# Transverse Relaxation Mechanisms in Articular Cartilage

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**Introduction.** The role of $T_{1\rho}$ as a marker of early stages of osteoarthritis is not yet clear. It was suggested that the relaxation times in the rotating frame ($T_{1\rho}$) are sensitive to the loss of proteoglycans (PG) and can be used for quantifying early degenerative changes of articular cartilage (1-4). However, Menezes *et al.* (5) found no correlation of the cartilage $T_{1\rho}$ with PG concentration. Duvvuri *et al.* reported that the dominant $T_{1\rho}$ relaxation mechanism at low spin locking fields is proton exchange between NH and OH groups and water, which is affected by the loss of PG (6). On the other hand, Shinar *et al.* (7) concluded that the dominant transverse relaxation mechanism is intramolecular dipolar interaction due to interaction of water molecules with the oriented collagen fibers. Thus, we measured $T_{1\rho}$ and $T_2$ in a cartilage specimen from a human femoral condyle, both in the deep part of the cartilage layer with radially oriented collagen fibers and in its transitional zone with variably oriented collagen fibers, at various spin locking field amplitudes ($T_{1\rho}$ dispersion), at different orientation of the specimen in the magnetic field and at different static magnetic field strengths.

**Materials & Methods.** The measurements were performed on a 3 T Bruker Medspec whole body scanner and on a 7 T Bruker AM 300 WB spectrometer, which were equipped with microimaging gradient systems. The $T_2$ relaxation times were calculated from series of single spin echo images (TR/TE = 1500/6-26 ms). The $T_{1\rho}$ relaxation times were obtained using the spin-locking preparation sequence followed by a gradient or a spin echo sequence, using the spin locking times of 5-30 ms and the amplitudes $\nu_1$ of 300-2500 Hz (3 T) or 1000 Hz (7 T).

**Results & Discussion.** A significant $R_{1\rho}$ dispersion as well as orientation dependence of $R_{1\rho}$ in the radial zone of articular cartilage was observed at 3 T, with the maximum dispersion found at the angle of 0° and the minimum dispersion at 55° (Fig. 1a). However, we found that there was almost no dispersion and no orientation dependence in the transitional zone (Fig. 1b). Thus, the dominant relaxation mechanism in the radial zone is dipolar and is related to the oriented collagen fibers. A significant contribution of dipolar relaxation can also be expected in the transitional zone due to the random orientation of the collagen fibers. The negligible dispersion of $R_{1\rho}$ between $\nu_1$ = 300 and 2500 Hz suggests that the dominant contributing relaxation mechanisms have their correlation times outside this range. Hence, the dominant contribution of the scalar relaxation due to exchange between OH and NH protons with water is highly improbable as it should cause significant $R_{1\rho}$ dispersion in the studied range of $\nu_1$ (6). The magnitude of the scalar contribution was estimated from the relaxation rates at 3 T and 7 T (Fig. 1a,b), based on its quadratic dependence on $B_0$, and was found to be about 1.6 $s^{-1}$ at 3 T (only 10% or less of the total $R_{1\rho}$ at $\nu_1$ = 1000 Hz).

The $R_2$ values showed the expected orientation dependence caused by collagen-related dipolar interaction with structures having very slow motion. However, the $B_0$ dependence was nonuniform. This seems to be due to multicomponent decay of the magnetization, which is different at both fields (Fig. 2). In summary, the dominant relaxation mechanism in the rotating frame in cartilage at $B_0 \leq 3$ T is probably dipolar interaction, in particular its component associated with the oriented collagen fibers. The multicomponent character of the $T_2$ magnetization decay might be responsible for discrepancies between previous in vitro and in vivo $T_2$ studies.

**References**

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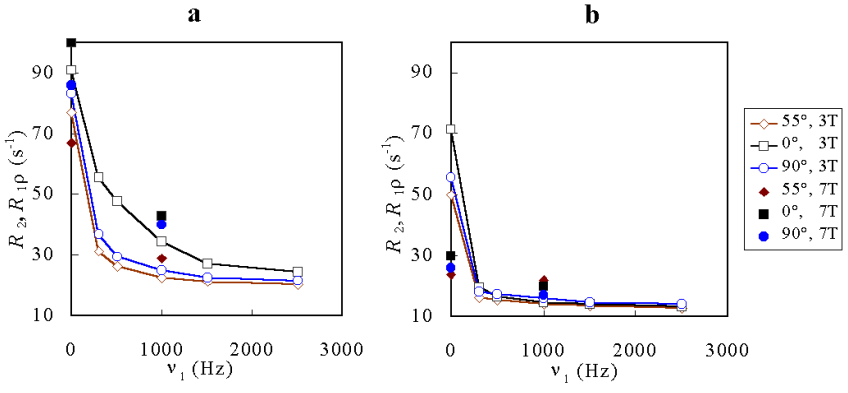


Fig. 1. $R_2$ and $R_{1\rho}$ dependence on $\nu_1$, orientation of the specimen, and $B_0$ in radial (**a**) and transitional (**b**) part of cartilage

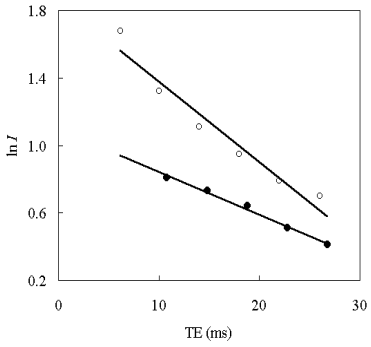


Fig. 2. Nonexponential (open circles, 3T) and exponential (filled circles, 7T) $T_2$ magnetization decay