A P-Type Finite Element Solution for the Simulation of O_2 Transport in Articular Cartilage Tissue: Heterogeneous and Porous Media

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Introduction

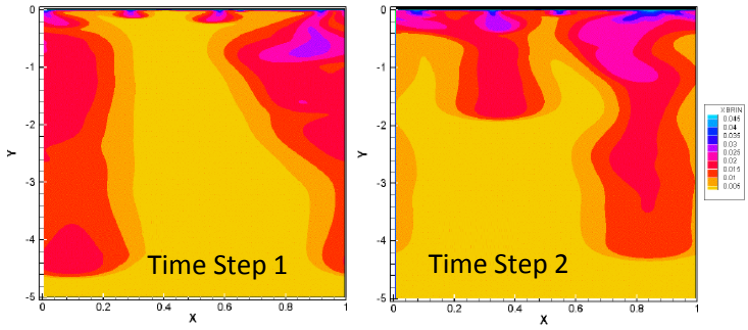
Partial pressure of oxygen (pO_2) is speculated to have a regulatory effect on chondrocyte biosynthetic activity and its effect during expansion is unknown. While there are plenty of studies on measuring and/or modeling pO_2 in articular cartilage (AC) for rest conditions, to the best of the authors' knowledge, there are no such studies on pO_2 in AC for dynamic conditions such as swelling or tissue deformation. We hypothesize that oxygen tension due to mechanical deformation or swelling could be as important as direct mechanical effects. In this study, for the first time a high-precision hybrid element is designed using the p-type finite element method (FEM) by which both, diffusion and convection, are incorporated as a single element.

Method

In this study, high-order FEM is implemented. Our formulations is based on a domain decomposition method that allows us to use a different type of discretization with independent discretization variables in non-overlapping subdomains, for a generic three-dimensional approach to elliptic boundary value problems of order two or higher.

Results

As one of the analyses performed, an indentation at the center of the cartilage surface is applied using a round-tipped indenter (diameter of 2 mm) with a linear axial velocity of 0.7 mm/s with a magnitude of 0.5 mm (half of the AC thickness).



PO_2 distribution at the superficial zone of the articulate cartilage in two time steps, each time step is considered 5 cycles. The values in the color bar are X1000 mmHg.

Conclusion

Mechanical deformations of cartilage that occur during daily activities, or changes in osmotic pressures associated with cartilage degeneration, can significantly affect oxygen tension in the vicinity of chondrocytes. At rest, pO2 decreases from the surface to the cartilage-bone interface, while it is approximately uniform during dynamic loading. The average value of oxygen tension is ~ 50 mmHg which is the initial oxygen tension in the interstitial fluid [1]. This study is a first step towards understanding the effects of oxygen tension on chondrocyte function.

Reference

[1] Gardner et al. (1987), *In: Lott DJ, Jasani MK, Birdwood GFB, Eds. Studies in Osteoarthrosis. Chichester: John Wiley and Sons, 21–48.*