# Effect of Static- and Cyclic-loading on Meniscus MR Relaxation Times

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**Introduction**: The meniscus which is fibrocartilaginous tissue found within the knee joint, is responsible for shock dissipation, load transmission, and stability within the knee joint. The mechanical function of the meniscus largely depends on the structural and molecular integrity of its matrix, composed of a network of collagen fibers (Type I) immobilizing proteoglycans (PG) [1]. Recent studies have shown the potential of quantitative MR imaging, including $T_2$ and $T_{1\rho}$ quantifications for studying biochemical composition of meniscus [2]. $T_{1\rho}$ relaxation time, also known as spin-lattice relaxation in the rotating frame, probes the interaction between motion-restricted water molecules and the macromolecular environment [3]. It has been shown in literature that $T_{1\rho}$ relaxation is negatively correlated with PG content and tissue hydration [3]. $T_2$ reflects the energy exchange between free water proton molecules and is related to collagen matrix structure and water content [4]. However, to our knowledge, the effect of acute loading on the meniscal MR relaxation times ($T_{1\rho}$ and $T_2$) values has not been studied. The purpose of this study was to determine the response of PG and collagen, which are responsible for the compressive stiffness and tensile strength of meniscus [5], respectively, to static- and cyclic-loading using magnetic resonance (MR) relaxation times ($T_{1\rho}$ and $T_2$) in young healthy adults.

**Methods**: ***Static-loading***: Eight healthy volunteers were included in the study (5 males, 3 females, age: 35-40 years and BMI: 20-29 kg/m2). MR imaging was performed on a 3T scanner (Signa HDx, General Electric, Milwaukee, WI), using an 8-channel phased array transmit-receive knee coil (Invivo, Gainsville, FL), and an in-house built loading apparatus mounted on the scanner table (Fig. 1). Two sets of MR images of one knee (dominant knee) were acquired under both unloaded and loaded conditions. 50% of the subject's weight at the bottom of subjects' foot by a footplate through a pulley system was applied, to simulate static standing conditions.
***Cyclic-loading***: To simulate cyclic-loading in-vivo running exercise was chosen. 10 young healthy volunteers (5 males, 5 females, age: 20-35 years, BMI: 19-27 kg/m2) with no knee pain/stiffness, no prior knee trauma/surgery, no joint disorders, and who run at least 3 days/week were recruited. The pre-run images of one knee (dominant knee) were acquired after a 30-mins rest (to reduce the influence of preceding physical activities). Then subjects were instructed to run on a treadmill for 30 minutes (speed was recorded but not controlled). Immediately after completion of running, post-run images were acquired.
***MR image acquisition and analysis***: MR imaging was performed with a 3T GE MR scanner. The imaging protocol included sagittal 2D intermediate-weighted fast spin echo (FSE) images to evaluate cartilage and meniscus morphology, sagittal 3D fat-suppressed spoiled gradient-echo (SPGR) images to segment meniscus, and 3D sagittal $T_{1\rho}$- and $T_2$- weighted images to quantify $T_{1\rho}$ and $T_2$. Six regions of meniscus (medial and lateral posterior horns (MPHN and LPHN), anterior horns (MAHN and LAHN), and body (MBOD and LBOD)) were also segmented using an in-house spline-based segmentation software. Paired samples t-tests were performed to determine whether the meniscus MR relaxation times immediately after running and with loading were significantly ($p<0.05$) different from the baseline.

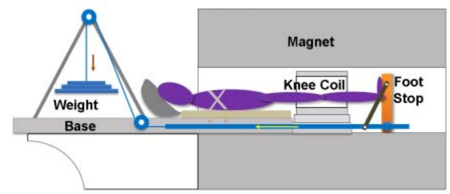


*Fig.1: Schematic representation of static-loading setup (50% body weight applied on footplate)*

**Results**: Collated data shows a decrease in $T_{1\rho}$ and $T_2$ times in the medial compartment of meniscus with static loading, while an increasing trend was observed in the lateral compartment. Figure 2 shows $T_{1\rho}$ and $T_2$ values in different regions of meniscus with static and cyclic loading in the healthy subjects. Decrease in $T_{1\rho}$ times were observed in all regions of both medial and lateral menisci, except lateral posterior horn, after running exercise (cyclic or repetitive loading) while $T_2$ showed an increasing trend, except in the medical posterior horn region. Relative change in $T_{1\rho}$ time with static- and cyclic-loading was higher than corresponding change in $T_2$ time (Fig. 2 (c), (d)).

