INFLUENCE OF CARTILAGE SURFACE TOPOGRAPHY ON INTRA-ARTICULAR FLOW

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Introduction

Natural cartilage has a non-regular, rough surface at the microscale [Shekhawat, 2009]. It was proposed that by interacting with synovial fluid, this rough microstructure may benefit the lubrication of the natural joint [McNary, 2012]. However, how this rough surface influences the synovial fluid flow is still unclear. In the present study, a three-dimensional finite volume model was created to investigate the significance of specific roughness factors on the intra-articular flow of synovial fluid.

Methods

A rectangular flow volume (120µm width, 120µm length and 1µm gap) was defined as a fluid domain (Fig.1). The top surface was a rough surface composed of 121×121 nodes, having multiple height values. These heights were defined by a (121,121) matrix, which was produced using a Matlab script. The three-dimensional domain was then imported into Ansys Meshing for creating a mesh of hexahedral elements. Boundary conditions were set as: constant mass flow rate at the inlet surface (3.6×10^{-9} kg/s), constant pressure at the outlet (0 Pa), a symmetry condition at both side walls, and 'no slip' condition at the flat bottom and rough top surfaces. The fluid had 1 Pa·s viscosity and 1225 kg/m^3 density. The finite volume CFD solver, FLUENT, was used to obtain the laminar flow solutions.

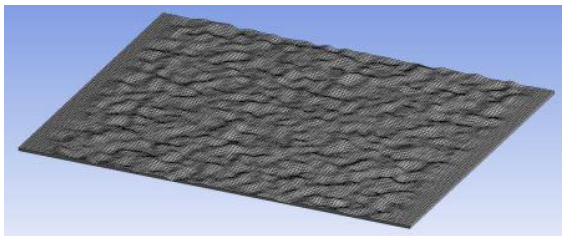

Figure 1: Geometry of the three dimensional fluid domain, with a rough top surface and flat bottom.

By using different matrices of geometry control points, various rough surfaces could be studied. Four roughness factors were investigated: root mean roughness (Rms), asperity density (AD), flow-surface angle (FSA), and asperity height distribution (AHD) (Table.1). Rms was defined as a Gaussian function, while AD and FSA were defined as sinusoidal functions. Topography parameters were varied individually (i.e. the other three were held constant).

Results

The pressure drop between the inlet and outlet was compared within each group (Table.1).

Group	Value/Pressure-Drop ($\times10^7$Pa)/ Relative Change (%)		
Rms (µm)	0.05/3.6/0	0.15/3.7/3.3	0.25/3.9/8.3
AD	×1/3.83/0	×2/3.85/0.6	×4/3.95/3
FSA (º)	0/3.88/0	11/03.90/0.6	23/3.91/0.75
AHD	G/3.87/0	U/3.84/-0.6	T/4.0/3.4

Table 1: Pressure drop and relative changes with different roughness factors in each group. G represents Gaussian surface, U represents uniform distributed height surface, and T represents discrete height (2 values) surface.

The result shows that Rms, asperity density and asperity height distribution can all regulate the pressure drop to a certain degree, however, the flow-surface angle only contributes to less than 1% of the pressure drop variation, and hence can be neglected.

Discussion

In this study, the influence of four surface roughness factors on intra-articular fluid flow resistance was investigated. Understanding the impact of these factors could help to explain synovial fluid flow behaviour for different natural cartilage surface topographies. This, in turn, will increase our understanding of the complex, coupled inter- and intra-articular fluid flows that regulate cartilage lubrication.

References

Shekhawat V. K. *et al*, Osteoarthritis and Cartilage, 17:1197-1203, 2009.
McNary S. M. *et al*, Tissue Eng Part B Rev, 18(2):88-100, 2012.