FORCE ASYMMETRY DURING ISOMETRIC CONTRACTIONS FOLLOWING ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

Timothy Exell[1], Joseph Moore[1], Jenny Burbage[1], and David Mullineaux[2]

School of Sport, Health & Exercise Science, University of Portsmouth, Portsmouth, UK[1]
School of Sport & Exercise Science, University of Lincoln, Lincoln, UK[2]

The aim of this study was to compare isometric strength asymmetry in participants that have previously undergone anterior cruciate ligament (ACL) reconstruction and a healthy control group. Three-dimensional force data (1000 Hz) were collected from 21 ACL (3.2 ± 1.8 years post-surgery) and 21 control participants during maximal isometric contractions. Peak knee flexion force displayed significant asymmetry differences between groups, with ACL participants showing greater asymmetry (7.6 %) than the control group (0.1 %). No significant asymmetry differences were found between groups for peak extension, adduction and internal rotation force. Results suggest that following ACL reconstruction and rehabilitation, external force production during knee flexion is significantly less on the affected side than the uninjured side, which has implications on rehabilitation monitoring.

KEYWORDS: rehabilitation, strength, deficit.

INTRODUCTION: The anterior cruciate ligament (ACL) of the knee is a key stabiliser of the joint, resisting anterior tibial translation and internal tibial rotation (Noyes, 2009). Incident rates of ACL rupture are greatest in 16-39 year olds at almost 1-in-1,000 (Sanders et al., 2016). Injuries to the ACL can severely impact on mobility, physical activity and quality of life. Furthermore, ACL injuries account for some of the largest amounts of time lost to injury in elite sports people, at a substantial cost to players and their clubs. Treatment following ACL injuries can range from prescribed rest to surgical reconstruction, which most commonly involves use of a graft harvested from the patient’s hamstring tendon (Chechik et al., 2013; Legnani et al., 2016). Both the ACL injury and the reconstruction process can lead to weakness in the injured limb, resulting in strength asymmetry (Schmitt et al., 2012).

Biomechanical asymmetry has been previously identified as an important factor when returning to sport following ACL reconstruction and greater asymmetry may predispose participants to increased risk of re-injury (Clark, 2001; Hewett et al., 2012; Noyes et al., 1991). There is no clear consensus on the presence of strength asymmetry following ACL reconstruction, with Schmitt et al. (2012) reporting asymmetry in some participants when tested using an isokinetic dynamometer, whereas Flanagan et al. (2008) found no differences in force production asymmetry during functional dynamical movements on an instrumented force sled. In addition to weaknesses in knee flexion, extension and adduction forces following ACL reconstruction, it has been suggested that hamstring graft harvesting can also limit a patient’s ability to produce internal rotation moment of the tibia in the affected limb (Viola, 2000). Asymmetry has previously been reported to vary between individuals of similar sporting level and background (Exell et al., 2017); therefore, it would be useful to quantify the range of asymmetry in healthy people to determine whether recovered ACL participants have similar asymmetry values.

The aim of this study was to compare isometric strength asymmetry in participants that have previously undergone ACL reconstruction and an uninjured control group. It was hypothesised that asymmetry would be greater in recovered ACL participants than the control group, with larger forces and moments produced at higher rates on their uninjured side.

METHODS: Following institutional ethical approval, force plate data (9281CA, Kistler, Winterthur, Switzerland) were collected (1000 Hz) from 21 recreational team sport participants that had previously undergone unilateral ACL reconstruction more than two years previously and returned to full activity (mean ± SD: age 21 ± 3 years, height 1.73 ± 0.10 m, mass 69 ± 11 kg & 3.2 ± 1.8 years post-surgery) and 21 recreational team sport control participants who had not previously experienced any knee ligament injury (age 21 ± 1 years, height 1.70 ± 0.08 m, mass 68 ± 12 kg). Participants were seated in a height-adjustable chair, rigidly attached to the force plate, with their knee flexed at 90º. The force plate was aligned so that the 'x' axis corresponded to the participant's antero-posterior direction, the 'y' axis to the medio-lateral direction and the 'z' axis to the vertical. Data were collected from left and right limbs separately, whilst participants applied maximal effort to push against a foot plate rigidly attached to the force plate. Data were collected using Qualisys Track Manager (Qualisys, Gothenburg, Sweden) during four different isometric tasks where participants attempted to perform knee flexion and extension and foot adduction and internal rotation. During each task, participants positioned their foot inside the foot plate (Figure 1) so that it was not touching the force plate surface and were instructed to apply maximal force in the relevant direction for a period of 10 s. Data were collected for 12 s, starting before participants were instructed to start their effort. Each trial was repeated twice for each limb and the order of trials was randomised between directions and limb side.