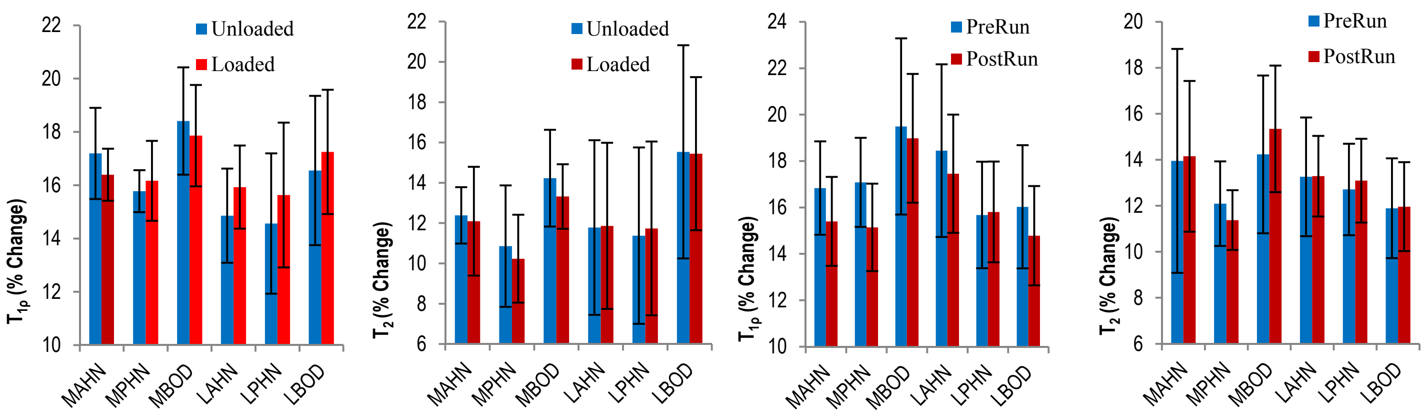


*Fig.2 : Relative change (%) in MR relaxation times in various regions of meniscus; (a) and (b) show change in $T_{1\rho}$ and $T_2$ of meniscus with and without static loading; (c) and (d) show change in $T_{1\rho}$ and $T_2$ of meniscus before and after running exercise (cyclic-loading); Error bars indicate standard deviations*

**Discussion**: Reduction in $T_{1\rho}$ values with static and cyclic loading suggest an overall increase in proteoglycan concentration as the meniscus loses its water. Larger change in MR relaxation times with cyclic loading compared to static loading suggests that cyclic loading leads to larger alterations in water content. Decrease in $T_{1\rho}$ and $T_2$ values in the medial compartment suggests larger load sharing compared to the lateral compartment. Though earlier studies [3] have shown that, in the menisci $T_2$ values were more useful than $T_{1\rho}$ values for differentiating patient population with and without osteoarthritis, this study results suggest that $T_{1\rho}$ values were more sensitive to acute loading than $T_2$ values. Greater change in $T_{1\rho}$ values with loading may be related to meniscus biomechanical characteristics and could potentially be a more sensitive biomarker of meniscus than morphological measures in the early phase of degeneration or change due to micro damage (tear).
**References**: [1] Pedrini-Mille *et al*., JOR, 1988; 6:196-204. [2] Rauscher *et al*., Radiology, 2008; 249:591-600. [3] Li *et al*., MRM 2008; 59:298–307. [4] Stikov *et al*. MRM 2011; 66:725–734. [5] Williams, Exer Sport Sci Rev, 1985; 13:1389-441.
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