LOWER LIMB PERFORMANCE IN ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTED INDIVIDUALS

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This experiment examined lower limb performance in individuals with previous history of anterior cruciate ligament rupture and reconstruction. 10 volunteers took part in the study. Lower limb performance was assessed with maximal effort countermovement, drop and rebound jumps on a force sledge apparatus. The subjects' contra-lateral, uninjured leg was used as an internal control. No significant differences were observed in any of the measured variables, in any of the jumping procedures between the involved and uninvolved leg. This suggests that current reconstructive practices and post-surgery rehabilitation techniques may have the ability to restore ACL deficient legs to a similar level of performance to an uninvolved control leg in dynamic, non-fatiguing, maximal effort jumping activity.

KEY WORDS: reactive strength index, leg spring stiffness, force sledge apparatus.

INTRODUCTION: The anterior cruciate ligament (ACL) is a broad ligament joining the tibial plateau to the femoral intercondylar notch. The ACL provides mechanical stability and proprioceptive feedback to the knee. ACL injuries are common in competitive sport, particularly in sports with sprinting, jumping and cutting components. Individuals with ACL deficiency who receive non-operative care develop disabling knee conditions at a high rate and as a result surgical reconstruction is often the prescribed treatment (O'Connor et al., 2005). Research has shown that post-operatively, despite full rehabilitation programmes, ACL reconstructed patients may suffer decreased proprioception (Bonfim et al., 2003), increased latency (Bonfim et al., 2003) and decreased strength (Keays et al., 2000) in comparison to contra-lateral, uninjured control limbs. Decreased proprioception and increased latency of musculature surrounding the knee may reduce individuals' ability to control leg spring stiffness. Leg spring stiffness plays a key role in functional joint stability (Riemann & Lephart, 2002). Stiffer muscles resist sudden joint displacements quicker and more effectively, serving as a protective mechanism against acute knee injury. Too low a level of stiffness has been associated with excessive joint motion leading to soft tissue injury (Butler, 2003). An underlying deficiency affecting the control of leg spring stiffness in an ACL reconstructed limb could therefore increase the risk of re-injury. Reactive Strength Index (RSI) has been defined as the ability to change quickly from an eccentric to concentric contraction (Young, 1995). RSI can be a useful tool for examining an athlete's rapid impulse production capabilities (McClymont and Hore, 2003) during dynamic jumping tasks. Between-leg imbalances in RSI could represent a functional weakness that may inhibit optimal sporting performance. The purpose of this investigation was to examine the biomechanical status of the lower limbs of individuals with previous history of ACL rupture and surgical reconstruction. Individuals who had made a full return to participating in their chosen sport were specifically selected to establish if any residual deficits in lower limb function existed, which may increase re-injury likelihood or reduce performance capacity. Biomechanical analysis during dynamic jumping activity allows for observation of movement behavior in a dynamic manner similar to the sporting environment in which ACL rupture commonly occurs.

METHOD: Adults with history of ACL reconstruction, who had undergone post-surgery rehabilitation and returned to a level of physical activity comparable to that of their pre-injury status were recruited. Exclusion criteria included any episode of re-injury to the ACL following reconstructive surgery or any pathology or surgery in the hips, knees, ankles or feet of the involved or uninvolved leg within the last 6 months. Ten adults participated in the study, consisting of eight males and two females. The group was of age (mean ± S.D.) 23.8 ± 6 years; height 176.5 ± 7 cm and mass 79 ± 14 kg. 4 of 10 reconstructions utilised a hamstring autograft while 6 used a patellar tendon autograft. Mean time from surgery to participation in the study was 27 ± 14.5 months. Recruited subjects were participants in a variety of sports including soccer, rugby and Gaelic games. The University's research ethics committee approved the study and all subjects provided signed informed consent.

