN)SSIBLE? CAREFUL, NOT THAT MUCH!

Sébastien LAPORTE (1), Alexandre SEGAIN (1), Pierre-Yves ROHAN (1)

1. Arts et Métiers Institute of Technology, EPF Engineering School, Université Sorbonne Paris Nord, IBHGC–Institut de Biomécanique Humaine Georges Charpak, F-75013 Paris, France

Quasi-incompressibility is commonly invoked in soft tissue mechanics to account for their high-water content and improve numerical robustness. In many studies, this concept is applied by setting the Poisson's ratio to a value close to 0.5, then deducing the compressibility modulus from the linear elasticity at low strain. This practice is convenient, but it can become misleading in the case of finite deformation: the value of '$\nu \approx 0.49$' does not guarantee $J \approx 1$ for large deformations and can lead to results that seem mechanically incomprehensible [1].

Focusing on Ogden-type compressible hyperelasticity, we recall the purely theoretical mechanism behind these problems. When the deviatoric terms become highly sensitive to stretching (e.g., when Ogden's exponents are high), the volumetric penalty often used in practice may be too small compared to the deviatoric stiffness. The model can then drift towards significant volume changes under moderate to large deformations, even if it has been tuned to be 'quasi-incompressible' in the infinitesimal regime. This issue is closely related to the choice and scaling of volumetric strain energy functions [2], and motivates the design of volumetric formulations that remain effective under large distortions [3].

The practical message is simple: be cautious with quasi-incompressibility shortcuts. For any targeted load path, systematically monitor J (or the volume change) over the entire relevant deformation range, and ensure that the volumetric part of the energy is scaled consistently with the non-linearity of the deviatoric response. If necessary, favour mixed (e.g., u-p) or fully incompressible strategies rather than relying solely on a Poisson's ratio close to 0.5.

References

1. Fougeron N et al. Comput Methods Biomech Biomed Engin; 27(14):1999–2008 (2024).
2. Doll S, Schweizerhof K. J Appl Mech; 67(1):17–21 (2000).
3. Moerman KM et. Int J Solids Struct; 193-194:474–491 (2020).

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

POROMECHANICS TO INVESTIGATE THE IMPACT OF MECHANICAL LOADING ON HUMAN SKIN MICRO-CIRCULATION

Thomas Lavigne (1,2,3), Stéphane Urcun (1), Bérengère Fromy (4,5), Audrey Josset-Lamaugarny (4,5), Alexandre Lagache (2,3), Camilo A. Suarez-Afanador (1), Stéphane P. A. Bordas (1), Pierre-Yves Rohan (2), Giuseppe Sciumè (3,6)

1. University of Luxembourg, Esch-sur-Alzette, Luxembourg; 2. Arts et Métiers Institute of Technology, Paris, France; 3. University of Bordeaux, Talence, France; 4. LBTI, Lyon, France; 5. Claude Bernard University Lyon, Villeurbanne, France; 6. Institut Universitaire de France (IUF), France

Human skin functions as a complex multi-scale and multi-phase system, where moving fluids significantly influence mechanical and biological responses. Managing skin injuries, such as pressure ulcers (PU), requires a deep understanding of structural composition and mechanical behaviour, especially given that between 9% and 20% of hospitalized patients in Europe are affected [1]. This paper introduces a hierarchical two-compartment poromechanical model that accounts for fluid distribution within the interstitium and blood micro-circulation. The model is based on a hierarchical porous media framework [3] that conceptualizes the interstitium as a biphasic system able to distinguish between the characteristic timescales of cells and interstitial fluid. Experimental evaluation was performed using Laser Doppler Flowmetry (LDF) on 11 healthy volunteers. Controlled loads were applied directly to the skin via a specialized pivotmeter device [2] to investigate ischaemic and hyperaemic responses. All numerical simulations were conducted using the open-source software FEniCSx v0.9.0. Results demonstrated that while absolute LDF values vary between individuals, relative responses to load-induced ischaemia and post-occlusive reactive hyperaemia (PORH) are comparable across sexes when normalized to basal blood flow. Sensitivity analysis identified Young's modulus and the vessel permeability exponent as dominant parameters governing the micro-circulatory response. This work successfully demonstrates the model's qualitative ability to replicate in vivo hemodynamic responses.

