Estimation of cartilage properties using indentation tests, finite element models, and artificial neural networks

V. Arbabi[1], G. Campoli[1], H. Weinans[1,2], A.A. Zadpoor[1]

[1]Department of Biomechanical Engineering, Faculty of Mechanical, Maritime, and Materials Engineering, Delft University of Technology (TU Delft), Mekelweg 2, 2628 CD, Delft, The Netherlands
[2]Department of Orthopedics and Department of Rheumatology, UMC Utrecht, Heidelberglaan100, 3584CX Utrecht, The Netherlands

Abstract

One of the most widely used techniques for determining the mechanical properties of cartilage is based on indentation tests and interpretation of the obtained force-displacement data. In the currently used approaches, one needs to simulate the indentation test with finite element models and use an optimization algorithm to estimate the mechanical properties of cartilage such that the difference between the simulated and measured force-displacement is minimized. The modeling procedure is time consuming and complicated, and the simulations need to be repeated for every new experiment.

In this study, we propose a method for fast and simple estimation of the mechanical properties of poroelastic materials such as cartilage. First, a finite element modeling program is used to simulate the indentation test for poroelastic materials with many different combinations of mechanical properties. The obtained force-displacement curves are then divided into two parts: one part of the data is used for training an artificial neural network and the other part is used for testing the trained network. The trained neural network receives the force-displacement curve as input and provides the mechanical properties of the tested cartilage sample as output. It has been shown that the trained network could accurately predict the mechanical properties of poroelastic materials such as cartilage. Using the proposed method, the mechanical properties of cartilage can be estimated very fast and no additional FE modeling is required once the neural network is trained. The robustness of the trained artificial neural network in determining the mechanical properties of cartilage based on actual force-displacement data is assessed by introducing noise to the simulated force-displacement data. It has been shown that the training procedure of the network could be optimized so as to maximize the robustness of the neural network against noisy force-displacement data.