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Asymmetries in explosive strength following anterior cruciate ligament reconstruction

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ABSTRACT

Background: Despite its apparent functional importance, there is a general lack of data regarding the time-related changes in explosive strength and the corresponding side-to-side asymmetries in individuals recovering from an ACL reconstruction (ACLR). The present study was designed to assess changes in the maximum and explosive strength of the quadriceps and hamstring muscles in athletes recovering from an ACLR.
Methods: Twenty male athletes with an ACL injury completed a standard isometric testing protocol pre-ACLR, four and six months post-ACLR. In addition to the maximum strength (F_{max}), the explosive strength of quadriceps and hamstrings was assessed through four variables derived from the slope of the force–time curves over various time intervals (RFD_{max}, RFD_{50}, RFD_{150} and RFD_{250}). Side-to-side asymmetries were calculated relative to post-ACLR measures of the uninvolved leg ("standard" asymmetries), and relative to pre-ACLR value of the uninvolved leg ("real" asymmetries).
Results: Pre-ACLR asymmetries in quadriceps RFD (average 26%) were already larger than in F_{max} (14%) ($p < 0.05$). Six months post-ACLR real asymmetries in RFD variables (33–39%) were larger than the corresponding standard asymmetries (26–28%; $p < 0.01$). Average asymmetries in hamstrings' RFD and F_{max} were 10%, 25% and 15% for pre-ACLR and two post-ACLR sessions, respectively (all $p > 0.05$).
Conclusions: In addition to the maximum strength, the indices of explosive strength should also be included in monitoring recovery of muscle function following an ACLR. Furthermore, pre-injury/reconstruction values should be used for the post-ACLR side-to-side comparisons, providing a more valid criterion regarding the muscle recovery and readiness for a return to sports.

1. Introduction

Evaluation of the quadriceps and hamstrings' maximum strength is of profound importance in monitoring recovery following an ACL reconstruction (ACLR) [4–7]. Among a number of methods applied to the assessment and monitoring of the muscle strength following an ACLR has been the standard isometric test based on the maximum voluntary contraction of the tested muscle [6,8–10]. The routinely recorded dependent variable that depicts the maximum strength has been the maximum force (F_{max}), typically achieved over three–five s of a sustained maximum contraction [11,12].

In addition to the maximum strength, the so-called explosive strength (i.e., the ability to quickly exert high muscle force [13,14]) has been considered an important functional property of tested muscles. Explosive strength has been typically assessed from the slope of the force–time curve as the rate of force development (RFD) at various time intervals from the onset of the muscle contraction [13]. It has been previously demonstrated that the RFD could be influenced by different neurophysiological mechanisms at the early (<100 ms) and late phase (>100 ms) of the isometric contractions [15]. Specifically, the indices of explosive strength that obtained from the early phase of force development may predominantly depend upon the level of neural excitation. Note that a diminished quadriceps control has been observed in people with ACL deficiency [1]. Namely, loss of afferent feedback from knee joint structures leads to suppressed feedback from the ACL to gamma motor neurons and results in chronic suppression of recruitment of high-threshold motor units during voluntary contraction of the quadriceps [2,3]. Conversely, the same indices obtained from the later phase may be more dependent upon the muscle contractile mechanisms [13,16]. A number of studies have shown that the ability to quickly exert a high level of muscle force should be more important

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for maximizing movement performance than the maximum strength, particularly in the movement tasks of limited duration [13,17–19] where quick and forceful muscle contractions are needed [16,19,20], such as in athletic activities like jumping and sprinting [14,21]. A high level of explosive strength may be equally important when stabilizing the posture during standing, locomotion, or in response to mechanical perturbations [22,23].

Despite its apparent functional importance, there is a general lack of data regarding the time-related changes in the explosive strength and the corresponding side-to-side asymmetries in individuals recovering following an ACLR. Some aspects of the measures in monitoring recovery following musculoskeletal injuries have only recently been addressed [13,18,24]. Thus, the indices of explosive strength were introduced for the purpose of a predisposing risk factor for an ACL injury [18], and as a complementary measure to maximum strength aimed to follow up the recovery of muscle function after an ACLR [17]. Note that although a positive relationship between the maximum and explosive strength has been documented [19,25,26], the same muscle abilities should also be partly independent [19,20,27]. Namely, previous studies have suggested that short-term improvements in explosive and maximum force production may require distinct training stimuli that elicit specific adaptations (e.g., high-load contractions have proved effective in increasing maximum strength, while there is equivocal evidence for its effects on explosive force production). In addition, the different phases of RFD curves can be differently modified by resistance training protocols [14,15,19]. Consequently, both an ACL injury and the post-ACLR rehabilitation process could selectively affect the maximum and explosive strength. This assumption has been supported by studies in which mechanisms of quadriceps weakness following an ACLR were explained by a loss of afferent feedback from the ACL [3,28]. The loss could have caused a prolonged disuse and hypotrophy of fast-twitch muscle fibres, which are predominantly responsible for force production in fast contractions. This could also lead to a more pronounced decrease in muscle ability to quickly exert the needed force, than in providing an overall high strength. Nevertheless, none of the cited studies have investigated time-related changes in the quadriceps and hamstrings' maximum and explosive strength during rehabilitation following an ACLR.