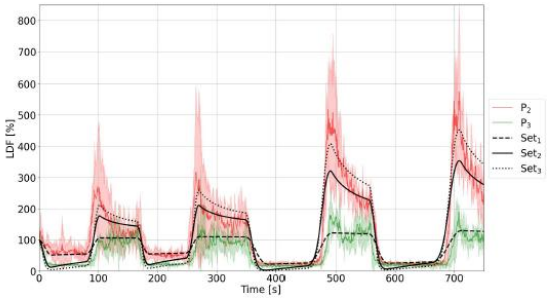


Figure 1: Two representative patient mean and interquartile range curves (P1, P3) along with the model response of 3 different sets of parameters.

References

1. Vanderwee K *et al.*, J Eval Clin Pract. 2007;13(2):227-235.
2. Fromy B *et al.*, Brain Res. 1998;811(1-2):166-168.
3. Lavigne T *et al.*, Int. J. Numer. Meth. Biomed. Eng. 2025; 41:e70066

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

PREDICTING AND UNDERSTANDING SOFT TISSUE MECHANICS BY DATA-DRIVEN MATERIAL MODELING

Kevin Linka (1) und Christian J. Cyron (2)

1. RWTH Aachen University, Germany; 2. Hamburg University of Technology, Germany

Traditional material modeling is theory-driven, relying on constitutive equations that relate strains and stresses through assumed functional forms and identified material parameters. In contrast, data-driven approaches bypass these assumptions by directly learning the material behavior from data. To combine the strengths of both paradigms, we introduce Constitutive Artificial Neural Networks (CANNs) a hybrid machine learning framework that integrates theoretical knowledge from continuum mechanics and constitutive theory with the flexibility of data-driven modeling [1]. CANNs require only limited stress-strain data to infer complex material laws and can generalize across known and previously unseen materials. They are particularly well-suited for applications in computational biomechanics, where they leverage heterogeneous input data to predict the mechanical properties of biological tissues [2]. Beyond accurate predictions, CANNs enable a deeper understanding of soft tissue mechanics by incorporating explainable artificial intelligence, model discovery techniques, symbolic regression, and probabilistic machine learning. These tools help identify and quantify the relevance of microstructural features in shaping macroscopic mechanical behavior, ultimately advancing both predictive capabilities and mechanistic insights into soft biological materials.

References

1. Linka et al, Journal of Computational Physics 429, 110010 (2021).
2. Linka et al, Acta Biomaterialia 147, 63-72 (2023).

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

MULTISCALE MODELLING OF PERFUSED SOFT TISSUES IN WAVE PROPAGATION AND TRANSPORT PROBLEMS

Eduard Rohan(1), Fanny Moravcová(1), Vladimír Lukeš(1)

1. Department of Mechanics, Faculty of Applied Sciences, University of West Bohemia in Pilsen

Soft tissues are usually considered as a kind porous, or multiporous media with solid phase governed by a visco-hyperelastic constitutive law. Multiscale homogenization approaches provide a natural way how to construct models describing the hierarchical organization of the tissues and its relationship with the effective medium parameters. The paper focuses on the use the asymptotic homogenization for multiscale modelling of soft tissues in the context of the blood perfusion and related transport of species due to the advection-diffusion phenomena [1]. For the medical treatment research, such as new drug delivery systems, imaging based diagnostics and tissue engineering, it is of interest to study the influence of the acoustic wave propagation including the secondary effects, such as the acoustic streaming (AS), on the microcirculation in the vasculature and transport in the parenchyma. In particular, the sonoporation due to the shear flow affected by the AS can be studied.

From this perspective, the paper summarizes our recent theoretical results as well as implemented models describing particular phenomena in perfused soft tissues: these include the homogenized multi-compartment Biot type medium based on the incremental Eulerian formulation of large deforming double-porosity medium [2], acoustic wave propagation in fluid saturated strongly skeleton with high contrast in the elasticity [3], and the induced AS affected by skeleton deformation, cf. [4]. The microflow provides the advection velocity fields in the transport equations imposed in the double porosity microstructures. Various issues in the homogenization of transient problems leading to time convolutions and multi-time scale problems are discussed.

