

Associations Between Preoperative Tibiofemoral Articular Cartilage Composition and Cumulative Loading 2 Months Following ACL Reconstruction

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BACKGROUND

- Lower proteoglycan density (PGD) of the tibiofemoral articular cartilage is a marker of cartilage degeneration that is of concern following ACL injury¹
- Higher T1rho interlimb ratios, which indicate decreased PGD, have shown to be associated with aberrant gait mechanics at 6-months post-ACLR, including decreased vGRF²
- Cumulative joint loading is a metric characterizing both habitual loading magnitude and frequency
- ACLR patients often display lower activity levels in comparison to healthy controls³
- Fewer steps per day after ACLR associate with a worse cartilage metabolic response to walking⁴
- However, it is not clear whether the initial response to ACL injury is linked to habitual loading characteristics early after ACLR

PURPOSE

Purpose: To determine the association between pre-operative PGD and cumulative loading 2 months post-ACLR.

Hypothesis: We hypothesize that higher interlimb ratios of tibiofemoral cartilage T1rho relaxation times will be associated with lower levels of cumulative loading at the 2-month timepoint following ACLR.

METHODS

- Participants: Twenty-one individuals who underwent unilateral ACLR (47.6% Female; 21.0±3.4 years old; 24.6±4.3 kg/m²)
- Bilateral T1rho MRI scans were performed preoperatively with a Siemens Magnetom Prisma 3T PowerPack scanner using a three-dimensional fast-low angle shot T1rho sequence with a spin lock power of 500 Hz at five spin lock durations (0, 10, 40, 70 ms)
- At 2 months post-ACLR, all participants completed 5 error-free walking trials at a self-selected pace (TF100, Tractronix) across two staggered force plates (40 × 60 cm, FP406010, Bertec Corporation, Ohio, USA) embedded in the lab floor
- Kinetic data was sampled at 1200Hz and low-pass filtered at 10Hz using a 4th order recursive Butterworth filter
- Subjects were instructed to wear a GT9X Link ActiGraph activity monitor on their right hip for 7 days at 2 months post-ACLR and steps per day were averaged across the wear period
- A valid wear period was identified as 3 weekdays and 1 weekend day, worn for at least 10 hours each day

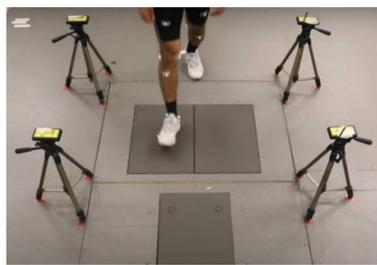


Figure 1. Peak vGRF was extracted during the first 50% of stance phase, recognized as occurring between heel strike (>20N) and toe-off (<20N)

RESULTS

Table 1. Descriptive Statistics (Mean ± SD). N=21

Age (Years)	21.0 ± 3.4
Sex	47.6% Female
Body Mass Index (kg/m ²)	24.6 ± 4.3
KOOS Quality of Life	41.7 ± 12.4
Global MFC T1rho ILR	0.98 ± 0.08
Global MTC T1rho ILR	0.96 ± 0.09
Global LFC T1rho ILR	0.97 ± 0.07
Global LTC T1rho ILR	0.96 ± 0.05
Cumulative Loading	3106 ± 1227
Steps-per-day	6226 ± 2334

SD: Standard Deviation; KOOS: Knee Osteoarthritis Outcome Score; ILR: Interlimb Ratio

Table 2. Associations between Global Interlimb Ratios of T1rho Relaxation Times (ms) and Cumulative Loading of the Involved Limb 2 Months Post-ACLR

Measures	Mean ± SD	Global Interlimb Ratios			
		Global MFC	Global MTC	Global LFC	Global LTC
		Pearson r (95% CI)	Pearson r (95% CI)	Pearson r (95% CI)	Pearson r (95% CI)
Cumulative Loading (Bodyweights Per Day)	3105 ± 1227	-0.16 (-0.55, 0.29)	0.36 (-0.08, 0.69)	-0.04 (-0.46, 0.40)	0.36 (-0.09, 0.68)

CI: Confidence Interval; SD: Standard Deviation; ACLR: Anterior Cruciate Ligament Reconstruction

Table 3. Associations between Cartilage Sub-region Interlimb Ratios of T1rho Relaxation Times (ms) and Cumulative Loading of the Involved Limb 2 Months Post-ACLR

Measures	Anterior LTC		Central LTC		Posterior LTC		Anterior MTC		Central MTC		Posterior MTC	
	Pearson r (95% CI)	Pearson r (95% CI)	Pearson r (95% CI)	Pearson r (95% CI)	Pearson r (95% CI)	Pearson r (95% CI)	Pearson r (95% CI)	Pearson r (95% CI)	Pearson r (95% CI)	Pearson r (95% CI)	Pearson r (95% CI)	
Cumulative Loading (Bodyweights Per Day)	0.58*** (0.19, 0.81)	0.17 (-0.28, 0.56)	0.19 (-0.27, 0.57)	0.38* (-0.06, 0.70)	0.32 (-0.13, 0.66)	0.20 (-0.25, 0.58)						
Daily Steps	0.62*** (0.25, 0.83)	0.22 (-0.23, 0.60)	0.24 (-0.21, 0.61)	0.42* (-0.01, 0.72)	0.37 (-0.07, 0.69)	0.26 (-0.20, 0.62)						
Peak vGRF (Bodyweights)	-0.13 (-0.52, 0.32)	-0.36 (-0.69, 0.08)	-0.35 (-0.68, 0.10)	-0.15 (-0.55, 0.30)	-0.27 (-0.63, 0.18)	-0.34 (-0.68, 0.10)						

