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Successful feed-forward strategies following ACL injury and reconstruction

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Abstract

The purpose of this study was to elucidate the most successful feed-forward strategies responsible for enhancing dynamic restraint following anterior cruciate ligament (ACL) injury and ACL reconstruction (ACLR). Ten male ACL deficient (ACLD) subjects (18–35 years) together with 27 matched males who had undergone ACLR (14 using a patella tendon graft and 13 using a combined semitendinosus and gracilis graft) and 22 matched-control subjects were recruited. After their knee functionality (0- to 100-point scale) was rated using the Cincinnati Knee Rating System, each subject performed a maximal, countermovement hop for distance on their involved limb while EMG data were collected from the vastus lateralis (VL), vastus medialis (VM), semitendinosus (ST) and biceps femoris (BF) muscles. Acceleration transients at the proximal tibia were recorded using a uniaxial accelerometer mounted at the level of the tibial tuberosity. Whilst pre-programmed muscle activation strategies and tibial acceleration transients when landing from a single-leg long hop for distance were not contingent upon ACL status, a number of significant correlations were identified between neuromuscular variables and knee functionality of ACLD and ACLR subjects. Increased hamstring preparatory activity together with a greater ability to control tibial motion during dynamic deceleration was associated with higher levels of knee functionality in the ACLD subjects. Successful feed-forward strategies following ACLR were related to graft selection; STGT subjects with superior knee function activated their quadriceps earlier and were better able to synchronise peak hamstring muscle activity closer to initial ground contact whilst more functional PT subjects demonstrated enhanced tibial control despite a lack of evidence supporting modified pre-programmed muscular activation patterns. Our conclusion was that more functional individuals used sensory feedback to build treatment-specific, feed-forward strategies to enhance dynamic restraint when performing a task known to stress the ACL.

Keywords: ACL injury; ACL reconstruction; Feed-forward strategies; Dynamic restraint; Knee functionality

1. Introduction

Although rare, some anterior cruciate ligament deficient (ACLD) patients have minimal impairment following rupture of their ligament and are able to participate in strenuous activities with few functional limitations (e.g. Daniel et al., 1994; Steele and Brown, 1999; Walla et al., 1985; Wojtys and Huston, 1994). Clearly, those with ACL injuries who return to high levels of physical activity, despite the absence of surgical reconstruction, possess the most successful adaptive mechanisms, overcoming considerable passive joint laxity and in doing so, minimising repeated bouts of functional instability and serious pathologic sequelae (McNair et al., 1992; Swanik et al., 2004).

Rather than relying upon reflexive muscular activation in response to stimuli occurring during an activity, more functional ACLD patients are thought to use sensory feedback to build a new internal model to compensate for mechanical instability (Steele and Brown, 1999; Swanik

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et al., 2004). As the quadriceps and hamstring muscles apply opposite (anterior and posterior) shear forces to the tibia, it is acknowledged that the control of these muscles might be adapted at a subconscious level to stabilise the ACLD knee during dynamic weightbearing activity (Shelburne et al., 2005). In support of this notion, several studies (Bulgheroni et al., 1997; Sinkjäer and Arendt-Nielsen, 1991) incorporating electromyography (EMG) have linked preparatory and early support phase muscle activation strategies of the quadriceps and hamstrings to enhanced dynamic restraint following ACL injury. However, relatively few investigations have incorporated a single-limb landing task known to stress the ACL, such as a single-limb stride landing, when examining adaptive patterns of muscle synchrony displayed by ACLD patients (Branch et al., 1989; Branch et al., 1994; McNair and Marshall, 1994; Steele and Brown, 1999; Swanik et al., 2004). Furthermore, fewer studies (McNair and Marshall, 1994; Swanik et al., 2004) have attempted to elucidate the relationship between the muscle activation patterns of ACLD patients and a reliable clinical rating of knee functionality.