References

1. Rohan E, Camprová Turjanicová, J. CMBBE 2023 conference: Springer; 2024. p. 224-232
2. Lukeš V, Rohan E. Comput. & Math. Appl. 110 (2022) p. 40-63
3. Rohan E, Nguyen V-H, Naili S. Appl. Math. Mod. 125, Part B, 2024. p. 750-777
4. Rohan E, Moravcová F. Jour. of Sound and Vibration. 2025;618, Part B, 119252 (2025)

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

NEURAL CONSTITUTIVE MODELLING FOR SOFT TISSUES: SUPERVISED DISCOVERY, BAYESIAN UNCERTAINTY, AND FINITE ELEMENT DEPLOYMENT

Mathias Peirlinck
Delft University of Technology, the Netherlands

Soft tissues remain difficult to characterise and simulate because they combine strong nonlinearity, anisotropy, and heterogeneity with the practical experimental reality of limited testing and pronounced specimen-to-specimen variability. In this talk, I will provide a compact overview of several recent contributions on automated constitutive modelling, spanning multiple tissues and methodological paradigms, and concluding with two complementary finite-element deployment strategies.

Supervised model discovery across tissues: We start with ultrasoft brain tissue, where automated model discovery over structured libraries of strain-energy functions reduces ad-hoc model choice and identifies compact isotropic hyperelastic descriptions directly from combined tensile, compression, and shear experimental stress-strain responses[1]. We then move to arterial tissue and demonstrate supervised, structure-aware learning of constitutive behaviour for clinically relevant large vessels, highlighting how constrained neural constitutive representations can capture anisotropy while remaining compatible with standard continuum mechanics requirements [2-4]. Next, for atrial tissues we show how supervised constitutive learning supports biaxial data when classical model selection is ambiguous, enabling tissue-specific constitutive descriptions without a priori committing to a single hand-crafted functional form [5]. Finally, for ventricular myocardium, we further extend to automated model discovery of orthotropic hyperelasticity, using model selection over competing candidate forms to obtain accurate, data-consistent constitutive laws describing combined biaxial tensile and shear testing data [6].

Unsupervised model discovery uncertainty quantification: We move beyond supervised identification and consider unsupervised, Bayesian full-field inference for orthotropic myocardial hyperelasticity from a single heterogeneous biaxial experiment, explicitly quantifying parameter uncertainty and identifiability under realistic noise and corrupted experimental data conditions [7].

Deployment in finite elements: To make our automated model discovery pipelines usable in practice, I will conclude with two complementary deployment routes. The first is a universal material model subroutine implemented as an Abaqus UMAT, providing a single extensible interface for a broad family of hyperelastic models (including newly discovered candidates) within established industrial workflows [8]. The second is COMMET, a purpose-built finite element framework designed for blazingly fast simulations via batched/vectorised constitutive evaluation and optimised derivative computation. This new open-source FE solver will become particularly impactful where traditional FE implementations of neural constitutive model updates become the bottleneck [9].

