CONSTITUTIVE MODEL AND PARAMTER IDENTIFICATION FOR THE CEMENT INFILTRATION OF OSTEOPOROTIC BONE

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Introduction: Cement infiltration of osteoporotic bone is an emerging surgical procedure to prevent osteoporotic fractures. Numerous surgeons practice cement infiltration, but the cements and injection techniques employed vary widely. Injection parameters (e.g., magnitude and duration of cement pressurization, flow rate) and cement choice must be optimized to make cement infiltration a reliable and reproducible procedure and to avoid complications (e.g., cement leakage, embolism). Our purpose is to **(a)** develop a poroelastic model for cement infiltration into osteoporotic bone and **(b)** identify the model parameters using uniform experiments. Computation can be employed to optimize the surgical procedure.

Method: *Theory*: To model bone-marrow-filled trabeculae, we adopted a geometrically linear biphasic mixture model of isotropically linear solid and fluid. The frictional forces of the mixture depended linearly on fluid flow rate. The moment conservation yielded an infiltration law similar to that of Darcy's-Law: $v_f=-\kappa \, \mathrm{grad} p$, where v_f is the apparent fluid velocity, p is the pressure, and $\kappa=\alpha_f/(1-\alpha_f)\lambda(\eta)$ is bone permeability. The symbol α_f denotes bone porosity and $\lambda(\eta)$ is an infiltration function. *Experiments*: Ten cancellous bone cores were harvested from osteoporotic spines. Using Simplex cement, a constant uniform flow of 2 mm/sec was established through the bone cores and the pressure drop was measured. The model was fit to the testing data. In addition, we measured cement viscosity using a capillary extruder.

Results and Analysis: Bone porosity was approximately 90%. Bone permeability, using Simplex cement, was $49.7 \pm 6.4 \times 10^{-12}$ m^4/Nsec. We employed a power law for cement viscosity $\eta=K\gamma^{n-1}$. The WEISSENBERG correction n was determined using a logarithmic regression. The parameters K and n for Simplex cement (22C^0) were 196.14 Nsec and 0.68 respectively. We introduced an infiltration function $\lambda= \beta\,\eta=$ 196.14 Nsec $\gamma^{-0.32}$. The effective shear rate γ of the cement infiltrating the bone cores was approximately 4.7 sec^{-1}. The parameter β was then calculated to be 1.06×10^{-9} m^4. Thus, permeability becomes $\kappa = \beta^{-1} \cdot \alpha_f \cdot (1-\alpha_f)^{-1} \cdot \eta^{-1}$.

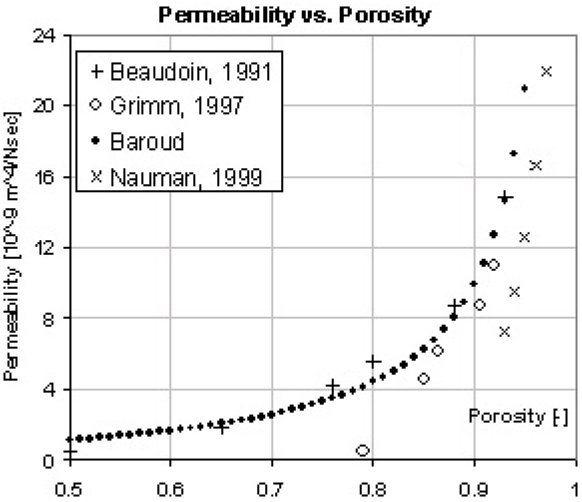

Figure 1: The present model fitted to experimental data.

Discussion: The present model decouples the effects of the cement viscosity and morphological bone properties on the permeability of the cancellous bone.

Cement viscosity can be determined using rheological methods, while bone morphology (porosity) can be evaluated using stereological methods. Only a single phenomenological parameter β remains to be determined using infiltration tests. With the parameter β calculated from the present measurements, the model correctly predicted bone permeability values at different bone porosities similar to those experimental values from the literature (figure 1).

Given our findings for bone permeability and clinical measurements of the injection pressures, we conclude that the pressures generated during a cement infiltration procedure (as high as 1.5 MPa) are excessively high by a factor of at least 10. Such pressures may lead to a quick uncontrolled spread of cement and consequently to cement leakage. We hypothesize that a continuous but slow injection may result in a uniform spread of cement and reduce the leakage risk.

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