A biomechanical model for cartilage replacement material

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Motivation and aim

Experiment
  Bioreactor
  Fotos of specimens

Theory and simulations
  Constitutive equations
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  Simulations

Summary and future work
Motivation and aim

- Replacement of human meniscus by cell-seeded collagen gel
- Experimental, theoretical and numerical investigation
- Remodeling of cell-seeded collagen gel due to mechanical stimulus
Periodic loading: frequency $= (3\text{sec})^{-1}$, amplitude $= 0.5\text{ mm}$
For comparison In bioreactor
Diffusion model

\[
\dot{\sigma} = \dot{\sigma}^e + \dot{\sigma}^{ve} + \dot{\sigma}^d
\]

\[
= C : \dot{\varepsilon} + \tilde{C}(\dot{\varepsilon}) : \dot{\varepsilon} - D(\varepsilon_v) \sigma
\]

where \(\sigma\): Cauchy stress tensor, \(\varepsilon\): strain tensor, \(\varepsilon_v\): volume strain

\(C\): elastic moduli tensor, \(\tilde{C}\): viscoelastic moduli tensor and

\(D\): diffusion parameter \(D(\varepsilon_v) = D_0 + D_1\varepsilon_v\)
Evolution of density and Young’s modulus

\[
\frac{d\rho}{dt} = B \left( \frac{U}{\rho} - k \right) \quad (2)
\]
\[
E = c\rho^\gamma \quad (3)
\]

where $\rho$: density, $B$ and $k$: material parameters

$U$: strain energy density, $c$ and $\gamma$: material parameters

\[
U = \frac{1}{2} \lambda \ln^2(J) + \frac{1}{2} \mu \left( I_1^C - 3 \right) - \mu \ln(J)
\]

\[1\]
Weinans et al. J. Biomechanics Vol. 25, No. 12, pp. 1425-1441, 1992
Finite element model

User-defined subroutine UMAT in Abaqus

(a) FE model

(b) Distribution of $E$

Boundary condition: $E_m = \frac{\int_0^h E(y)dy}{h}$
Evolution of density

(a) t = 0sec
(b) t = 6sec
(c) t = 12sec
(d) t = 24sec
(e) t = 30sec
Evolution of Young’s modulus

(a) t = 0sec
(b) t = 6sec
(c) t = 12sec
(d) t = 24sec
(e) t = 30sec

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Summary

- A biomechanical model of cell-seeded collagen gel is suggested.
- The remodeling of density and Young’s modulus due to a mechanical loading is explained.

Outlook

- What would be the parameters?
- How do cells react to the mechanical load?
- How can a replacement material be optimized?
Thank you very much!