References

[1] M. Peirlinck, K. Linka, J. A. Hurtado, and E. Kuhl, "On automated model discovery and a universal material subroutine for hyperelastic materials," *Computer Methods in Applied Mechanics and Engineering,* vol. 418, 2024, doi: 10.1016/j.cma.2023.116534.
[2] M. Peirlinck, K. Linka, J. A. Hurtado, G. A. Holzapfel, and E. Kuhl, "Democratizing biomedical simulation through automated model discovery and a universal material subroutine," *Computational Mechanics,* 2024/08/14 2024, doi: 10.1007/s00466-024-02515-y.
[3] T. Vervenne, M. Peirlinck, N. Famaey, and E. Kuhl, "Constitutive neural networks for main pulmonary arteries: discovering the undiscovered," *Biomech. Model. Mechanobiol.,* Feb 24 2025, doi: 10.1007/s10237-025-01930-1.
[4] T. Vervenne *et al.*, "Stretching the Limits: From Planar-Biaxial Stress-Stretch to Arterial Pressure-Diameter," *bioRxiv,* p. 2025.07.17.665394, 2025, doi: 10.1101/2025.07.17.665394.
[5] M. Peirlinck, K. Linka, and E. Kuhl, "Atrial Constitutive Neural Networks," pp. 249-259, 2025, doi: 10.1007/978-3-031-94559-5_23.
[6] D. Martonová, M. Peirlinck, K. Linka, G. A. Holzapfel, S. Leyendecker, and E. Kuhl, "Automated model discovery for human cardiac tissue: Discovering the best model and parameters," *Computer Methods in Applied Mechanics and Engineering,* vol. 428, 2024, doi: 10.1016/j.cma.2024.117078.
[7] R. P. Krijnen, S. Kumar, and M. Peirlinck, "Unsupervised full-field Bayesian inference of orthotropic hyperelasticity from a single biaxial test: a myocardial case study," *arXiv,* 2025, doi: 10.48550/arXiv.2510.09498.
[8] M. Peirlinck, J. A. Hurtado, M. K. Rausch, A. n. B. Tepole, and E. Kuhl, "A universal material model subroutine for soft matter systems," *Engineering with Computers,* 2024, doi: 10.1007/s00366-024-02031-w.
[9] B. Alheit, M. Peirlinck, and S. Kumar, "COMMET: Orders-of-magnitude speed-up in finite element method via batch-vectorized neural constitutive updates," *Computer Methods in Applied Mechanics and Engineering,* vol. 452, 2026, doi: 10.1016/j.cma.2026.118728.

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

EXPERIMENTAL STUDY OF STRUCTURAL CHANGES IN SUBCUTANEOUS TISSUE DURING LARGE VOLUME INJECTION

Aurélien Baquié (1, 2), Pascal Dugand (2), Baptiste Pierrat (1), Jérôme Molimard (1)

1. Mines Saint-Étienne, INSERM, U 1059 Sainbiose, Centre CIS, Saint-Étienne, France
2. Nemera, Lyon, France

Introduction – While subcutaneous (SC) injections of large volumes are generally tolerable [1], their self-administration is not repeatable [2]. To develop safe and effective delivery devices for these larger volumes, a detailed understanding of the mechanical phenomena occurring in SC tissue during injection is therefore essential [1]. To characterize the nature, location, and pressure thresholds of these phenomena, we propose a 3D visualization approach to analyse SC samples before, during, and after injection.

Material and Methods – 14 ex-vivo samples from the abdomen skin of pigs are obtained from local slaughterhouse; they comprise epidermis, dermis, and subcutaneous (SC) tissues. They are put in a chamber transparent to x-ray, specifically designed. The chamber confines partially the pig samples, as only a portion of the epidermal surface is left exposed. A catheter is inserted through the epidermis of each sample and connected to a syringe via tubing. Hydrostatic pressure at the injection site is monitored during the procedure. Samples are imaged at each pressure plateau using X-ray local phase contrast microtomography at the ANATOMIX beamline (Synchrotron SOLEIL). This imaging procedure reveals key mesoscopic structures (subcutaneous lobules, septa) and the formulation distribution. Geometrical information are extracted from segmented images such as the thickness of the formulation depots, the volume-to-surface ratio of the depots, and the ratio of volume of the substructures infiltrated by the formulation before and after injection.

Results – Data analysis is still ongoing (48 scans from 9 samples). Preliminary findings indicate that catheter insertion alters the organization of subcutaneous substructures. Although the formulation diffuses within samples, it predominantly remains in the septa, whose thickness increases markedly with pressure. The observed mechanical changes in septa appear irreversible and are likely due to hydraulic fracturing, occurring at pressures ranging from 0 to 30 kPa depending on the sample.

Acknowledgements – We are grateful to Dr. Mario Scheel and to the SOLEIL staff for their assistance in running the facility.

References

1. W.D. Woodley et al., Clin. Transl. Science 15(1), 92-104 (2021).
2. A. Allmendinger and S. Fischer, Pharm. Research 37(10), 184 (2020).