Another problem associated with the assessments of muscle function in individuals recovering from an ACLR is related to the use of strength measures when assessing an athlete's readiness for their return to unrestricted athletic activity. Namely, a number of studies have recommended using the side-to-side asymmetry (i.e., the ratio between the strength of the involved leg and uninvolved leg in further text "standard" asymmetries) for that purpose [5,17,29–31]. In particular, a side-to-side asymmetry below 15% has been accepted as a general criterion for athletes to return to sports activity [4,29,32,33]. However, an important problem with this approach could originate from the differences between legs obtained from the period following an ACLR, which could underestimate the real magnitude of asymmetry. Namely, an ACL injury typically leads to a cross-over effect in the uninvolved leg resulting in both strength and functional loss based on various central and peripheral mechanisms [4,16,33]. Therefore, it has recently been suggested that the use of pre-injury values could provide a more valid criterion [4,17,30]. Although the discussed approach has clear advantages over the standard one based on the post-ACLR side-to-side asymmetries, the pre-injury measures are usually unknown, making this approach difficult to use in routine procedures. However, in the absence of pre-injury measures, the muscle function of either both legs or only the uninvolved leg could be routinely assessed prior to the ACLR, and thereafter used for the comparison with post-ACLR measures (in further text "real" asymmetries), which could provide a potentially more valid assessment of the magnitude of side-to-side asymmetries.

To address the discussed problems, the current study was designed to evaluate the changes in the maximum and explosive strength of the quadriceps and hamstring muscle in athletes recovering from an ACLR. We hypothesized that 1) the asymmetries in explosive strength would be larger when compared with the maximum strength, as well as that 2) real asymmetries (where pre-ACLR value of the uninvolved leg was used as a control) would be larger than standard asymmetries obtained from post-ACLR measurements. The obtained results are expected to contribute to further refinement of the methods used for muscle function testing in individuals recovering after an ACLR.

2. Methods

2.1. Participants

According to standard guidelines [34] with effect size of 0.5, power of 0.8 and an alpha level of 0.05 (calculated by G*Power 3.1 free software [35]), the required sample size was 15. Twenty-three ACLR participants were initially recruited through the Clinic for Orthopaedic Surgery and Traumatology, but three were lost to follow-up. The remaining 20 participants were males soccer (N = 12), handball (5) and judo (3) competitors engaged in professional sport at the national level. Their age was 22 ± 0.9 years, body mass 84.0 ± 2.5 kg, height 180.3 ± 0.9 cm (data presented as mean ± SE). The inclusion criteria were: first ACL injury and participation in competitive sports at the national level or higher. The exclusion criteria were: other knee ligaments injured, history of concurrent fractures, osteoarthritis, as well as hereditary and neuromuscular diseases. The ACLR procedure was performed by the same experienced surgeon, using the bone–patellar–bone tendon (BPTB) autograft. Following the surgery, the participants were allocated to a standard postoperative rehabilitation program for athletes. All participants received a complete explanation regarding the purpose and procedures of the study, as well as the possible risks. Ethical clearance for the study was obtained from the pertinent institutional review board. In line with the Helsinki Declaration, the institutionally approved informed consents were obtained from participants and their rights were protected.

2.2. Testing procedure

All measurements were taken from three separate sessions: pre-ACLR (i.e. within seven days prior to surgery), as well as four and six months post-ACLR. Standard clinical assessments included questionnaires (International Knee Documentation Committee (IKDC) subjective score [36] and Tegner score [37]) and knee laxity test performed with KT1000 instrumented arthrometer (MEDmetric Corporation, San Diego, CA) at 13.61 kg of force [17]. All clinical assessments were performed by an experienced orthopedist. At six months post-ACLR, all participants performed a one-leg hop test for distance as a functional assessment of the dynamic stability of the knee. The hop test was performed both with the uninvolved leg and involved leg, according to the standard procedure [38].

Strength measurements were performed within a university research laboratory, using a Kin-Com AP125 isokinetic dynamometer (Chatex Corp., Chattanooga, Tennessee, USA) set to isometric conditions. The subjects were seated in an upright position and fixed to the testing apparatus, with the straps around the pelvis, the thigh, and malleoli. The axis of rotation of the dynamometer was aligned with the lateral femoral epicondyle. The knee angle was fixed at 45° in flexion (0° corresponded to full extension) [39,40]. Prior to muscle strength testing, each subject was given a five min warm-up period on a stationary bicycle, followed by passive stretching exercises, and two submaximum isometric contraction trials performed using the dynamometer. The uninvolved leg was always tested first. A real time visual feedback of the force–time curve was available during the assessment of the maximum isometric strength [19,41]. The same experienced test leader supervised all the tests. A detailed explanation and a qualified demonstration were both provided prior to each muscle