Quadriceps Strength is Protective of Knee Joint Bone Mineral Density Following an ACL Reconstruction

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INTRODUCTION: Anterior cruciate ligament (ACL) tears are common sports-related injuries resulting in altered movement mechanics [1] and increased risk of post-traumatic osteoarthritis development (PTOA) [2,3]. Injury-induced changes in femoral and tibial bone mineral density (BMD) persist following ACL reconstruction (ACLR) and may be related to the development of PTOA [4,5]. However, the role of post-surgical knee strength and walking mechanics in maintaining BMD is less studied. The purpose of this study was to quantify between-limb differences in femoral and tibial BMD at six months post-ACLR, as well as identify correlations between involved limb BMD, strength, and gait mechanics. We hypothesized that the involved limb would exhibit deficits in BMD compared to the non-involved limb and that higher involved limb strength would correlate to higher involved limb BMD.

METHODS: 19 individuals (13 female, age: 17.8±3.0 years, height: 1.7±0.1m, weight: 71.4±14.0kg, BMI: 25.7±4.5 kg/m^2) six months post-ACLR consented to participate in this IRB-approved study. 18 participants had a bone-patellar tendon-bone graft, and one graft type was unknown. Dual-energy x-ray absorptiometry (DXA) scans of each participant's bilateral distal femurs and proximal tibias were acquired using a modified forearm sequence [6] (Lunar iDXA, GE Healthcare). Participants then walked on an instrumented treadmill at a standard speed (1.5m/s) while kinematic data were collected at 200 Hz using a 13-camera motion capture system (Motion Analysis Corp). Ground reaction forces (GRFs) were simultaneously collected at 2000 Hz from two force plates within the treadmill (Bertec Corp.). Finally, quadriceps strength was assessed via four maximum voluntary isometric contractions per limb (90° flexion, 5s hold) (Biodex Medical Systems).

Using a custom MATLAB program, BMD of the medial and lateral compartments of each femur and tibia were quantified from the segmented DXA scans. All kinematic and kinetic data were filtered using a 4th order Butterworth low-pass filter. Internal knee joint moments, knee joint powers, knee angular impulse, and GRF impulse (propulsive, braking, vertical, medial, and lateral) were computed in Visual 3D and averaged across all trials for each participant. Internal knee moments and powers were normalized to participant height * mass and GRF impulse was normalized to participant mass. Peak isometric knee extensor torque and rate of torque development (RTD) from each trial were averaged per participant and normalized to participant mass. Data were assessed for normality using a Shapiro-Wilk test and paired t-tests assessed between-limb differences in BMD. Spearman's correlation assessed relationships between BMD, walking mechanics, and strength within the involved limb. Significance was set at $p<0.05$ for all tests.

RESULTS: At six months post-surgery, medial and lateral femoral BMD and lateral tibial BMD were lower in the involved limb than the non-involved limb (Table 1). Significant correlations between strength and walking mechanics variables and compartmental BMD are shown in (Table 2). In the involved limb, greater isometric knee extensor torque was correlated with higher femoral and tibial BMD in the lateral compartment. Similarly, greater involved limb isometric RTD was correlated with higher lateral femoral BMD.

Dynamically, individuals who walked with higher knee extensor moment tended to have higher lateral tibial BMD. Similarly, higher frontal plane power during walking was correlated to higher femoral lateral BMD and medial/lateral tibial BMD. GRF impulse was also significantly correlated to involved limb BMD, with lower propulsive impulse correlating to global BMD increase (strongest correlation to BMD [Figure 1]) and greater medial impulse correlating to greater lateral femoral/tibial BMD.

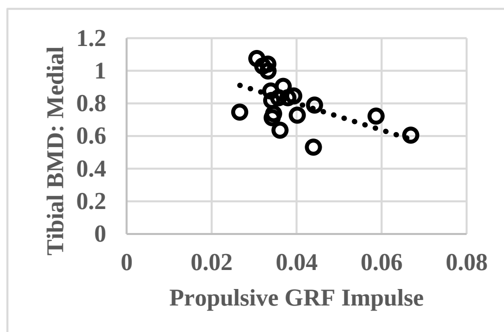

Figure 1: Relationship between propulsive GRF impulse and medial tibial BMD.

DISCUSSION: Our results highlight the significant relationship between quadriceps strength, power, and compartmental BMD after ACLR, suggesting that developing stronger knee musculature may be a key factor in maintaining BMD after surgery. This work adds to the growing body of literature showing the interdependencies of muscle and bone and pointing to prioritizing regaining strength over gait retraining measures for improving bone health after ACL reconstruction and avoiding further degenerative changes. Given that the subchondral bone closely supports knee cartilage health, our findings of decreased BMD in this young and predominantly female population are concerning but also provide a targeted pathway to potentially reverse negative outcomes. In contrast, the relationship between post-operative walking mechanics and BMD remains less clear, as the magnitude of these metrics vary greatly between movements and their relationship with BMD may change when investigating sport-specific motions.

SIGNIFICANCE/CLINICAL RELEVANCE: Prioritizing strength training and multi-directional movements within rehabilitation protocols may be an important step in preventing subchondral bone loss that occurs prior to PTOA in individuals with ACL reconstruction.

REFERENCES: [1] Slater, J Athl Train, 2017. [2] Chaudhari, Med Sci Sports Exerc, 2008. [3] Wellsandt, AJSM, 2016. [4] Sievanen, Bone, 1994. [5] Kroker, JOR, 2019. [6] Bakkum, Med Eng Phys, 2014.

Table 1: Compartmental BMD of the involved (INV) and non-involved (NON) limbs, shown as mean (standard deviation). * indicates significant difference.

	Variable	INV	NON	$p_{adjusted}$
Femoral BMD	Medial (g/cm^2)	1.0 (0.2)	1.1 (0.1)	***0.005**
	Lateral (g/cm^2)	0.8 (0.1)	1.0 (0.2)	***<0.001**
Tibial BMD	Medial (g/cm^2)	0.8 (0.1)	0.9 (0.1)	0.39
	Lateral (g/cm^2)	0.7 (0.1)	0.9 (0.1)	***<0.001**

Table 2: Strength and walking mechanics variables that significantly correlate to femoral and tibial compartmental BMD.

		Femur BMD		**Tibial BMD**	
		Lateral	**Medial**	**Lateral**	**Medial**
Strength	**Peak Knee Extensor Torque (Nm/kg)**	p=0.035 r=0.486	--	p=0.020 r=0.539	--
	RTD (Nm/[kg*s])	p-0.027 r=0.505	--	--	--
Walking	**Peak Knee Extensor Moment (Nm/kg)**	--	--	p=0.035 r=0.486	--
	Peak Frontal Plane Power (W/[kg*m])	p=0.026 r=0.316	--	p=0.006 r=0.602	p=0.011 r=0.572
	Propulsive GRF Impulse ([N*s]/kg)	p=0.017 r=-0.539	p=0.009 r=-0.579	p=0.012 r=-0.563	p=0.004 r=-0.626
	Medial GRF Impulse ([N*s]/kg)	p=0.041 r=0.472	--	p=0.029 r=0.502	--