LARGE-SCALE FINITE ELEMENT MODELING OF PRE-STRESS IN ARTICULAR CARTILAGE

Seyed Shayan Sajjadinia* (1), Bruno Carpentieri (1), Gerhard A. Holzapfel (2,3)

1. Faculty of Computer Science, Free University of Bozen-Bolzano, Italy; 2. Institute of Biomechanics, Graz University of Technology, Austria; 3. Department of Structural Engineering, Norwegian University of Science and Technology, Norway

*Corresponding author: e-mail: ssajjadinia@unibz.it

1. Introduction

Articular cartilage (AC) is largely modeled by finite element (FE) methods and multiphasic equations, e.g., [1]. Since the *in vivo* stress-free state of AC is usually unknown, a pre-stressing algorithm (PSA) is typically needed to determine this state by custom optimizers, which has been successfully implemented in small-scale models with simple geometries [2]. The main goal of this work is the extension to a large-scale AC model in a human tibiofemoral joint.

2. Materials and Methods

An FE model is extracted from the Open Knee Project [3] to be integrated into the multiphasic model and the PSA. Since most AC constitutive equations are depth dependent, the normalized depth (ND) of each point is approximated by the points on the surfaces. Then the fibrillar orientations are approximated by their corresponding split lines and NDs. The FE analysis of pre-stressing is performed using an accelerated PSA with a unified optimizer (comparing to our previous work that requires separate optimizers for geometrical and material parameters).

3. Results

The optimizer finds the pre-stressed state by forward and inverse FE analyses in around 3 hours (and 14 steps) with a regular computer. The recorded stresses (Fig. 1) are strongly dependent on the depth. To assess the validity of the results, the load-resistance of the AC constitutive components, e.g., the stress in the fibrils, is calculated and compared.

4. Discussion and Conclusions

While previous large-scale FE models of AC simplified the multiphase equations by ignoring the pre-stressing and osmotic pressure, this work could present an automatic framework with a pre-stressing optimizer for large-scale and multi-physics FE modeling of AC, which is also used to demonstrate the significant zone-dependent effect of pre-stress.

5. References

1. Sajjadinia SS et al., Proc. Inst. Mech. Eng. Part H J. Eng. Med; 233(9):871–882 (2019).
2. Sajjadinia SS et al., J. Mech. Behav. Biomed. Mater; 114: 104203 (2021).
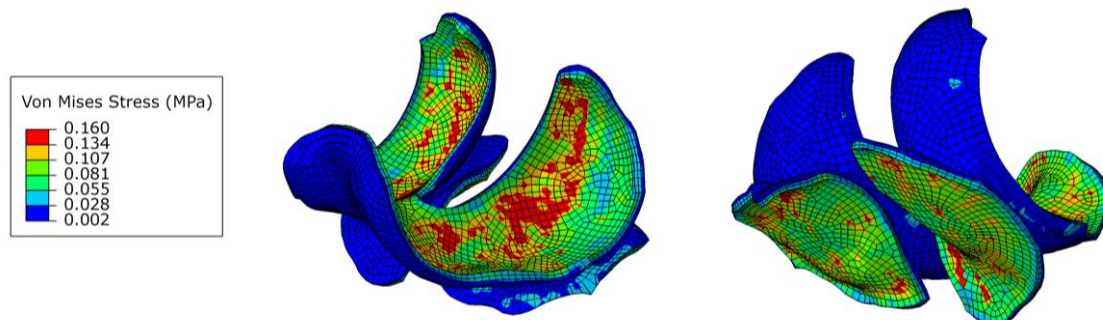3. Erdemir A, J. Knee Surg; 29(2):107–116 (2016).

Figure 1. Von Mises stress contours (in MPa) after applying the pre-stress.