MULTIPARAMETRIC MR RELAXOMETRY FOR ARTICULAR AND EPIPHYSEAL CARTILAGE DURING SKELETAL MATURATION IN A GOAT MODEL

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Target Audience: Scientists and clinicians interested in articular and epiphyseal cartilage imaging, MR relaxometry, novel pulse sequences.

Purpose: Utilize noninvasive MR relaxometry to better understand skeletal maturation of the articular-epiphyseal cartilage complex (AECC) by monitoring matrix changes longitudinally during skeletal development.

Methods: In this animal care and use committee approved study, distal femoral specimens were harvested from goats, aged 3, 4, 5, 6, 9 and 10 weeks. MRI scans were performed using a 9.4T Varian scanner (Agilent Technologies, Santa Clara, CA). MR relaxation times of articular and epiphyseal cartilage were quantified for the goat knees. Conventional continuous wave (CW) $T_{1\rho}$, adiabatic $T_{1\rho}$, T_1 and T_2 relaxation times were measured. In addition, relaxation along a fictitious field (RAFF) and the corresponding relaxation time constant (T_{RAFF}) were measured. Table 1 provides the detailed scan parameters that were used.

Results: Quantitative relaxation time mapping, T_1, T_2, CW $T_{1\rho}$, adiabatic $T_{1\rho}$, and T_{RAFF}, revealed relaxation times that were consistently higher in articular compared to epiphyseal cartilage. The relaxation parameters are shown at weekly intervals between 3 and 6 weeks of age and at 9 and 10 weeks (Figure 1). An increase in the values of all parametric measures, except CW $T_{1\rho}$ was noted at the 4 week time point, then values decreased incrementally during the rest of the study. The articular cartilage appeared as a thin superficial layer in both the (a) histological and (b) MR images (Figure 2). The relaxation times were uniform within both the articular and the epiphyseal cartilage, which corresponds with the isotropic properties of hyaline cartilage on MRI. With increasing age, the epiphyseal cartilage became thinner due to replacement by the advancing ossification front, while the thickness of the articular cartilage remained stable. The T_1 relaxation time tended to be stable during the growth, with average values of approximately 1500 and 1100 ms at 9.4T for articular and epiphyseal cartilages, respectively (Table 2). For all the other relaxation parameters, the values were higher in the younger animals (3, 4 weeks of age), and gradually decreased to stable values at about 6 weeks of age. In contrast to all other relaxation times, T_{RAFF} showed an increase at 10 weeks of age.

Discussion: Our knowledge regarding cartilage matrix changes during skeletal maturation is limited, largely due to a lack of measurement tools. Evaluating temporal changes occurring in the AECC is important to better understand the normal skeletal development in children [4] and respective animal models. Establishing normal values is the first step towards identifying pathologic changes occurring in developmental orthopaedic diseases such as Perthes disease of the hip or osteochondritis dissecans of the knee. A limitation of the study is that the estimated values (other than T_1 and adiabatic $T_{1\rho}$) could be potentially influenced by the magic angle effect in the articular cartilage [5].

Conclusion: MR relaxometry provides a noninvasive means to obtain information about articular and epiphyseal cartilage during maturation, as was demonstrated in goats in this study. The data suggest that MR relaxometry might be used to characterize developmental abnormalities during skeletal maturation in both animals and human beings.

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References: [1] Ellermann, J. et al. Magn. Reson. imaging. 2013;31(9):1537-43. [2] Rautiainen, J. et al. Magn. Reson. Med. DOI: 10.1002/mrm.25401. [3] Tóth, F. et al. Osteoarthritis and Cartilage. Accepted Manuscript: OAC1713R1. [4] Cobb, J. et al. J. Magn. Reson. Imaging. 2013;38(2):299-305. [5] Nissi. M. et al. ISMRM 2013, abstract #3552, Salt Lake City, Utah, US.