CI: Confidence Interval; vGRF: Vertical Ground Reaction Force; ACLR: Anterior Cruciate Ligament Reconstruction; ***p<0.01; **p<0.05; *p<0.10

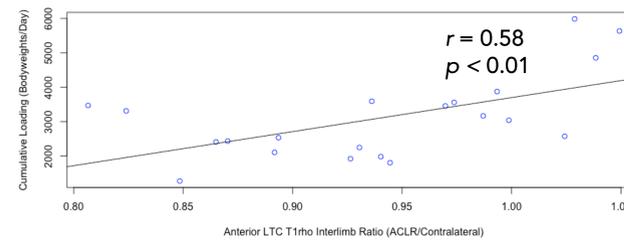


Figure 3. Association between the T1rho ILR of the anterior LTC and cumulative loading at 2-months post-ACLR

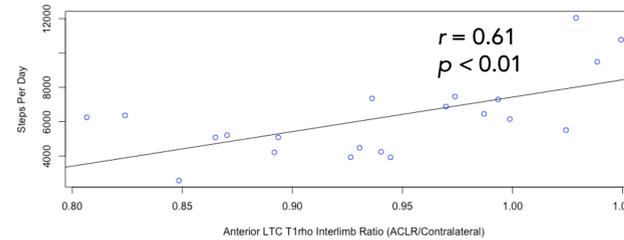


Figure 4. Association between the T1rho ILR of the anterior LTC and daily steps at 2-months post-ACLR

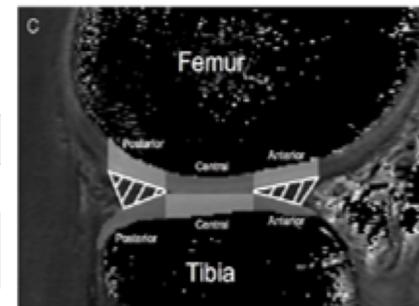


Figure 2. Weightbearing regions of the tibiofemoral articular cartilage were separated into anterior, central, and posterior regions based on the location of the meniscus in the sagittal plane

Primary Findings

- Moderate associations that were trending towards statistical significance were observed between T1rho relaxation times in both the global LTC ($p=0.11$) and MTC ($p=0.11$)

Post Hoc Findings

- Greater cumulative loading was moderately associated with greater T1rho interlimb ratios in the anterior LTC ($p<0.01$; $r=0.58$)
- Greater steps-per-day was uniquely associated with the anterior LTC region ($p<0.01$; $r=0.62$)
- Greater steps-per-day were moderately associated with greater T1rho interlimb ratios in the anterior MTC, but did not achieve statistical significance ($p=0.057$; $r=0.42$)

METHODS (CONTINUED)

- Cumulative loading was calculated as: $Cumulative\ Loading = \frac{(Daily\ Steps)}{2} \times (peak\ vGRF)$
- T1rho maps were calculated and cartilage from the medial and lateral tibial and femoral condyles were segmented into 3 and 5 distinct regions, respectively
- T1rho interlimb ratios (ACLR/contralateral) were calculated to account for natural inter-subject T1rho variability, with greater T1rho interlimb ratios interpreted as decreased ACLR limb proteoglycan density
- Statistical Analysis:** Pearson product-moment correlation coefficients (r) and associated 95% confidence intervals were calculated to determine the strength of association between preoperative T1rho interlimb ratios for each cartilage region of interest and cumulative loading at 2-months post-ACLR
- Post hoc Analysis:** The primary analysis was replicated for each subregion within the global weightbearing regions of the articular cartilage that showed statistically significant association. We also assessed the unique components of cumulative loading by assessing the separate associations between steps-per-day and peak vGRF with subregional T1rho relaxation times.

DISCUSSION

Conclusions:

- Greater interlimb differences in PGD in the anterior LTC are associated with lesser cumulative loading two months post-ACLR
- Trends concerning the MTC appear similar to that of the LTC, but they do not exhibit statistical significance to the degree of the LTC patterns
- Concomitant injuries and non-weightbearing status preoperatively may contribute to earliest compositional changes within the articular cartilage

Limitations:

- The sample size was small ($n=21$)
- Preoperative T1rho assessments are limited in the scope of interpretation as no pre-injury scans are available to serve as a baseline measure

Future Research:

- Future studies should develop interventions that address cumulative loading as a modifiable risk factor to reduce risk of post-traumatic osteoarthritis following ACLR
- Other biomechanical metrics of interest, such as knee adduction moment, should be assessed at 2-months post-ACLR for association with preoperative T1rho relaxation times of the tibiofemoral cartilage

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