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ACL RECONSTRUCTED PATIENTS WITH A BPTB GRAFT PRESENT AN IMPAIRED VASTUS LATERALIS NEUROMUSCULAR RESPONSE DURING HIGH INTENSITY RUNNING.

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ABSTRACT

The purpose of the present study was to investigate whether the electromyographic response of the vastus lateralis (VL) muscle in the anterior cruciate ligament (ACL) reconstructed leg is similar to that of the intact contralateral leg and healthy controls, during moderate and high intensity running. Fourteen bone-patellar tendon-bone (BPTB) ACL reconstructed amateur soccer players and fourteen healthy control amateur soccer players volunteered to participate in the study. Electromyographic (EMG) traces from the vastus lateralis (VL) muscle were collected bilaterally, as athletes ran on a treadmill for 10 minutes on separate occasions, at moderate and high intensity. The dependent variable examined was the EMG amplitude during stance. During the moderate intensity running, EMG amplitude of the VL did not increase with time for any of the tested legs. During the high intensity running, the EMG amplitude of the VL increased significantly with time for the intact ($F=6.747$, $p=0.001$) and the control leg ($F=4.258$, $p=0.008$), but remained unchanged for the ACL reconstructed leg. During moderate intensity running, there was no difference in the neuromuscular response of the VL in the reconstructed leg compared to the intact and control leg. High intensity running resulted in an impaired neuromuscular response of the VL in the reconstructed leg compared to the intact and control leg. It seems that potential impairments of the neuromuscular response after ACL reconstruction should be tested under high rather than moderate intensity efforts.

Key words: telemetric electromyography, running, ACL reconstruction, exercise intensity

INTRODUCTION

Anterior cruciate ligament (ACL) function is closely associated with optimal activation of the muscles surrounding the knee joint [1, 2]. Rupture of the ACL leads to alterations in muscle recruitment patterns [3, 4]. It has been demonstrated that reconstruction of the ACL re-establishes muscle activation levels, as assessed by surface electromyography (EMG) amplitude, towards normative values during moderate intensity activities [5-7]. However, moderate intensity exercises do not resemble situations that are encountered during participation to sports activities.

One feature of the neuromuscular response after ACL reconstruction that has not been investigated by previous studies is the progression of EMG activation levels with time during the exercise. It is well established that EMG amplitude time course is greatly influenced by exercise intensity [8, 9, 10]. During moderate intensity, EMG amplitude does not increase with time [9, 11, 12], while during high intensity, it does [9, 11-13]. The increasing EMG amplitude with time, during high intensity exercise is considered to reflect the physiological response that is required for the increasing metabolic demands of the exercise [8, 9, 10].

Previous EMG studies reported that ACL reconstructed (ACLR) subjects exhibit neuromuscular alterations, such as selective muscle fiber atrophy in the involved vastus lateralis (VL) [14-16], altered motor unit activation of the quadriceps following surgery and subsequent retraining [17] and loss of joint afferent information which may lead to suboptimal muscle activation [1, 18]. These neuromuscular alterations may therefore impair the proper physiological response required at high exercise intensities. Thus, it is possible that the VL muscle of the operated leg could exhibit impaired neuromuscular response resulting in inability to naturally increase the EMG amplitude with time during high intensity exercise.

Therefore, the purpose of the present study was to investigate the effect of ACL reconstruction with BPTB graft on VL activation levels with time during moderate and high intensity running. It is well established that exercise intensity is best assigned relative to the lactate threshold and VO_2max [8, 19]. We hypothesized that (a) during moderate intensity exercise the EMG amplitude of the VL will not increase with time for any of the ACLR, intact and control legs, (b) during high intensity exercise

the EMG amplitude of the VL will increase with time for the control and intact leg but not for the ACLR leg.