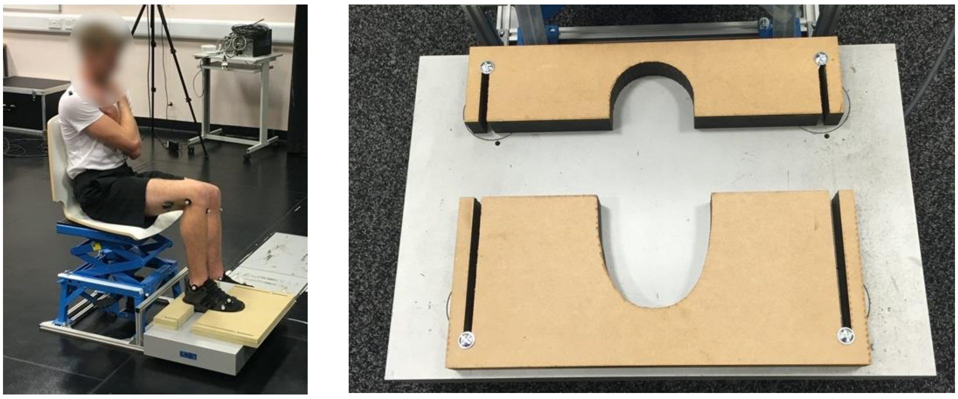

Figure 1: (left) participant seated on testing rig during isometric adduction trial and (right) adjustable foot plate attached to force plate.

Data were processed in Matlab (2020a, Mathworks, Natick, USA). For each trial, peak force and instantaneous rate of force development (RFD) were calculated in the positive or negative X or Y axis direction that corresponded with the direction of effort. For internal rotation trials peak positive or negative moment and rate of moment development (RMD) were calculated about the Z axis of the force plate for left and right leg trials, respectively. RFD and RMD were calculated by differentiating the force (RFD) and moment (RMD) data with respect to time. For each pair of trials in each direction, the trial with the highest RFD or RMD value was used for further analysis. Peak force and RFD/ RMD values were rectified for trials performed with the right leg so that all values were positive. Asymmetry was calculated between left and right limb trials for all trial directions using the method of Zifchock et al. (2008):

$$\theta_{SYM} = (45 - (\mathrm{atan}\ (X_1 / X_2)) / 90) \times 100$$

where X_1 and X_2 are the reconstructed or non-dominant and uninjured or dominant limb values for ACL and control participants, respectively. Following Shapiro-Wilk tests of normality, data were found to be non-parametric. Therefore, median ± inter-quartile range (IQR) asymmetry values for ACL and control groups were calculated. Wilcoxon rank-sum tests were used to compare asymmetry values between ACL and control groups

RESULTS: Asymmetry magnitudes are presented in Figures 2 and 3 for peak force and rate of force (moment for internal rotation) development, respectively. Both figures include median and IQR as well as individual participant values to show the spread of results for each group. Results of the statistical comparison of asymmetry magnitude indicated that only peak force during the flexion trials was significantly ($p < 0.05$) different between control and ACL groups, with ACL participants showing more asymmetry that tended to be caused by larger values on the uninjured (median 107 ± 45 N) than injured (median 81 ± 27 N) side. This only significant difference was caused by smaller within-group variability displayed for this variable compared with the other, particularly for the ACL group. Within-group variability tended to be larger for the ACL group than the control group, indicated by the larger IQR values in Figures 2 and 3.

