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Activity progression for anterior cruciate ligament injured individuals

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ABSTRACT

Background: Functional exercises are important in the rehabilitation of anterior cruciate ligament deficient and reconstructed individuals but movement compensations and incomplete recovery persist. This study aimed to identify how tasks pose different challenges; and evaluate if different activities challenge patient groups differently compared to controls.

Methods: Motion and force data were collected during distance hop, squatting and gait for 20 anterior cruciate ligament deficient, 21 reconstructed and 21 controls.

Findings: Knee range of motion was greatest during squatting, intermediate during hopping and smallest during gait ($P < 0.01$). Peak internal knee extensor moments were greatest during distance hop ($P < 0.01$). The mean value of peak knee moments was reduced in squatting and gait ($P < 0.01$) compared to hop. Peak internal extensor moments were significantly larger during squatting than gait and peak external adductor moments during gait compared to squatting ($P < 0.01$). Fluency was highest during squatting ($P < 0.01$). All patients demonstrated good recovery of gait but anterior cruciate ligament deficient adopted a strategy of increased fluency ($P < 0.01$). During squatting knee range of motion and peak internal knee extensor moment were reduced in all patients ($P < 0.01$). Both anterior cruciate ligament groups hopped a shorter distance ($P < 0.01$) and had reduced knee range of motion ($P < 0.025$). Anterior cruciate ligament reconstructed had reduced fluency ($P < 0.01$).

Interpretation: Distance hop was most challenging; squatting and gait were of similar difficulty but challenged patients in different ways. Despite squatting being an early, less challenging exercise, numerous compensation strategies were identified, indicating that this may be more challenging than gait.

1. Introduction

Rehabilitation is recommended for individuals with anterior cruciate ligament (ACL) injury that have a surgical reconstruction (ACLR) and for those that manage their injury conservatively and remain ACL deficient (ACLD). Despite rehabilitation quite a large proportion of ACLR and ACLD individuals demonstrate incomplete recovery; this can result in altered movement strategies and/or inability to return to pre-injury activity (Ardern et al., 2011; Button et al., 2005, 2006; Deneweth et al., 2010; Gobbi and Francisco, 2006; Gustavsson et al., 2006; Myklebust et al., 2003; Orishimo et al., 2010; Salem et al., 2003; Strehl and Eggli, 2007; Zabala et al., 2013). A number of rehabilitation protocols have been published and/or assessed within randomised control trials. These have focused on; perturbation, strengthening and neuromuscular control exercises or generalised programmes that combine the different exercise types within the rehabilitation programmes (Beynnon et al., 2005; Chmielewski et al., 2005; Eitzen et al., 2010; Hartigan et al., 2009; Risberg et al., 2007; White et al., 2013; Wilk et al., 2012). Functional exercises are favoured in rehabilitation to address knee and lower limb strength and motor control because they are closely related to everyday activities and sport. This includes important exercises such as walking (GAIT), double leg squat (DLS) and single leg distance hop (SLDH). Greater insight into the biomechanical differences between GAIT, DLS and SLDH is required so that exercise prescription within rehabilitation can be more targeted. In addition an understanding of biomechanical compensation strategies in ACLR, ACLD compared to healthy controls is required so that rehabilitation can be more specific.

This study addressed the following two aims. Firstly to identify how GAIT, DLS and SLDH exercises pose different knee motion, moment and control challenges to the knee. Secondly to evaluate if these activities challenge ACL deficient (ACLD) and ACL reconstructed (ACLR) individuals differently compared to controls (CONT). There is a wide range of functional exercises but GAIT, DLS and SLDH are being evaluated in the current study because they are presumed to span the early (GAIT), intermediate (DLS) and advanced (SLDH) phases of rehabilitation.

