Multi-scale mechanics of traumatic brain injury

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Introduction

Traumatic brain injury can be caused by accidents and often leads to health issues or even death. The mechanical load on the head causes local axonal injury where axons have to deviate for an inclusion, such as a blood vessel (Fig. 1) [1]. It is assumed that this is caused by local strain concentrations depending on the axonal microstructure. The aim of this study is to investigate the influence of the axonal microstructure on traumatic brain injury.

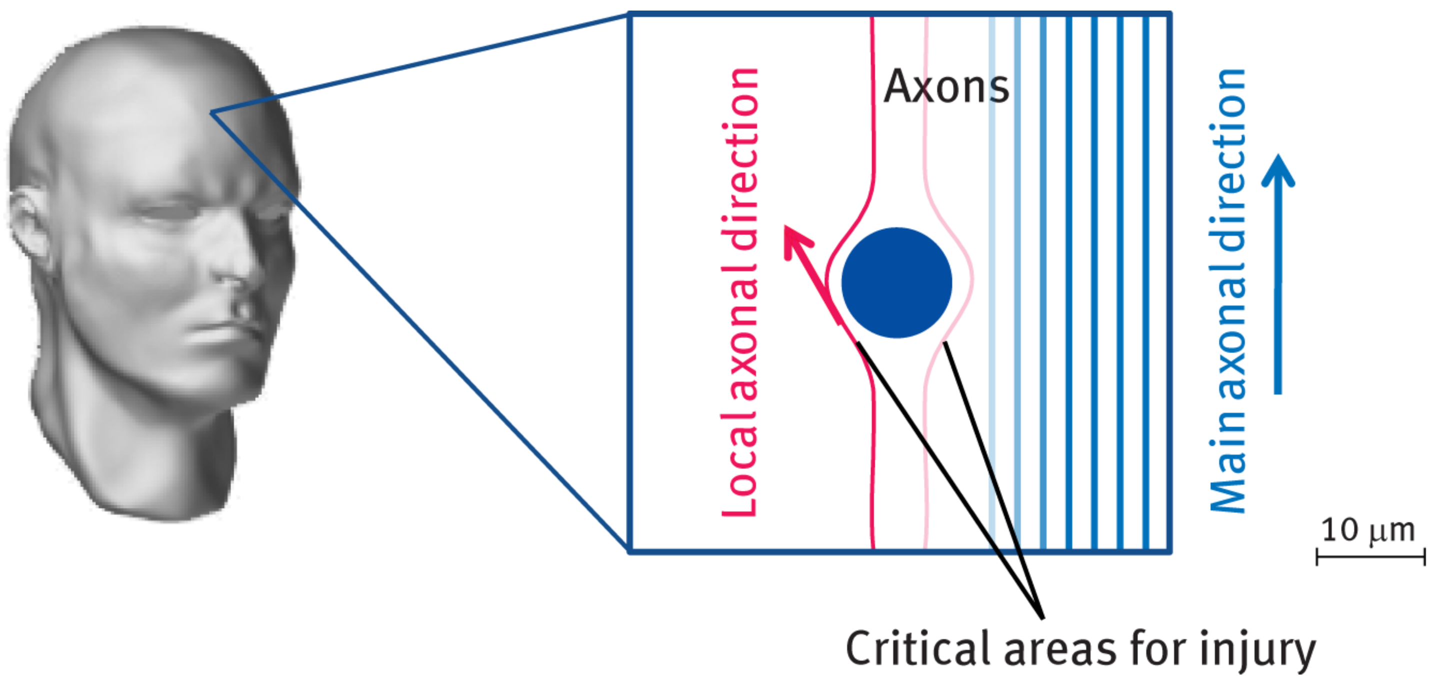

Figure 1: A mechanical load on the head causes injury at the axonal level.

Method

A previously developed FE macro model [2] is used in a multi-scale mechanics approach with an FE micro model (Fig. 2) [3].

