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Lecture

Lower extremity muscle activation onset times during the transition from double-leg stance to single-leg stance in anterior cruciate ligament reconstructed subjects

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ABSTRACT

Background: Previous studies mainly focused on muscles at the operated knee after anterior cruciate ligament reconstruction, less on muscles around other joints of the operated and non-operated leg. The aim of this study was to investigate muscle activation onset times during the transition from double-leg stance to single-leg stance in anterior cruciate ligament reconstructed subjects.
Methods: Lower extremity muscle activation onset times of both legs of 20 fully returned to sport anterior cruciate ligament reconstructed subjects and 20 non-injured control subjects were measured during the transition from double-leg stance to single-leg stance in eyes open and eyes closed conditions. Analysis of covariance (ANCOVA) was used to evaluate differences between groups and differences between legs within both groups, while controlling for peak center of pressure velocity.
Findings: Significantly delayed muscle activation onset times were found in the anterior cruciate ligament reconstructed group compared to the control group for gluteus maximus, gluteus medius, vastus medialis obliquus, medial hamstrings, lateral hamstrings and gastrocnemius in both eyes open and eyes closed conditions ($P < .05$). Within the anterior cruciate ligament reconstructed group, no significant different muscle activation onset times were found between the operated and non-operated leg ($P > .05$).
Interpretation: Despite completion of rehabilitation and full return to sport, the anterior cruciate ligament reconstructed group showed neuromuscular control deficits that were not limited to the operated knee joint. Clinicians should focus on relearning multi-segmental anticipatory neuromuscular control strategies after anterior cruciate ligament reconstruction.

1. Introduction

The main goal of an anterior cruciate ligament (ACL) reconstruction is to restore mechanical knee joint stability. However, the restoration of mechanical knee stability after ACL reconstruction does not automatically imply a return to normal neuromuscular control (Ageberg, 2002; Wojtys and Huston, 2000). Developing optimal neuromuscular control strategies during rehabilitation after ACL reconstruction is considered to be essential to facilitate successful short- and long-term outcomes (Di Stasi et al., 2013).

Alterations in neuromuscular control after a knee joint injury may not only occur at the involved joint, but also at proximal and distal joints (Riemann and Lephart, 2002). Nevertheless, most studies measuring muscle activity after ACL reconstruction only focused on muscles surrounding the operated knee joint (Beard et al., 2000; Bryant et al., 2009; Coats-Thomas et al., 2013; DeMont et al., 1999; Oeffinger et al., 2001; Vairo et al., 2008; Wojtys and Huston, 2000). Only a scarcity of research focused on neuromuscular control of the whole lower extremity (including hip, knee and ankle muscles) after ACL reconstruction (Gokeler et al., 2010; Nyland et al., 2010, 2013). Furthermore, it is difficult to draw firm conclusions due to the differences in tasks, graft selection, time after ACL reconstruction and outcome measurements in these studies. Bilateral neuromuscular control deficits may exist after unilateral ACL reconstruction (Beard et al., 2000; Nyland et al., 2010, 2013; Wojtys and Huston, 2000). Caution is therefore warranted

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when conclusions are based on the comparison of the operated leg with the non-operated leg after ACL reconstruction. The rationale to investigate muscle activation patterns not only of muscles surrounding the operated knee joint, but also of the adjacent joints and the contralateral leg, is supported by the growing evidence demonstrating the crucial role of central nervous system (CNS) adaptations after ACL injury and reconstruction (Grooms et al., 2015).

The transition from double-leg stance to single-leg stance has previously been used to assess neuromuscular control deficits in subjects with a variety of musculoskeletal impairments of the lower quadrant (Dingenen et al., 2015b; Hodges and Richardson, 1998; Hungerford et al., 2003; Morrissey et al., 2012; Sole et al., 2012; Van Deun et al., 2007). The advantage of this transition task is that the sensorimotor system can be experimentally challenged in specific ways when eliminating or altering for example the visual input, changing movement speed or decreasing the movement preparedness. In addition, this transition task allows measuring subjects across different stages of a rehabilitation process. An anticipatory muscle activity during this task can be interpreted as a strategy selected by the CNS to prepare the lower extremity for the upcoming postural perturbation created by the transition task, while slower muscle recruitment may decrease the ability to effectively stabilize the lower extremity joints (Bouisset and Do, 2008; Dingenen et al., 2015b).

Dingenen et al. (2015b) were the first to focus on muscle activation patterns of the whole lower extremity during this transition task in ACL-deficient subjects, tested prior to ACL reconstruction surgery. Delayed muscle activation onset times were not only found at the knee but also at the hip and ankle muscles. Furthermore, no consistent differences between the injured and non-injured leg of the ACL injured group were reported (Dingenen et al., 2015b). These bilateral and multi-segmental neuromuscular deficits support the contribution of alterations in the organization of the CNS after ACL injury (Grooms et al., 2015; Kapreli et al., 2009). However, it remains unclear whether these altered muscle activation patterns are still present after ACL reconstruction. These insights might allow clinicians to broaden their vision on neuromuscular alterations after ACL injury and reconstruction, which can assist improving rehabilitation approaches (Williams et al., 2001).