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This means that they pose different challenges to the knee; single versus double leg stance, range of motion and internal/external moments (Escamilla et al., 2012; Risberg et al., 2007; White et al., 2013; Wilk et al., 2012). Based on the literature we hypothesised that SLDH would be the most challenging task, followed by DLS and then GAIT. The second hypothesis was that ACLD would demonstrate the most compensation strategies that would reflect the challenges posed by each functional exercise.

2. Methods

20 ACLD, 21 ACLR and 21 healthy control (CONT) subjects provided informed consent to participate in this study (demographics are in Table 1). All ACLR had a single bundle gracilis–semitendinosus tendon graft reconstruction, with an 'anatomical' tunnel position. Ethical approval for this study was obtained from the South East Wales Research Ethics Committee. Inclusion criteria were that patients were aged between 18 and 50 years, had an ACL rupture that may or may not be accompanied with a meniscal tear or collateral ligament sprain, or a primary ACL reconstruction; had finished their rehabilitation; had no other pathology which affects their movement; had no previous knee surgery and were able to provide informed consent independently. All ACL individuals had an MRI scan and were reviewed by an expert clinician to ensure the inclusion criteria were met.

Knee function was scored for ACLD and ACLR using the International Knee Documentation Subjective Knee (IKDC) questionnaire (Irrgang et al., 2001). Fear of re-injury was measured using the modified Tampa Scale of Kinaesiophobia (Kvist et al., 2005). Sports activity level was measured using the Cincinnati Sports and Activity Scale (CSAS) (Barber-Westin et al., 1999). Knee extensor ($S_{KneeExt}$) and flexor ($S_{KneeFlex}$) isokinetic strengths (concentric/concentric) were measured at 90°/s on a Biodex System 4 PRO dynamometer (Biodex Medical Systems Inc., USA). This was measured on both legs, but presented for the injured (ACLR and ACLD) and the dominant stance leg (CONT) only.

Standardised instructions were given on how to carry out the activities. For GAIT participants were asked to walk along a 15 metre walkway at their 'normal' walking speed. For DLS participants were instructed to squat to their maximum depth and then return to their starting position. For SLDH individuals were asked to hop their maximum single leg hop distance and regain their balance after landing. Participants were asked to perform eight DLS and SLDH trials and five GAIT trials, four successful trials for each activity were analysed. Individuals were given time to rest between SLDH trials. All ACL injured subjects hopped using their injured leg and the controls using their dominant stance leg.

Anthropometric measurements were taken and used for the inverse dynamic calculations. Ground reaction force data were collected using a Kistler force plate (Kistler Instruments Ltd., Winterthur, Switzerland) at 1000 Hz. Kinematic data were collected at 250 Hz using an eight camera VICON MX motion analysis system (Oxford Metrics Group Ltd., Oxford., UK). Reflective markers were placed using the 'Plug-in-Gait' full body marker set. Two additional markers were placed on the left and right lateral sides of the iliac crest (LILC and RILC). A static anatomical calibration trial was collected on each participant. The knee axes were aligned using the anatomical calibration trial. In some trials the trunk and hips flexed as such that the markers on the left and right anterior superior iliac crests (LASI and RASI) were occluded; these gaps were filled using the data of the LILC and RILC markers in a custom written programme in ViconBodyBuilder for Biomechanics (version 1.2, Oxford Metrics Group Ltd., Oxford, UK). Inverse dynamics calculations were performed within VICON Nexus software (version 1.6.1 (Oxford Metrics Group Ltd., Oxford., UK)) and data were further processed and analysed in Matlab R2010b (The Mathworks Inc., Natick, USA). This analysis focused on the stance phase of GAIT, the descent and ascent phases of DLS and the landing phase of SLDH.

Table 1
Mean and standard deviation for demographic variables and time since injury/surgery, muscle strength and patient rated questionnaires for ACLR, ACLD and CONT. *Signifies $P < 0.05$. S_{KnExt} represents peak torque for the quadriceps muscle, and S_{KnFlex} represents peak torque for the hamstrings. The patient rated questionnaires are the Tampa Scale of Kinaesiophobia (FOI), International Knee Documentation Committee (IKDC) and Cincinnati Sports and Activity Scale (CSAS).