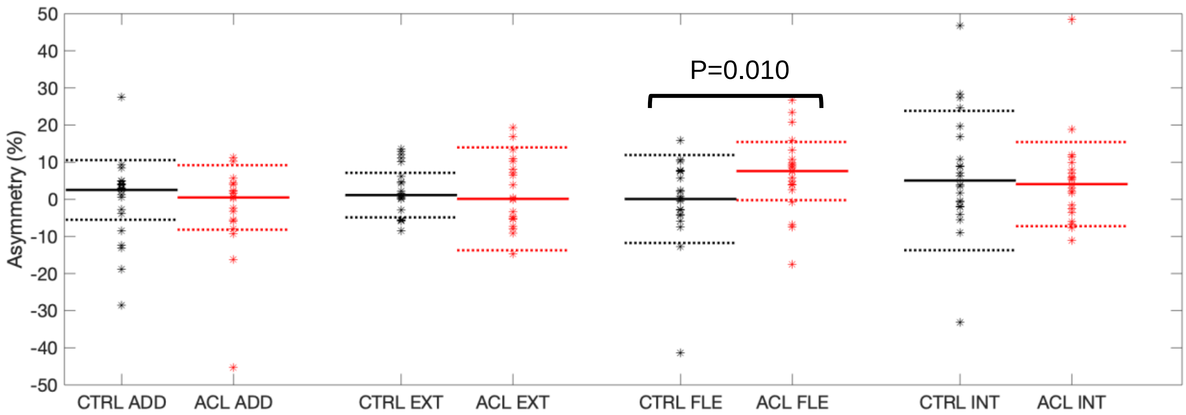

Figure 2: Peak force asymmetry magnitude for control (black, left) and ACL (red, right) participants during adduction (ADD), extension (EXT), flexion (FLE) and internal rotation (INT) trials. Solid lines = median and dashed lines inter-quartile range. Positive asymmetry = larger values for dominant (control) or uninjured (ACL) side.

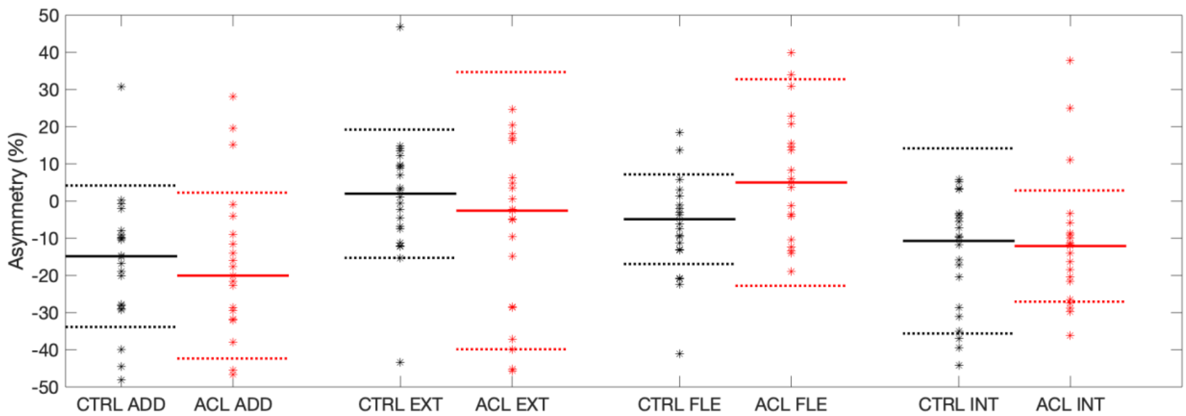

Figure 3: Peak rate of force (moment) development asymmetry magnitude for control (black, left) and ACL (red, right) participants during adduction (ADD), extension (EXT), flexion (FLE) and internal rotation (INT) trials. Solid lines = median and dashed lines inter-quartile range. Positive asymmetry = larger values for dominant (control) or uninjured (ACL) side.

DISCUSSION: The aim of this study was to compare isometric strength asymmetry in participants that have previously undergone ACL reconstruction and a healthy control group. With the exception of peak flexion force, no significant differences were found between ACL and control groups for asymmetry magnitude; therefore, the null hypotheses were partially accepted. The lack of significant differences for some other variables was due to the large variability within both groups, with the only significantly different variable also displaying the lowest IQR (±7%). The inter-participant variability in asymmetry values displayed supports previous investigation into asymmetry magnitude (Exell et al., 2017). On a group level, the results of this study agree with the previous finding of Schmitt et al. (2012), that ACL injured participants that have returned to sport display similar asymmetry values to healthy control participants. However, when considering the range of asymmetry values displayed by ACL and control groups, there was a tendency for larger IQR values in the ACL group showing more inconsistency in asymmetry magnitude and direction. An example of the range of asymmetry values can be seen for extension rate of force development, where the median ACL asymmetry value was close to 0% but with individual values for 8 of the 21 participants exceeding a magnitude of 20% asymmetry. A key factor affecting an individual's rehabilitation from ACL reconstruction is their rehabilitation programme and adherence (Niven, 2007) and possible differences in these between participants may explain the large variation in asymmetry results.

