Introduction: The exceptional structural relationships of molecular collagen in the extracellular matrix ECM of tissues of the musculoskeletal system is the root cause of the orientational contrast changes in MRI referred to as the “magic angle effect”. Fundamental understanding of molecular relationships between water and collagen will enhance the ability of radiologists to interpret subtle changes in contrast in tendons, ligaments, cartilage and other tissues of the ECM.

Hydration of Collagen: The triple helix structure of collagen molecule was among the first deciphered from x-ray diffractions experiments in the middle of the 20th century. Francis Crick and Alexander Rich [1] proposed the three strand arrangement of alpha-helices with one direct hydrogen bond per tripeptide as summarized Figure 1. Ramachandran in 1968 [2] was the first to propose formation of water bridges to reduce the electrostatic energy of backbone partial charges too distant to allow direct hydrogen bonds. Fullerton and colleagues [3, 4] extended these concepts to include double water bridges and dielectric water clusters surrounding the bridges as shown in Figure 2 to demonstrate the sequential hydration of collagen from the absolute dry state.

Tendon Hydration: The collagen in native tendon and other tissues is covered by a single layer of water that is highly aligned in the plane transverse to the axis of the tendon by the alignment of the polar water molecules to reduce the electrostatic field energy of partial charges on the backbone of the collagen. This anisotropic motion of water on the collagen surfaces reduces motional averaging of the dipole-dipole

Figure 1 Triple helix structure of collagen spontaneously associates in tendon and ECM

Figure 2 Formation of water bridges on the collagen triple helix confines water to the transverse plane.
interchange and spreads the resonance over a wide range of frequencies. This causes rapid dephasing of the coherent magnetization and rapid loss of signal. Orientation of tendons parallel to $B_0$ produces very small signal and is as a result black in almost all imaging sequences. Orientation of the tendon to the cone at an angular displacement of 55° from the direction of the static magnetic field of the MRI causes nearly complete recovery of the signal by the process described in Figure 3. The $x$, $y$ and $z$ components of the dipolar coupling average to zero just as they do for protons on bulk water.

![Figure 3](image)

**Impact of Collagen Orientation on Contrast.** As shown in Figure 4 with these images of bovine tendon sample at zero degrees (parallel to $B_0$) has nearly zero signal with all pulse sequences due to rapid dephasing of the magnetization. Injection of collagenase to selectively destroy the collagen structure causes the signal of the water to become visible. Orientation at the magic angle (55° relative to $B_0$) causes the signal to depend on the mobile water induced relaxation characteristic $T1$ and $T2$ parameters of the tissue.

**Clinical Implications.** There are two sets of application of knowledge of the orientation contrast phenomena called “magic angle” effect. The most common is the need to avoid misdiagnosis of orientational increase in signal as tear, mechanical disruption or biological resorption of the collagen. The second possibility is to use the large change in signal intensity with orientation as a clinically useful source of diagnostic contrast as shown by Bydder and colleagues[3, 5-10].
TENDINOSIS MODEL of tissue remodeling with Collagenase injection 0.2 cc – high MRI SNR and CNR

Parallel to Bo

FFE T1w  FFE T2w  SE T1w  TSE PDw  TSE T2w

Magic angle

T1FFE MA  T2FFE MA

Figure 4. In vitro imaging of bovine tendon allows complete display of the contrast behavior induced by the unique structural relationships of the collagen molecule.

References