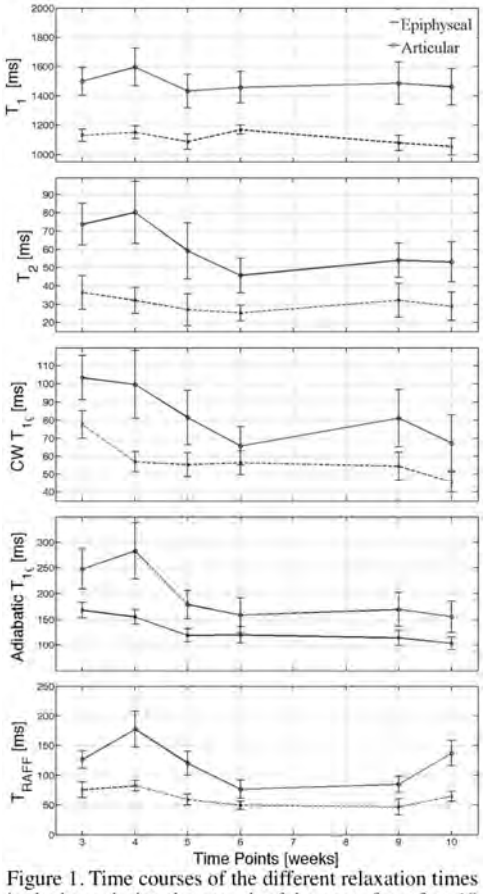

Figure 1. Time courses of the different relaxation times in the knee during the growth of the goats from 3 to 10 weeks of age. The articular cartilage (solid line) consistently had higher values compared to the epiphyseal cartilage (dashed line).

Table 1. MRI sequences and parameters

FSE Readout	TR = 5s, ETL = 8, thk = 1 mm, FOV = 4 cm, 256 × 256, coronal
T_1	IR, TI = 0.07, 0.08, 0.1, 0.16, 0.32, 0.64, 1.28, 2.56, 5.12 s, TE = 10 ms
T_2	Double spin echo preparation, T = 4, 20, 40, 60, 80, and 100 ms, TE = 10 ms
CW $T_{1\rho}$	γB_1^{max} = 500 Hz, T = 0, 10, 20, 40, and 80 ms, TE = 10 ms
Adiabatic $T_{1\rho}$	Train of 0, 4, 8, 12, 16 AFP pulses, duration = 6 ms, γB_1^{max} = 2.5 kHz, TE = 10 ms
T_{RAFF}	Train of 0, 8, 16, 24, 32 RAFF pulse, duration = 4.53 ms, γB_1^{max} = 625 Hz, TE = 5 ms

Table 2. Relaxation times (mean ± SD in ms) at different ages

		3 weeks	4 weeks	5 weeks	6 weeks	9 weeks	10 weeks
T_1	Articular	1500 ± 94	1598 ± 129	1434 ± 114	1458 ± 108	1487 ± 144	1463 ± 125
	Epiphyseal	1131 ± 42	1152 ± 43	1088 ± 52	1169 ± 30	1079 ± 52	1054 ± 58
T_2	Articular	73.8 ± 11.4	80.2 ± 16.8	59.2 ± 15.4	45.7 ± 9.4	54.0 ± 9.4	53.1 ± 11.0
	Epiphyseal	36.4 ± 9.2	32.1 ± 7.0	27.0 ± 8.7	25.3 ± 4.2	32.2 ± 9.2	28.8 ± 7.7
CW $T_{1\rho}$	Articular	103.5 ± 12.1	99.7 ± 18.6	81.5 ± 15.1	65.8 ± 10.6	81.1 ± 15.9	67.4 ± 15.4
	Epiphyseal	77.6 ± 7.5	56.9 ± 5.5	55.4 ± 6.6	56.5 ± 6.6	54.5 ± 7.8	45.6 ± 5.6
Adiabatic $T_{1\rho}$	Articular	248.1 ± 38.7	283.3 ± 54.7	179.1 ± 27.6	158.5 ± 33.5	169.6 ± 32.8	155.2 ± 30.5
	Epiphyseal	168.0 ± 15.2	155.1 ± 14.3	119.0 ± 12.9	119.7 ± 16.0	114.3 ± 15.4	103.5 ± 12.3
T_{RAFF}	Articular	126.4 ± 15.0	177.7 ± 30.3	120.4 ± 20.2	76.4 ± 15.5	84.7 ± 13.7	137.4 ± 21.4
	Epiphyseal	75.4 ± 13.2	82.5 ± 9.0	59.1 ± 9.3	49.4 ± 6.9	46.9 ± 13.2	64.7 ± 8.4

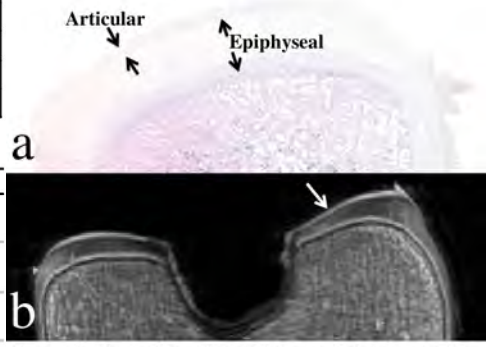

Figure 2. Illustration of the thin superficial layer of the articular cartilage and the underlying thick layer of epiphyseal cartilage (indicated by arrows) by (a) histology and (b) MRI at the 6 weeks of age.