Timetable

Time	Monday September 15	Tuesday September 16	Wednesday September 17	Thursday September 18	Friday September 19
08:00 - 09:00	Registration				
09:00 - 09:45	Holzapfel	Nordsletten	Holzapfel	Cyron	Avril
09:45 - 10:30	Quarteroni	Holzapfel	Holzapfel	Ogden	Nordsletten
Break					
11:00 - 11:45	Nordsletten	Quarteroni	Cyron	Quarteroni	Ogden
11:45 - 12:30	Nordsletten	Quarteroni	Nordsletten	Quarteroni	Holzapfel
Lunch					
14:30 - 15:15	Cyron	Ogden	Quarteroni	Nordsletten	
15:15 - 16:00	Ogden	Avril	Avril	Avril	
Break					
16:30 - 17:15	Avril	Cyron	Presentations of Participants*	Presentations of Participants*	
17:15 - 18:00	Avril	Cyron			

*Participants are encouraged to present their work in the form of a poster, ask questions and stimulate discussion. Please send a title of your poster to biomech@TUGraz.at by August 31.

Audience

The Summer School is addressed to PhD students and postdoctoral researchers in biomedical engineering, biophysics, mechanical and civil engineering, applied mathematics and mechanics, materials science and physiology and more senior scientists and engineers (including some from relevant industries) whose interests are in the area of biomechanics and mechanobiology of proteins cells, soft tissues and organs.

Registration

The registration fee is 610 €. The fee covers the attendance at all lectures. In addition, lunches as well as light refreshments and snacks will be provided in the morning and afternoon breaks; a guided city tour and welcome reception will also be included.
Payment is required by August 20, 2025. The fee for payments after this date is 660 €. Arrangements for registration and payment are posted on the Summer School website.

Accommodation

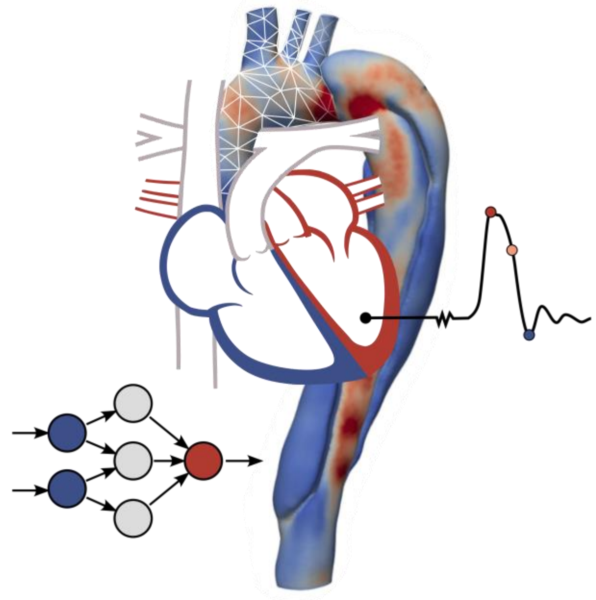
Participants are asked to make their own reservations. Detailed information about conveniently located and nearby student residences and hotels can be found on the Summer School website:
www.summerschool.tugraz.at

Organization

Gerhard A. Holzapfel
Graz University of Technology
Institute of Biomechanics
Stremayrgasse 16-2
8010 Graz, Austria
E-mail: holzapfel@TUGraz.at

11th Summer School on

Physics-Informed Modeling, Simulation and Experiments With Emphasis on the Cardiovascular System



Graz University of Technology
Austria
September 15 – 19, 2025

Summer School coordinated by

Gerhard A. Holzapfel
Graz University of Technology, Austria

Ray W. Ogden
University of Glasgow, UK

WEBSITE:
www.summerschool.tugraz.at

Objectives

This is the 11th Summer School on Biomechanics in the series we have organized since 2001. Its aim is to provide a state-of-the-art overview of physics-informed modeling, simulation and experiments on the cardiovascular system, the stomach and brain tissues.

The lectures will cover the key ingredients of continuum mechanics, focusing on nonlinear elasticity. Details of the mechanical and structural modeling of fiber-reinforced soft materials, and characterization of their properties will be explained along with an analysis of the influence of residual stresses and the cross-linking of collagen fibers. In addition, aortic dissection and related *in silico* models with fluid-structure interactions will be analysed. Machine learning and physics-based computational modeling for solving real-world mathematical problems will be discussed, including simulating cardiac function in both normal and diseased states. Benchmark tests based on the finite element method will be discussed with examples taken from collaborations with cardiologists. There will also be a discussion of viscoelastic tissues and their modeling, in particular application of fractional viscoelasticity to models of the heart and arteries. A study is presented on the different effects between muscular and elastic arteries during aging. With a focus on biomechanics, machine learning and data-driven modeling are discussed. Attention is devoted to constitutive artificial neural networks. Homogenized constrained mixture theory with restricted mixing is provided. The biomechanics of stomach and brain tissues will also be analyzed. Experimental techniques for the determination of the mechanical properties of tissues, cells, cellular components, and proteins will be described. The area of parameter identification is covered by using full-field optical measurements with the virtual fields method in elasticity.

