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Costley, Jill, Miles, Joshua, King, Enda and Daniels, Katherine  (2020) The effect of autograft type on progression of phase-specific loading asymmetries in the counter-movement jump from six to nine months post-ACLR. In: International Society of Biomechanics in Sports Conference (ISBS Conference 2020), 20 July 2020 - 24 July 2020, Liverpool, UK [online due to COVID-19].

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Additional Information: Article published in the ISBS Proceedings Archive, Volume 38, Issue 1.

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THE EFFECT OF AUTOGRAFT TYPE ON PROGRESSION OF PHASE-SPECIFIC LOADING ASYMMETRIES IN THE COUNTER-MOVEMENT JUMP FROM SIX TO NINE MONTHS POST-ACLR

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Hamstring tendon (HT) and bone-patellar tendon-bone (BPTB) autografts are associated with different strength and jump impulse asymmetries after anterior cruciate ligament reconstruction (ACLR). The aim of this study was to evaluate graft-specific effects on changes in isokinetic strength and bilateral countermovement jump (CMJ) phase-specific impulse asymmetries during late-stage rehabilitation post-ACLR. Male athletes (n=44) with either a HT or BPTB autograft completed testing at 6 and 9 months post-surgery. Autograft type did not influence progression of isokinetic strength, eccentric deceleration or concentric impulse asymmetry. Asymmetries in concentric impulse, knee flexor strength and knee extensor strength decreased over the three-month period. Changes in strength asymmetry had little or no ability to explain changes in jump impulse asymmetry.

KEYWORDS: anterior cruciate ligament, autograft, jumping, strength, rehabilitation, asymmetry.

INTRODUCTION: Anterior cruciate ligament (ACL) rupture is a common injury in multi-directional field sports (Agel *et al.* 2016). Treatment for athletes who desire to return to sport (RTS) often comprises surgical ACL reconstruction (ACLR) using a hamstring tendon (HT) or bone-patellar-tendon-bone (BPTB) autograft, followed by rehabilitation (Smith *et al.* 2019). Rehabilitation aims to satisfy criteria set for RTS and frequently focuses on establishing inter-limb symmetry of neuromuscular, strength and power parameters (Buckthorpe *et al.* 2019). Typically, athletes RTS following approximately 9 months of post-operative rehabilitation (Grindem *et al.* 2016).

Progress of rehabilitation has recently been found to be influenced by graft type, and is likely associated with donor site morbidity (Xergia *et al.*, 2011). Nine months following ACLR, HT athletes (i.e. those whom underwent HT ACLR) displayed smaller counter-movement jump (CMJ) eccentric and concentric impulse asymmetries than BPTB athletes (i.e. those whom underwent BPTB ACLR) (Miles *et al.*, 2019). Moreover, BPTB athletes required longer to fulfil RTS criteria than HT counterparts (Smith *et al.* 2019). Significantly higher 3-year post-surgical contralateral and ipsilateral re-rupture rates were also reported in BPTB and HT cohorts respectively (Rousseau *et al.*, 2019). Consequently, many authors report current ACLR outcomes as suboptimal (Wellstandt *et al.* 2018; Buckthorpe, 2019) and highlight the paucity of information regarding graft specific effects throughout ACLR rehabilitation (Smith *et al.* 2019).

Later-stage rehabilitation prior to the on-field demands of RTS represents an imperative preparatory phase for establishing inter-limb symmetry; influencing RTS performance parameters, post-RTS injury risk and quality of later life (Buckthorpe, 2019). Knowledge of graft-specific influences on rehabilitation progression may not only aid specificity of RTS criteria and rehabilitative programmes but also enable suitable modifications of timescales and practitioner/patient expectations for recovery. Thus, the objectives of this study were to establish whether asymmetries in phase-specific CMJ impulses and flexor-extensor strength displayed systemic changes from 6 to 9 months post-ACLR, to determine whether graft type was associated with changes in these asymmetries, and to ascertain the contribution of strength to impulse asymmetry changes. It was hypothesised that non-graft-specific reductions

in strength and phase-specific kinetic asymmetries would be observed between 6 and 9 months post-ACLR.

