Focus on diffuse axonal injury

M@terials Technology

Technische Universiteit **Eindhoven** University of Technology

Focus on Diffuse Axonal Injury

R.J.H. Cloots*, J.A.W. van Dommelen*, T. Nyberg♯ and M.G.D. Geers*
*Eindhoven University of Technology
♯Royal Institute of Technology, Stockholm, Sweden

Introduction

In Diffuse Axonal Injury (DAI), injury is widespread over the brain. Despite this name, focal injury is occurring at the cellular level [1]. The aim of this study is to focus on the mechanical aspects of DAI at the cellular level.

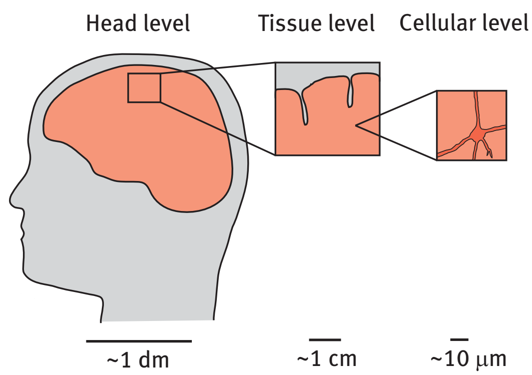

Figure 1: Length scales involved in DAI from a human head via tissue level structures to the brain cells.

Method

Geometry

The geometry (50x50 μm) of the plane strain model contains one inclusion (e.g., a cell body) that is surrounded by axons (Fig. 2b). The neurofilaments, which give the axons its mechanical strength, are modeled as fibers. Three configurations are made, in which the diversion angle φ of the fiber orientations are 30°, 45° and 60°.

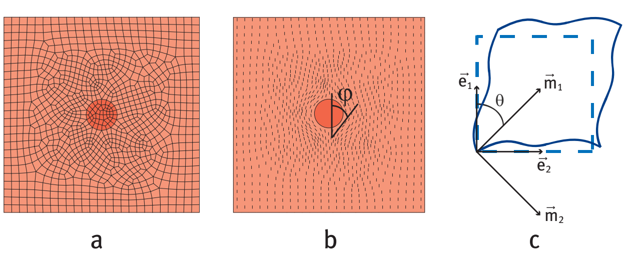

Figure 2: a) Mesh and b) fiber orientations, where φ represents the variation in fiber orientations. c) Deformation with loading angle θ.

Boundary conditions

An isochoric deformation with a principal stretch direction $\vec{m}_1$ that varies with angle θ (Fig. 2c) is imposed on the model via periodic boundary conditions [2].

Material model

The material behavior is described by a fiber reinforced constitutive model [3]. The Cauchy stress tensor is

$$\sigma = \sigma^h + \frac{1}{J}\left(G\tilde{B}^d + 2k\langle \tilde{I}_4 - 1\rangle \tilde{I}_4 (\vec{n}\vec{n})^d\right)$$

where $\sqrt{\tilde{I}_4}$ and $\vec{n}$ are the fiber stretch and the fiber direction, respectively.

Results

The logarithmic axonal strain with respect to the applied logarithmic tissue strain depends on the loading angle and is highest at $\theta = 0°$ (Fig. 3). An increase of either the fiber diversion angle φ or the inclusion shear modulus results in a higher relative strain, which can be over 1.6. The equivalent stress is concentrated equatorial to the inclusion with respect to the loading direction .

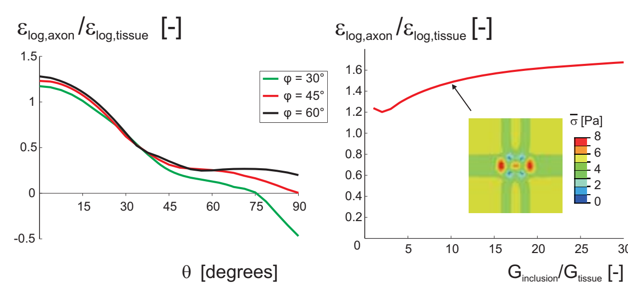

Figure 3: Relative axonal strain versus loading angle θ (for $G_{inclusion}/G_{tissue} = 3$) and relative shear modulus (for $\theta = 0°$). Inset: equivalent stress field.

Discussion and conclusions

A relative high shear modulus inclusion in brain tissue combined with a loading direction in the main axonal direction can increase the logarithmic strain of the axons locally by more than 60%, which might lead to axonal injury. Therefore, the heterogeneities at the cellular level have to be accounted for in the understanding of DAI.

References

1. Povlishock (1993) *Ann. Emerg. Med.* 22, 980–986
2. Kouznetsova et al. (2001) *Comp. Mech.* 27, 37–48
3. Gasser et al. (2006) *J. R. Soc. Interface* 3, 15–35