The greater consistency in asymmetry magnitude demonstrated for knee flexion peak force generation and lower forces displayed by the reconstructed side suggest that this is an area of strength that is lacking in ACL reconstructed participants. This finding is of functional importance, given that the role of the ACL is to prevent anterior motion of the tibia relative to the femur, which occurs during knee extension (Noyes, 2009). Therefore, the results of the study suggest that the difference in force generation may be caused by hamstring weakness following graft harvesting rather than laxity in the reconstructed ACL, with hamstring grafts being the most commonly used (Chechik et al., 2013). The reduced flexion strength in the reconstructed limb may be the result of the reconstructed ACL allowing more movement of the tibia relative to the femur during isometric flexion activities. Another possible explanation for the asymmetry in this variable is strength deficits caused by the harvesting of grafts, which are most often taken from the injured limb (Jari & Shelbourne, 2002).

CONCLUSION: This study compared asymmetry values for ACL reconstructed and control participants and showed that, on a group level, asymmetry values for ACL participants display a similar range to those of healthy control participants. However, large variability in some variables, particularly flexion and extension rate of force development, indicate that some ACL participants have large asymmetry for these variables and that greater rehabilitation is required. The significant weakness of the injured limb during flexion activities highlights this as an area for future investigation and focus during rehabilitation prior to return to sports activity.

REFERENCES
Chechik, O., Amar, E., Khashan, M., Lador, R., Eyal, G., & Gold, A. (2013). An international survey on anterior cruciate ligament reconstruction practices. *International orthopaedics*, 37(2), 201–206.

Clark, N. C. (2001). Functional performance testing following knee ligament injury. *Physical Therapy in Sport*, 2(2), 91-105.

Exell, T.A., Irwin, G., Gittoes, M.J.R., & Kerwin, D.G. (2017). Strength and performance asymmetry during maximal velocity sprint running. *Scandinavian Journal of Medicine & Science in Sports*, 27(11), 1273-1282.

Flanagan, E. P., Galvin, L., & Harrison, A. J. (2008). Force production and reactive strength capabilities after anterior cruciate ligament reconstruction. *Journal of Athletic Training*, 43(3), 249-257.

Hewett, T.E., Di Stasi, S.L., & Myer, G.D. (2013). Current concepts for injury prevention in athletes after anterior cruciate ligament reconstruction. *The American Journal of Sports Medicine*, 41(1), 216-224.

Jari, S. & Shelbourne, K.D. (2002). Staged bilateral anterior cruciate ligament reconstruction with use of contralateral patellar tendon autograft: a case report. *The American Journal of Sports Medicine*, 30(3), 437–440.

Legnani, C., Zini, S., Borgo, E. & Ventura, A. (2016). Can graft choice affect return to sport following revision anterior cruciate ligament reconstruction surgery? *Archives of Orthopaedic and Trauma Surgery*, 136, 527–531.

Niven, A. (2007). Rehabilitation adherence in sport injury: sport physiotherapists' perceptions. *Journal of Sport Rehabilitation*. 16(2), 93-110.

Noyes, F.R., Barber, S.D. & Mangine, R.E. (1991). Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. *The American Journal of Sports Medicine*. 19(5), 513-8.

Noyes F.R. (2009). The function of the human anterior cruciate ligament and analysis of single- and double-bundle graft reconstructions. *Sports Health*, 1(1), 66–75.

Sanders, T.L., Maradit Kremers, H., Bryan, A.J., Larson, D.R., Dahm, D.L., Levy, B.A., Stuart, M.J. & Krych, A.J. (2016). Incidence of anterior cruciate ligament tears and reconstruction: a 21-year population-based study. *The American Journal of Sports Medicine*, 44(6), 1502-1507.

Schmitt, L.C., Paterno, M.V. & Hewett, T.E. (2012). The impact of quadriceps femoris strength asymmetry on functional performance at return to sport following anterior cruciate ligament reconstruction. *Journal of Orthopaedic & Sports Physical Therapy*, 42:9, 750-759.

Viola, R.W., Sterett, W.I., Newfield, D., Steadman, J.R., & Torry, M.R. (2000). Internal and external tibial rotation strength after anterior cruciate ligament reconstruction using ipsilateral semitendinosus and gracilis tendon autografts. *The American Journal of Sports Medicine*, 28(4), 552–555.

Zifchock, R.A., Davis, I., Higginson, J., & Royer, T. (2008). The symmetry angle: a novel, robust method of quantifying asymmetry. *Gait & Posture*, 27(4), 622-627.