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Research paper

Biaxial mechanical modeling of the small intestine

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ABSTRACT

Capsule endoscopes are pill-size devices provided with a camera that capture images of the small intestine from inside the body after being ingested by a patient. The interaction between intestinal tissue and capsule endoscopes needs to be investigated to optimize capsule design while preventing tissue damage. To that purpose, a constitutive model that can reliably predict the mechanical response of the intestinal tissue under complex mechanical loading is required. This paper describes the development and numerical validation of a phenomenological constitutive model for the porcine duodenum, jejunum and ileum. Parameters characterizing the mechanical behavior of the material were estimated from planar biaxial test data, where intestinal tissue specimens were simultaneously loaded along the circumferential and longitudinal directions. Specimen-specific Fung constitutive models were able to accurately predict the planar stress–strain behavior of the tested samples under a wide range of loading conditions. To increase model generality, average anisotropic constitutive relationships were also generated for each tissue region by fitting average stress–strain curves to the Fung potential. Due to the observed variability in the direction of maximum stiffness, the average Fung models were less anisotropic than the specimen-specific models. Hence, average isotropic models in the Neo–Hookean and Mooney–Rivlin forms were attempted, but they could not adequately describe the degree of nonlinearity in the tissue. Values of the R^2 for the nonlinear regressions were 0.17, 0.44 and 0.93 for the average Neo–Hookean, Mooney–Rivlin and Fung models, respectively. Average models were successfully implemented into FORTRAN routines and used to simulate capsule deployment with a finite element method analysis.

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1. Introduction

Capsule endoscopes (Iddan et al., 2000) have been used to assist clinicians in the diagnosis of pathologies affecting the small intestine for the past ten years. The design currently available to medical practitioners features pill-sized capsule endoscopes containing a camera, a battery and a transmitter that passively reach the gastrointestinal (GI) tract upon oral ingestion by the patient. As the capsule is moved forward by natural peristaltic contractions,