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Pores and prejudices: experimental evaluation of Darcy's permeability in brain tissue with biomimetic hydrogels

Manuel P. Kainz[1], Michele Terzano[2], Luka Boticki[3], Julia Fuchs[4], Alexander Greiner[5], Silvia Budday[6], Paul Steinmann[7], Gerhard A. Holzapfel[8]

[1] Institute of Biomechanics, Graz University of Technology, Austria. kainz@tugraz.at
[2] Institute of Biomechanics, Graz University of Technology, Austria. michele.terzano@tugraz.at
[3] Institute of Biomechanics, Graz University of Technology, Austria. luka.boticki@gmail.com
[4] Department of Cell Biology, Histology and Embryology, Gottfried Schatz Research Center, Medical University of Graz, Austria. julia.fuchs@medunigraz.at
[5] Institute of Continuum Mechanics and Biomechanics, Department of Mechanical Engineering, FAU Erlangen-Nürnberg, Germany. alexander.greiner@fau.de
[6] Institute of Continuum Mechanics and Biomechanics, Department of Mechanical Engineering, FAU Erlangen-Nürnberg, Germany. silvia.budday@fau.de
[7] Institute of Applied Mechanics, Friedrich-Alexander-Universität Erlangen-Nürnberg & GCEC, University of Glasgow, Germany. paul.steinmann@fau.de
[8] Institute of Biomechanics, Graz University of Technology & Department of Structural Engineering, NTNU, Austria. holzapfel@tugraz.at

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Abstract

Accurate biomechanical modeling of brain tissue is essential for understanding neurological disorders and advancing neurosurgery, injury prediction, and drug delivery. As an ultrasoft, highly hydrated material, brain tissue exhibits a mechanical response governed by interstitial fluid flow and is therefore increasingly modeled as a biphasic medium. In this context, hydraulic permeability is a critical parameter; however, its direct experimental determination remains a significant challenge. As a result, permeability is often treated as a fitting parameter with limited experimental validation. In this study, we introduce a novel experimental setup for characterizing fluid transport in ultrasoft materials under defined flow conditions similar to Darcy's law. The system utilizes a cylindrical chamber to simultaneously measure hydrostatic pressure, fluid flow rate, and global deformation. Using soft tissue-mimicking hydrogels with tunable stiffness and porosity, we quantitatively investigate pressure-dependent permeability. Our results reveal how material features influence the validity of Darcy's law and identify conditions under which it fails. Furthermore, we successfully transfer this methodology to animal brain tissue, providing the first direct measurement of brain tissue permeability under confined, pressure-driven flow conditions. These findings provide critical, experimentally validated data that can substantially improve the predictive accuracy of biphasic biomechanical models.

Keywords:

biomechanics hydrogels brain tissue biomaterial testing porous media experimental mechanics porosity permeability