
A constitutive law for the tensile and compressive behaviour of fibrin networks applied to the simulation of aspiration thrombectomy

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Abstract

Traditional models for fibre-reinforced soft tissues assume that fibres are only active in tension (1-4). In such models it is assumed that wavy fibres, such as collagen, will buckle when shortened and therefore cannot support compressive stress. However, compression-tension experiments of pure fibrin blood clots, as retrieved from acute ischemic stroke patients, suggest that fibrin can support both tensile and compressive stress (5, 6). Therefore, the current study focuses on the development of a model in which fibre shortening results in the development of compressive axial fibre stress.

Published constitutive laws for fibres in soft tissues include exponential strain-stiffening (1, 2), and bilinear strain-stiffening models (4). Firstly, we demonstrate that the simple extension of existing fibre formulations to the shortening/compressive regime results in unphysical softening during high levels of applied compression. We propose a novel fibre constitutive law which prevents such softening in compression (compression-tension fibre (CTF) model). This allows us to model pure fibrin networks without the need to add an artificial isotropic matrix component.

In order to simulate a fibrin clot, we construct a network of discrete fibres in which the mechanical behaviour of each fibre is described by our novel constitutive law. The fibre model is implemented in Abaqus/Standard using a user defined subroutine (UMAT). Converged results were achieved with 1741 fibre segments. Computed results reveal that our discrete fibre network with a bilinear CTF formulation can replicate experimental compression and tension data for pure fibrin platelet contracted blood clot analogues.

Additionally, we use this novel material model to simulate the aspiration of a fibrin clot into a thrombectomy catheter, with an applied suction pressure of 80 kPa. This simulation correctly predicts the corking of the clot at the tip of the catheter as validated by bench-top aspiration tests of platelet-contracted fibrin clot analogues. The simulation further reveals regions of shortened fibres where the clot is compressed against the catheter wall, in addition to regions of fibres in tension in the centre of the clot. This new physically-based constitutive formulation provides new insights into fibrin clot biomechanical behaviour that can be incorporated into the design of thrombectomy devices.

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