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

INTRAMURAL INJECTION ON PORCINE AORTA: INJECTION RATE MODULATES DISSECTION PROPAGATION THRESHOLDS

Baptiste Pierrat (1), Mathieu Simon (1), Cristina Cavinato (3)

1. Mines Saint-Etienne, Univ Lyon, Univ Jean Monnet, INSERM, U 1059, Sainbiose, Centre CIS, 42023 Saint-Etienne, France; 2. LMGC, Univ. Montpellier, CNRS, Montpellier, France

Aortic Dissection is one of the most prevalent catastrophic cardiovascular events, affecting 35 out of 100 000 patients for people aged 65-75 [1]. Its onset depends on the interplay between arterial pressure, wall micro-structure, and an initial defect.

In this study, we present an experimental model of interlamellar dissection, triggered by injecting a traceable liquid into the media of porcine thoracic aortas using an external needle. Intramural injections were performed while varying axial stretch, injection rate, and needle gauge. Pressure–volume curves showed a characteristic steep rise followed by stepwise fluctuations, indicative of successive medial micro-failures prior depressurization of the false lumen. Higher axial stretch significantly increased peak pressures and injected volumes, whereas faster injection rates induced sharp pressure elevations at lower volumes, consistent with observations in injection-based delamination studies [2].

In-situ injection experiments under synchrotron X-ray phase-contrast tomography allowed direct visualization of fluid-lamellar interactions before propagation and the subsequent dissection path (Figure 1), revealing two distinct propagation phenomena depending on the injection rate. Morphometric analyses using optical methods confirmed that injection rate, together with axial loading determine propagation thresholds and dissection morphology, reinforcing the robustness of sCT-based observations across modalities.

Together, these findings demonstrate that intramural flow rate critically modulates dissection propagation thresholds and morphology. Future work will integrate these results with computational modeling to refine predictive criteria for tear progression under clinically relevant loading conditions.

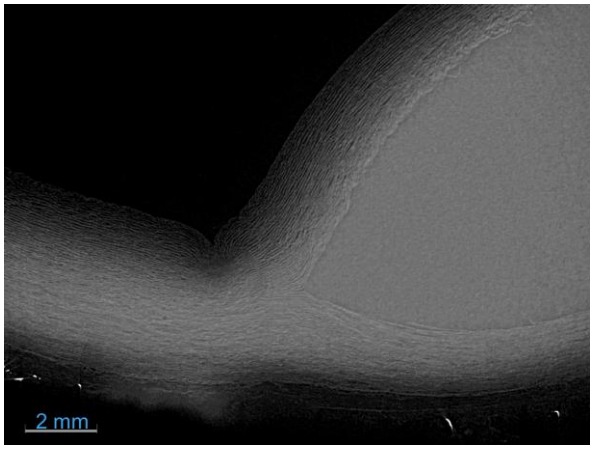


Figure 1: High-resolution s-CT image of post-dissected aorta.

References

1. Nienaber C.A. et al., Nature Reviews. Disease Primers. 2(1):16053 (2016)
2. Roach M. R. Et al., Can. J. Cardiol., 15(5):569-575 (1999)

EUROPEAN MECHANICS SOCIETY

COLLOQUIUM 670

BREAKING BARRIERS IN SOFT TISSUE RESEARCH: COLLABORATIVE INSIGHTS AND FUTURE DIRECTIONS

9 April — 10 April 2026, Rennes, France

DISCRETE FIBER-NETWORK MODELING OF SOFT-TISSUE

Jérémie Girardot (1), Alexandre Lagache (2), Claudio Vergari(2), Anthony Roux (2), Christophe Muth-sen (2), Ivan Iordanoff (1), Sebastien Laporte (2),

1. Arts et Metiers Institute of Technology, I2M, UMR, CNRS 5295, Talence, F-33400, France;
2. Arts et Metiers Institute of Technology, EPF Engineering School, Université Sorbonne Paris Nord, IBHGC-Institut de Biomécanique Humaine Georges Charpak, Paris, F-75013, France;

