Biomechanical Strategies for Obstacle Crossing in Patients with Anterior Cruciate Ligament Deficiency

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The current study aimed to investigate the biomechanical control strategies in patients with anterior cruciate ligament deficiency (ACLD) when crossing obstacles of different heights. Eighteen patients with unilateral ACLD and sixteen age-matched healthy controls were recruited. They crossed obstacles of heights of 10%, 20% and 30% of their leg lengths at a self-selected pace while the kinematic and kinetic data were measured and analyzed using inverse dynamics analysis. Patients with ACLD were found to avoid using the quadriceps on both affected and unaffected sides during stance phase. Training programs on both quadriceps are needed for more efficient rehabilitation of the patients with unilateral ACLD.

KEY WORDS: gait, anterior cruciate ligament deficiency, obstacle crossing.

INTRODUCTION: Anterior cruciate ligament (ACL) has been reported to be the most vulnerable structure in sports. Since the anterior cruciate ligament plays an important role in the structural stability and sensory feedback at the knee, anterior cruciate ligament deficiency (ACLD) can thus lead to instability, decrease of the muscular strength, and impaired somatosensory of the knee. Owing to these impairments, patients with ACLD would adopt compensatory strategies to prevent the symptoms of instability during functional activities (Noyes, Matthews, Mooar, & Grood, 1983). Little is known whether patients with ACLD would have deficits that appear only during complex motor tasks, such as negotiating obstacles, and whether they have adopted particular strategies in performing these activities.

A successful and safe obstacle-crossing requires not only sufficient foot clearance of the swing limb, but also the stability of the body provided mainly by the stance limb (Chen & Lu, 2006). Failure to meet these demands may lead to falls owing to loss of balance or tripping over obstacles. Since this highly challenging functional task is often used for evaluating disease recovery and for task-orientated training, it has been studied extensively (Lu, Chen, & Wang, 2007). However, little has been done on patients with ACLD. It would be helpful to identify the motor deficits and/or strategies during obstacle-crossing in patients with ACLD for a more complete motor assessment. The purpose of the current study was thus to bridge the gap by quantifying the altered biomechanical controls in patients with ACLD during crossing obstacles at different heights.

METHODS: Eighteen unilateral patients with ACLD and sixteen age-matched healthy controls participated in the current study with written informed consent as approaved by the Institutional Research Board. The subjects crossed obstacles of heights of 10%, 20% and 30% of their leg lengths at a self-selected pace while the kinematic and kinetic data were measured with a 7-camera motion analysis system (Vicon, Oxford Metrics, U.K.) and two force plates (AMTI, U.S.A.), and analyzed using inverse dynamics analysis.

The leading toe clearance was calculated as the vertical distances between the toe marker and the obstacle when the leading toe was directly above the obstacle. Angular motions of the pelvis and the joints of both lower limbs as well as joint moments of the trailing limb were calculated, and their values when the leading toe was above the obstacle (crossing angles and moments) were extracted for subsequent statistical analysis. The peak joint moments and the corresponding joint angles during stance phase were also extracted for statistical analysis.

A 2 by 3, 2-way mixed-model analysis of variance with one between-subject factor (group) and one within-subject factor (obstacle height) was performed ($\alpha=0.05$). SPSS version 15.0(SPSS Inc., Chicago, IL) was used for all statistical analysis.

Table 1
Means (Standard Deviations) of the crossing angles of the pelvis and joints of the leading swing limb when the leading toe was above the obstacle.

