The cells role in collagen modelling in tissue engineering constructs: A theoretical framework
A.L.F. Soares, C. W. J. Oomens and F.P.T. Baaijens

Introduction

Tissue engineered (TE) protocols to increase collagen modelling, may result in increased tissue compaction. This highly coupled interplay between mechanical loading, collagen modelling and tissue compaction can be investigated with the assistance of numerical models. In this study, a structural constitutive framework is introduced that relates the local mechanical conditions within the tissue to the cell mechanics. In its turn, the cells mechanics is related to the tissue collagen fiber architecture.

Methods

The cell mechanics is incorporated in the theory of Driessen et al. [1].

\[ \sigma = \bar{\tau} + \sum \phi_j \left( \tau_{j} - \bar{\tau}_j \cdot \bar{\tau}_j \right) \bar{\phi}_j \bar{\phi}_j \] (1)

with \( \bar{\tau} \) the isotropic compressible matrix stress, \( \tau_j \) the cell stress-fibres stress, the \( \phi_j \) fiber volume fraction, \( \phi_j \) the collagen fiber stress and \( \bar{\tau}_j \) the fiber direction in the deformed configuration.

The constitutive behaviour of the cells is described by the theory of Desphande et al. [2]. In the theory, the mechanical response of the cell comprises an active stress arising from the formation and dissociation of the \( \alpha \)-actin stress fibers:

\[ \eta_j = \left[ 1 - \eta_j \right] \frac{C_k_j}{\beta} - \left[ 1 - \frac{\tau_j}{\tau_{c0}} \right] \frac{\eta_j \bar{k}_s}{\beta} \] (2)

with \( \tau_j \) the stress-fiber stress, \( \tau_{c0} \) the corresponding isometric stress, \( k_i \) and \( k_d \) dimensionless constants governing the rate of formation and dissociation of the cell stress-fibers. The stress in the stress-fiber \( \tau_j \) is dependent on the extension/shortening of the fiber. This relation is given by a Hill-like equation.

As a first approximation, the collagen fiber distribution is assumed to be equivalent to the cell stress-fiber distribution \( \phi_j = \eta_j \).

Preliminary results

The computational framework was implemented in the finite element package SEPRAN [3]. Assuming symmetry, a 1/8 of the sample was modelled. Preliminary results are obtained with specimens under uniaxial static conditioning where \( \lambda_s \) is kept constant (Fig. 1).

The results show a decrease in the sample volume through the unconstrained directions (Fig. 2a). The results also show a final anisotropic fiber distribution in the direction of the constrain (Fig. 2b).

Discussion

The preliminary results demonstrate the model capability in predicting the TE constructs typical collagen fiber orientation under uniaxial static conditions. As a next step, the model will be validated with experimental data.

Furthermore, the findings suggest that the model offers possibilities to investigate and control collagen orientation and compaction in TE constructs.

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