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*Original Research*

# Comparison of Lower Limb Mass, Thigh Circumference, and Balance Ability after Anterior Cruciate Ligament Reconstruction and in Control Participants

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ABSTRACT

***International Journal of Exercise Science 17(1): 1306-1317, 2024.*** Injury of the anterior cruciate ligament (ACL) in the knee is common, with up to 250,000 cases annually in the United States. Such injuries can lead to muscle atrophy, impaired balance, and limited movement. This study aimed to compare the lower limbs of individuals with ACL reconstruction to a Control group. We hypothesized that ACL participants would exhibit greater asymmetry between lower limbs as compared to Controls. Data were collected from 12 ACL participants and 30 Control participants. Measurements included lower limb muscle mass assessed using bioelectrical impedance, thigh circumference at 10 cm and 15 cm superior to the patella, and postural sway during single-leg stance. The results showed no significant difference in mass between the surgical and non-surgical lower limbs of ACL participants. Additionally, no significant differences were found in thigh circumference, or postural sway for ACL participants between the two limbs. In contrast, the Control group demonstrated significantly greater muscle mass ($p = 0.005$) in the dominant lower limbs compared to the non-dominant limbs. Thigh circumference at the 10 cm mark was also significantly greater on the dominant lower limbs than non-dominant lower limbs ($p = 0.040$). Our hypotheses were not supported, as asymmetry in mass and thigh circumference was demonstrated in Control but not ACL participants. No differences in postural sway were found between lower limbs in either ACL or Control participants. Loss of the ability to rely on the strength of a dominant lower limb may lead to functional deficits when participants undergo dominant limb ACL reconstruction.

KEY WORDS: Anterior cruciate ligament injury, leg dominance, postural stability, limb differences, lower limb symmetry

## INTRODUCTION

Anterior cruciate ligament (ACL) injury is the most common knee ligament injury (8). An ACL injury can result in instability of the knee, loss of movement or inability to return to activities. It is estimated that every year there are 100,000 to 250,000 ACL injuries in the United States (4, 14). The ACL runs posteriorly to anteriorly from the femur to the tibia and stops the tibia from moving too far anteriorly in relation to the femur. The ACL also provides rotational support to the knee. ACL injuries can range from mild to severe sprains or mild to severe tears. Many factors can contribute to an individual injuring their ACL such as physical activity level, the sport they play, biological sex, family predisposition, age, and hormones (5, 7, 13, 17). The literature shows that females, especially in sports with lateral cutting (i.e., soccer), have higher incidence rates than males to injure the ACL (7). There are several studies comparing factors such as walking and running after ACL reconstruction surgery, atrophy of muscle during recovery, whether the injury occurred during a sport, physical activity level, and whether the dominant or non-dominant lower limb was injured (4, 8, 11, 18).

A person's walking and running gait including ground reaction forces, muscle activation and knee flexion angles can change after ACL reconstruction (1, 2, 9). Davis-Wilson et al. (2) found that after ACL reconstruction the injured leg had less vertical ground reaction force during the beginning stance phase and had greater ground reaction force during the mid-stance stage of walking compared to controls. It has been reported that people who had ACL reconstruction have higher co-contraction of the vastus lateralis and biceps femoris which can lead to changed walking gait patterns (1). Research has demonstrated that women compared to men who had ACL reconstruction have higher co-contraction of the lateral gastrocnemius which can also influence walking patterns after surgery (1). Similarly, Miles et al. (9), found that during change of direction trials, persons with bone-patellar tendon-bone autografts had greater asymmetries between lower limbs in knee extension moment, ground reaction force, and knee flexion angles than individuals with hamstring tendon autografts. Adjustments in gait and loading of the lower limbs during cutting maneuvers has also been demonstrated after ACL reconstruction (2, 9). A common occurrence for people who have had ACL reconstruction surgery is quadriceps atrophy, muscle weakness, and self-reported poor function of the quadriceps (3). Suh et al. (18) reported that six months after dominant leg ACL reconstruction individuals had significantly more strength in their quadriceps and hamstrings than those who had non-dominant leg surgery. Taken together, previous research has revealed that ACL reconstruction is related to differences between lower limbs in muscle activation as well as in biomechanical measures such as ground reaction forces and knee moments.