Procedures: Measures of lower limb performance were obtained with the force sledge apparatus using varying jumping protocols. The force sledge apparatus provides control of eccentric loadings and minimisation of the contribution of extraneous factors such as arm swing and contra-lateral leg action. It has been described in detail elsewhere (Flanagan & Harrison, 2005). Subjects performed three protocols in a randomised order on the apparatus during testing: one-legged, maximal effort countermovement jumps (CMJ), drop jumps (DJ) and rebound jumps (RBJ). Subjects performed the CMJ seated in the force sledge apparatus, jumping from and landing on the force plate, which is positioned at a right angle to the base of the sledge's inclined track. For the DJ subjects were dropped using the force sledge from a height of 0.30 m. On landing the subjects performed a single, maximal effort jump against the force plate. In the RBJ subjects were again dropped from a height of 0.30cm and on landing performed four, single-legged, repeated maximal jumps. The first jump of this set of four was considered a drop jump; the following three jumps were considered rebound jumps and were selected for analysis. The reliability and rationale of such a testing protocol has been discussed previously (Flanagan & Harrison, 2005). Before all jumps, subjects were given a visual demonstration and allowed to practice the appropriate action before performing the protocol on each leg in a randomised order. Full recovery was afforded between all jumps and the protocol was non-fatiguing. For drop and rebound jumps subjects were instructed to minimise ground contact time and apply maximal effort. A reflective marker was attached to the sledge and sagittal plane SVHS video recordings (50 Hz.) were obtained. The video recordings were digitised using Peak Motus® (Peak Performance Technologies, Colorado, USA) and the displacement of the sledge was calculated. Ground reaction force measurements were obtained for each jump using an AMTI force plate sampling at 1000 Hz. Instants of initial foot contact, full crouch depth, take-off and landing were identified using the acquired video footage and ground reaction force traces. Flight time (FT) was calculated as the time between take-off and landing. Contact time (CT) was defined as the time between initial foot contact and take-off. A spring mass model was used to analyse vertical leg spring stiffness. Vertical stiffness of the spring which occurs normal to the force plate, (K_{VERT}), was defined as the ratio of the peak force in the spring, Fy_{peak}, to the displacement of the spring, ΔL, at the instant the leg spring is maximally compressed. Fy_{peak} and ΔL both occur simultaneously in the mass spring model (Ferris & Farley, 1997). ΔL was calculated as the displacement of the sledge from the point of initial foot contact and full crouch depth. RSI was calculated as the height jumped divided by CT, where, considering the 30° inclination of the force sledge apparatus, jump height was approximated as $(9.81 * FT^2)/16$.

Statistical Analysis: All statistical analysis of the data was carried out in SPSS © (Version 13.0). Comparative analysis, between the involved and uninvolved legs utilised a general linear model (GLM), ANOVA with repeated measures. The GLM had two within-subjects factors: Leg (with 2 levels: involved or uninvolved) and Trial (with 3 levels: trial 1, 2 and 3). Dependent variables analysed were FT, RSI, K_{VERT} and Fy_{peak}. The model included all interaction terms. A significance level of 0.05 was adopted for all statistical analysis of the data.

RESULTS AND DISCUSSION: Past research has demonstrated that the testing protocol utilised in this study is a reliable form of data collection with Cronbach's alpha reliability co-efficients of ≥ 0.95 and single measures intra-class correlations of ≥ 0.94 observed for all variables measured here (Flanagan & Harrison, 2005). Table 1 presents the FT and Fy_{peak} data for the CMJ, DJ and RBJ. The GLM ANOVA detected no significant differences between the involved and uninvolved legs ($p \geq 0.05$, in all cases). The data demonstrates that these subjects, despite previous history of ACL rupture and surgical repair, can now jump to comparable heights with both legs and generate highly similar levels of ground reaction force during these jumps.

Table 1: Mean (± S.D.) FT and Fy_{peak} for all force sledge jumping protocols. No significant differences observed between legs.

		Uninvolved	**Involved**
CMJ	FT (s)	0.656 (± .06)	0.655 (± .07)
	Fy_{peak} (N)	1136 (± 196)	1108 (± 198)
DJ	FT (s)	0.674 (± .06)	0.675 (± .08)
	Fy_{peak} (N)	1376 (± 233)	1357 (± 308)
RBJ	FT (s)	0.684 (± .06)	0.673 (± .08)
	Fy_{peak} (N)	1611 (± 346)	1577 (± 411)

Figure 1 displays K_{VERT} and RSI for both legs during the DJ and RBJ. Again no significant differences and low effect sizes are observed between legs in either variable, in either jumping protocol ($p \geq 0.05$). Subjects have comparable control of leg spring stiffness and can rapidly generate similar levels of impulse in both legs. This suggests that the involved leg of this particular group of subjects is not at an increased re-injury risk and these individuals do not express any force production imbalances, which may inhibit optimal sporting performance.

