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Knee kinematics during stair descent 20 years following anterior cruciate ligament rupture with and without reconstruction

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ABSTRACT

Background: Changes and asymmetries for walking gait have been explored extensively following injuries of anterior cruciate ligaments within ten years of injury or reconstruction. We examined longer term knee joint kinematics of reconstructed and non-reconstructed knees during stair descent compared to controls.
Methods: Three-dimensional knee kinematics during stair descent were registered for 33 subjects with ACL reconstruction, 36 subjects with ACL rupture managed with physiotherapy only and 31 uninjured controls. Injured subjects were 23.5 (2.1) years following injury. Linear mixed models were used to compare temporal variables and knee kinematics during stance phase between groups and contralateral sides.
Findings: Walking speed was slower for the both ACL-injured groups compared to controls and stance duration was longer for the injured than the uninjured sides of the physiotherapy-only group. Compared to controls, the physiotherapy-only group had significantly less adduction at initial foot contact of the injured and uninjured knees. The uninjured side of the physiotherapy-only group also had less flexion than controls at initial foot contact and during weight acceptance. Compared to the surgically-managed group, the injured sides of the physiotherapy-only groups had significantly less adduction at initial contact, peak adduction during weight acceptance, and peak flexion during propulsion.
Interpretation: Independent of treatment, altered knee kinematics exist more than 20 years following ACL injury during stair descent. We suggest that future studies investigating short and long-term kinematic outcomes of ACL injury could evaluate stair descent with particular emphasis on weight acceptance of stance, and potential associations to perceived knee function.

1. Introduction

Anterior cruciate ligament (ACL) rupture is common in sports such as floorball, handball, football, and skiing, and is considered one of the most severe sports-related injuries (Hrysomallis, 2013; Renstrom et al., 2008). Approximately 55% of athletes return to previous level of sports following reconstruction (Ardern et al., 2014). Furthermore, 50–70% of people with ACL injury have symptoms associated with osteoarthritis 10 years post-injury (Lohmander et al., 2007). Knowledge of long-term consequences of ACL injury may help to understand physical variables to be considered following injury, in an effort to improve/maintain physical activity and decrease disability.

Stair negotiation is an activity that necessitates greater lower limb joint angles and generates up to three times greater external knee flexion torque than level walking, particularly during descent (Andriacchi et al., 1980). Stair descent is associated with highest tibial contact forces and moments compared to stair ascent, standing up, sitting down and walking (Kutzner et al., 2010). Impairments associated with knee loading during activities of daily living may thus be most evident during stair descent (Edd et al., 2015). The relevance for this task as a measure for functional ability is also evident by stair climbing being included in tools focussing on knee-related health after an ACL injury, e.g., the Knee Injury and Osteoarthritis Outcome Score (KOOS, Roos & Lohmander, 2003) and the Lysholm questionnaire (Tegner & Lysholm, 1985). Thus, investigating symptoms during stair negotiating and movement patterns during this task can be helpful as part of a clinical assessment and to determine outcomes of ACL injuries.

Knee kinematics have been explored in participants with ACL deficiencies and following reconstructions (Gao et al., 2012; Hall et al., 2012). Gao et al. (2012) found an extension deficit in subjects with ACL injuries compared to controls during stair ascent and descent <1 year following injury or reconstruction, while Hall et al. (2012) found less peak knee flexion for ACL-reconstructed (ACL_R) knees, on average six years following surgery. The ACL_R knees also had increased tibial adduction, internal rotation during stair ascent compared to controls (Gao et al., 2012). These kinematic differences may indicate changes in joint loading (Gao & Zheng, 2010; Thambyah et al., 2004;

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Zabala et al., 2013). While knee kinematics during stair ambulation have been reported at one year (Gao et al., 2012) and at six years (Hall et al., 2012) following ACL_R, the longer term outcomes are unknown. The present aim was thus to determine the long term effects of ACL injury managed with reconstruction and with physiotherapy alone on knee joint kinematics variables during stair descent.

2. Methods

2.1. Subjects

Subjects with unilateral ACL-injury were identified in a cross-sectional research programme, KACL20-study (Knee injury — Anterior Cruciate Ligament, after more than 20 years) involving two separate cohorts in two different county councils in northern Sweden were invited to participate via postal letters. Seventy subjects participated; 33 had ACL reconstruction followed by physical therapy (ACL_R), and 37 had been treated with physical therapy alone (ACL_{PT}). Recruitment and descriptors of subjects, surgery and rehabilitation, were described previously (Tengman et al., 2014a). The ACL_{PT} and ACL_R groups had incurred their injury 23.1 (1.2) years and 23.9 (2.8) years previously, respectively. The ACL_R underwent surgery 3.6 (2.3) years following injury; 19 underwent reconstructive surgery with a patella tendon auto-graft augmented with a synthetic polypropylene braid [Kennedy ligament augmentation device (LAD); Kennedy et al. (1980)]. Nine subjects had a LAD graft placed through a femoral tunnel (Odensten & Gillquist, 1986) and five received a bone-patella tendon-bone auto-graft (Jones, 1970). Data for stair descent was missing for one subject of the ACL_{PT} group, resulting in 36 subjects. Exclusion criteria were bilateral ACL-injury, other musculoskeletal, rheumatologic or neurological pathology; severe injury or disease to the other leg; multiple joint structural damage in addition to ACL. Thirty-one non-injured healthy controls without knee problems, but of similar sex and age ratio as those of the ACL_R and ACL_{PT} groups, were recruited through advertisements and convenience sampling. Demographics, physical activity level according to the Tegner activity scale (Tegner & Lysholm, 1985) and knee function according to Knee Injury and Osteoarthritis Outcome Score (KOOS) (Roos et al., 1998) are reported in Table 1 (Tengman et al., 2014a). Function and muscle strength were presented recently for the same two ACL injured groups compared to controls (Tengman et al., 2014a, 2014b, 2015). All subjects provided written informed consent and the project was approved by the Regional Ethical Review Board.

