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Numerical Simulation of Failure of Ventricular Tissue due to Deep Penetration

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ABSTRACT

Although experimental studies to characterize failure properties of vascular tissue have been reported in the literature [1], failure mechanisms of soft biological tissue are not yet well understood. Apart from few analytical [2] and numerical studies [3], failure of soft biological tissue is a fairly unexplored field of biomechanics. In general the identification of failure properties from experimental data is not straight forward and requires sophisticated approaches. Consequently, mixed experimental computational methods are proposed in the literature, where experimental data is analyzed using detailed numerical models of the associated experimental investigation.

This paper focuses on the identification of failure properties of ventricular tissue from experimental data of deep penetration with cylindrical punches, which is of particular clinical and industrial interest to understand, e.g., the mechanisms of perforation of pacemaker electrodes [4]. To this end, a detailed FE model of our previously performed penetration experiments has been developed, where the identified failure mechanisms are reflected by the introduction of cohesive failure zones. Here, the primary failure mode, i.e. where the crack faces are wedged open by the advancing punch, is represented by cohesive interface elements, whereas the secondary failure mode, i.e. where medial laminar units are dissected, is captured by Partition of Unity (PU) finite elements. Hence, interface and PU elements are combined, which allows to reflect the experimentally observed type of crack interaction. To this end, the developed interface element formulation accounts for enhanced degrees of freedom, as they are provided by the PU elements.

Within this work we focused on deep penetration of the middle layer of the ventricle, i.e. the myocardium, and the arising contact problem was formulated within the target-contractor concept, where the contact constraint was enforced by standard penalty regularization [5]. The proposed concept states a powerful approach not only to estimate failure properties from experimental data but also for design optimization of clinical devices, like pacemaker electrodes.

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