METHODS

Two groups of athletes participated in the study. Fourteen amateur male soccer players [mean (SD) age, body weight and height, 24.8 (5.3) years, 77.3 (7.5) kg and 177 (5.3) cm] with ACL-reconstructed knees and fourteen healthy amateur male soccer layers who had never suffered of any kind of orthopaedic or neurological condition [mean (SD) age, body weight and height, 21.7 (4.4) years, 72.2 (8.3) kg and 180 (9.0) cm]. The operated athletes had undergone ACL reconstruction with bone-patella tendon-bone (BPTB) graft, 18.5 (4.3) months before testing. ACL reconstruction was performed sub-acutely within 6 months after the injury from the same surgeon (A.G). All subjects had a unilateral ACL tear confirmed by MRI and arthroscopy.

All operated athletes underwent the same rehabilitation protocol, starting from the first post operative 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 well accepted criteria [20]. All subjects agreed with the testing protocol and gave their consent to participate in accordance with the Institutional Review Board policies of our Medical School. Prior to any data collection, a clinical evaluation was performed in all athletes by the same clinician. During this evaluation, the Tegner and Lysholm scores were obtained, while anterior tibial translation was evaluated using the KT-1000 knee arthrometer (MEDmetric Corp., San Diego, California) [21].

The athletes reported to the laboratory on three different occasions, separated by 48 hours, within a two weeks period. For their first visit to the laboratory, athletes performed an incremental treadmill (Technogym Runrace 1200, Italy) running test to volitional exhaustion with 3 minute-stages, to determine VO_2max and lactate threshold (LT) [22]. A computerized system was used for all metabolic measurements (CPX Ultima, Medical Graphics, St Maul, MN, USA). At the end of each stage, capillary blood samples were collected and analyzed for lactate (Accutrend, Roche Diagnostics, Germany). Prior to each test, all analyzers were calibrated according to the manufacturer instructions. Attainment of VO_2max was verified according to criteria established by the American College of

Sports Medicine [22]. Lactate threshold was determined according to Cheng et al [23]. The high intensity running was set at 40% of the difference between VO_2max and lactate threshold (40%D) and the moderate intensity running was set at 80% of the lactate threshold [19].

In each of the two subsequent visits to the laboratory, athletes were required to perform a 10-minute run at the pre-selected intensities. We tested one intensity at each visit and the order was randomly assigned for every athlete. During running, EMG data were collected for 15 seconds at the 3rd, 5th, 7th and 10th minute. Gas exchange data were recorded simultaneously breath-by-breath, heart rate was measured throughout the test and blood lactate was measured prior to running and immediately after termination of exercise.

EMG traces were obtained from the VL muscle bilaterally using bipolar, circular, pre-amplified, pre-gelled Ag/AgCl electrodes with 10 mm diameter and fixed inter-electrode spacing of 20 mm (Noraxon Inc, Scottsdale, AZ, USA). EMG data were recorded with a wireless 8-channel EMG system (Telemyo 2400T, Noraxon Inc, Scottsdale, AZ, USA) and displayed real-time on a personal computer using dedicated software (MyoResearchXP, Noraxon Inc, Scottsdale, AZ, USA). The surface of the skin was prepared by shaving hair, rubbing it with abrasive paper and cleaning it with alcohol. The electrodes were fixed longitudinally over the muscle belly. Electrodes were placed at the antero-lateral muscle bulge at 2/3 of the proximo-distal thigh length [24, 25]. The visually largest area of muscle belly was selected using a contraction against manual resistance. The ground electrode was placed on lateral femoral condoyle of the right leg. Electrodes and cables were secured with surgical tape, in order to avoid any interference with the running pattern of the subjects.

Footswitches (Noraxon Inc, Scottsdale, AZ, USA) placed under the heel and big toes of both legs were used to denote heel-strike and toe-off. EMG was acquired at a sampling rate of 1500 Hz. The raw EMG was measured in a band of 10 to 500 Hz, full-wave rectified, high pass filtered (cut-off frequency at 20 Hz) with an 8th order Butterworth filter to remove movement artifacts and smoothed with a 100 ms RMS algorithm.. Values from 20 strides were averaged to calculate the mean peak amplitude during stance for each of the four time intervals.