Regarding postural sway, people who had ACL reconstruction demonstrated less balance ability than a control group, and in some cases, there was decreased balance ability for the uninjured leg as well (11). Individuals who have undergone ACL reconstruction have been shown to have less postural control with single leg balancing on a foam surface with their injured leg than uninjured healthy adults (15). Heijne and Werner (6) found that individuals who used patellar tendon graft for ACL reconstruction had less anterior knee laxity, less postural sway, and were able to return to sport sooner and at a higher level than those that had hamstring grafts. Furthermore, those with hamstring grafts had to undergo a different slower rehabilitation protocol that focused on hamstring strength (6). Overall, previous research has indicated that ACL reconstruction can result in postural control asymmetries between lower limbs. It is possible that changes in strength of the lower limbs after ACL reconstruction could contribute to differences in balance ability. Examining differences in mass between the injured and non-injured limbs may provide insight into possible factors contributing to between-limb differences in force production, knee kinematics, and postural control after ACL reconstruction.

A few previously published studies have investigated muscle atrophy after ACL surgery, including possible asymmetry of muscle volume between lower limbs (8). Tsifountoudis et al.

(19) found that after hamstring tendon graft ACL reconstruction all participants had thigh muscle atrophy and almost 90% of these individuals had atrophy in the calf muscles as well. Muscle atrophy may occur independently of graft type and rehabilitation protocol after surgery (8). A magnetic resonance imaging study demonstrated atrophy and a difference of 20% of muscle volume in several muscles in the thigh and calf when comparing the ACL operated lower limbs to the non-operated lower limb (12). More research is needed on lower limb muscle mass after ACL reconstruction. Use of technologies such as bioelectrical impedance may be a quicker and more accessible way to assess mass in each lower limb as compared to imaging techniques. Additional quantitative measures of lower limb mass with bioelectrical impedance after ACL reconstruction will allow comparison to other measurement techniques and contribute to understanding the possible asymmetries in mass and the link to changes in strength, ground reaction forces, and knee angle after surgery (2).

The goals of this research were to compare the surgical lower limbs and the non-surgical lower limbs for differences in thigh circumference, mass assessed by bioelectrical impedance, and the ability to balance during single-leg stance. We will also compare these same measures for dominant lower limb to non-dominant lower limb in a Control group. Based on previous literature (12, 15, 18), we hypothesize that there will be decreased mass and thigh circumference for the limb with the surgically repaired ACL when compared to the lower limb that did not have reconstruction surgery. We also hypothesize that there will be a greater amount of postural sway when comparing the lower limb that had ACL reconstruction surgery to the lower limb that did not have surgery during single-leg standing. Further, we expect that there will be greater differences between lower limbs in those who have had ACL reconstruction than in those who have not with regard to mass, thigh circumference, and balance ability.

## METHODS

*Participants*

All participants provided informed written consent forms for protocols approved by the Institutional Review Board at California State University San Marcos (IRB#1907511-2). This research was carried out fully in accordance to the ethical standard of the *International Journal of Exercise Science* (10). G*Power Analysis statistical software (Universitat Keil, Germany) was used to determine that 24 total participants, 12 in each of two groups, were needed to power factorial ANOVA for the study with medium effect size and level of significance of $\alpha=0.05$. For comparisons made using a paired t test, statistical power analysis predicted that 12 participants were needed to power the study with a large effect size and $\alpha = 0.05$. Therefore, we recruited a minimum of 12 participants for each group. Participants were recruited from the university and surrounding community as a convenience sample. All participants in the Control group were individuals who had never had lower limb surgery. We informed potential participants of exclusion criteria during recruitment, such that eligibility could be determined. Previous bilateral ACL injury excluded a person from participating. Persons with ACL reconstruction whom a physician did not clear to return to physical activity were also excluded. Some health factors could exclude participants from the study, including neurological disorder, stroke, traumatic brain injury, any medically diagnosed or non-medically diagnosed concussion, or any lower limb injury other than ACL surgery in the past year that would affect muscle mass or balance excluded a person from participation. No volunteers were excluded from participating. We asked participants if they were willing to report their race and ethnicity on a questionnaire, or they could state they prefer not to provide race and ethnicity.