Understanding the mechanical behavior of soft fibrous tissues is essential for interpreting their physiological roles and for developing patient-specific biomechanical analyses. We present here a discrete computational framework designed to simulate the behavior of soft tissues (such as fasciae and muscles) based on their mesostructural organization. This type of model reproduces key experimental features reported for fibrous tissues, including nonlinear hyperelastic responses, anisotropy driven by preferential fiber alignment, and localized stress patterns induced by inter-fiber interactions. As the figure 1 illustrates it, the approach is evaluated through uniaxial tensile simulations using parameter sets that capture a range of fiber recruitment thresholds and orientations. Despite relying on limited microstructural input, the simulations achieve close agreement with published tensile data and reveal strong sensitivity to subtle variations in fiber properties. The presentation will try to establish a state of the art of the previous work in the laboratory [1-7] using this technique and to highlight the potential of discrete mesostructural modeling for exploring tissue-specific mechanics and paving the way toward personalized soft-tissue simulations.

References

1. Lagache A. *et al*., JMBBM vol. 176 107317, **2026**.
2. Roux A. *et al*., JMBBM vol; 142 105823, **2023**
3. Roux A. *et al*., CMBBE vol. 24, **2021**
4. Muth-Seng C. *et al*., CMBBE vol. 20, **2017**
5. Roux A. *et al*., J. of. BioMech. vol. 49 252–258, **2016**
6. Roux A. *et al*., CMBBE vol. 18, **2015**
7. Roux A. *et al*., CMBBE vol. 17, **2014**

PRELIMINARY RESULTS ON A MODEL MATERIAL FOR CHARACTERIZING HYDRO-CHEMICAL-MECHANICAL COUPLINGS

Alexis Da Rocha (1,2), Simon Le Floc'h (3), Cristina Cavinato (3), Anaïs Lavrand (4), Halima Kerdjoudj (4), Chrystelle Po (2), Adrien Baldit (1)

1. Université de Lorraine, CNRS, Arts et Métiers Institute of Technology, LEM3 UMR 7239, F-57000 Metz, France; 2. Université de Strasbourg, CNRS, ICube UMR 7357, 67000 Strasbourg, France; 3. LMGC, Univ. Montpellier, CNRS, Montpellier, France; 4. Université de Reims Champagne Ardenne, 51100 Reims, France

Soft biological tissues' behaviour involves various couplings that remain a challenge to capture and model. This lack of knowledge remains paramount for predictive simulations for medical applications [1,2]. A model material has been produced from Wharton's jelly with the capability to be tuned in terms of cross-linking and glycosaminoglycans content. It has already shown interesting results to understand damage of such model material [3]. These tunings also affect the mechanical response highlighting non-linear, viscous and chemo-sensitive behaviour as presented in Fig 1a.

a) b)

