# T1ρ dispersion in articular cartilage: relationship to material properties and macromolecular content

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**Introduction** MRI may be useful to non-invasively determine cartilage material properties and macromolecular content. Cartilage modulus, a measure of cartilage stiffness, may characterize cartilage health [1], and is related to macromolecular content [2]. Although, cartilage macromolecules, e.g. glycosaminoglycan (GAG) and collagen, have been correlated with MRI measurements [3-5]; previous studies relating MRI and cartilage modulus report inconsistent results [4-6].

T1ρ dispersion, the change in T1ρ with increasing spin-lock frequencies, may be related to cartilage macromolecular content [3] and thus, modulus. We propose a simple estimate of T1ρ dispersion, ΔT1ρ: the difference between T1ρ relaxation time at two spin-lock frequencies. Our purpose was to assess the potential of ΔT1ρ to evaluate changes in cartilage with and without visible damage on MR. We asked: 1) does initial elastic modulus, $E_0$, correlate with ΔT1ρ; and 2) does GAG or collagen content correlate with ΔT1ρ?

**Methods** Patellae from 17 human cadavers (20-90 years old, median age 57) were studied without chemical degradation. Patellae were imaged in a T/R wrist coil at 3T. A 2D spiral sequence was used to acquire T1ρ [7] images at spin-locking frequencies 0, 500 and 1000 Hz with 3.0 mm slice thickness, 0 mm spacing, 10 cm FOV, 2 s TR and 5 spin-lock times: 7, 21, 36, 65, 124 ms. Mono-exponential T1ρ relaxation times were fit using OsiriX to echoes having SNR greater than 5. A 3D SPGR sequence was also acquired (Fig. 1a). Creep indentation tests [8] were performed at locations across the surface of the patella, and $E_0$ was determined [9] ($t_0$=0.15s). To measure macromolecular content, 3 mm diameter plugs were removed from locations close to the indentation test sites, careful to avoid the site of needle-probe thickness measurements. At these locations, DMMB and hydroxyproline assays were used to measure the sulfated GAG and collagen contents. A radiologist performed modified Noyes scoring [10] using the SPGR images and divided the locations into two groups: those with (Noyes>0) and without (Noyes=0) visible cartilage damage. Data from 79 locations were pooled, and linear regression analyses were performed using Stata (stata.com).

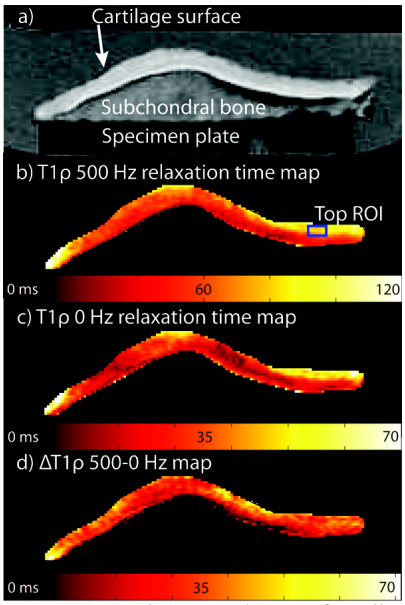


**Figure 1**: MR images and maps of patella specimen. Novel ΔT1ρ measure is related to cartilage modulus and macromolecules.

**Results** $E_0$ decreased with increasing ΔT1ρ; the coefficients of determination ($R^2$) were larger in the subset without visible damage on conventional MR compared to the entire data set (Table 1). ΔT1ρ 1000-0 Hz increased with decreasing sGAG and collagen content (Table 2). T1ρ 1000 Hz increased with decreasing $E_0$, sGAG and collagen content in the subset without visible cartilage damage. $E_0$ increased with increasing sGAG and collagen content (Table 3).

**Discussion** When there is no visible damage on conventional MR, ΔT1ρ can predict changes in cartilage modulus and macromolecular content. The relationships established in this study are modest, but are also novel and warrant further research. ΔT1ρ can potentially advance the understanding of osteoarthritis and other cartilage diseases with non-invasive assessment of cartilage properties.

| **Table 1: $R^2$ values** | | T1ρ | | | ΔT1ρ | | |
|---|---|---|---|---|---|---|---|
| | Group (N) | 0 Hz | 500 Hz | 1000 Hz | 500-0 Hz | 1000-0 Hz | 1000-500 Hz |
| $E_0$ | Noyes = 0 (58) | | | 0.10* | 0.09* | 0.15** | 0.12** |
| | Noyes > 0 (21) | 0.14^ | | | | | |
| | All (79) | | | 0.05^ | 0.04^ | 0.09** | 0.09** |

**p < 0.01. *p < 0.05. ^0.05 ≤ p < 0.10.

| **Table 2: $R^2$ values** | | T1ρ | | | ΔT1ρ | | |
|---|---|---|---|---|---|---|---|
| | Group (N) | 0 Hz | 500 Hz | 1000 Hz | 500-0 Hz | 1000-0 Hz | 1000-500 Hz |
| sGAG content | Noyes = 0 (58) | | | 0.08* | | 0.07* | 0.07^ |
| | Noyes > 0 (21) | 0.28* | | | | | 0.16^ |
| | All (79) | | | | | 0.05* | 0.08* |
| Collagen content | Noyes = 0 (58) | | 0.07* | 0.07* | 0.09* | 0.06^ | |
| | Noyes > 0 (21) | | | | 0.15^ | 0.16^ | |
| | All (79) | | 0.08* | 0.08* | 0.08* | 0.06* | |

**p < 0.01. *p < 0.05. ^0.05 ≤ p < 0.10.

| **Table 3:** $E_0$ | sGAG content | Collagen content |
|---|---|---|
| Noyes = 0 (58) | $R^2$ = 0.38*** | 0.06^ |
| Noyes > 0 (21) | 0.50*** | 0.34** |
| All (79) | 0.42*** | 0.10** |

***p < 0.001. **p < 0.01. ^p = 0.059.

**References**: [1] Hayes+ J Appl Phys 1971;31:562-8. [2] Kempson+ Bio Bio Acta 1970;215(1):70-7. [3] Duvvuri+ MRM 1997;38(6):863-7. [4] Samosky+ JOR 2005;23(1):93-101. [5] Lammentausta+ JOR 2006;24(3):366-74. [6] Nissi+ OA&C 2007;15(10):1141-8. [7] Li+ MRM 2005;54(4):929-36. [8] Keenan+ CMBBE 2009;12(4):415-22. [9] Hayes+ JBiomech 1972;5:541-51. [10] Kijowski+ Rad 2009;251(1):185-194. **Support**: NIH EB002524, EB005790; GE; VA #A2592R.