Participants answered questions on an ACL surgery questionnaire developed by the researchers. Questions included which lower limb had ACL reconstruction surgery or injury, the type of graft, if the meniscus was torn in addition to the ACL, if the meniscus was repaired, the date of surgery, the time between injury and surgery, if the participant had physical therapy and if they were physically active. We asked participants to wear comfortable activewear clothing. Participants removed their shoes and socks for the measurements in the study.

*Protocol*

A researcher measured thigh circumference bilaterally at 10 cm and 15 cm proximal to the superior pole of the patella. The 15 cm level was chosen as this is a common mid-thigh level for circumference measurements (16). We additionally chose to measure thigh circumference at 10 cm above the patella to ensure we captured potential differences in thigh circumference after ACL reconstruction as the muscles of the thigh may be affected differently along the length of the muscles. The same researcher took all thigh circumference measurements. Participants reported their height and dominant lower limb as their kicking leg. We used an InBody 770 (InBody, USA) bioelectrical impedance system to analyze body composition measures including body mass, percent body fat, skeletal muscle mass, and lean mass in each lower limb. Lean mass is the mass of muscle and water. Participants stood with each foot on an instrumented pad and held their thumbs on the electrodes of two paddles for 1 minute for the body composition measurement (Figure 1).

For the postural sway measurements, participants completed single-leg stance on a force plate (Bertec Corporation, OH) for 30 seconds per trial. The force plate software recorded the center of pressure (COP) displacement in the anterior/posterior and medial/lateral directions. The participants were given instructions and a demonstration of how to perform single-leg stance. Participants were instructed to keep their eyes open during the postural sway trials. The research team implemented safety measures including spotting the participant. Participants stood on each lower limb on two different surfaces for the postural sway measurements including the firm surface of the force plate and a 7.6 cm -thick piece of foam (Humac Balance System, Australia) that was placed on top of the force plate (Figure 1). Four conditions of postural sway were completed for each participant. We randomized the order of surface conditions for postural sway measurement by alternating whether the first trial was on the foam or firm surface. Researchers also alternated whether participants' left or right leg was used for their first trial. Participants completed both lower limb trials on one surface and then moved to the next surface condition. Participants were allowed to practice the single leg stance on each lower limb until they felt comfortable. During data collection, additional trials were completed if participants did not complete the entire 30 seconds on one foot. All participants successfully completed the trial in 3 or less attempts. Researchers gave participants a minimum of 30 seconds of rest between trials and allowed participants to stretch or walk between trials if they chose.

**Figure 1.** Depiction of body composition assessment using bioelectrical impedance (InBody 770, left). Participants performed single-leg stance for 30 s trial on the firm surface of the force plate (middle) and a foam surface (right).

*Statistical Analysis*
Data was analyzed using Microsoft Excel (Microsoft, Redmond, WA) and SPSS software (IBM, Armonk, NY). Averages and standard deviations (SD) were computed for thigh circumference, lean mass per lower limb, and anterior-posterior and medial-lateral displacement of the center of pressure during single-leg stance. Data were checked for normality in Excel and boxplots were used to assess outliers. All data were normally distributed and there were no outliers. SPSS was used to evaluate covariance between the ACL group and the Control group based on age and sex. Paired t tests were used to compare dominant and non-dominant limbs in the Control participants and surgical to non-surgical lower limb in the participants with ACL reconstruction or injury for skeletal muscle mass per lower limb. A mixed factorial ANOVA with planned comparisons was used to compare within lower limbs and between ACL reconstruction and Control participants for thigh circumference and postural sway measurements in the anterior/posterior and medial/lateral directions. If Mauchly's Test of sphericity was non-significant, we used assumed sphericity for the $F$ and $p$ values, but if it was significant, we used $F$ and $p$ values with Greenhouse-Geisser correction. Bonferroni Post Hoc testing was used to determine which comparisons were significant. Significance level for all statistical tests was $p < 0.05$.