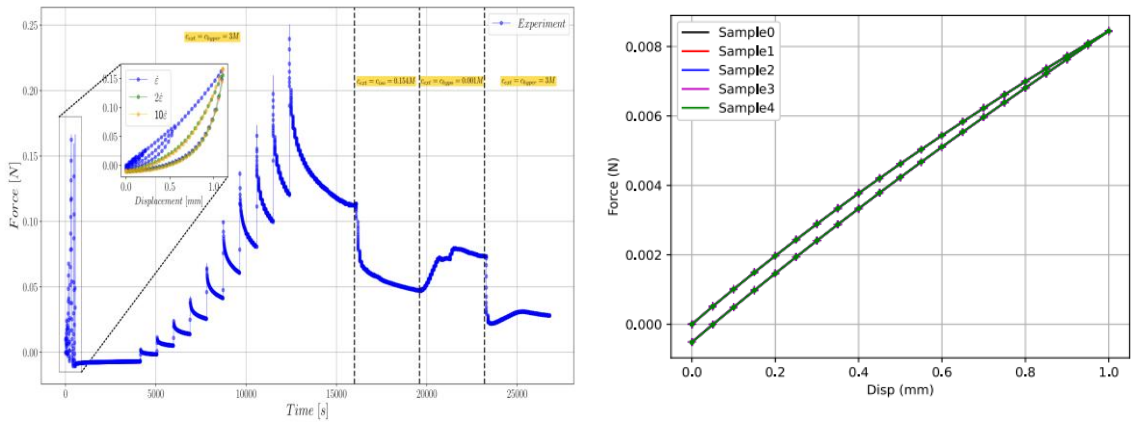


Figure 1: a) Force displacement curves showing hydro-chemo-mechanical couplings during a uniaxial tensile test of a representative Wharton's jelly sample and b) Illustration of the non-unicity problems showing five very similar force-displacement curves for five very different samples. Those numerical samples have up to a factor 3 folds on the hydraulic conductivity [0.01 – 0.0303 mm4/sec/N], and Poisson's ratio in the range [0.1 – 0.38] yet having the same apparent solid-phase behaviour.

At the point of identifying the multi-phasic model parameters from experimental data, some non-unicity problem raises. The multi-phasic nature of the models leads to the presence of an infinite number of different sets of parameters that lead to the same macroscopic apparent solid-phase behaviour during cyclic tensile tests, for example, as presented in Fig 1b. We propose some strategies, that couple modelling to experimental protocols, in order to take into account and avoid the non-unicity problem. Our remaining challenge and discussion is the decoupling of the intrinsic solid-phase viscous response from the poro-elastic behaviour that both exhibits creep and/or relaxation behaviours during tensile tests.

Funding sources

This work is supported by grants from the National Agency of Research (ANR-23-CE51-0039-01) and the Grand-Est region.

References

1. Dubus, M. et. al, Frontiers in bioengineering and biotechnology 10, 828424 (2022)
2. Baldit, A. et al., Journal of the Mechanical Behavior of Biomedical Materials 126, 104981 (2022)
3. Da Rocha, A. et al., Journal of the Mechanical Behavior of Biomedical Materials 174, 107236 (2026)

IN-VIVO MULTIMODAL INDENTATION-BASED IDENTIFIABILITY OF SOFT TISSUE MATERIAL PARAMETERS

Dana Solav (1), Zohar Oddes (1), Amit Ashkenazi (1), Nolwenn Fougeron (1, 2)

1. Technion – Israel Institute of Technology, Israel; 2. Univ. Rennes, Inria, France

Accurate in vivo identification of soft-tissue material parameters remains challenging due to complex mechanical behaviour, the inapplicability of standard mechanical tests, and the frequent non-uniqueness of identified parameters. Indentation enables in vivo characterisation, but requires inverse finite element analysis since closed-form solutions are unavailable. Our recent study of isotropic hyperelastic constitutive laws showed that indentation force-depth data alone leads to poor identifiability, even with simplified two-parameter material models [1]. Adding full-field surface deformations from 3D digital image correlation (3D-DIC) substantially improves identifiability, although some parameters still exhibit large uncertainty bounds [1]. Extension to isotropic bi-layer tissues (e.g., muscle-fat) using multimodal synthetic measurements (i.e., indenter force, 3D-DIC surface deformation, and ultrasound B-mode imaging) demonstrated that combining modalities can markedly reduce parameter uncertainty, depending on the constitutive law and measurement errors [2]. Further extension to anisotropic tissues showed that integrating force with 3D-DIC data enables identification of fibre direction and two parameters of an incompressible transversely isotropic model [3]. Overall, these studies show that reliable indentation-based parameter identification requires carefully designed multimodal experimental protocols. Systematic numerical identifiability analyses offer rigorous guidance for experimental design, construction of effective cost functions, and specification of acceptable measurement errors [4], thereby supporting the development of personalised biomechanical models for clinical applications.

References

1. Oddes Z, Solav D. J Mech Behav Biomed Mater. 140:105708 (2023).
2. Fougeron N, Oddes Z, Ashkenazi A, Solav D. J Mech Behav Biomed Mater. 155:106572 (2024).
3. Ashkenazi A, Shultz A, Jordan L, Solav D. J Mech Phys Solids. 208:106417 (2026).
4. Ashkenazi A, Solav D. Int J Eng Sci. 206:104163 (2025).