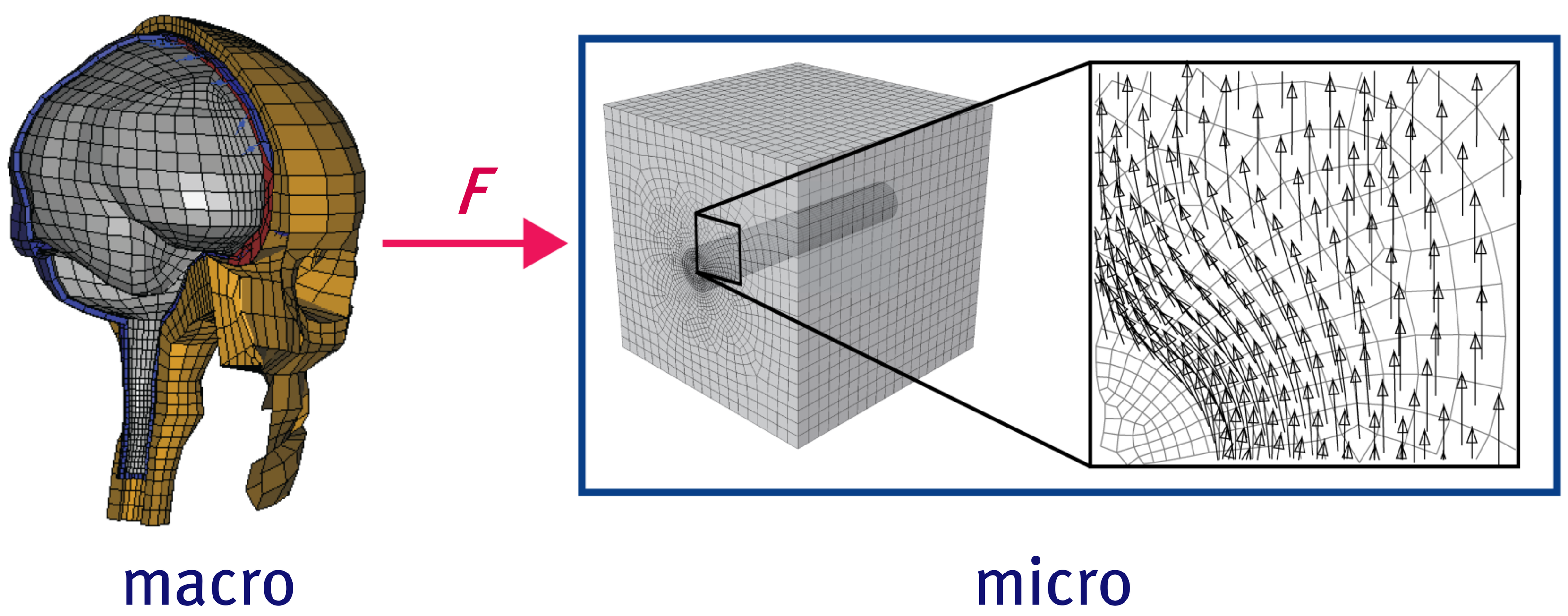

Figure 2: The macro deformation gradient tensor *F* is applied to the micro model by means of periodic boundary conditions.

Macro model: represents a human head containing brain tissue that is described by an isotropic viscoelastic material model. In this study, the brainstem is analyzed, since it is an important region for axonal injury [1].

Micro model: accounts for the critical situation caused by an inclusion in between the axons. The same material model as in the macro model is used. The axonal strains are obtained in the axonal directions, which is described by a vector field.

Results

The strain field of the brainstem is shown in Fig. 3 for both the macro and micro model simulations.