## RESULTS

There were 12 ACL participants (8 female, 4 male; mean ± SD age 24.2 ± 6.6 yrs, height 172.6 ± 6.1 cm, mass 80.2 ± 11.7 kg) who either had an ACL reconstruction surgery or ACL injury. Participants self-reported their race; the ACL group reported 58% White, 8% Black, 17% more than one race, and 17% preferred not to answer. The ACL group self-reported their ethnicity as 42% Hispanic and 58% non-Hispanic. Characteristics of ACL surgery or injury participants are in Table 1. Of the 12 ACL participants, 83% had surgery. Of the 10 who had surgery, 50% had a patellar tendon graft, 40% had a hamstring tendon graft and 10% had a quadriceps tendon graft. All of the ACL participants reported their right leg as their dominant leg. Of those that had ACL surgery, 50% injured their dominant lower limb and 50% injured their non-dominant lower limb. The mean time from ACL surgery or injury was 5.1 ± 3.2 yrs. All ACL participants were physically active and 11 of the 12 participants had physical therapy (Table 2). There were 30 participants in the Control group (18 female, 12 male; age 24.5 ± 6.6 yrs, height 168.8 ± 8.9 cm, mass 72.0 ± 19.9 kg). The Control group was age and sex (percentage of males and females) matched to ACL participants. Analysis of covariance demonstrated there was no significant difference in age and sex between the ACL and Control groups. The Control group self-reported as 60% White, 10% Asian, 3.3% Black, 3.3% American Indian/Alaskan Native, 3.3% Native Hawaiian/Pacific Islander, 7% more than one race, and 13% preferred not to report race. Of the Control participants, 30% self-reported ethnicity as Hispanic and 70% as non-Hispanic.

For the ACL participants there was no significant difference in mean lean mass between surgical lower limbs, 8.7 ± 1.3 kg, and non-surgical lower limbs, 8.7 ± 1.2 kg. Skeletal muscle mass for ACL participants was 32.8 ± 5.6 kg and percentage body fat was 27.3 ± 8.4%. In comparison, in Control participants the dominant lower limbs had significantly more lean mass at 8.2 ± 1.9 kg than the non-dominant lower limbs at 8.1 ± 1.9 kg ($p = 0.005$). Skeletal muscle mass for Control participants was 30.3 ± 9.8 kg and percent body fat was 25.7 ± 7.5%.

In general measurements demonstrate that if an ACL participant had ACL surgery on their dominant lower limb, more muscle mass was maintained on the surgical leg versus non-surgical lower limb (Table 3). If an ACL participant had surgery on their non-dominant lower limb, then the dominant leg had more muscle mass (Table 3). For Control participants, the difference in mass computed as dominant limb minus non-dominant limb averaged 0.06 ± 0.12 kg.

In ACL participants, there were no significant differences between the thigh circumferences of the lower limbs at the 10 cm mark or the 15 cm mark ($p = 0.247$ and $p = 0.266$, respectively, Table 4). There was a main effect difference in thigh circumference between the ACL and Control participants via ANOVA ($F = 144.287$, $p < 0.0001$). In Control participants, there was a significant difference at the 10 cm measurement mark in dominant lower limb thigh circumference compared to non-dominant lower limb thigh circumference ($p = 0.040$, Table 4). There was no significant difference in thigh circumference at the 15 cm measurement mark in dominant lower limb compared to the non-dominant lower limb for Control participants ($p = 0.243$, Table 4).

For both ACL and Control participant groups there was no significant difference in postural sway in the anterior/posterior or medial/lateral direction for single-leg stance when comparing dominant to non-dominant lower limb or for surgical compared to non-surgical lower limb (Table 5).