Crossing Angle (Degree)	Obstacle height (%LL) 10%		20%		30%		P value
	ACLD	Normal	ACLD	Normal	ACLD	Normal	
Affected limb leading							
Hip Flexion	52.4 (6.6)	42.8 (8.7)	59.5 (8.3)	52.2 (8.9)	68.5 (7.0)	59.2 (8.7)	$p_H<0.01$↑ $p_G=0.02$*
Knee Flexion	82.8 (6.4)	76.5 (8.5)	94.7 (8.4)	94.1 (8.5)	107.0 (8.5)	101.2 (8.2)	$p_H<0.01$↑, $p_G=0.18$
Ankle Dorsiflexion	10.7 (5.8)	11.5 (8.2)	10.7 (5.4)	10.3 (4.2)	11.4 (6.5)	9.8 (3.8)	$p_H=0.75$, $p_G=0.30$
Pelvis Anterior-tilt	8.7 (4.7)	4.3 (3.0)	6.9 (5.5)	2.9 (3.1)	6.2 (5.8)	2.3 (3.0)	$p_H<0.01$↓ $p_G=0.03$*
Unaffected limb leading							
Hip Flexion	53.8 (6.7)	42.8 (8.7)	57.8 (11.6)	52.2 (8.9)	68.3 (10.8)	59.2 (8.7)	$p_H<0.01$↑ $p_G=0.03$*
Knee Flexion	86.1 (9.7)	76.5 (8.5)	97.2 (8.5)	94.1 (8.5)	108.7 (8.2)	101.2 (8.2)	$p_H<0.01$↑ $p_G=0.03$*
Ankle Dorsiflexion	10.2 (4.9)	11.5 (8.2)	9.9 (6.7)	10.3 (4.2)	10.3 (4.2)	9.8 (3.8)	$p_H=0.69$ $p_G=0.92$
Pelvis Anterior-tilt	7.7 (3.1)	4.3 (3.0)	6.2 (3.8)	2.9 (3.1)	5.3 (3.7)	2.3 (3.0)	$p_H<0.01$↓ $p_G=0.03$*

*: significant group effects ($p_G<0.05$), ↑or ↓: significant height effects ($p_H<0.05$)
With increasing obstacle height, an upward arrow indicates a statistically significant, linearly increasing trend, while a downward arrow indicates a statistically significant, linearly decreasing trend.

RESULTS: No significant difference in the leading toe-clearance was found between groups and obstacle heights (p=0.81). Significantly greater pelvic anterior tilt and hip flexion both in the swing and stance limbs (p<0.05) were found in the patients with ACLD when the leading toe was above the obstacle (Table 1). Meanwhile, no significant difference in crossing moments (p=0.31) was found in patients with ACLD (Fig. 1). Significantly greater peak hip extensor moments (p=0.02) and lesser peak knee extensor moments of the trailing stance limb (p=0.03) were found in the patients with ACLD during obstacle crossing (Fig. 1). When the peak knee extensor moments occurred, the ACLD group showed significantly less knee flexion in the stance limb (p<0.01) (Table 1 and Fig. 1).