Based on our hypotheses, the dependent variable examined in the present study was the mean peak EMG amplitude during the stance phase. A 2-way fully repeated ANOVA within the control

group, with time (four levels) and leg (two levels) as within-subjects factors, revealed no time*leg interactions for the EMG amplitude for either the moderate or high intensity running. Thus, the left leg was selected as the control leg.

The time course of the EMG amplitude during running was compared between the reconstructed and intact leg with a 2-way fully repeated ANOVA, with time (four levels) and leg (two levels) as within-subjects factors. Similarly, the time course of the EMG amplitude during running was compared between the reconstructed and the control leg and between the intact and control leg, with 2-way mixed ANOVAs, with time (four levels) as within- and group (two levels) as between-subject factor. Significant main effects and interactions were investigated with Tukey's post hoc analyses. The level of significance was set at a=0.05.

RESULTS

At the time of data collection no clinical evidence of knee pain and effusion was found in the ACL reconstructed athletes. All athletes in the ACL-reconstructed group were satisfied with the outcome of the surgery and resumed their pre-injury level of sports participation. Negative Lachman and pivot-shift tests indicated that the knee joint stability was regained clinically for all ACL reconstructed athletes. For the athletes with ACL reconstruction, the median Lysholm score was 95 (range 94-100) and the Tegner score was 8 (range 7-9) at the time of examination. KT-1000 results revealed that the mean difference between the anterior tibial translation of the reconstructed and intact sides in the ACL reconstructed group was 1.6 mm (range 1 to 2 mm) for the 134N test and 1.8 mm (range 1-2 mm) for the maximum manual test, respectively.

During the moderate intensity running, EMG amplitude did not increase with time for both the intact and ACL reconstructed leg (F=0.477, p=0.7). Similarly EMG amplitude did not increase with time for both the control and the reconstructed leg (F=0.838, p=0.477). Finally, EMG amplitude remained unchanged with time for both the control and intact leg (F=0.782, p=0.507).

During the high intensity running, the EMG amplitude of the VL increased significantly with time for the intact but not for the reconstructed leg (time*leg interaction: F=6.747, p=0.001, power=0.89). Similarly, the EMG amplitude of the VL increased significantly with time for the

control but not for the reconstructed leg (time*group interaction: F=4.258, p=0.008, power=0.85). Finally, the EMG amplitude of the VL increased significantly with time for both the control and intact leg (main effect of time: F=11.28, p<0.001, power=0.99) with no difference between legs (time*group interaction: F=1.23, p=0.303).

All effects for the moderate and high intensity running are presented in Table 1.

INSERT TABLE 1 ABOUT HERE

DISCUSSION

The purpose of the present study was to investigate the effect of ACL reconstruction with BPTB graft on VL activation levels with time, during moderate and high intensity running. We hypothesized that that (a) during moderate intensity running, the EMG amplitude of the VL will not increase with time for any of the ACLR, intact and control legs, (b) during high intensity running, the EMG amplitude of the VL will increase with time for the control and intact leg but not for the ACLR leg.

Our results indicated that during 10 minutes of moderate intensity running, the EMG amplitude of vastus lateralis remained unchanged with time for each of the control, intact and reconstructed legs. Thus, our results supported our first hypothesis. This is in agreement with previous studies indicating that in healthy individuals performing moderate intensity exercise, EMG amplitude of the exercising musculature remains unchanged with time [9, 11, 12]. Thus, our results verify that under low demand activities there are no differences between the reconstructed and either the intact or control leg [5-7].