For those more symptomatic and less functional ACLD patients who wish to return to high stress activities, ACL reconstruction (ACLR) is typically performed in an effort to restore dynamic joint support. Whilst ACLR using either the patella tendon (PT) or combined semitendinosus and gracilis tendon (STGT) is known to restore static anterior knee stability (Frndak and Berasi, 1991; Tibone and Antich, 1988), the neurosensory potential and, hence the capacity of the ACL substitute to contribute to the modification and formulation of motor programs necessary to pre-activate muscles prior to ground contact when performing abrupt landing tasks remains unclear. Even if the ACL graft is 'inert' from a neurosensory potential, it is clear from studies incorporating ACLD patients that neuropathways other than those mediated by receptors in the ACL exist and can provide sensory feedback to pre-program muscle activation patterns in anticipation of movements and joint loads. Nevertheless, the true nature of the pattern of quadriceps and hamstring muscle activation which protects the maturing ACL substitute and maximises knee functionality following ACLR has defied detection. Confounding the notion of a single, 'ideal' pattern of muscle synchrony following ACLR is the possibility that muscle recruitment strategies, which enhance functionally of the post-surgical limb, are graft-specific given that the process of harvesting the ACL substitute might cause neural inhibition and/or altered mechanics of the donor musculotendinous unit (Mattacola et al., 2002).

During abrupt deceleration, acceleration transients at the proximal tibia generate tibiofemoral shear forces that load the passive knee joint structures (Gauffin and Tropp, 1992; Lafortune and Hennig, 1991; Shelburne et al., 2004). Typically, peak tibial acceleration (TA_p) occurs too early for sensory feedback from the peripheral sites to contribute to modification of the deceleration technique in response to joint loading (McMahon and Greene, 1979; Steele and Brown, 1999; Swanik et al., 2004). Hence, the pre-programmed sequence of muscular commands formulated by previous experience and dispatched by the central nervous system before initial ground contact are thought to be the major source dictating the amplitude and temporal characteristics of tibial acceleration transients. Conceivably, the ability to control anterior tibial acceleration transients following ACL injury and ACLR via modified feed-forward processes might influence knee functionality. Identifying patterns of aberration in pre-programmed neuromuscular strategies of ACLD and ACLR patients during an abrupt landing task and assessing the relationships between these adaptations and knee functional status might clarify the most advantageous characteristics of the dynamic restraint mechanism. Therefore, the purpose of this study was twofold: (i) to delineate differences in feed-forward processing of ACLD patients and patients having undergone ACLR using different grafts (PT and STGT) by examining muscle activation patterns and accelerations of the proximal tibia when performing a dynamic landing task known to stress the ACL and, (ii) to identify relationships between pre-programmed neuromuscular strategies and the functional status of ACLD and ACLR patients. It was hypothesized that ACLD subjects, on average, would demonstrate earlier hamstring activation compared to ACLR and control subjects (H_1) and furthermore, more functional ACLD and ACLR subjects would activate their hamstrings earlier than their less functional counterparts (H_2 and H_3, respectively).

2. Materials and methods

2.1. Subjects

Ten male ACLD patients together with 14 ACLR subjects who had undergone reconstruction using the PT graft and 13 ACLR subjects reconstructed using the STGT graft volunteered as subjects. Female subjects were excluded as hormonal fluctuations can affect joint dynamics including joint laxity (Hewett, 2000; Romani et al., 2001; Romani et al., 2003; Shultz et al., 2004) and the viscoelastic properties of the lower limb musculature (Eiling et al., 2007). All reconstructions were performed by the same orthopaedic surgeon and ACLR subjects in the PT and STGT groups were matched for the time since reconstructive surgery. On clinical examination, all ACLR subjects had regained full ROM and were stable in flexion and extension (i.e. negative Lachman and pivot shift tests). For the ACLD subjects, isolated complete rupture of the ACL was confirmed by previous arthroscopy and initial injury occurred at least 1 year before testing. All ACLD subjects demonstrated a minimum of a grade two Lachman (mean = 2.5 ± 0.4) and pivot shift (mean = 2.4 ± 0.4) test. Subjects in the ACLD and ACLR groups also met the following inclusion criteria: