# Ultrashort Echo Time Magnetization Transfer (UTE-MT) Imaging of Meniscus

Jiang Du[1], Shihong Li[1,2], Michael Carl[3], Monica Tafur[1], Nikolaus Szeverenyi[1], Eric Chang[1], Christine Chung[1], and Graeme Bydder[1]

[1]*Radiology, University of California, San Diego, San Diego, CA, United States,* [2]*Huadong Hospital, Fudan University, Shanghai, China,* [3]*Global Applied Science Laboratory, GE Healthcare, San Diego, CA, United States*

## INTRODUCTION

Clinical magnetization transfer (MT) sequences employ off-resonance saturation pulses followed by a conventional data acquisition [1-3]. The MT pulse typically results in selective saturation of tightly bound water and collagen protons which exchange with the loosely bound water and then free water, leading to a loss of longitudinal magnetization and hence a signal reduction (Figure 1) [3]. MT is ideal for probing interactions between protons bound to macromolecules and free water protons. Clinical MT sequences cannot detect MT effects in short $T_2$ tissues such as the menisci, ligaments, tendons and bone when there is little or no detectable signal present [4, 5]. In this study we evaluated ultrashort echo time (UTE) MT imaging of the meniscus. The angular dependence of MT ratio (MTR) as well as T2 and T1rho of meniscus were investigated.

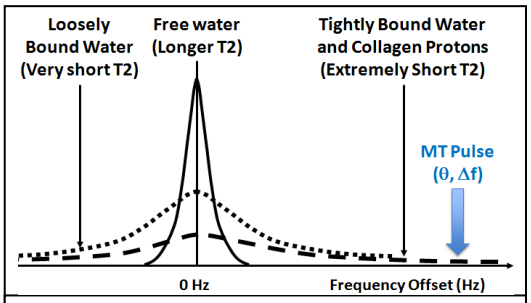


***Fig 1*** *Diagram showing three pools of protons in meniscus. The tightly bound water and collagen protons are selectively suppressed by the MT pulse with a high Δf. Loosely bound water is also suppressed with lower Δf. The efficiency of MTR is related to the MT power θ and frequency offset Δf.*

## MATERIALS AND METHODS

Four human knee menisci samples were harvested from cadavers. Each meniscus sample was subject to UTE-MT imaging as well as T2 and T1rho imaging using a 3 T GE whole-body scanner. The UTE-MT sequence was based on a regular 2D UTE sequence with a minimal nominal TE of 8 µs preceded by a MT pulse (a Fermi pulse with a duration of 8 ms). The 2D UTE-MT imaging protocol used the following parameters: TR = 300 ms, field of view (FOV) = 8 cm, matrix = 256×256, band width = 125 kHz, four echoes with TEs of 0.008, 4, 8 and 12 ms. The MT pulse was placed at ten off-resonance frequencies (1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 kHz) with five different levels of MT power (300°, 500°, 700° and 1000°). The UTE-MT scans were repeated with each meniscus re-oriented at 10 different angles (0°, 20°, 40°, 60°, 80°, 100°, 120°, 140°, 160° and 180°) relative to the B0 field. T2 measured with 2D clinical CPMG sequence (TEs of 10 to 80 ms) and T1rho with a 2D spiral T1rho sequence (spin locking time of 0 to 40 ms) were also performed [6]. A home-build surface coil (~2.5 cm in diameter) was used for signal reception. Each meniscus sample was placed in a plastic container filled with perfluorooctyl bromide (PFOB) during MR imaging to maintain hydration and minimize susceptibility effects at air-tissue junctions. Images at different angular orientations were registered using a rigid-body model before quantitative analysis. The same ROIs were used for all subsequent MTR, T2 and T1rho calculations. MTR was plotted as a function of MT pulse frequency offset Δf, MT power θ and sample orientation.

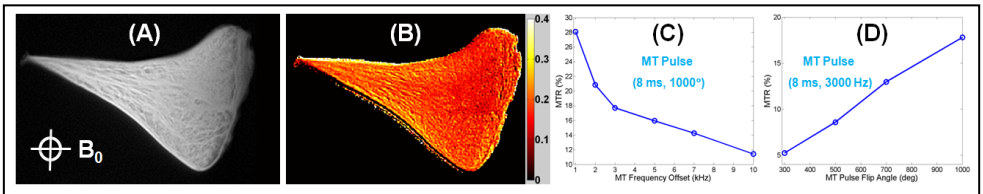


***Fig 2*** *2D UTE-MT imaging of a meniscus sample shows excellent detail of its structure (A), MTR map (B), and MTR as a function of MT pulse frequency offset (C) and power (D). MTR decreases with higher frequency offset, but increases with higher MT pulse power. Each scan took ~2 min.*

## RESULTS and DISCUSSION

Figure 2 shows UTE-MT imaging of a meniscus at different frequency offsets and MT pulse powers. Clinical MT sequences show little signal from the meniscus. MTR values are difficult to assess with these sequences. The UTE-MT sequence provides high quality morphological images with high signal and resolution, as well as high quality MTR maps of the meniscus.

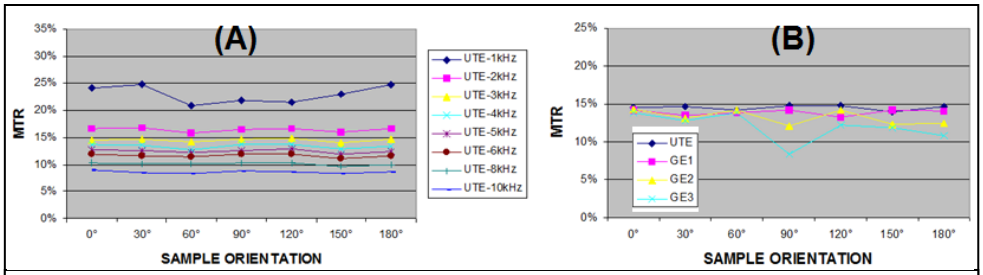


***Fig 3*** *MTR of a meniscus sample as a function of sample orientation from 0° to 180° relative to the B0 field with a θ of 1000° and ten Δfs (1 to 10 kHz) (A), and MTR at four TEs of 8 µs, 4 ms, 8 ms and 12 ms with a θ of 1000° and Δf of 3 kHz(B). There is little magic angle effect in MTR with Δf higher than 2 kHz. Increased magic angle effect in MTR was observed with longer TEs.*

Figure 3A shows UTE MTR of a meniscus sample at seven angular orientations (0° to 180°) and 10 different frequency offsets (1 to 10 kHz). The MT power was fixed at 1000°. MTR was increased by 19% near the magic angle at 1 kHz frequency offset. MTR showed almost no angular dependence when the frequency offset was greater than 2 kHz. Figure 3B shows the angular dependence of MTR at four TEs of 8 µs, 4 ms, 8 ms and 12 ms with a fixed MT power of 1000° at 3 kHz. MTR decreased while the magic angle effect increased with longer TEs, While MTR showed nearly zero angular dependence for the first three TEs, a significant magic angle effect of 64% MTR increase was observed for the 4th echo.

Figure 4 shows the angular dependence of spiral T1rho of a meniscus sample. A maximal T1rho value of 23 ms was observed, which is about 64% higher than the minimal T1rho value of 14 ms. This result shows that T1rho is more sensitive to the magic angle effect than MTR.

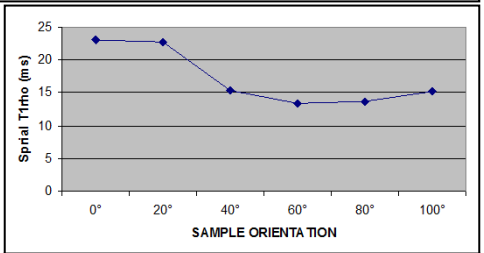


***Fig 4*** *Angular dependence of T1rho of a meniscus sample measured with a 2D spiral T1rho sequence.*

## CONCLUSIONS

This study shows little magic angle effect for MTR but a strong magic angle effect for both T1rho and $T_2$. These results suggest that UTE MT may be more robust in evaluating early OA.

## REFERENCES

1. Henkelman RM, et al., NMR Biomed 2001.
2. Li W, et. al., Tissue Eng 2010.
3. Grossman RI, RadioGraphics 1994.
4. Springer F, et. al., MRM 2009.
5. Hopfgarten C, et al, ISMRM 2012.
6. Li X, et. al., Osteoarthritis Cartilage 2007.