**Table 1.** Anterior cruciate ligament (ACL) reconstructed or injured participant characteristics.

| ACL P # | Sex | Age (yrs) | Lower Limb Injured | Meniscus Tear/Repair | Graft Type | Year of Surgery or **Injury** | Time Since Surgery or Injury (yrs) |
|---|---|---|---|---|---|---|---|
| 1 | M | 24 | R | Yes/yes | Hamstring | 2014 | 9 |
| 2 | F | 21 | R | No/no | Patellar tendon | 2017 | 6 |
| 3 | F | 27 | R | No/no | Hamstring (cadaver) | 2022 | 0.4 |
| 4 | F | 21 | R | No/no | - | **2016** | 7 |
| 5 | F | 21 | L | Yes (little fraying)/yes cleaned up | Hamstring | 2019 | 4 |
| 6 | M | 22 | R | Yes (one side)/yes | Hamstring | 2020 | 3 |
| 7 | F | 24 | L | No, partial MCL tear | - | **2014** | 9 |
| 8 | F | 20 | L | was bruised healed on its own | Quadriceps tendon | 2020 | 3 |
| 9 | M | 44 | R | Yes/ medial meniscus, no repair | Patellar tendon | 2013 | 10 |
| 10 | F | 23 | L | Yes/yes | Patellar tendon | 2021 | 2 |
| 11 | F | 19 | L | Yes,/yes | Patellar tendon | 2021 | 2 |
| 12 | M | 24 | L | Yes/removed 1/4 of it | Patellar tendon | 2017 | 6 |

*Bolded italicized year indicates ACL participants with injured ACL and not surgically repaired.

**Table 2.** Anterior cruciate ligament (ACL) reconstruction or injured participant self-reported physical activities and rehabilitation.

| ACL P # | Sports or Physical Activities | Rehabilitation |
|---|---|---|
| 1 | Resistance and aerobic exercise | No formal PT, exercised as tolerated, automatic range of motion machine |
| 2 | Soccer | PT 5x a week, 1-hr sessions |
| 3 | Biking, exercises for strengthening knee and hip 4x a week | PT 2x a month |
| 4 | Track | PT for one month, 2x a week |
| 5 | Basketball | PT for 4 weeks, then AT for 8 months |
| 6 | Weightlifting | PT 3x a week for 2 months, then AT for 8 months |
| 7 | Soccer, pilates, weightlifting | PT 2x a week for 3 months, then AT 4x a week for 5 months |
| 8 | Weightlifting | PT 2x a week for 6 months |
| 9 | Crossfit, running | Standard PT, then sport specific PT |
| 10 | Volleyball | PT 2x a month for 7 months, then AT 4-5x a week for 7 months, no leg extension machine |
| 11 | Volleyball | PT 1x a week, then AT 4x a week for 1-hour sessions, no leg extension machine |
| 12 | Weightlifting | PT 1x a week for 9 months, no leg extension exercises for 2 years |

PT = physical therapy; AT = working with an athletic trainer.

**Table 3.** Anterior cruciate ligament (ACL) participants ($n$ = 12) lower limb lean (muscle and water) mass.

| ACL Participant | ACL Surgery or Injury Limb | Dominant Limb | Lean Mass Surgical Limb (kg) | Lean Mass Non-surgical Limb (kg) | Difference in mass between limbs (kg) |
|---|---|---|---|---|---|
| 1 | R surgery | R | 9.96 | 9.70 | −0.26 |
| 2 | R surgery | R | 7.95 | 7.94 | −0.01 |
| 3 | R surgery | R | 6.75 | 7.02 | 0.27 |
| 4 | R injured | R | 8.23 | 8.38 | 0.15 |
| 5 | L surgery | R | 7.58 | 7.62 | 0.04 |
| 6 | R surgery | R | 11.08 | 11.06 | −0.02 |
| 7 | L injured | R | 8.68 | 8.74 | 0.06 |
| 8 | L surgery | R | 8.87 | 8.88 | 0.01 |
| 9 | R surgery | R | 10.99 | 10.92 | −0.07 |
| 10 | L surgery | R | 8.26 | 8.34 | 0.08 |
| 11 | L surgery | R | 8.30 | 8.43 | 0.13 |
| 12 | L surgery | R | 7.93 | 8.13 | 0.20 |
| Average | | | 8.72 | 8.76 | 0.05 |
| SD | | | 1.33 | 1.23 | 0.14 |

Difference in mass between lower limb was computed as nonsurgical minus surgical lower limb. Positive number for difference in mass indicates the nonsurgical lower limb had more mass.