The aim of the present study was therefore to investigate muscle activation onset times of knee, hip and ankle muscles of both legs in ACLR and non-injured control subjects. First, it was hypothesized that ACLR subjects would show delayed muscle activation onset times compared to non-injured control subjects, not only around the operated knee joint, but also around the hip and ankle. Second, it was hypothesized that no significant differences would be found between the operated and non-operated leg of the ACLR group.

2. Methods

2.1. Subjects

The same 40 subjects of the study of Dingenen et al. (2015a) were tested. Before participating in the study, all subjects read and signed an informed consent form, which was approved by the local ethical committee. The ACLR group ($n = 20$) included subjects with a history of one ACL reconstruction at least 9 months before the testing, who completed rehabilitation and fully returned to their pre-injury competitive sport involving pivoting, jumping and/or cutting activities. The time after ACL reconstruction was mean (SD) = 22.98 (13.97) months (range: 9.60–54.70 months). Subjects reporting ankle, knee, hip or low back pain during athletic activities or previous lower extremity surgery (except the primary ACL reconstruction) on a custom-made self-report questionnaire were excluded. All ACL injuries were caused by a non-contact injury mechanism and treated with an ipsilateral hamstring autograft. From all ACLR subjects, an equal number of subjects had undergone surgery on the dominant ($n = 10$) or non-dominant leg ($n = 10$). The dominant leg was defined as the preferred leg to kick a ball. The control group ($n = 20$) included subjects with no history of ankle, knee, hip or low back injury (Dingenen et al., 2013). The activity level of all subjects was evaluated with the Tegner activity rating scale (Briggs et al., 2009; Negahban et al., 2013). Subjects younger than 18 and older than 55 years old, and with the following conditions were also excluded: chronic ankle instability (subjects with a history of at least 2 ankle sprains at the same ankle in the past 2 years and reporting a subjective feeling of “giving way” of the ankle) (Dingenen et al., 2013), Parkinson, multiple sclerosis, cerebrovascular accident, peripheral neuropathies, circulation disorders, serious joint disorders (rheuma, osteoarthritis, etc.).

2.2. Data collection

Ground reaction forces and muscle activity of 10 lower extremity muscles were measured simultaneously and synchronously during the transition from double-leg stance to single-leg stance (Dingenen et al., 2015b). Ground reaction forces were measured by a 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. Surface electromyography (EMG) (Noraxon Myosystem 1400®) signals were measured at 2000 Hz using MyoResearch 2.0 (Noraxon USA, Inc., Scottsdale, AZ) and Spike2 software. The gluteus maximus, gluteus medius, tensor fascia latae, vastus lateralis, vastus medialis obliquus, hamstrings medial, hamstrings lateral, tibialis anterior, peroneus longus and gastrocnemius were measured unilaterally on the upcoming single-leg stance leg (Dingenen et al., 2015b). Placement of the electrodes was based on the instructions of Basmajian and De Luca (Basmajian and De Luca, 1985). One reference electrode was put on the anteromedial side of the tibia. The silver-silver chloride, pre-gelled bipolar surface EMG electrodes (Medicotest Inc., Rolling Meadows, IL) were placed over the muscle belly and aligned with the longitudinal axis of the muscle, with a center-to-center distance of 10 mm. The minimum distance between electrode pairs was set at 3 cm to reduce the possibility of cross-talk between neighboring muscles. The skin area where electrodes were applied was shaved and gently cleaned with 70% isopropyl alcohol to reduce the impedance. The EMG signals were stored on a PC for further analysis. The position of the electrodes was confirmed by isolated manual muscle tests.

2.3. Procedure

The procedure used in this study is based on previous studies (Dingenen et al., 2013, 2015a, 2015b, 2015c, 2015d, 2015e). Subjects were asked to stand barefoot 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 (Fig. 1). The leg that was tested first was assigned randomly. 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 toward approximately 60° of hip flexion within 1 s, using a metronome as a reference. For all subjects, an equal number of fake trials (shifting the weight to the non-tested leg) were randomly included to avoid preparedness. The transition task from double-leg stance to single-leg stance was tested with eyes open and with eyes closed. Both conditions were repeated 3 times in an alternating order. In the eyes open tests, subjects were instructed to keep their gaze straight ahead facing a white wall. The eyes closed condition was included as one may hypothesize to find more apparent differences between groups because of the increased reliance on visual information during postural control tasks after ACL injury and reconstruction (Grooms et al., 2015). All subjects were allowed to familiarize with