A major finding of the present investigation was that during 10 minutes of high intensity running, EMG amplitude of the VL increased with time for the control and intact leg but not the reconstructed leg. Our results confirmed our second hypothesis. Previous studies have shown that during high intensity exercise, there is a need by the neuromuscular system to compensate for the accumulating physiological stress [8, 9]. This is accomplished by enhanced activation of the exercising muscles as exercise progresses and is detected as increased EMG amplitude with time [9, 11-13]. The fact that our two separate groups of athletes responded by increasing EMG amplitude with time is in good agreement with the above studies. However, the results of our study revealed that during high intensity exercise the VL muscle of the reconstructed leg failed to respond in a similar

manner and showed no increase in EMG amplitude with time compared to either the intact or the control leg (FIGURE 1). This behaviour may indicate that discrepancies in the neuromuscular response of the reconstructed leg may be revealed under high intensity sustained athletic efforts.

INSERT FIGURE 1 ABOUT HERE

Several explanations can be given for the lack of increase in EMG amplitude with time for the VL of the reconstructed leg. These may include selective muscle fiber atrophy in the involved quadriceps [14-16], altered motor unit activation following surgery and subsequent retraining [17] and loss of joint afferent information which may lead to suboptimal muscle fiber activation [18]. These neuromuscular alterations following ACL reconstruction may be responsible for the lack of increase in the EMG amplitude with time at high intensities, where there is a need for neuromuscular compensation of the accumulating physiological stress [8, 9, 11-13].

To the best of our knowledge this is the first study that investigated EMG activation levels with time during running in ACL reconstructed and healthy athletes. Previous studies on ACL reconstructed athletes have compared EMG levels under moderate intensity activities but no study has investigated the progression of EMG levels with time [5-7]. Furthermore, studies on healthy subjects have investigated neuromuscular response with time but only during high intensity cycling [11, 12, 13]. Our approach enabled us to extend our findings to intense running which represents a highly functional activity for the ACL reconstructed athlete. Furthermore, using preliminary VO_2max and lactate threshold testing, we assigned moderate and high intensity exercise according to individual fitness levels. Thus, all subjects exercised under identical controlled conditions.

In the present study, we recruited athletes with BPTB autograft. Thus, it is unknown if a similar response pattern is observed in athletes with a different graft, such as hamstrings. EMG signal capturing, recording and processing was performed according to established guidelines [27, 28]. We examined EMG activity developed solely during the stance period, thereby reducing to some extent the role of the signal non-stationarities [10]. Furthermore, the activity of many successive steps was averaged providing a reasonable estimation of peak EMG amplitude. Normalisation of EMG data (for example to maximum voluntary contraction) was not performed due to the additional error introduced by this process and the fact that our study design involved repeated measures, thereby overcoming

influences of electrode positioning and inter-electroded distance on the signal value [26]. Additionally, we incorporated 2 different control conditions (the intact leg of the reconstructed athletes and the control leg of a separate group of athletes) to ensure the existence of differences in our dependent variable. We assumed that because the same instrumentation was use for all subjects, the level of measurement noise would be consistent for all subjects and that any differences could be attributed to changes within the system itself.

Practical applications

- Moderate intensity activities may not reveal differences in the neuromuscular response between the reconstructed and either the intact or the control leg.
- High intensity sustained efforts are more likely to expose neuromuscular defects of the ACL reconstructed knee.
- Endurance type activity may represent a more functional approach to assess neuromuscular response under fatiguing conditions in ACL reconstructed athletes.

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FIGURE LEGENDS

FIGURE 1: (a) EMG amplitude over time for the intact (n=14) and ACL reconstructed leg (n=14) during the high intensity running. EMG amplitude increased compared to initial values only for the control leg. * indicates significantly higher than initial value. Vertical bars represent ±95% confidence intervals. (b) EMG amplitude over time for the control (n=14) and ACL reconstructed leg (n=14) during the high intensity running. EMG amplitude increased compared to initial values only for the intact leg. * indicates significantly higher than initial value. Vertical bars represent ±95% confidence intervals.