**Table 4.** Mean ± SD thigh circumference measured at 10 cm and 15 cm proximal to the superior pole of the patella for Control and anterior cruciate ligament (ACL) participants.

| | Distance Proximal to Patella | |
|---|---|---|
| | 10 cm | 15 cm |
| Control Participants | | |
| Dominant leg (cm) | 48.9 ± 4.1 | 53.2 ± 4.2 |
| Non-Dominant leg (cm) | 48.3 ± 4.1* | 52.9 ± 4.2 |
| | | |
| ACL Participants | | |
| Surgical leg (cm) | 49.9 ± 5.1 | 54.5 ± 5.0 |
| Non-Surgical leg (cm) | 50.8 ± 4.2 | 55.5 ± 5.0 |

*Significantly different from dominant lower limb ($p < 0.05$)

**Table 5.** Control participants' mean ± SD postural sway as measured by center of pressure displacement during single-leg stance on a foam surface and a firm surface.

| | Foam | | Firm | |
|---|---|---|---|---|
| | ΔAP (cm) | ΔML (cm) | ΔAP (cm) | ΔML (cm) |
| Control Participants | | | | |
| Dominant leg | 6.77 ± 11.27 | 3.54 ± 4.13 | 4.93 ± 4.91 | 3.70 ± 5.89 |
| Non-Dominant leg | 5.26 ± 7.05 | 4.79 ± 7.37 | 4.96 ± 4.28 | 4.06 ± 6.18 |
| | | | | |
| ACL Participants | | | | |
| Surgical leg | 4.09 ± 5.15 | 5.63 ± 8.17 | 4.76 ± 4.41 | 2.85 ± 3.37 |
| Non-Surgical leg | 3.25 ± 3.77 | 1.81 ± 2.13 | 5.38 ± 5.33 | 2.86 ± 2.53 |

ΔAP is anterior/posterior displacement and ΔML is medial/lateral displacement.

## DISCUSSION

The goals of this research were to compare the surgical lower limbs and the non-surgical lower limbs for differences in lean mass, thigh circumference, and the ability to balance during single-leg stance. We compared lower limbs in individuals with ACL reconstruction surgery or injury and the lower limbs in a Control group. Based on previous literature (12, 15, 18), we expected that there would be greater asymmetry between lower limbs in those who have had ACL reconstruction than in Control participants, but our data did not support this hypothesis. Instead, the results indicate significant asymmetry between lower limb lean mass only in the Control group. In the Control participants, the dominant lower limb had consistently more lean mass than the non-dominant lower limb contrary to our hypothesis. We also found that there was a significant difference in thigh circumference at 10 cm proximal to the patella for Control participants. The data for the ACL participants did not support our hypothesis that there would be a difference in lean mass between surgical and non-surgical lower limb. We did not find a significant difference for thigh circumference in ACL participants at the 10 cm or 15 cm mark. For ACL participants, it is possible that leg dominance may play a role in lean mass in the surgical leg and non-surgical leg. We also did not find a significant difference between lower limbs for COP displacement measures in either our ACL participants or Control participants on a firm or foam surface. The results did not support our hypotheses regarding postural sway being greater for the surgical limb of ACL participants.

Our study is similar to that of Norte et al. (12), as both studies looked at differences in lower limb muscle mass in persons who had ACL reconstruction surgery. Norte et al. (12) researched lower extremity muscle volume and quadricep muscle function pre and post ACL reconstruction surgery. They used magnetic resonance imaging (MRI) to assess muscle volumes in the thigh and calf (12). Their results demonstrated that thigh muscles were more than 15% smaller on the ACL injured limb pre-surgery and were 20% smaller than the muscles on the uninjured limb postoperatively. We, on the other hand, used bioelectrical impedances to measure lower limb lean mass postoperatively, and found that the lower limb that had ACL surgery or injury was only an average of 0.5% smaller than the uninjured limb. The difference in results between the present study and Norte et al. (12) could be related to the amount of time between ACL surgery and the muscle mass measurements. Specifically, the participants in the Norte et al. (12) were on average 7.4 months post-ACL surgery, whereas those in the present study were measured on average 60 months (5.1 yrs) after surgery or injury. Another potential reason for differences in results may be attributed to differences in the method of data collection as we used bioelectrical impedance to assess lower limb mass while previous imaging studies reported individual muscle volume.