2.2. Procedures

Kinematic variables were collected using an optical 8-camera motion capture system (Oqus, Qualisys AB, Gothenburg, Sweden), and 42 reflective skin markers. A static calibration trial for the segment model building was obtained before the subject completed ten descending trials, five for each side. Qualisys Track Manager (version 2.2, Qualisys AB, Gothenburg, Sweden) was used to identify markers and interpolate momentarily hidden markers (interpolation limit 125 ms). Data were sampled at 240 Hz and then low-pass-filtered at 6 Hz using a second-order zero lag Butterworth digital filter. The 6 degrees-of-freedom body segment model was calculated with Visual 3D (C-motion, USA) (Grip & Häger, 2013).

Subjects stood at the top of a customized stair case consisting of three steps (step height: 16 cm; upper step: 50 cm; middle and lower step: 39 cm tread length). On a sound signal, they walked down the stairs at a self-selected pace, ensuring that only one foot hit each step. Barefoot walking was chosen to negate potential influences of footwear (Sacco et al., 2012). Arms were folded across the chest to avoid covering skin markers (Grenholm et al., 2009). Five trials were performed for each side. Three subjects in the ACL_{PT} group completed three trials only: one due to severe knee discomfort and two due to time constraints.

Knee kinematic data were analysed for the stance phase according to established event settings (e.g. Mcfayden & Winter, 1988), defined by initial foot contact (IFC) on the middle step of the leading leg and ended with the toe-off from that step. IFC was defined as the first time point when the leading foot stopped its downward motion, that is, when the derivative in the upward–downward direction of the lateral malleolus marker showed a local minimum. Toe-off was defined as the time when the marker between second and third metatarsal heads reached its maximal velocity in upward direction.

For our study, the first and second parts of stance were defined as *weight acceptance* and *propulsion*. *Weight acceptance* of the leading leg was defined as the phase from the IFC of that leg on the middle step to toe-off of the trailing leg on the starting step, and included the first double-support stance phase. *Propulsion* of the leading leg was defined

Table 1
Participant characteristics Background data has been reported more in detail in Tengman et al., 2014a.

	Group			*P*-value	Significant pairwise comparisons
	ACL_R	ACL_{PT}	Controls		
Male/female (n)	21/12	22/14	19/12		
Age (yrs)	45.6 (4.5)	48.0 (6.0)	46.8 (5.1)	0.156	
Height (cm)	174.0 (9.1)	173.5 (8.1)	175.8 (9.6)	0.575	
Weight (kg)	83.0 (15.6)	87.1 (15.1)	75.9 (13.8)	0.011	ACL_{PT}–control: $P = 0.008$
BMI (kg/m^2)	27.2 (3.3)	28.9 (4.7)	24.4 (2.3)	<0.001	ACL_R–controls $P = 0.007$; ACL_{PT}–control: $P < 0.001$
Injured side: dominant/non-dominant	21/12	19/17	16/15[a]		
Cause of injury					
Soccer	24	24			
Alpine	2	5			
Other sports	6	2			
Non-sporting	1	5			
Tegner activity scale					
Before injury	9 (3–10)	9 (3–9)		0.436	
Current	4 (3–7)	4 (2–7)	6 (3–7)	0.001	ACL_R–controls: $P = 0.003$; ACL_{PT}–controls: $P = 0.001$
KOOS					
Pain	78 (18)	84 (16)	99 (1)	<0.001	ACL_R–controls $P < 0.001$; ACL_{PT}–control: $P < 0.001$
Symptoms	79 (20)	72 (19)	98 (2)	<0.001	ACL_R–controls $P < 0.001$; ACL_{PT}–control: $P < 0.001$
Activities of daily living	84 (16)	90 (15)	100	<0.001	ACL_R–controls $P < 0.001$; ACL_{PT}–control: $P = 0.050$
Sport and recreation	50 (28)	65 (29)	99 (2)	<0.001	ACL_R–controls $P < 0.001$; ACL_{PT}–control: $P < 0.001$; ACL_R–ACL_{PT}: $P = 0.027$
Quality of life	49 (22)	60 (25)	98 (3)	<0.001	ACL_R–controls $P < 0.001$; ACL_{PT}–control: $P < 0.001$

Figures are means ± SD or medians (range). ACL_R: ACL rupture managed with reconstructions and physical therapy; ACL_{PT}: ACL rupture managed with physical therapy only.
[a] Dominant versus non-dominant sides randomised for control group.