ASSESSMENT OF NMR TECHNOLOGY IN CORTICAL BONE AND ITS SENSITIVITY

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INTRODUCTION

Magnetic resonance imaging (MRI) techniques have been widely applied in biomedical researches; however, no current MRI technology can obtain useable images of cortical bone and teeth, due to the resolution limitation. The objective of this study is to demonstrate that low field (static magnetic field of 0.06 to 0.6 Tesla) NMR can be used to characterize the cortical bone and teeth microstructure changes. It was first to prove the concept of a low field pulsed NMR process for assessing the cortical porosity and pore size distribution of bone in vitro and then applying the technique to detect age-related changes of bone in these parameters. It was demonstrated that this technology could be used to detect the level of micro cracks caused by stresses in bone, and the microstructural changes of cortical bone between the normal and the disuse (weightless) bones. In addition, the evidence of the NMR signal from human whole tooth and extracted dentin could be used to help prove that NMR can characterize the cortical pore sizes including canaliculi in human bones.

MATERIALS AND METHODS

A Southwest Research Institute (SwRI) built 0.5 to 40 MHz broad-line NMR was configured for a proton frequency of 2.3 MHz for these measurements. A 1.5-inch diameter RF coil was used for cortical bone in the experiment. Sample size ranges were typically 0.5-1.2 inches in diameter and 1 to 1.5 inches long. A 0.5-inch diameter RF coil was used for whole tooth and extracted dentin measurements. ^{1}H spin-spin (T_2) relaxation profiles were obtained by using the NMR CPMG (90^0 - τ - 180^0 -delay - echo - delay - 180^0 -) spin echo method with a 4.2 μs duration 90^o pulse, τ of 500 μs, and a T_R (sequences repetition rate) of 10 s. For each T_2 profile, 1000 echoes were acquired and 32 or 64 scans were used. The bone data were measured at room temperature after fresh frozen human femurs (saturated with phosphate buffered saline, ph=7.4, a 99+% H_2O solution) completely thawed at room temperature (21 ± 1^oC). The experimental data were compiled in the form of mean ± standard deviation. A simple *t-test* was performed to detect differences in the porosity and the relaxation distribution of bone calculated from the NMR data for the different age groups. Significant differences were noted if $p<0.05$.

RESULTS AND DISCUSSIONS

Concept of proves. Using these techniques, cortical porosity and pore size distribution of 8 samples of human cadaveric bone, ranging from 21 to 89 years of age were assessed. The NMR results were compared with the histomorphometric data of same bone samples to verify the efficacy of the NMR approach. Moreover, correlation coefficient relating the pore size to the T2 relaxation time was determined empirically for the Haversian canals and the osteocytic lacunae. This study demonstrates that the in virto NMR approach using T2 relaxation techniques can directly assess the porosity and pore size distribution (Haversian canals and osteocytic lacunae) in human cortical bone. In addition, this study shows a good correlation of age-related cortical bone porosity between the NMR results and histomorphometry results.

Bone Microdamage. By using CPMG T2 relaxation measurement, the differences from cortical bone sample before and after damaged can be detected. Data demonstrated that this method can distinguish the differences in the decay signals, particularly in the fast decay components (for example, decay < 50 ms). In contrast to the fast decay, in the slow decay component, there are almost no differences in T2 between the spectra before and after damage induction (for example, decay > 70 ms). The fast decay component corresponds to the protons contributed from small pore sizes and changes in the fast decay component are due to the bone microdamage. These results were compared with the photo of light microscopy photograph obtained from specimen after mechanical damage. The cracks are visually under the magnification. Furthermore after using the inversion T2 relaxation technique, the obtained spectra demonstrate that due to the presence of microcracks, the small and the medium pore size distributions have changed.

Sensitivities. The sensitivities of NMR results were tested on turkey cortical bones by using these techniques on the normal and the disuse (weightless treatment) bones. The NMR results were compared with SEM images of cross-section of bones. Each sample was divided by 8 equal pies (top), in which SEM images were taken in the middle of the cortex. Histomorphometric analysis was applied to obtain total porosity areas and identify pore size, i.e., Harversian canals and lacunae. Porosity for the normal intact bone was observed at 8 to 10% and in disuse bone was increased to 17%, which agreed with the NMR results.

An additional test for the verification and detection of small changes in porosity were conducted. An NMR measurements on extracted human whole tooth and then NMR measurement on the extracted dentin from this whole tooth. The NMR dentin only signal was in good agreed with the smaller pore size signal in the range of NMR whole tooth signal. Since the pore sizes in the dentine can be as smaller as in the sub-micrometer range, thus, it is believed that NMR obtained bone pore sizes can be at least as smaller as sub-micrometer range and may include canaliculi. Figure 1 shows an example of an NMR signal from the whole tooth and NMR signal from the extracted dentin of whole tooth.

COCLUSIONS

The dentin characterization data can be used to reinforce previous work on the characterization of cortical bone microstructure changes. In cortical bone, there are three major natural types of cavities. Since the pore size for canaliculi is so small, it is very difficult to separate the canaliculi from the rest of the pores by conventional methos. Because of the difficulty in obtaining a reference measurement, it has difficult to prove that NMR can characterize the pore sizes of canaliculi in cortical bones. However, in this study, it was demonstrated that the NMR signal from the extracted dentin closely matched the NMR signal pertaining to the smaller pore sizes of the whole tooth. This evidence can be used to find the sensitivity of NMR applied on characterization of cortical bones.

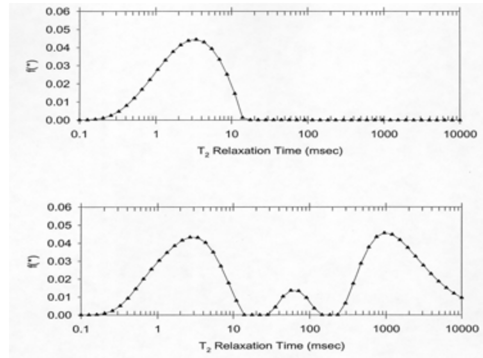

Figure 1. The inversion T2 relaxation spectra. Top: extracted dentin from the whole tooth; Bottom: the extracted whole tooth.