METHODS: Forty-four male multi-directional field sport athletes aged 18-35 who had undergone ACLR surgery with either a HT ($n = 22$; mean \pm SD; age: 26.1 ± 4.4 years; height: 179.4 ± 6.1 cm; weight: 79.8 ± 9.4 kg) or BPTB ($n = 22$; age: 23.4 ± 4.4 years; height: 181.8 ± 6.4 cm; weight: 85.2 ± 11.5 kg) autograft participated in this study. Each participant undertook two post-ACLR testing sessions: Test 1 at approximately 6 months post-surgery (mean: 6.2 ± 0.4 months) and Test 2 at approximately 9 months post-surgery (mean: 9.3 ± 0.4 months).

Bilateral vertical ground reaction forces (GRFs) from three maximal-height CMJs with hands on the iliac crests were recorded from two force platforms (BP400600; AMTI; Massachusetts, USA) following a standardised warm-up and two familiarisation CMJs. Data were sampled at 1000 Hz. Concentric knee extensor and flexor strength were then assessed through a 100° range via a standardised isokinetic dynamometry (IKD; Cybex Humac NORM, CSMI) protocol at $60^\circ/\text{second}$ (Undheim *et al.*, 2015). A familiarisation set preceded maximal-effort IKD sets and verbal encouragement was provided throughout.

Centre of mass vertical velocity was calculated from GRFs using the impulse-momentum relationship and used to identify the eccentric deceleration, concentric and landing phases of the CMJ with respective time intervals: 1) maximal negative velocity to zero velocity 2) zero velocity to take-off 3) landing to zero velocity. Force-time curves from each limb were integrated to obtain limb-specific impulses, which were divided by body mass. The mean of the three trials was used for analysis. Thereafter, IKD peak torques in extension and flexion relative to body mass were extracted and used for analysis. For each group, phase-specific impulse and IKD peak extension and flexion torque asymmetry indexes (AIs) were calculated. AI was calculated as the difference between limbs (uninjured limb – ACLR limb) divided by the maximum of both limbs, multiplied by 100: a positive AI thus signifying higher outputs from the uninjured limb.

Paired Student's t-tests were used to test for differences in AI between Test 1 and Test 2 for eccentric deceleration, concentric and landing phases of the CMJ, and for extensor and flexor isokinetic strength. Standardised effect size (ES) (Cohen's *d*) was calculated for all comparisons with negative ESs indicating improved symmetry (Cohen, 1988). Two one-sided t tests (TOST) was used to assess equivalence of HT and BPTB AI changes for phase-specific CMJ impulses and IKD peak torques from Test 1 to Test 2 using an equivalence threshold of 10% to correspond to the $\leq 10\%$ GRF inter-limb asymmetry criterion often incorporated into RTP decision-making (Myer *et al.*, 2006). When the alternative hypothesis of equivalence was not accepted, two-tailed Student's independent t-tests were utilised *post hoc*. Linear regression analyses were used to assess the extent to which variation in changes in CMJ phase-specific AI could be explained by variation in the change in knee extensor AI. Alpha was set at 0.05.

RESULTS: There were no significant differences in eccentric deceleration AI ($t = 1.533$; $p = 0.13$; ES = -0.15) or landing AI ($t = 0.908$; $p = 0.37$; ES = 0.14) from Test 1 to Test 2, although a reduction in concentric CMJ impulse AI ($t = -4.953$, $p < 0.001$, ES = -0.42) was observed. Reductions in strength AIs were exhibited for the knee flexors ($t = -2.552$, $p = 0.01$, ES = -0.37) and knee extensors ($t = 4.296$; $p < 0.001$; ES = -0.50) (Figure 1).

Graft-type did not affect inter-test changes in impulse AI within eccentric deceleration ($P = 0.003$) or concentric ($p < 0.001$) phases, nor change in torque AI in flexion ($p = 0.002$) or extension ($p = 0.02$). Neither equivalence ($p = 0.33$) nor difference ($p = 0.10$) tests reached significance for change in landing impulse AI.

The change in isokinetic knee extensor strength AI from Test 1 to Test 2 exhibited a small positive association with changes in eccentric deceleration AI ($p = 0.02$; $r^2 = 0.12$) though did

not demonstrate significant associations with change in AI for the other CMJ phases ($p = 0.13 - 0.50$; $r^2 = 0.01 - 0.05$).

