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Postural stability during the transition from double-leg stance to single-leg stance in anterior cruciate ligament injured subjects

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ABSTRACT

Background: An anterior cruciate ligament injury may lead to deteriorations in postural stability. The goal of this study was to evaluate postural stability during the transition from double-leg stance to single-leg stance of both legs in anterior cruciate ligament injured subjects and non-injured control subjects with a standardized methodology.
Methods: Fifteen control subjects and 15 anterior cruciate ligament injured subjects (time after injury: mean (SD) = 1.4 (0.7) months) participated in the study. Both groups were similar for age, gender, height, weight and body mass index. Spatiotemporal center of pressure outcomes of both legs of each subject were measured during the transition from double-leg stance to single-leg stance in eyes open and eyes closed conditions. Movement speed was standardized.
Findings: The center of pressure displacement after a new stability point was reached during the single-leg stance phase was significantly increased in the anterior cruciate ligament injured group compared to the control group in the eyes closed condition ($P < .001$). No significant different postural stability outcomes were found between both legs within both groups ($P > .05$). No significant differences were found during the transition itself ($P > .05$).
Interpretation: The anterior cruciate ligament injured group showed postural stability deficits during the single-leg stance phase compared to the non-injured control group in the eyes closed condition. Using the non-injured leg as a normal reference when evaluating postural stability of the injured leg may lead to misinterpretations, as no significant differences were found between the injured and non-injured leg of the anterior cruciate ligament injured group.

1. Introduction

Anterior cruciate ligament (ACL) tears are serious injuries with substantial short- and long-term consequences, even when ACL reconstruction is performed (Ardern et al., 2014; Wright et al., 2011). Studying postural stability in ACL injured (ACLI) subjects has become prevalent in literature (Ageberg et al., 2001; Bonfim et al., 2008; Gauffin et al., 1990; Lysholm et al., 1998; Negahban et al., 2009; Okuda et al., 2005; Zatterstrom et al., 1994), as these measurements may provide insights in the complex body's adaptation mechanisms after injury. In fact, the ACL is more than just a mechanical constraint of the knee joint. Proprioceptive deficits have been shown in ACLI subjects (Barrack et al., 1989; Corrigan et al., 1992). This altered afferent information may lead to adaptations in the organization of the central nervous system (CNS) (Kapreli et al., 2009), which may provide a possible explanation for the findings of a recent systematic review whereby it was concluded that postural stability is impaired not only in the injured leg, both also in the non-injured leg after ACL injury (Negahban et al., 2013). However, because of the heterogeneity in outcome measurements within the included studies, it was not possible to conduct a meta-analysis. Most of the previous studies focused on a single-leg stance task while standing on a fixed force plate to measure postural stability in ACLI subjects (Ageberg et al., 2001; Bonfim et al., 2008; Gauffin et al., 1990; Lysholm et al., 1998; Negahban et al., 2009; Okuda et al., 2005; Zatterstrom et al., 1994). Before a person is standing on one leg, weight needs to be shifted from a relatively stable double-leg stance position towards a smaller base of support during single-leg stance. Subjects with pathology tend to perform this transitional

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movement slower when moving at their preferred speed, possibly as a strategy to decrease the postural perturbation created by the transition (Dingenen et al., 2013). Indeed, moving faster significantly alters both the spatiotemporal characteristics of the transition from double-leg stance to single-leg stance, as well as postural stability outcomes when standing on one leg (Dingenen et al., 2013). Previous studies only focused on the single-leg stance phase without taking the spatiotemporal characteristics of the transition into account. This may limit our ability to better understand how this movement is performed. Furthermore, the criteria to determine the exact start of the single-leg stance phase were undefined (Ageberg et al., 2001; Bonfim et al., 2008; Gauffin et al., 1990; Lysholm et al., 1998; Negahban et al., 2009; Okuda et al., 2005; Zatterstrom et al., 1994). The time after injury varied between studies, although the majority of studies focused on chronic ACLI subjects (Bonfim et al., 2008; Gauffin et al., 1990; Lysholm et al., 1998; Negahban et al., 2009; Zatterstrom et al., 1994).

A standardized methodology to evaluate the functional ability to effectively stabilize one's body before, during and after the transition from double-leg stance to single-leg stance has been recently developed (Dingenen et al., 2013). Using this method, it has been shown that subjects with chronic ankle instability (Dingenen et al., 2013) and ACL reconstructed subjects who were fully returned to sport (Dingenen et al., 2014) had a significantly increased center of pressure (COP) displacement after a new stability point was reached during the single-leg stance phase compared to non-injured control subjects. The spatiotemporal characteristics of the transition were not significantly different between the ACL reconstructed and control group when standardizing movement speed. Furthermore, no significant differences were found between the operated and non-operated leg after ACL reconstruction (Dingenen et al., 2014). Studying the ability to stabilize one's body during the transition from double-leg stance to single-leg stance in both legs of an ACLI population in a standardized way might be a next step to enhance our understanding of postural stability deficits after ACL injury, which is essential to design optimal rehabilitation programs.

