Hamstring-Dominant Strategy of the Bone–Patellar Tendon–Bone Graft Anterior Cruciate Ligament–Reconstructed Leg Versus Quadriceps-Dominant Strategy of the Contralateral Intact Leg During High-Intensity Exercise in Male Athletes

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Purpose: The purpose of this study was to investigate the effect of anterior cruciate ligament (ACL) reconstruction on the quadriceps-dominant strategy as a parameter associated with the neuromuscular control of the knee joint. **Methods:** In this study 14 competitive soccer players who had undergone ACL reconstruction with bone–patellar tendon–bone autograft and 14 healthy competitive soccer players performed two 10-minute treadmill runs, 1 at moderate intensity and 1 at high intensity. Electromyographic recordings were acquired by use of a telemetric system at the third, fifth, seventh, and tenth minute of the runs from the vastus lateralis and the biceps femoris bilaterally. The dependent variable examined was the peak electromyographic amplitude during the stance phase. Analyses of variance were used to examine significant main effects and interactions. **Results:** Vastus lateralis electromyographic activity during high-intensity running increased for both the control leg and intact leg ($F = 4.48$, $P < .01$), whereas it remained unchanged for the reconstructed leg ($P > .05$). Biceps femoris electromyographic activity during high-intensity running increased for the reconstructed leg only compared with both the control leg ($F = 3.03$, $P < .05$) and intact leg ($F = 3.36$, $P < .03$). **Conclusions:** There is no presence of the quadriceps-dominant strategy in ACL-reconstructed athletes during moderate-intensity exercise. During high-intensity exercise, the intact contralateral leg develops the quadriceps-dominant strategy whereas the reconstructed leg does not. The reconstructed leg instead increases biceps femoris activity, developing a "hamstring-dominant" strategy, and this "asymmetry" may theoretically be in favor of the reconstructed knee. **Level of Evidence:** Level III, retrospective comparative study.

After anterior cruciate ligament (ACL) reconstruction, several alterations in the neuromuscular control of the knee joint may develop, including selective muscle fiber atrophy in the involved quadriceps,[1,2] altered motor unit activation after surgery and subsequent retraining,[3] and loss of joint afferent in-

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The authors report that they have no conflicts of interest in the authorship and publication of this article.

Received June 9, 2011; accepted February 7, 2012.

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0749-8063/11367/$36.00

doi:10.1016/j.arthro.2012.02.014

formation, which may lead to suboptimal muscle fiber activation.[4] These neuromuscular response perturbations of ACL-reconstructed knees may affect the amount of stress that is applied on the ACL graft postoperatively because of selective muscle activation and thus may have important implications for the graft integrity. Moreover, because relevant neuromuscular control strategies have been previously considered as potential risk factors for native ACL injury,[5-7] they most likely have dual interests in the case of an ACL-reconstructed individual, namely the reconstructed knee and the contralateral intact knee.

Even if pure muscular response is measured, the combined recordings from both anterior and posterior thigh muscle activity may provide important information regarding the amount of stress that is applied to the ACL (either the native ACL or a graft substitute). For instance, the quadriceps-to-hamstring ratio has been considered a parameter associated with neuromuscular control that can affect ACL integrity.[7] Because exercise intensity has been related to muscle activity,[8-10] it would be reasonable to observe such neuromuscular response parameters with reference to the exercise intensity. During moderate-intensity activities such as walking and jogging, ACL reconstruction reestablishes the extensor electromyographic (EMG) activity of the operated leg toward normative values.[11-14] On the contrary, no relevant information exists regarding high-intensity exercise in ACL-reconstructed individuals. High-intensity exercise represents a particular condition where metabolic fatigue is accumulated and special neuromuscular demands evolve. The quadriceps-dominant strategy that has been described for healthy subjects while performing high-intensity exercise consists of an increase in agonist (extensor) EMG activity without a concomitant increase in antagonist (flexor) EMG activity.[8,15,16] This response is considered to represent an optimization strategy to compensate for the deleterious effects of fatigue on joint neuromuscular control.[8,15,16]

However, the literature lacks information about the neuromuscular response of the ACL-reconstructed leg during high-intensity exercise. In addition, what the neuromuscular response behavior of the intact contralateral knee of an individual with unilateral ACL reconstruction is during high-intensity activities is unknown.

The purpose of this study was to investigate the effect of ACL reconstruction on the quadriceps-dominant strategy as a parameter associated with the neuromuscular control of the knee joint during moderate- and high-intensity exercise. We hypothesized that (1) during moderate-intensity exercise, there would be no evidence of the quadriceps-dominant strategy for the control, intact, or reconstructed leg, and (2) during high-intensity exercise, the quadriceps-dominant strategy would be evident for the control and intact contralateral legs but not for the reconstructed leg.

METHODS

Two groups of athletes participated in the study. The first group consisted of a consecutive series of 14 competitive male soccer players with ACL-reconstructed knees (mean age, 24.8 years [SD, 5.3 years]; mean body mass, 77.3 kg [SD, 7.5 kg]; mean height, 177 cm [SD, 5.3 cm]), and the second group consisted of 14 healthy competitive male soccer players who had never had any kind of orthopaedic or neurologic condition (mean age, 21.7 years [SD, 4.4 years]; mean body mass, 72.2 kg [SD, 8.3 kg]; mean height, 180 cm [SD, 9.0 cm]). The operated athletes had undergone ACL reconstruction with bone–patellar tendon–bone autograft, on average 18.5 months (SD, 4.3 months) before testing. ACL reconstruction was performed subacutely within 6 months after the injury by the same surgeon (range, 1 to 4 months). All subjects had a unilateral ACL tear confirmed by magnetic resonance imaging and arthroscopy.

All subjects underwent the same rehabilitation protocol, starting from the first postoperative day with the use of passive exercises. Return to sports was permitted 6 months after reconstruction provided that the athletes had regained stability and full functional strength, according to the following criteria[17]: (1) full range of motion, (2) KT-1000 (MEDmetric, San Diego, CA) side-to-side difference of less than 3 mm, (3) quadriceps strength greater than 85% compared with the contralateral side, (4) hamstring strength of 100% compared with the contralateral side, (5) hamstring-to-quadriceps strength ratio greater than 70%, and (6) functional testing greater than 85% compared with the contralateral side. The subjects' strength was determined with the BIODEX System-3 isokinetic dynamometer (Biodex, Shirley, NY), showing acceptable symmetry in quadriceps and hamstring strength, as well as an acceptable hamstring-to-quadriceps ratio. All subjects agreed to undergo the testing protocol and gave their consent to participate in accordance with the institutional review board policies of our medical school.

Before any data collection, a clinical evaluation was performed on all subjects by the same clinician. During this evaluation, the Tegner and Lysholm