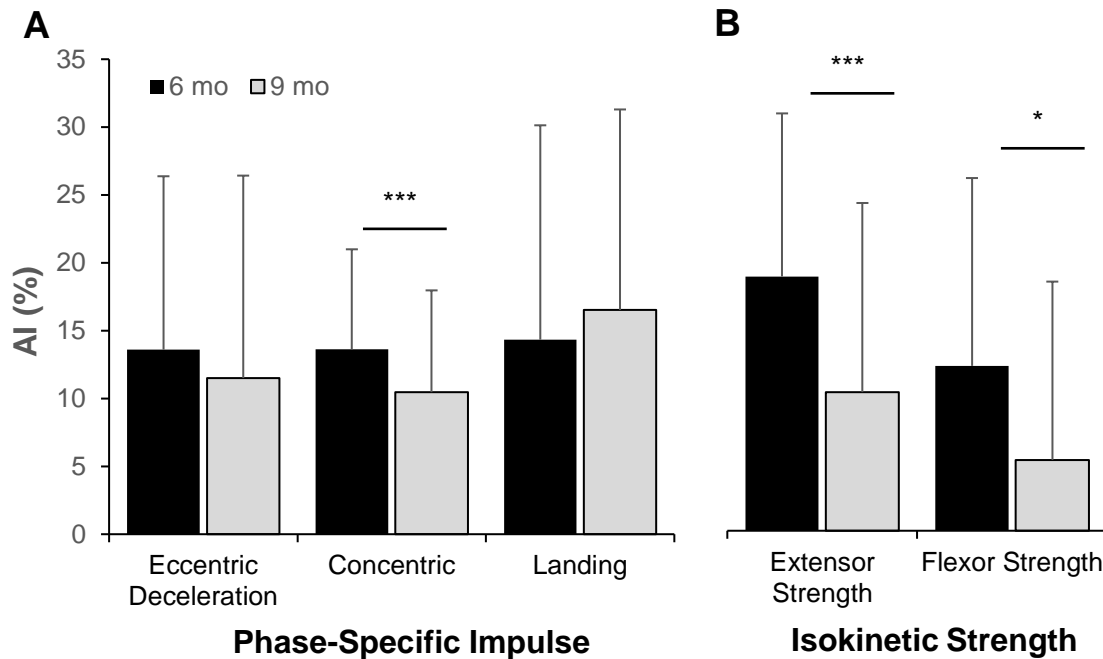


Figure 1 – Phase-specific impulse and isokinetic strength AIs for 6 month (Test 1) and 9 month (Test 2) testing sessions. Bars represent means \pm SD. N = 44. ***Significant difference between testing sessions at $p \leq 0.001$. *Significant difference between testing sessions at $p < 0.05$.

DISCUSSION: Our findings suggest autograft type does not influence the progression of CMJ phase-specific asymmetries or isokinetic knee flexor and extensor strength during late-phase ACLR rehabilitation (6 – 9 months post-surgery). Overall, reductions in concentric phase and strength asymmetries were observed, and no significant changes in asymmetries within eccentric jump phases (i.e. eccentric deceleration and landing) were apparent. The graft-specific differences reported 9 months post-ACLR by Miles *et al.* (2019), thus presumably arise in the first 6 months following surgery.

The lack of changes within eccentric phases during late-phase rehabilitation, in addition to the large AIs at 9 months (Miles *et al.*, 2019), may indicate slower recovery of eccentric qualities and/or insufficient specificity of currently employed rehabilitative regimes; especially in BPTB athletes who also displayed the greatest eccentric asymmetries 9 months post-ACLR (Miles *et al.* 2019). The limited transfer of IKD symmetry improvements to eccentric parameters highlights the need for a multi-faceted and comprehensive approach to ACLR rehabilitation (Buckthorpe, 2019). As non-contact ACL ruptures tend to occur within 50 ms of initial ground contact (Krosshaug *et al.*, 2007), deficits in eccentric qualities may place athletes at increased re-rupture risk (Shimokochi and Shultz, 2008). Specific monitoring and targeting of eccentric capabilities during rehabilitation may thus be indicated, particularly following BPTB-ACLR.

CONCLUSION: Progression of IKD and CMJ impulse asymmetries during late-stage ACLR rehabilitation (6-9 months) does not appear to be influenced by autograft type, suggesting that previously-observed rehabilitative differences between autografts occur as a result of pre-operative, intra-operative or early post-operative (<6 months) factors. Changes in impulse symmetry displayed little or no relationship to changes in concentric isokinetic strength symmetry.

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Acknowledgements

This work was supported by Sports Surgery Clinic, Dublin, Ireland.