The first research question of this study was whether the findings reported in literature during the single-leg stance phase (the significant differences between groups, but not between legs within groups) that were based on different methodologies with their respective limitations were still evident when using a more standardized methodology. The second research question was whether there are any differences in spatiotemporal postural stability outcomes during the transition from double-leg stance to single-leg stance. Therefore, the purpose of the present study was to evaluate postural stability during the transition from double-leg stance to single-leg stance of both legs in ACLI subjects and non-injured control subjects with a standardized methodology. The first hypothesis was that ACLI subjects will show an increased COP displacement after a new stability point is reached during the single-leg stance phase compared to non-injured control subjects. Based on the reports that bilateral postural stability deficits may exist after unilateral ACL injury (Negahban et al., 2013), our second hypothesis was that postural stability outcomes are not significantly different between the injured and non-injured leg of the ACLI group. Our third hypothesis was that the spatiotemporal postural stability outcomes during the transition are not significantly different between groups when standardizing movement speed.

2. Methods

2.1. Subjects

Thirty subjects participated in this study, after reading and signing an informed consent form, which was approved by the local ethical committee. The sample size of this study was based on a previous study where 15 subjects with chronic ankle instability were compared to 15 non-injured control subjects with the same methodology (Dingenen et al., 2013). The ACLI group ($n = 15$) included subjects with (1) a unilateral complete ACL injury confirmed by magnetic resonance imaging exams and (2) a passive knee range of motion of at least 120°. Exclusion criteria were: (1) a history of previous lower extremity or low back surgery, (2) reporting severe or extreme knee pain on the Knee Injury and Osteoarthritis Outcome Score (KOOS) questionnaire, (3) moderate or severe knee joint effusion at the time of data collection (International Knee Documentation Committee (IKDC) grade C or D), (4) meniscal injuries exceeding 1/3 of the meniscus, (5) other complete ligamentous knee injuries, (6) reporting a subjective feeling of "giving way" at the ankle (ankle instability), (7) knee osteoarthritis (Kellgren–Lawrence > grade 1) and (8) reporting ankle, hip or low back pain. The time after ACL injury was mean (SD) = 1.4 (0.7) months (range: 0.4–2.7 months). All tests were done immediately before the planned ACL reconstruction. From all ACL injuries, 13 were caused by a non-contact injury. Four subjects were injured on the preferred and 11 on the non-preferred leg. The preferred leg was defined as the preferred leg to kick a ball. The control group ($n = 15$) included subjects with no history of ankle, knee, hip or low back injury (Dingenen et al., 2013). Subjects younger than 18 and older than 55 years old, and with the following conditions were also excluded: Parkinson, multiple sclerosis, cerebrovascular accident, peripheral neuropathies, circulation disorders, serious joint disorders (rheuma, osteoarthritis, etc.).

Subjective knee function was assessed with the IKDC Subjective Knee Form and KOOS questionnaire. The IKDC Subjective Knee Form is a reliable and valid measure of symptoms, function and sports activity for patients with knee-specific problems, including ACL injuries (Irrgang et al., 2001). The KOOS questionnaire is another subjective measure to evaluate the patients' opinion about their knee problems and covers five subscales (pain, symptoms, activities of daily living, sport and recreation function, and knee-related quality of life) (Roos & Lohmander, 2003; Roos et al., 1998). The scores on the individual items of both the IKDC Subjective Knee Form and KOOS questionnaire (for each subscale separately) were summed and then transformed to a scale that ranges from 0 to 100, whereby higher scores represent higher levels of function and lower levels of symptoms. Both the IKDC Subjective Knee Form (Haverkamp et al., 2006) and KOOS questionnaire (de Groot et al., 2008) were previously translated and validated for a Dutch population.

2.2. Data collection

Ground reaction forces and moments were measured by a single force plate (Bertec Corporation®) at 500 Hz using a Micro 1401 data-acquisition system and Spike2 software (Cambridge Electronic Design, UK) and low pass filtered with a cut-off frequency of 5 Hz.

2.3. Procedure

The procedure used in this study is based on a previous study (Dingenen et al., 2013). In short, subjects were asked to stand on a force plate with the feet separated by the width of the hips and the arms hanging loosely at the side. They performed a transition task from double-leg stance (13 s) to single-leg stance (13 s). Both legs of both groups were tested. The position of the feet during double-leg stance was indicated on a paper lying on the force plate to ensure that subjects returned to the same starting position after each trial. Subjects were instructed to lift one leg on the command of the examiner towards approximately 60° of hip flexion within 1 s, using a metronome as a reference. As most postural stability outcomes during this experimental task can be influenced by the speed (Dingenen et al., 2013), we standardized the speed of movement. The transition task from double-leg stance to single-leg stance was tested with eyes open and with eyes closed (Fig. 1). Both conditions were repeated 3 times in an alternating order. In the eyes open tests, subjects were instructed to keep their gaze