Feasibility of Temperature Imaging of Knee Joint Cartilage under Thermal Therapy using Water Proton Resonance Frequency Shift

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INTRODUCTION

Thermal therapy for osteoarthritis is becoming one of the options for pain-relief(1). Although various heating methods have been devised, temperature visualization technique for the knee joint cartilage has been rarely investigated to date. This work was dedicated to examine feasibility of noninvasive temperature imaging of knee joint cartilage under thermal therapy using water proton resonance freqrequency shift.

METHODS

Calibration

Proton spectra of cartilage segment samples collected from porcine knee joints were observed in 9.4 T NMR spectrometer. The sample was immersed in deuterium oxide (D_2O, 99%, Sigma-Aldrich) in a NMR sample tube of 5 mm in diameter. Trimethylsilyl propanoic acid (TSP) was added as an internal reference. After turning off auto magnetic-field-frequency locking and shimming, the proton spectra were evaluated at various temperature ranging from room temperature and 50 ^{o}C. The measurement conditions were TR, 4.09 s; TE, 6.50 ms; FA, 30 degree.

Laser Heating

A porcine knee joint cartilage sample in vitro was placed in a sample container and heated by laser (Lightsurge, Osada Medical) inside a 9.4-T MRI with a vertical bore. The laser power and duration were set at 0.6w and 60 sec, respectively. The sample temperature was monitored by a 2-channel fiber optic thermometer at the cartilage (Ch1) and atmospheric temperature (Ch2) in the bore. Temperature imaging with the conventional proton resonance frequency shift method(2) with a fast gradient echo technique was performed in the saggital slices with the following conditions; TR, 31 ms; TE, 4.63 ms; FA, 20 degree; slice thickness, 1mm; and acquisition matrix, 96 x 256. When necessary, static magnetic field drift was compensated by approximating the drift with a first order plane estimated from the phase change in the complex MR signals in the bone marrow regions. Phase change in the articular cartilage was then converted to temperature elevation using the coefficient of the resonance frequency obtained in the spectrometer experiment.

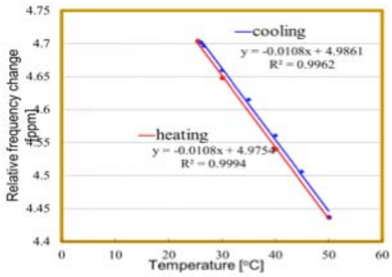

Figure 1 Relationship between the water proton resonance frequency and temperature in a porcine knee sample in vitro at 9.4T.

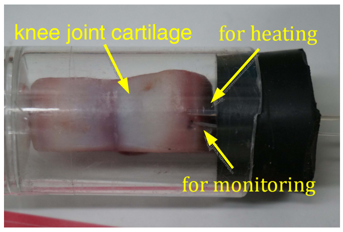

Figure 2 Porcine knee cartilage sample in a plastic container. Optical fibers for heating and temperature monitoring (Ch 1) are inserted in the sample.

RESULTS

The spectrum of the cartilage sample exhibited only a water signal with a tiny (0.02-0.03 %) fractions of the other components. Thus the water proton resonance frequency was readily measured from the spectrum. The temperature coefficient of the water proton resonance frequency was approximately -0.0108 ppm/^{o}C for both heating and cooling period as shown in Figure 1. Signal to noise ratio in the magnitude image was more than 100 at the articular cartilage. In the laser heating experiment, temperature of the cartilage elevated from the room temperature to around 30^{o}C as exemplified in Figure 3. Typical examples of the resultant temperature elevation images corresponding to Figure 3 are shown in Figure 4. Temperature elevation around the heating fiber is clearly visualized.

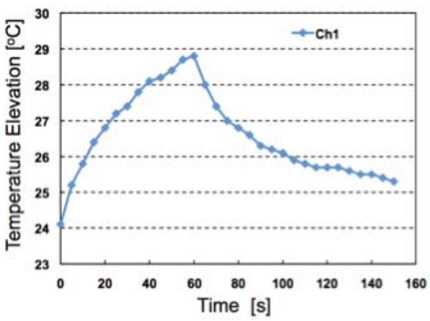

Figure 3. A typical example of temperature elevation in the porcine knee joint cartilage in vitro heated with laser.

DISCUSSIONS

The knee joint cartilage was an aqueous tissue, and the relationships between water proton resonance frequency and temperature was quite similar to the other aqueous tissues. Signal to noise ratio was sufficient for measuring the change in the resonance frequency. Thus the temperature imaging of the knee joint cartilage was successful in this particular in vitro study. A separate measurement at 3T demonstrated that the signal to noise ratio of the water signal from the cartilage of a similar sample was 38. This means that the results here will be readily applicable to a clinically available scan conditions. However, the present simple approach may be valid only when heating is performed in a scanner. When a functional therapy, or a therapy using knee joint exercise like jogging, is applied(4), such a simple approach will be problematic. Since referenceless-types of technique cannot be used in this application as the entire tissue region will be heated. Region registration and magnetic field change compensation techniques have to be incorporated.

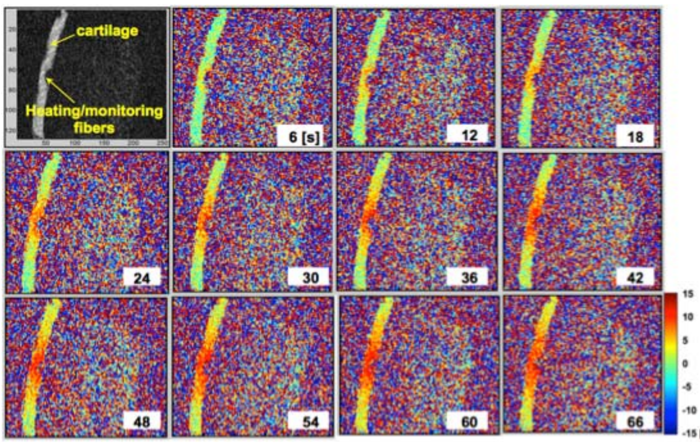

Figure 4 Temperature elevation images of the knee joint cartilage sample in vitro under laser heating. The thickness of the cartilage was around 2 mm. Numbers in each image are the time after start of heating.

CONCLUSION

Feasibility of noninvasive MR thermometry for knee joint cartilage using conventional water proton resonance frequency technique was demonstrated. Improvements must be made for applying this thermometric technique to various therapeutic options.

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