Articular and meniscal cartilage respond differently to functional loading

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ABSTRACT INTRODUCTION:

Functional loading at the knee during daily activities is known to influence cartilage health and plays a critical role in initiation and progression of degeneration seen in knee osteoarthritis (OA). Loads during walking, which is the most common daily activity, can be as high as upto 2-3 times the body weight[1]. Previous studies have shown that in young healthy people without knee pathologies, knee adduction moment (KAM) during walking, which is a surrogate measure for medial compartmental loads, is associated with a higher medial-lateral ratio of cartilage thickness[2]. Also, knee kinematics during walking have been shown to predict spatial distribution of cartilage thickness[3]. In knee OA, compositional changes in cartilage precede morphologic changes with early degeneration being characterized by a loss of proteoglycans and collagen disruption. Quantitative MRI measures of $T_{1\rho}$- and T_2 relaxation times are promising new imaging biomarkers for cartilage degeneration and are provide non-invasive assessment of cartilage composition[4]. High $T_{1\rho}$- and T_2 relaxation times in articular and meniscal cartilage indicate degeneration. Articular and meniscal cartilage have different composition, structure and function. Therefore it is likely that they respond differently to functional loads but it has never been demonstrated. The objective of this study was to evaluate the relationship between functional loading during walking and articular and meniscal cartilage composition as assessed using $T_{1\rho}$ and T_2 relaxation times.

METHODS:

22 young healthy, physically active subjects, between the ages of 20-35 years, BMI < 28 kg/m^2 underwent 3-D kinematic/kinetic analysis during walking at self-selected speed. All procedures were approved by an IRB and all subject signed and informed consent prior to study commencement. 3-T MR protocol included sagittal 2D T_2-weighted fast spin echo (FSE) sequence for semi-quantitative clinical assessment of knee cartilage morphology, sagittal 3D water excitation high-resolution spoiled gradient-echo (SPGR) images to segment cartilage, and 3D sagittal $T_{1\rho}$- and T_2- weighted images based on SPGR acquisition to quantify relaxation times. Thickness (Th.,AC), $T_{1\rho}$- and T_2 relaxation times were quantified for 6 regions of articular cartilage (medial/lateral-femoral condyle (MFC and LFC), tibial plateau (MTP and LTP), patella (PAT), and trochlea (TRO)). $T_{1\rho}$- and T_2 relaxation times were also quantified for 6 regions of menisci (anterior/body/posterior horn for medial and lateral meniscus). Overall and medio-lateral ratios of Th.AC $T_{1\rho}$- and T_2 relaxation times were also calculated for tibia, femur, tibiofemoral compartment, patellofemoral compartment and global knee.

Kinematic and kinetic data were collected using a 10 camera infrared motion capture system (250 Hz) and 2 force platforms (1000 Hz) while the subjects walked at self-selected speed for 10 trials. Sagittal and frontal plane kinematic (peak and excursion), kinetic (peak and rate of loading) were calculated for each subject. Pearson's correlations were calculated between kinematic/kinetic variables and articular/meniscal cartilage thickness, $T_{1\rho}$- and T_2 relaxation times. Variables with significant correlations were entered into a linear regression model to assess the strength of relationships.

RESULTS SECTION:

Data were analyzed from both knees where available providing a total sample size of 36 knees. 1st and 2nd peaks of KAM were related to high overall medio-lateral ratio of cartilage thickness. Total frontal plane excursion and flexion excursion during loading response were correlated with lower overall thickness in tibio-femoral and patella-femoral compartments. None of the frontal plane variables were found to be related to articular cartilage $T_{1\rho}$- and T_2 relaxation times. In sagittal plane, peak external flexion moment was related to high articular cartilage $T_{1\rho}$- and T_2 relaxation times for tibiofemoral compartment and peak external extension moment was related to low articular cartilage $T_{1\rho}$- and T_2 relaxation times.

1st and 2nd peaks of KAM and frontal plane Rate of Loading (ROL) were related to high medio-lateral ratio of meniscus $T_{1\rho}$- and T_2 relaxation times. Knee external extension moment was related to high $T_{1\rho}$- and T_2 relaxation times in 4 of 6 meniscus compartments studied.

Results from the regression analyses are shown in Table 1.

Table 1: Results from regression analyses. (KAM: knee adduction moment, KFM: knee flexion moment, KEM: knee extension moment,ROL:rate of loading)

Dependent Variable		Predictors	R^2	Sig.
Th.AC	**Tibiofemoral**	Flexion Excursion	24%	0.004
	Tibiofemoral$_{MLRatio}$	1st peak KAM	12.5%	0.047
T1ρ	**Tibiofemoral**	Peak KFM and KEM	50%	0.000
	Tibiofemoral$_{MLRatio}$	None	-	-
	Meniscus$_{Global}$	Frontal ROL & peak KEM	38.4%	0.001
	Menicus$_{MLratio}$	Frontal ROL	24 %	0.004
T2	**Tibiofemoral**	Peak KFM and KEM	48.2%	0.000
	Tibiofemoral$_{MLRatio}$	None	-	-
	Meniscus$_{Global}$	Frontal ROL & peak KEM	27.6%	0.009
	Menicus$_{MLratio}$	Frontal ROL	19%	0.013

DISCUSSION:

These are the 1st reports of the relationship between knee loading during walking and articular and meniscal cartilage composition. Walking is the most common daily activity and the loading over repeated strides in a lifetime leads to high amount of cumulative load over the knee tissues. In degenerated cartilage, as in knee OA, high knee loads are related to poor cartilage health with greater medial cartilage loss seen with high KAM[5].. In young healthy subjects, the relationship is different with high KAM associated with relatively thicker medial cartilageThese findings were replicated in this study. Furthermore, it was seen that magnitude of loading in sagittal plane was significantly related to cartilage composition. Whereas, in the frontal plane, it was the rate of the applied loads that was more predictive of $T_{1\rho}$- and T_2 relaxation times. Also, we found that for articular cartilage, high moments and lower excursion (which together leads to high loading over less area of cartilage) is associated with lower $T_{1\rho}$- and T_2 relaxation times but for meniscal cartilage high moments were related to high $T_{1\rho}$- and T_2 relaxation times. Articular cartilage is primarily exposed to axial and shear loads but meniscus responds by converting axial loads into radial hoop stresses. Also meniscus is primarily composed of Type I collagen whereas articular cartilage is composed of Type II collagen. Based on these results, it is plausible that meniscus might start to degenerate before cartilage when exposed to repetitive functional loads in the pathogenesis of knee OA. We continue to process the data to assess relationship of functional mechanics with articular cartilage laminar $T_{1\rho}$- and T_2 relaxation times and texture values. We are also in the process of doing subregional analysis of articular cartilage in light of the findings of different relationship of flexion and extension moments with $T_{1\rho}$- and T_2 relaxation times.

SIGNIFICANCE:

These results provide the link between movement patterns and cartilage health of the knee joint. Movement patterns are amenable to clinical interventions where neuromuscular retraining could be used to target patterns that appear to be related to poor cartilage health. These findings can provide the foundation for development of a prevention program for knee osteoarthritis in the subset of population where mechanical factors are shown to be primarily implicated in OA onset.

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