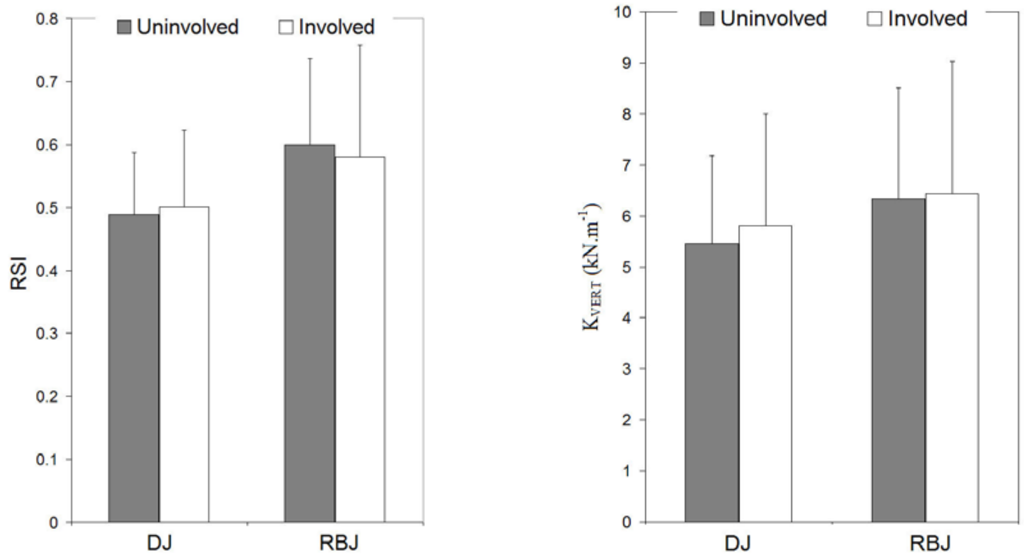

Figure 1: Mean (+ S.D.) RSI and K_{VERT} during the drop jump and rebound jump protocol. No significant differences observed between legs.

Strong between-leg balance, comparable to that reported between legs in normal uninjured populations in similar testing procedures (Flanagan & Harrison, 2006), was observed in all measured variables in the current study. It has been suggested that full recovery of knee function after ACL reconstructive surgery using a graft source, may be impaired as a result of deficits in sensory and mechanical properties. The sensory system of the cruciate ligaments is thought to significantly contribute to the functional stability of the knee joint (Riemann & Lephart, 2002). Sensory deficits may persist when the ACL is damaged and replaced with a graft as many of the original mechanoreceptors and nervous connections are not restored (Bonfim et al., 2003). We hypothesized that such deficits in sensory performance may be detrimental to the control of leg spring stiffness and dynamic force production. It should be noted however, that the current study does not directly consider proprioceptive function as subjects were allowed full auditory and visual capabilities. With close examination of our trial to trial reliability and the sensitivity of our testing, we have confidence in the validity of our findings showing that current surgical and rehabilitative techniques have the capacity to restore lower limb performance to full capacity in non-fatiguing, dynamic, maximal effort activity following ACL rupture.

A number of factors may have contributed to the highly positive outcome observed in this study. Firstly, our subjects were tested on average 27 months following surgery. Previous research by Keays et al., (2001) and Bonfim et al. (2003), which demonstrated post-operative deficits in knee function examined subjects within a mean of 6 and 18 months of surgery, in the respective studies. With our subject group afforded an extended duration following surgical repair, the involved leg may have been exposed to a longer training stimulus that could contribute to the positive performance observed in this study. Also, in should be noted that this study specifically recruited individuals who had returned to participation in their chosen sport. Rupture of the ACL can have a noteworthy effect on drop out from competitive sport (Mykleburst & Bahr, 2005). Our inclusion criteria automatically excluded individuals who had not been rehabilitated to a sufficient level to return to sport and resulted in us examining only the upper echelon of ACL reconstructed patients. Had a broader spectrum of ACL reconstructed subjects been selected for participation or had subjects been examined closer to the date of reconstruction, between-leg imbalances may have been more likely observed.

CONCLUSION: This study confirms that, with time, the involved leg of ACL reconstructed patients can be restored to highly similar levels of performance to that of their uninvolved leg following surgery. The data suggests that the surgical procedure itself is not a limiting factor to the extent of recovery and full recovery can be attainable in patients following appropriate rehabilitation and exercise regimes.

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