Analysis of Fluid Therapy during Arthritis

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1. Introduction

Osteoarthritis is one of the most common types of arthritis which causes breakdown of the joint's tissue, known as cartilage. Cartilage is the part of the joint that cushions the ends of bones. This cartilage breakdown causes bones to rub against each other, causing pain and loss of movement. Osteoarthritis more commonly affects hands and weight-bearing joints such as knees, hips, feet and the back.

In the late 80s, a joint fluid therapy was introduced, mainly for patients suffering from Osteoarthritis which led to various simulation studies [1-3]. The fluid is directly injected into the tissue which acts like a lubricant between bones. The fluids that are used are based on Hyaluronan which is a pure solution of sodium hyaluronate. Hyaluronan is a thick, viscous fluid naturally found in the body as a constituent is the connective tissue and sinovial fluid found in joints. It is generally injected in empirical quantities, periodically, depending upon the condition of the tissue and the patient. This quantity is purely empirical and does not take in account various factors such as – patient's weight, condition of the joint and joint absorbing characteristics. [4]

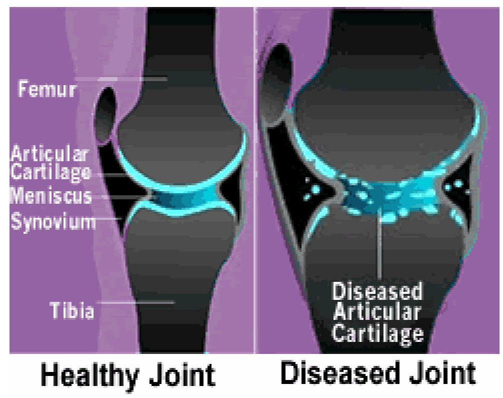


fig. 1:Source- Smith & Nephew Inc. website

The purpose of this study is to observe the absorption of the fluid by the tissue, using FLUENT. FLUENT, from Fluent, Inc., is a comprehensive CFD (computational fluid dynamics) analysis tool. The FLUENT solver can be used to model turbulence, combustion, and multiphase applications. Models and meshes are created using the preprocessor GAMBIT. Fluent mainly uses the Navier-Stokes and momentum equations and energy equation for combined thermal and fluid equations.

2. Governing Equations

Fluent uses the Navier-Stokes equation and the momentum equation for fluid flow. When solving porous models, FLUENT solves the following equations

Porous Jump:

$$\Delta p = - [(\mu/\alpha)v + C2(\rho v^2/2)] \Delta m$$

where μ is the laminar fluid viscosity, Δm is the thickness of the medium coefficient, v is the velocity normal to the porous face, α is the permeability of the medium and C2 is the pressure jump coefficient.

For homogeneous porous medium in two dimensions FLUENT solves the following equations

$$\rho u (\eth u / \eth x) + \rho v (\eth v / \eth y) = - (\eth p / \eth x) + \mu[(\eth^2 u / \eth x^2) + (\eth^2 u / \eth y^2)]$$ [5]

3. Discussion

FLUENT is capable of creating a material which resembles a tissue, using a function known as Porous Jump. Here the GAMBIT has been used for creating the mesh which is then exported to FLUENT. Properties of the cartilage and Hyaluronan have been given to the solid mesh and the fluid respectively. After giving appropriate boundary conditions to the mesh, the fluid is injected in to it. The assumption is that the fluid is injected from that side of the tissue that is most damaged. For this initial study, velocity along the x-axis has been considered.

The preliminary results are showing fig. 2 and 3. The figure 2 shows pathlines of the velocity magnitude along the x-axis decreasing from a value of 2m/s as it flows across the tissue. As can be expected, due to the high density and viscosity of sodium hyaluronate, the fluid is absorbed more on the side from which it is injected. The graph is figure 3 shows different values of the x-velocity against different positions of the tissue.

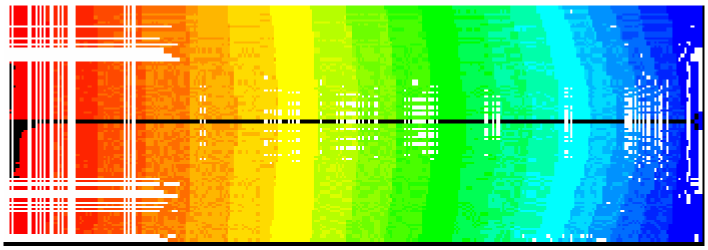
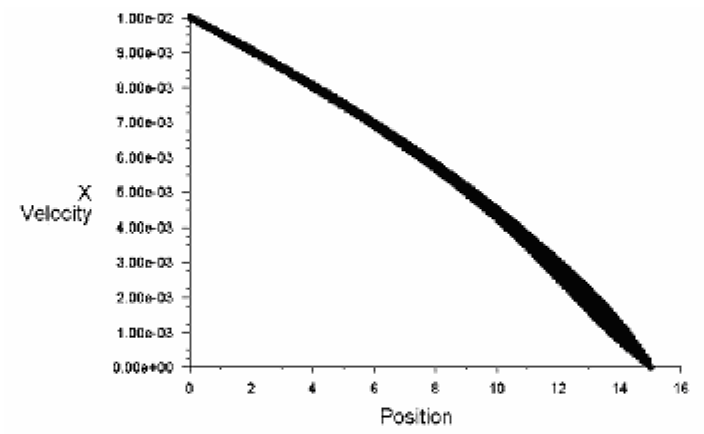


Fig. 2 Grid Dimensions: 15mm x 5mm.

Parameters	Tissue	Fluid	Water
Density	1070	1000	989
Viscosity	-	0.015	0.00103

Table 1: Synovial fluid properties.



Fluid velocity as a function of length.
Fig.3

4. Conclusion and Recommendations

From the above graph it is clear that even though outflow boundary conditions were given on all three sides of the sample tissue, the velocity of the joint fluid goes to zero when it reaches the end, and hence, absorbed throughout. Further studies will help in application of seepage of the fluid through the tissue. Also, this model can be the basis to analyse and optimize the number of injections per year for various patients.

5. References

[1] Wu, J. Z., Herzog, W., Simulating swelling and deformation behaviour in soft tissue, BioMedical Engineering Online 2002, 1:8
[2] Lai, W. M., Hou JS, Mow VC, A triphasic theory for the swelling and deformation behaviours of articular cartilage, *J Biomech Eng* 1991, 113:245-258.
[3] Edward J., Physical Characteristics of articular cartilage, Proc Inst Mech Eng 1967, 181:16-24.
[4] Mayo Clinic on Arthritis : Gene G. Hunter.
[5] Computational Methods for Fluid Dynamics: Joel H. Ferziger and Milovan Peric.