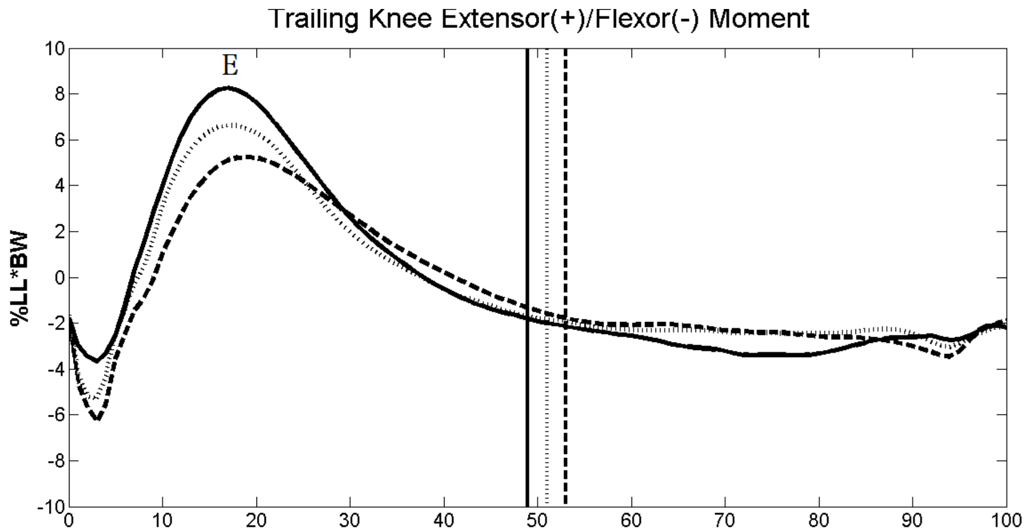

Figure 1: Ensemble-averaged trailing knee moments when crossing obstacles of 30% of leg length with the affected leading (dotted lines) and unaffected leading (dashed lines) in ACLD group and healthy controls (solid line). The vertical lines indicate the instances when the leading swing toe was above the obstacle. Marker E on the graph indicates the peak moment of whole gait cycle (p<0.05).

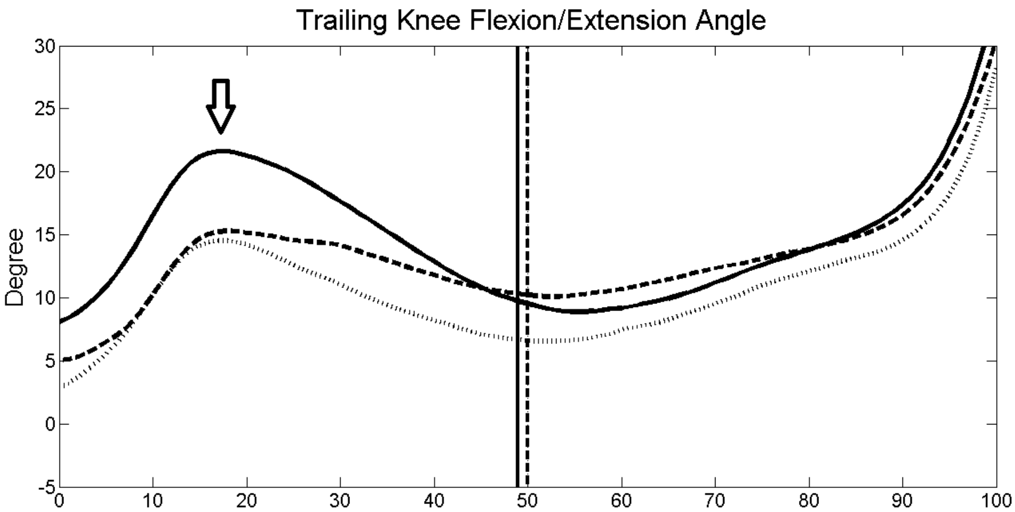

Figure 2: Ensemble-averaged trailing knee angles when crossing obstacles of 30% of leg length with the affected leading (dotted lines) and unaffected leading (dashed lines) in ACLD group and healthy controls (solid line). The vertical lines indicate the instances when the leading swing toe was above the obstacle. The arrow indicates the instances when the peak knee extensor moment occurred (p<0.05).

DISCUSSION: Patients with ACLD maintained more or less constant, close-to-normal end point controls during obstacle crossing, with altered joint kinematics and kinetics. Before crossing, the patients with ACLD showed reduced peak knee extensor moments of the stance limb, mainly through a more extended knee in the stance limb, and a greater pelvic anterior tilt and hip flexion that would displace body's center of mass more anteriorly. These results suggest that the patients avoided using the quadriceps on either affected or unaffected knees during stance for crossing obstacles. These symmetrical strategic changes are helpful for performing functional activities regardless of which side was affected. Future rehabilitation programs for patients with ACLD should include both affected and unaffected knees.

CONCLUSION: Patients with anterior cruciate ligament deficiency (ACLD) avoided quadriceps usage on either affected or unaffected knees during the stance phase of obstacle crossing while maintaining unaltered toe clearance. Training programs on both knees are needed for more efficient rehabilitation of patients with unilateral ACLD.

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