A Mechanical Cartilage Phantom for Magnetic Resonance Imaging

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Abstract

It would be useful to create a phantom to measure contact areas of simulated cartilage surfaces under load. We used a two-part gelatin/urethane molding system to create a material to simulate the MR and mechanical properties of human articular cartilage. Mechanical measurements indicate stiffness properties similar to articular cartilage. MR imaging properties of the gelatin/urethane material are also similar to cartilage, with a shorter T1 relaxation time. MnCl\textsubscript{2} was mixed with saline to create an MR equivalent of joint fluid. This cartilage and fluid phantom may be useful in quantitative MR imaging with load.

Introduction

For quantitative MR imaging of articular cartilage it would be useful to have a phantom that has mechanical and imaging properties comparable to cartilage. This phantom would enable one to create engineered models of articular surfaces with well-characterized geometric, material and imaging properties. Such phantoms would be useful, for example, in comparing the accuracy and precision of different segmentation techniques when using different pulse sequences. The purpose of this study is to present an evaluation of a simple and inexpensive phantom material that has mechanical stiffness properties and MR imaging characteristics comparable to human articular cartilage.

Methods

We created our phantom by mixing a two-part room-temperature vulcanizing urethane molding system (Tap Plastics, Inc) with powered gelatin (Gelatine; Knox Co). Creep indentation testing \textsuperscript{(1)} was performed to determine the equilibrium stiffness of both the gelatin/urethane composite and human articular cartilage. Five different mixtures of gelatin and urethane were examined, from 0\% to 20\% gelatin by weight. MnCl\textsubscript{2} (0.15 mmol/L) in saline was used to simulate synovial fluid \textsuperscript{(2)}.

T1 and T2 relaxation times were measured on a 1.5T GE Signa whole body imaging system. T1 measurements were obtained using inversion-recovery and varying the inversion time. T2 measurements were obtained using a multi-echo spin echo with TE of 15, 30, 45, and 60ms. T1 and T2 values were calculated by fitting the data to single exponentials using MATLAB (Mathworks).

Results

Results of our stiffness testing are shown in Figure 1. The 15\% mixture was the closest to human articular cartilage in terms of its compressive stiffness. In comparison to cartilage, the stiffness of the 15\% gelatin/urethane mixture was approximately 30\% less stiff after 20 seconds of load application, and approximately 80\% stiffer after 30 minutes of loading.

T1 and T2 relaxation times for all of the gelatin/urethane mixtures were approximately 100ms and 30ms, respectively (Table 1). The T1 relaxation time of the gelatin/urethane mixtures (100ms) is considerably shorter than cartilage T1 of about 800ms \textsuperscript{(3)}. The T2 relaxation time of 30ms is very close to published measurements of human cartilage \textsuperscript{(4)}. T1 and T2 relaxation times for our MnCl\textsubscript{2} saline mixture are within the wide range of published values of joint fluid \textsuperscript{(5, 6)}.

Discussion

Our phantom attempts to simulate both the MR and mechanical stiffness properties of cartilage. The 15\% gelatin/urethane mixture shows good stiffness properties. Stiffness measurements are less than cartilage in a short time frame, but greater in a long time frame.

T2 relaxation times of our phantom are similar to human articular cartilage. T1 relaxation times are shorter, which may facilitate faster imaging and testing of the phantom. Pulse sequence parameters can be adjusted for this difference \textit{in vivo}. We will continue to modify the material in this phantom to better simulate both the MR and mechanical stiffness characteristics of cartilage.

References


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