The Biexponential Nature of T_2 Decay in Articular Cartilage

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Introduction: The transverse relaxation rate, R_2, of the water protons in articular cartilage has been suggested as a marker for the early detection of osterarthritis and other degenerative diseases. The laminar appearance of cartilage in MRI images has been related to the residual dipolar interaction originating from anisotropic re-orientation of the water molecules in the vicinity of the oriented collagen fibers. R_2 may be divided into three main contributions: **a)** Intramolecular dipolar interaction modulated by isotropic re-orientation and thus sensitive to the viscosity and to interactions with disordered macromolecules. **b)** Proton exchange with chemically shifted OH and NH groups of proteins such as proteoglycans **c)** Residual dipolar interaction due to anisotropic re-orientation of the water molecules interacting with the oriented collagen fibers. This contribution, given by: $R_2 \alpha (3\cos^2\theta - 1)^2/k$ (1) (θ is the angle between the magnetic field and the director of the dipolar interaction and k is the proton exchange rate between water molecules) is responsible for the angular dependence of T_2. It is the dominant contribution when the collagen fibers are parallel to the magnetic field while the other two contributions are dominant at the magic angle. Thus, T_2 reflects the macromolecular organization (2,3) and may serve to characterize the state of the cartilage matrix.

Material and Methods: 8 mm cartilage bone plugs were excised from bovine condoyles and equilibrated in saline. Plugs were then immersed in fluorinated oil and about 40 SE images, TE ranging from 0.7 ms to 100 ms (FOV=1x1cm, 128x128, 8.45 T, 20 ^{0}C) were collected for each specimen. The intensity as a function of the echo time for an average of 5 pixels at each location was fitted to a biexponential decay (see Fig. 1).

Results: For cartilage bone plugs measured with the articular surface perpendicular to B_0, the decay curve was clearly biexponential throughout the calcified and deep radial zones (Figs.1, 2). The fast T_2 (T_{2f}) increased from less than 1ms in the deep calcified zone to approximately 8 ms in the radial zone. The relative amount of the fast T_2 component, A_f, increases from the about 50% in the calcified zone to 70% in radial zone. The decay curves in the transitional and surface zones could not be resolved into two exponentials. When the normal to the surface was at a magic angle to the field the transverse relaxation was much longer and only at the calcified zone biexponential relaxation could be resolved.

The above results for the ^{1}H MRI T_2 values were compared with ^{2}H double quantum filtered (DQF) spectroscopic images. As we have previously shown (4), a distribution of quadrupolar splittings (ν_Q) as a function of the depth from bone to surface can be obtained for articular cartilage. Unlike the proton T_2 that depends on the above three contributions, the deuteron ν_Q depends only on the third contribution and is given by: $\nu_Q \alpha (3\cos^2\theta - 1)$. For the same plug equilibrated in deuterated saline, the ^{2}H DQF spectroscopic image is given in Fig. 3 along with spectra extracted from different locations on the plug. At least two quadrupolar split satellites are evident in the calcified and radial zones. While the proton T_{2f} is likely to result from the compartment that gives the large ν_Q, the slow relaxation time, T_{2S}, may result from both the compartment with the small splitting and from the isotropic water.

Fig.1

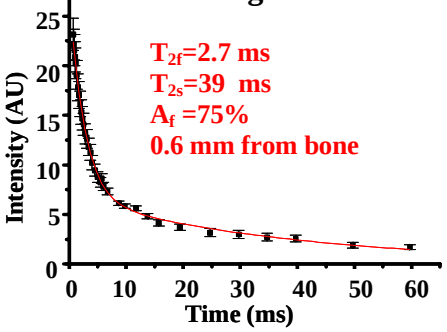


Fig.2

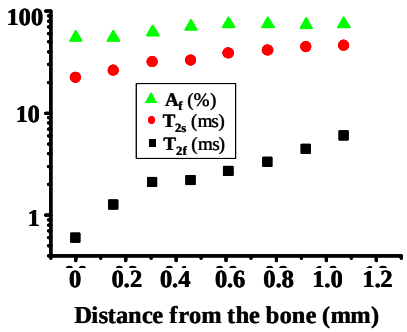
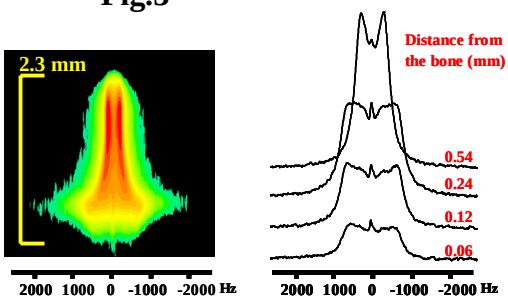


Fig.3



Conclusions: The decay of the transverse magnetization in cartilage bone plugs positioned with the surface perpendicular to the magnetic field is best described by a biexponential function. This result is in accordance with the observation of two quadrupolar split satellites in the ^{2}H spectroscopic images.

It should be noted that the observation of the biexponential nature of the decay depends on the choice and the number of echo times collected. In most previous reports, T_2 values were obtained from only a few points at relatively long echo times and were fitted to a monoexponential decay. The values obtained in this way depend on the choice of echo times and thus should be used with caution when following cartilage pathologies.

References: 1) U. Eliav et al. JMR, **137**, 295, 1999. 2) J. D. Rubenstein et al. Radiol, **188**, 219, 1993. 3) Y. Xia et al. MRM, 48, **460**,2002. 4) H. Shinar et al. MRM **48**,322,2002.