Patient-Specific Biomechanical Analysis of the Actively Contracting and Buckling (Stented) Esophagus

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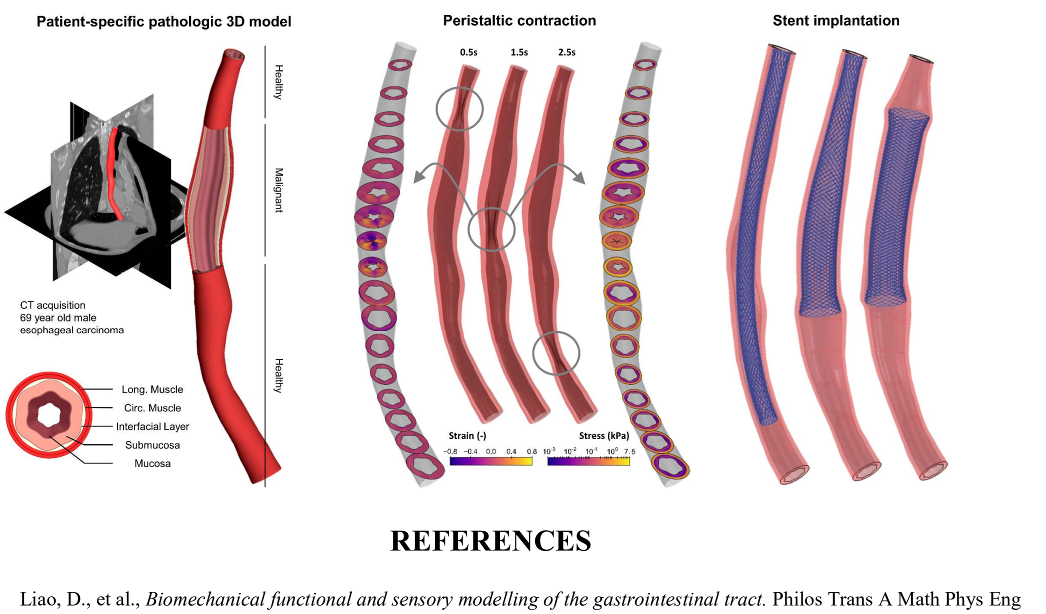
ABSTRACT

Malfunctioning of the esophagus can easily plague the patient with considerable discomfort and complications and might require treatment with (biodegradable) stents. To increase our understanding of esophageal (patho)physiology and its biomechanical interaction with (biodegradable) stents, detailed insights in the large deformability of this multi-layered muscular tube organ and the corresponding stress and strain distributions in the esophageal wall are crucial [1]. For that reason this study set forth to overcome the current limitations in finite element modelling human esophagi [2]. First, we proposed and fitted a combined constitutive material model to account for active tissue behavior complementary to the esophageal wall's passive behavior. Furthermore, linear eigenvalue buckling analyses were performed to incorporate the submucosa's characteristic buckling behavior. Due to the dependency of the results on geometry [3], a five-layered 3D patient-specific model of a pathologic esophagus was created based on esophageal histology and the CT acquisition of a patient suffering from oesophageal carcinoma. This lead to a numerical framework which, after the incorporation of the in vivo stress state of the tissue using a Backward Incremental approach [4], allows us to assess the remodeling processes of esophageal tissue in diseased states, to get more insight in the physiological process of food swallowing and to perform virtual device (e.g. stent) implantation or surgery. In more detail, a virtual implantation of a previously calibrated and validated biodegradable stent model [5] or a spatiotemporal activation (as it would be neurologically incited) of the muscle cells leading to a peristaltic contraction of the esophagus pushing a food or fluid bolus down, provoke computable contact pressures on the mucosa and stress and strain distributions in the submucosa and muscularis externa (see Figure).



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