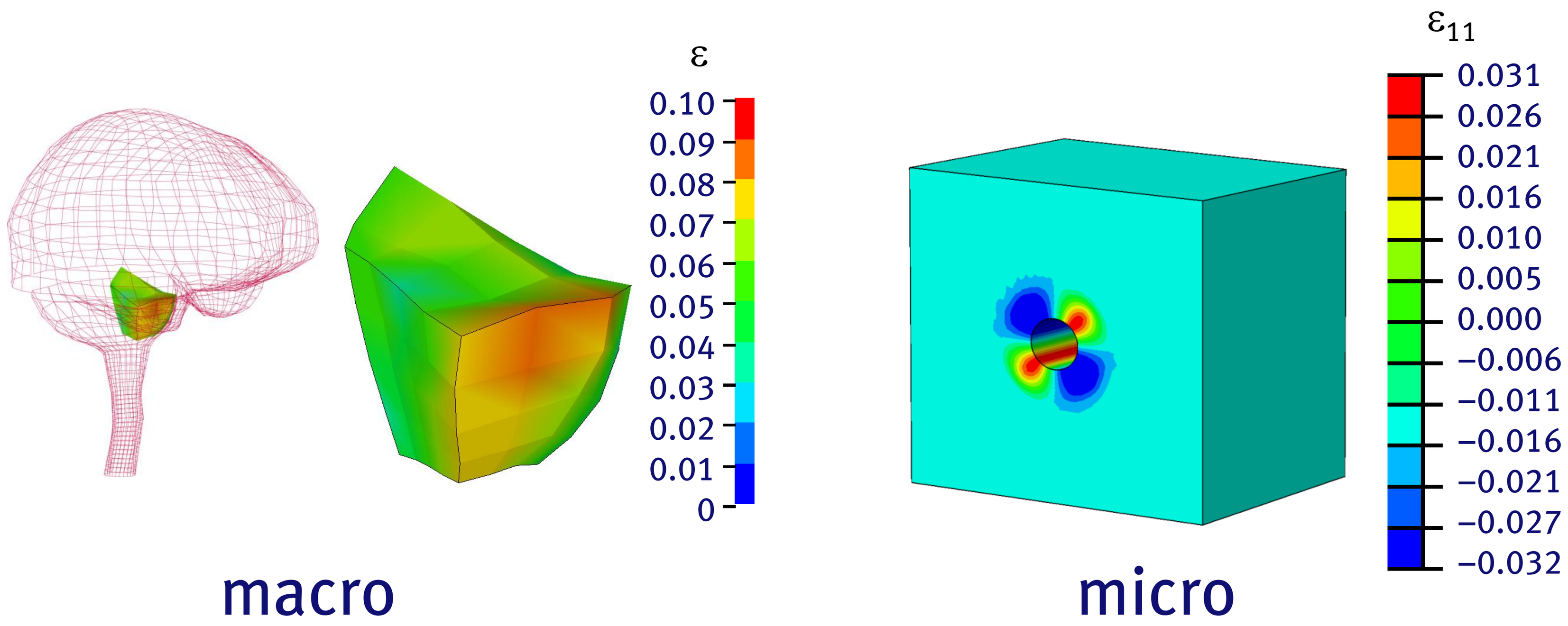

Figure 3: Tissue maximum principal strains in the brainstem and the axonal strains in the material 1-direction corresponding to the axonal direction.

In Fig. 4, the maximum axonal strains are plotted against the tissue strains. Axonal strains can be much lower than the tissue maximum principal strains (left), but also much higher than the tissue strain in the main axonal direction (right).

