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A unified electromechanical and contact framework for intestinal motility

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Abstract

The intestine is an active organ that contracts in response to electrical stimulation, generating motility patterns such as peristalsis and segmentation, which are essential for digestion [1]. Unlike the heart, which is constrained by the rib, the intestine is characterized by a degree of movement within the abdominal cavity, making it prone to self-contact and contact with surrounding organs. Despite the number of electromechanical modeling strategies aimed at describing intestinal behavior, the incorporation of contact phenomena remains limited [2]. Furthermore, the interaction between the intestine and devices like balloon dilators or stents is an aspect for clinical applications and has been insufficiently addressed in computational studies. In this study, we propose a comprehensive electromechanical modeling framework for intestinal motility that explicitly accounts for both self-contact and contact with external bodies. Our approach builds upon established electromechanical models that couple electrophysiology and tissue mechanics via the active strain formulation, which captures the contractile behavior induced by electrical activation [1]. The coupling between the electrophysiological and mechanical problems is handled using a staggered (operator-splitting) algorithm, which alternates between solving the electrical activation and the resulting mechanical deformation at each time step. Contact interactions are modeled with a formulation on the Lagrangian method, enabling treatment of self-contact of the intestinal wall and contact with bodies, such as dilation balloons or adjacent organs. The governing equations are discretized using the finite element method (FEM), allowing for resolved simulations on geometries—reconstructed from medical imaging data—and boundary conditions. The FEM implementation and solution algorithm were developed within the GetFEM software, leveraging its flexibility for multiphysics problems. The computational model was tuned via unique in vivo experiments conducted on pigs. Ethical approval was provided by the University of Auckland Animal Ethics Committee. A custom-designed pressure sensor device was developed to accurately measure contact pressures arising during intestinal self-contact. Simultaneously, the balloon volume was continuously monitored using a barostat, providing essential data to correlate mechanical deformation, pressure distribution, and Balloon expansion. Numerical simulations performed with the proposed framework reproduced key phenomena observed experimentally, including the onset and evolution of self-contact zones, the mechanical response to balloon inflation, and the complex interplay between electrical activation and tissue deformation under constrained conditions. Quantitative comparisons between simulated and measured pressures and volumes showed good agreement, confirming the model's ability to capture realistic intestinal motility during clinical interventions. Overall, this work introduces a versatile and robust modeling tool that advances the state of the art by integrating active strain electromechanics with contact mechanics in a patient-specific context. The proposed framework not only enhances our fundamental understanding of intestinal motility but also opens new avenues for simulating and optimizing medical devices and therapeutic procedures involving the gastrointestinal tract.

Keywords:

Motility patterns Self-contact Pressure sensor device Active strain electromechanics Balloon volume Electrical activation

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