Future directions for research in physics-informed biomechanics and mechanobiology will be identified during the lectures. This offers significant challenges for the advancement of knowledge of mechanical, biological, electrical effects and fluid-structure interactions.

Invited Lecturers

Stéphane Avril

Mines Saint-Étienne, France

Parameter identification using full-field optical measurements; digital image/volume correlation; optical coherence tomography; virtual fields method; elastography; vascular remodeling and adaptation; vascular SMCs; traction force microscopy; mechanotransduction; mechanobiology of aneurysms; endovascular aneurysm repair

Christian Cyron

Hamburg University of Technology, DE

Machine learning and data-driven modeling in biomechanics; Constitutive Artificial Neural Networks (CANNs); growth and remodeling of soft biological tissues (physiological foundations, experimental observations, mathematical and computational modeling); biomechanics of the stomach (mechanics, electrophysiology, brain-stomach axis)

Gerhard A. Holzapfel

TU Graz, Austria & NTNU, Norway

Soft tissue biomechanics: from structure to macroscopic response; collagen fiber dispersion: identification and analysis; cross-linking of collagen fibers: the inverse Pointing effect; aortic dissection: pathological changes, experimental and *in silico* models; mechanics of brain tissue

David Nordsletten

University of Michigan, USA

Viscoelasticity; fractional viscoelasticity; cardiac and arterial biomechanics; biomechanics of aging; biomechanical testing; objectivity; frame invariance; thermodynamics; image-based modeling; patient-specific modeling; model personalization; data assimilation; numerical methods

Ray W. Ogden

University of Glasgow, UK

Continuum mechanics essential for constitutive modeling of soft biological tissues; fiber-reinforced materials, fiber dispersion: the role of planar biaxial tests in characterizing material properties; residual stresses and their influence on material response; some modeling pitfalls

Alfio Quarteroni

Politecnico di Milano, Italy

Motivations, and methodological approach; modeling cardiovascular flows; physics-based mathematical models of cardiac function; data-based algorithms from machine learning and artificial neural networks; combined data-based and physics-based algorithms; application to clinically relevant problems

Preliminary Suggested Readings

S Avril. Hyperelasticity of soft tissues and related inverse problems, in: “Material Parameter Identification and Inverse Problems in Soft Tissue Biomechanics”, CISM Courses and Lectures No. 573, Int Centre for Mechanical Sciences, Springer, 2017, pp. 37-66

S Budday et al., Fifty shades of brain: a review on the mechanical testing and modeling of brain tissue. *Arch Comput Methods Eng,* 27:1187-1230, 2020

CJ Cyron et al., A homogenized constrained mixture (and mechanical analog) model for growth and remodeling of soft tissue. *Biomech Model Mechanobiol,* 15:1389-1403, 2016

M Fedele et al., A comprehensive and biophysically detailed computational model of the whole human heart electromechanics. *Comput Methods Appl Mech Engrg,* 410:115983, 2023

GA Holzapfel et al., Modelling non-symmetric collagen fibre dispersion in arterial walls. *J R Soc Interface,* 12:20150188, 2015

GA Holzapfel, RW Ogden. An arterial constitutive model accounting for collagen content and cross-linking. *J Mech Phys Solids,* 136:103682, 2020

GA Holzapfel et al., On fibre dispersion modelling of soft biological tissues: a review. *Proc R Soc Lond A,* 475:20180736, 2019

GA Holzapfel, RW Ogden. On planar biaxial tests for anisotropic nonlinearly elastic solids. A continuum mechanical framework. *Math. Mech. Solids,* 14:474-489, 2009

B Lane et al., Novel experimental methods to characterize the mechanical properties of the aorta. in “Biomechanics of the Aorta”, Academic Press, 2024, pp. 91-108

K Linka et al., Constitutive artificial neural networks: A fast and general approach to predictive data-driven constitutive modeling by deep learning. *J Comput Phys,* 429, 110010, 2021

D Nordsletten et al., A viscoelastic model for human myocardium. *Acta Biomater,* 135:441-457, 2021

RW Ogden. Nonlinear continuum mechanics and modelling the elasticity of soft biological tissues with a focus on artery walls, in: “Biomechanics: Trends in Modeling and Simulation”, Springer, 2016, pp. 83-156

A Quarteroni et al., Mathematical Modelling of the Human Cardiovascular System. Data, Numerical Approximation, Clinical Applications. Cambridge University Press, 2019

M Rolf-Pissarczyk et al., Mechanisms of aortic dissection: from pathological changes to experimental and in silico models. *Prog Mater Sci,* in press

W Zhang et al., A viscoelastic constitutive framework for aging muscular and elastic arteries. *Acta Biomater,* in press

Download these papers, and some more, from the website: www.summerschool.tugraz.at/objectives