Overall, the results demonstrate that people have a dominant lower limb, and the dominant lower limb had more lean mass regardless of whether a participant was in Control or the ACL group. It is worth noting that four out of the six ACL participants that had surgery on their dominant lower limb had more lean mass on their dominant limb compared to non-dominant lower limb when measured for this study. There were only two ACL participants that did not follow this trend. They had surgery on their dominant lower limb but were measured to have more lean mass on the non-dominant lower limb. One participant had surgery within six months of the study while the other individual had injured their ACL and did not have surgery. However, most participants who had ACL reconstruction on the non-dominant lower limb had more mass on the dominant lower limb after surgery. The implications are that the amount of mass in each lower limb after surgery may depend on whether the ACL reconstructed limb was the dominant limb. Analogous findings by Suh et al. (18) found that people who had ACL reconstruction on their non-dominant lower limb had lower quadriceps strength at six months postoperatively as compared to those who had ACL reconstruction on their dominant lower limb. In our study, we found that if an ACL participant had ACL surgery on their dominant lower limb, they had more lean mass in the surgical leg versus non-surgical leg. This is consistent with participants being able to generate more force with the dominant lower limb after surgery. Therefore, our data support that leg dominance can influence the muscle mass of a lower limb after surgery.

In contrast to the results of the present research, Smith and Bell (15) found that people who had ACL reconstruction did worse (non-overlapping 95% Confidence Intervals) during single lower limb balance testing on a foam surface than the controls (15). Smith and Bell (15) found no difference in balance between ACL and Control on a firm surface. We found that there was no difference in balance between ACL participants and Controls on either firm or foam surface. It is worth noting that the ACL reconstructed participants in the Smith and Bell (15) study had an average time after surgery of about 3 years compared to our average time after surgery of 5 years, which could contribute to differences in study results. Most of the ACL participants in our study had physical therapy and this could also have positively affected their balance ability after ACL injury.

When interpreting the data from the present study, it is important to consider some limitations. First, we did not make any comparisons based on sex of the participants in the study. Although we did not make sex-based comparisons, we did match the percentage of males and females in the Control group to the ACL group and evaluating covariance found no significant difference between groups for age and sex. Our data show that leg dominance may contribute to comparisons in lower limb mass and thigh circumference on average between lower limbs. Since we used a convenience sample, it is important to note that with the average age of participants being 24 years, the conclusions of this study should not be generalized to other age groups. Additionally, using a convenience sample, we had two participants who had an ACL injury but did not need surgery; however, the data from these participants fell within that of the ACL group and were not outliers. Finally, the present study measured lower limb mass by bioelectrical impedance and therefore reported the lean mass of the entire lower limb including the hip area. Bioelectrical impedance is an inexpensive and quick technique that can be utilized by clinicians to add to the knowledge of limb mass changes after surgery, but it is not the standard technique for mass measurement. Previous studies looking at muscle mass have used MRI to determine mass of individual thigh muscles (12) and therefore the difference in measurement techniques should be considered when interpreting data and comparing the current results to other studies.

In conclusion, we found that leg dominance played a role in lower limb lean muscle mass for Control participants. Control participants were asymmetric in lower limb lean mass with the dominant limb having significantly greater lean mass than the non-dominant limb. In contrast, the lower limbs in the ACL group were symmetric in lean mass and thigh circumference. It is possible that less asymmetry between lower limbs post-surgery may help protect the ACL injured limb and allow participants to use both lower limbs more equally compared to those who have never had surgery. Possible implications from this research are that for individuals with ACL reconstruction it may be important to consider which limb is the dominant lower limb when progressing through prehabilitation and rehabilitation. For people susceptible to ACL injury, new training styles could be created to be cognizant of asymmetry in the lower limbs since it was found that the Controls were more asymmetrical than the ACL participants. Specifically, individuals who had surgery on their dominant lower limb may need greater strengthening to regain the dominant limb strength after surgery to prevent future injury especially if they are returning to sport. Loss of the ability to rely on the strength of a dominant lower limb may also lead to movement deficits for participants who have dominant limb ACL reconstruction. For future research, it is important to consider leg dominance when evaluating muscle mass in lower limbs.

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