Computational model describes cell orientation in response to mechanics

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SMARTCARE a BMM project

Introduction

- Correct mechanical properties are essential for proper tissue functioning.
- Tissue is often anisotropic: it often has different properties in different directions.
- Engineered tissues also require this anisotropy.
- To obtain tissue anisotropy, control over cell orientation is required.
- Cell orientation is strongly influenced by the mechanics of the cellular environment.

Aim

Develop a model that describes cell orientation in response to the cell's mechanical surroundings

Method

A computational model is proposed, based on the following assumptions:

- Cells orient in their main stress fiber direction.
- Stress fibers apply tension to their environment.
- This tension is maximal when strain and strain rate are zero, and reduces with increasing strain and shortening rate.
- If fiber stress in a direction is high, this leads to a large amount of fibres in this direction.

Equations corresponding to these assumptions were implemented in Matlab and used to simulate three cases that have previously been investigated experimentally.

Conclusion & Future work

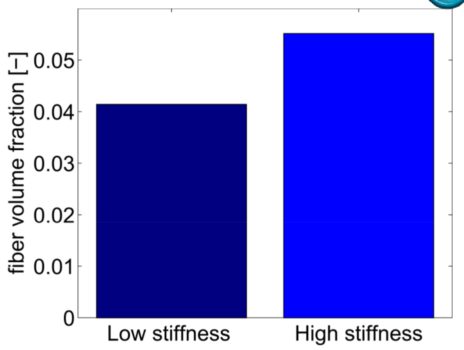
The proposed model qualitatively describes the preferred cell orientation seen experimentally in response to stiffness anisotropy, uniaxial cyclic strain and a combination of cyclic strain and compaction.

However, the performed simulations formed an initial investigation of rather simplified situations.

Therefore, in the future, we aim to implement this model in finite element code and investigate its predictions in more complex situations.

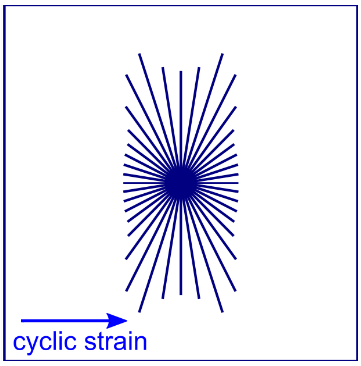
[1] Ghibaudo et al .(2008) Soft matter 4:1836-43
[2] Tondon et al. (2011) J Biomech 45:728-735
[3] Gauvin et al. (2011) Acta Biomater 7:3294-301

Cell orients in stiffest direction



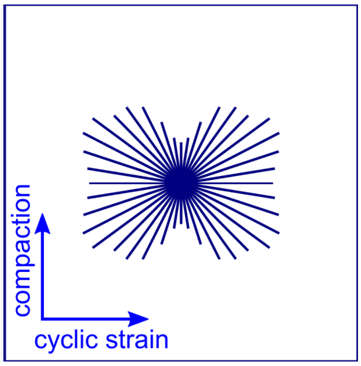
Cell on a substrate with anisotropic stiffness. Cell stress fiber volume fraction in high and low stiffness direction of substrate are shown. High stiffness ≈ 6 kPa and low stiffness ≈ 1.5 kPa. Fiber volume fraction is larger in high stiffness direction than in low stiffness direction, in agreement to [1].

Cell orients away from cyclic strain



Fiber distribution for cell undergoing uniaxial cyclic strain (1 Hz, 10%). Length of line in each direction is proportional to the amount of stress fibers in this direction. Shorter lines in cyclic strained direction than perpendicular to cyclic strain denote an avoidance of the strained direction, in agreement to [2].

Cell prefers a strained to a compacting direction



Fiber distribution for cell undergoing cyclic strain in one direction (1 Hz, 10%) and compaction (negative strain (16%); occurs experimentally due to tension applied by cells) in the other. Length of line in each direction is proportional to amount of stress fibers in this direction. Longer lines in cyclic strained than compacted direction denote a preference for this orientation, in agreement to [3].

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Hartstichting

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