

# Intramuscular Fat Infiltration Following ACL Reconstruction

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**DISCLOSURES:** NONE. **INTRODUCTION:** Whole muscle atrophy and muscle activation deficits are often to blame for persistent muscle weakness following ACL reconstruction (ACLR). However, focusing solely on atrophy or activation deficits overlooks other properties of muscle that are crucial for force generation. For instance, intramuscular fat represents a non-contractile element that can interfere with a muscle's contractile properties by increasing muscle stiffness. Intramuscular fat has been shown to be elevated in idiopathic osteoarthritis and related to early joint degeneration that affects greater than 50% of those who received ACLR. However, intramuscular fat has not been comprehensively explored utilizing advanced quantitative magnetic resonance imaging following ACLR. As such, our main objectives were to use magnetic resonance imaging (MRI) to characterize muscle size and intramuscular fat in the vasti muscles in participants with a chronic history of ACLR and in healthy controls. Additionally, we sought to explore if intramuscular fat and fat-cleared muscle volume were related to quadriceps isometric strength in the ACLR and Control limbs. **METHODS:** Twenty-four individuals with a protracted history of primary ACLR (male/female = 15/9, Age =  $22.8 \pm 3.6$  years, body mass index =  $23.2 \pm 1.9$ , time since surgery =  $3.3 \pm 0.9$  years), and 24 healthy controls (male/female = 14/10, Age =  $22.0 \pm 3.1$  years, body mass index =  $23.3 \pm 2.6$ ) underwent two testing sessions. MRI data of the bilateral upper thighs were acquired with a 3-Tesla MRI Philips Ingenia scanner. The vastus lateralis (VL), vastus intermedius (VI), vastus medialis (VM), and the femur were segmented (Figure 1A/B). All muscle segmentations were split into sub-regions of interests (ROIs). Proximal, central, and distal sub-ROIs were created by splitting each muscle into 3 equal lengths in the proximo-distal direction (Figure 1C). Deep and superficial sub-ROIs were discriminated using the distance from the femur gravity center (Figure 1D). Median fat fraction was computed in each whole and sub-ROI. The fat component of each ROI was computed by multiplying the median fat fraction and normalized muscle volume. Fat-cleared muscle volume was then computed by subtracting the fat component from the normalized muscle volume. Quadriceps isometric knee extensor strength, normalized to body mass ( $N \cdot m/kg$ ), was measured at 60 degrees of knee flexion using an isokinetic dynamometer. Linear mixed effects models compared intramuscular fat, fat-cleared muscle volume, and quadriceps strength between limbs (involved vs. uninvolved) and groups (ACLR vs. Control), with subject as a random factor and with sex and BMI included as control variables. Separate regression analyses, while controlling for sex and BMI, were also run to determine intramuscular fat or fat-cleared muscle volume was associated with quadriceps strength. **RESULTS:** We demonstrate that patients with history of ACLR exhibit muscle atrophy of all vasti muscles, where the involved limb was 7-9% smaller than the uninvolved limb ( $p < 0.05$ ). However, in this chronic cohort there were no significant group or limb differences were identified for intramuscular fat in any whole or sub-region ( $p = 0.180-0.999$ ). Despite a significant group by limb interaction for quadriceps strength ( $p = 0.049$ ), post-hoc analyses also revealed no between limb strength differences ( $p > 0.05$ ). Further, in ACLR- and Control-involved limbs, intramuscular fat nor quadriceps volume were associated with quadriceps strength ( $p = 0.092 - 0.219$ ). **DISCUSSION:** We demonstrate that patients with history of ACLR exhibit muscle atrophy that cannot be explained by muscle weakness or intramuscular fat. **SIGNIFICANCE/CLINICAL RELEVANCE:** This is the first study to comprehensively explore intramuscular fat in those with a protracted history of ACLR. These findings add to the growing body of literature suggesting that there are factors at the intrinsic level that may hinder muscle hypertrophy long after ACLR, but the development of intramuscular fat does not appear to hinder strength recovery.

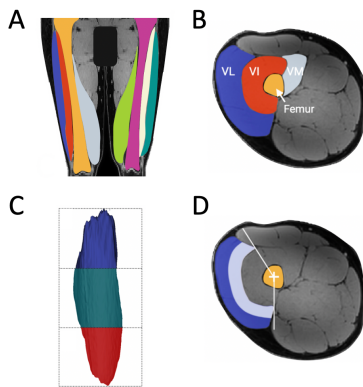


Figure 1. Representative Muscle Segmentations. Panels A and B represent whole muscle regions of interest (ROI) in the frontal (Panel A) and axial (Panel B) planes. VL indicates Vastus Lateralis; VI, Vastus Intermedius; VM, Vastus Medialis. Panel C represents an example of the proximal (top), central (middle), and distal (bottom) sub-ROI's for the VL where the muscle was split into 3 equal lengths in proximo-distal direction. Panel D represents an example of the superficial and deep muscle sub-ROIs for the VL, where the muscle was partitioned to two different depths using the distance from the femur gravity center.

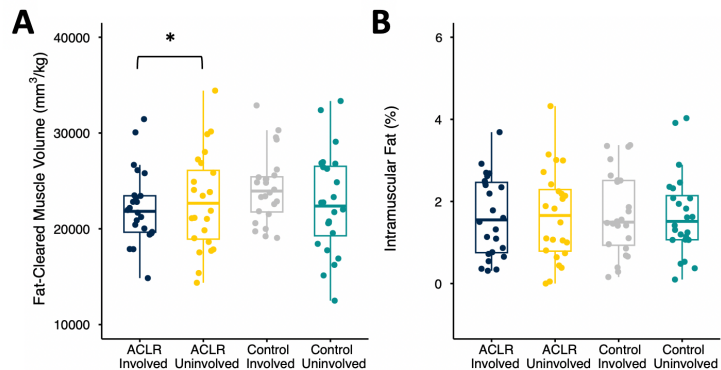


Figure 2. Total Vasti Muscle Volume (Panel A) and Intramuscular Fat (Panel B). Significant group by limb interactions for fat-cleared muscle volume were found. Post hoc analyses showed the significant interactions stemmed from the ACLR group where the ACLR involved limb was smaller than the ACLR-uninvolved limb (\* denoting statistical between-limb differences at the level of  $p < 0.05$ , Panels A). No significant group by limb interactions were identified between for intramuscular fat (Panel B).