	CONT	ACLR	ACLD
Age (years)	26.8 (7.7)	29.1 (9)	29.2 (6)
Height (m)	1.75 (0.13)	1.73 (0.07)	*1.80 (0.08)**
Mass (kg)	77.6 (19.6)	80.1 (9.5)	82.9 (12.5)
Gender	F: 9 M: 12	F: 5 M: 16	F: 3 M: 17
Time since injury (months)		24.1 (16.9)	19.6 (55.5)
Time since surgery (months)		13.5 (9)	
S_{KnExt} (Nm)	147 (71)	134 (64)	115 (42)
S_{KnFlex} (Nm)	86 (40)	80 (31)	75 (22)
FOI		32.4 (4.9)	*40.7 (5.1)**
IKDC		83.3 (10)	*61.5 (12.6)**
CSAS median	95	80	75

Performance variables were quantified for each of the activities; gait velocity for GAIT, squat depth for DLS and hop distance (d_{hop}) for SLDH. d_{hop} was calculated as the distance the ankle joint centre travelled along the axis of hopping and normalized to body height. Kinematic and kinetic variables used to evaluate exercise difficulty were knee flexion–extension range of motion (RoM_{knee}), hip flexion–extension range of motion (RoM_{hip}), ankle flexion–extension range of motion (RoM_{ankle}), peak internal knee extensor moment ($M_{kneeMax}$), peak external knee adductor moment (M_{addMax}), peak internal hip moment (M_{hipMax}), and peak internal ankle moment ($M_{ankleMax}$). In the coronal plane peak external knee adductor moments have been used because this corresponds to terminology most commonly used in the literature. The output variable calculated to assess knee control was *fluency*. This was calculated by a method adapted from Smeulders et al. (2001). It was defined as the number of times the velocity of the knee position in the coronal plane crossed zero, averaged per second. The inverse of this measure (Period (s): $T = 1/f$) was used so that a larger value agreed with a more fluent movement.

The data were checked for normality using the Kolmogorov–Smirnov test. The data were transformed when large differences in standard deviations existed using square root or logarithmic adjustment. To address aim 1, a one-way ANOVA with Bonferroni post hoc testing was used to investigate differences between GAIT, DLS and SLDH for the variable representing knee moments and motor control. To address aim 2 a univariate analysis was used to evaluate differences between ACLR and CONT and between ACLD and CONT for the performance, motion, moment and knee control variables. Gait velocity, squat depth and hop distance were used as covariates for each of the activities. An overall alpha level of $P < 0.05$ was used to signify significance. With Bonferroni adjustment for two comparisons $P < 0.025$ indicated significance. Not all of the ACLD individuals could do a SLDH. Descriptive data (means and standard deviations) for the demographics and key biomechanical parameters are presented for 12 ACLD that could hop ($ACLD_{hop}$) and for 8 ACLD that could not hop ($ACLD_{no\text{-}hop}$). These sub-groups were compared by means of descriptive statistics.

3. Results

The ACL groups were matched to CONT for height, mass, age and gender; however matching was not optimal (Table 1). Therefore, hop distance was normalized to height and all peak moments were normalized to height and weight. The ACLR were mean 25.5 (SD 16.9) months and the ACLD were mean 19.6 (SD 55.15) months post-injury. The ACLR subjects were on average 13.5 ± 9 months post-surgery (Table 1). The level of sports participation (CSAS values) was highest for CONT, intermediate for ACLR and lowest in ACLD. There was no significant difference between the ACL groups and CONT for S_{KnExt} (ACLR $P = 1.000$; ACLD $P = 0.318$) or S_{KnFlex} (ACLR $P = 1.000$; ACLD $P = 0.958$). A higher fear of re-injury