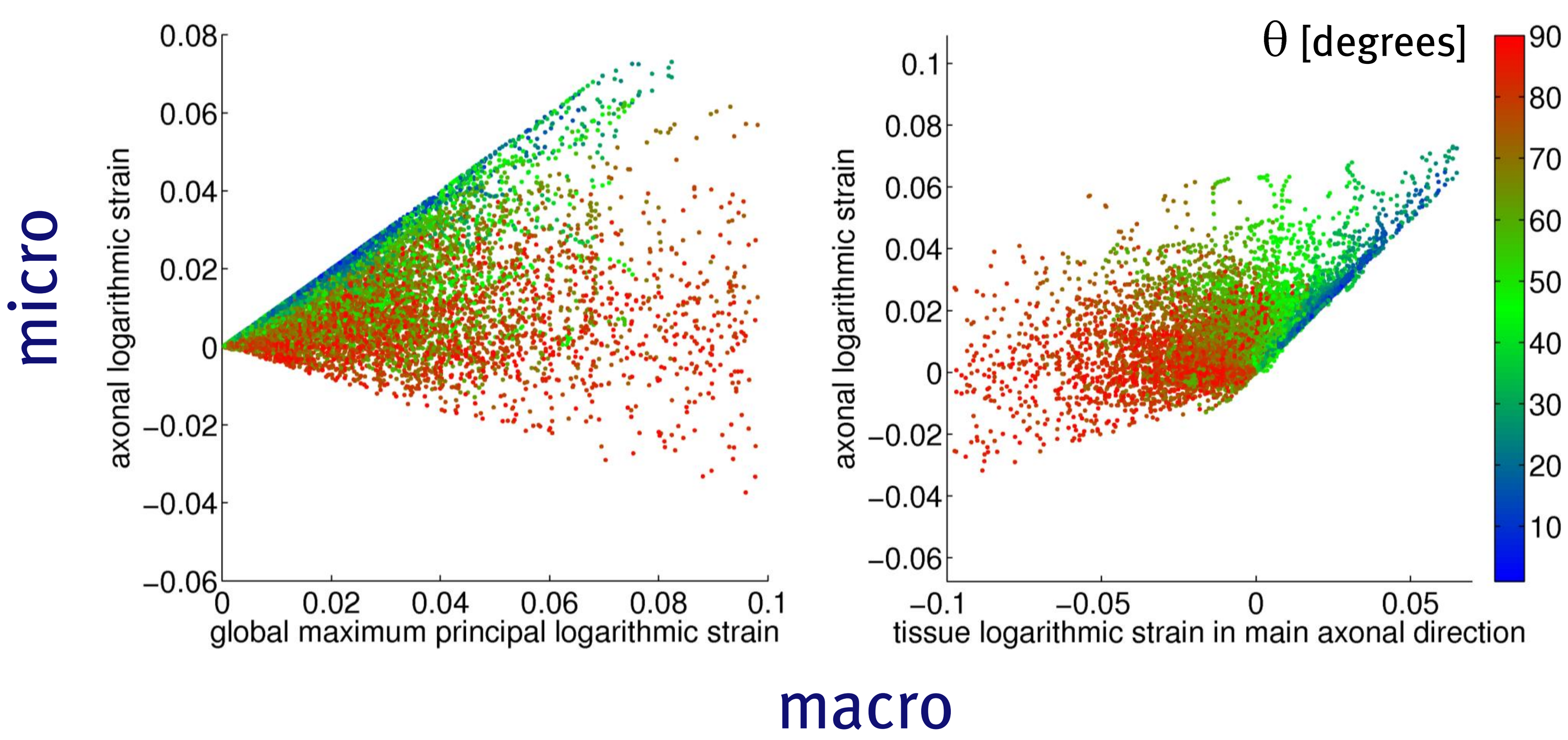

Figure 4: Maximum axonal strain versus tissue strain. The angle θ is the angle between max. principal tissue load and main axonal direction.

Discussion and conclusion

The maximum axonal strain locations agree with pathological observations. The microstructural influences are due to:

- The main axonal direction relative to the loading direction
- The local deviation in axonal directions

These effects should be accounted for in macro head model simulations for a better prediction of traumatic brain injury.

References

1. Povlischock (1993) *Ann. Emerg. Med.* 22, p. 980-986
2. Kleiven (2007) *Stapp Car Crash J.* 51, p. 81-114
3. Cloots *et al.* (2010) *Proc. IRCOBI*, p. 119-130