MECHANICAL AND PHYSIOLOGICAL CONSEQUENCES OF ECCENTRIC-CONCENTRIC KNEE EXTENSOR TRAINING

Outline booklet of the PhD Thesis

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I. INTRODUCTION

Delayed onset of muscle soreness is experienced 12-72 hours after unaccustomed exercise, and it develops due to micro injuries in muscle. Nature of micoinjuries experimentally evoked in laboratory conditions are well documented, and there is a general consensus that eccentric type of muscular contraction is responsible for their development.

Numerous investigations demonstrate that a single bout of eccentric exercise induces muscle soreness and elevates serum creatine kinase activity, indirect markers of muscle damage. Besides, most of the results indicate significant loss of voluntary force production and slow regeneration that may last a month in small muscle groups. With expansion of these studies researchers also observed that if unaccustomed exercise is repeated, responses from damage are less severe, and force deficit diminishes. This “repeated bout effect” is often explained with increasing “protective effect” of the muscle, which can be cellular or neural adaptation.

Less information is available of what happens if individuals keep up doing their maximal effort trainings when micro injuries are present and performance is declined. Research exploring the nature of consecutive training is missing. It is questioned how performance indicators decrease and increase during consecutive training, and how changes accumulate into sport specific adaptation. In elite sport the number of trainings may as many as 10-12 sessions per week and dynamic eccentric contractions are performed every day.

Though it is hypothesized that the protective effect is the consequence of neural changes, this has not been proved during early periods of consecutive training. If electric activity of the muscle increases in the early phase of consecutive training then this may compensate for less muscle damage induced by the second training session.

In a previous study it has been also demonstrated that muscle length during eccentric training influences the development of muscle damage, inducing different strength loss. Specifically eccentric training at larger range of motion induces greater muscle damage compared with training at smaller range of motion. However, it is unknown how similar training influences muscle damage and recovery if trainings are performed consecutively.

Therefore it is important to investigate the effects of consecutive training on the neuromechanical, biochemical variables and soreness of the muscle.

II. PURPOSE OF THE INVESTIGATIONS

Based on the literature reviewed the following purposes are stated:

1. Experiment: The purpose of the experiment was to investigate the effects of intensive, consecutive eccentric-concentric knee extensor training on the neuromechanical and biochemical variables and soreness of the muscle. In the experiment trained males performed 7 training sessions in 8 days.
2. Experiment: The purpose of the experiment was to investigate the effects of consecutive eccentric knee extensor training on muscle damage, when trainings are performed in different range of motion, resulting in different stretching length of the muscle. In this experiment males performed trainings for six consecutive days at either large or small range of motion.

I. METHODS

3.1. Methods of the first experiment

Subjects

Seventeen healthy, physically active males volunteered for the study age = 24.6 ± 5.4 years; bodyweight =77.8 ± 8.8 kg; height =176.9 ± 6.2cm). Subjects were randomly assigned into two groups: experimental group (E; n=10) and control group (C, n=7). All subjects have previously done resistance training, but did not do training directly before and during the experiment. None of the subjects had a history of orthopedic problems or injury. They received oral and written information regarding the purpose, procedure and risks of the experiment. After this they signed an informed consent based on the declaration of Helsinki that was previously approved by the University Ethical Committee.

Design

Group E trained for 8 days. After three consecutive training (Tr1-Tr3) a rest day was included followed by four more consecutive training days (Tr4-Tr7).

There were seven exercise tests (T1-T7) in the laboratory in order to determine mechanical changes caused by the training exercise: before and immediately after Tr1, before Tr2 and Tr3, on the rest day, and 1d and 3d after Tr7. Blood was drawn before all exercise test and EMG was recorded at T1, T4, T6 and T7. Group C did not train but performed all exercise tests.

Measuring and training apparatus

A custom-built computerized isokinetic dynamometer (Multicont II, Mediagnost, Budapest and Mechatronic Kft, Szeged, Hungary) was used for the exercise training and to test the mechanical properties of the quadriceps muscle. Subjects were seated on the dynamometer's seat. The torso was stabilized with shoulder harnesses and both thighs were secured with rubberized Velcro straps to the dynamometer's seat.. The shin of the treated lower extremity, above the ankle, was fastened with a strap to the lever of a servo motor (MA-10, Mavilors AC, Spain; maximal velocity: 6000 rpm). The apparent knee joint centre of rotation was aligned with the centre of rotation of the lever arm.

Eccentric-concentric training

Subjects performed knee extension exercise with the dominant leg only. E performed 6 sets of 15 repetitions of isokinetic eccentric-concentric contractions at $60° \cdot s^{-1}$ over 60° of range of motion that was set between 20 to 80° of knee flexion. Subjects had to exert torque against the lever arm and when the exerted torque exceeded the threshold of 50 Nm, the driver automatically started to flex the knee (eccentric phase). Subjects were encouraged to resist maximally against the dynamometer's rotating lever arm during the eccentric phase and then to extend the knee (concentric phase). There were 2 s of rest between trials and 2 min of rest between sets. The peak torque was determined for the eccentric phase of each of the 90 contractions and then averaged (MTr) in each training session.

Measurements

Maximal isometric torque

Subjects performed three maximal isometric contractions at 50° of knee flexion, i.e., at midpoint of the range of motion used during training (20-80 degrees). Subjects were instructed to slowly generate and reach maximal torque (M_0) in each of the 3 trials.

Maximal eccentric torque

Unlike the training contractions, in the testing protocol maximal voluntary eccentric torque was measured during a stretch-shortening exercise test in which the dynamometer rapidly applied a preset amount of energy to stretch the quadriceps. The stretch-shortening test contraction of the quadriceps muscle started at 20° of knee flexion and the subject had to exert force against the lever arm as fast and forcefully as possible. When the subject reached 60% of the maximal torque, measured previously at 20° of knee flexion, the dynamometer's lever arm started to rotate in the direction of knee flexion. Subjects were instructed to resist the rotating lever arm maximally and to stop it within the shortest range of motion (eccentric phase), and then extend the knee without a time delay and as fast as possible to the 20 degree position. The preset amount of energy to stretch the quadriceps was 120 J and it was applied at 300°/s initial velocity. As the eccentric knee flexion progresses, the energy stored in the servomotor diminishes to zero (the lever arm stops) and some of the energy is stored in the quadriceps muscle. The instructions given to the subjects ensured that transfer of the energy that stretched the quadriceps muscle occurred in a short time and over a small range of motion so that the concentric contraction would start without a delay. During the concentric phase the dynamometer's motor was turned off and it provided resistance through friction plus the inertia of the lever arm and lower leg. All subjects performed three trials. Torque, angular velocity and knee joint position as function of time were recorded for each contraction and we took measurements at two points in the torque-time curve: 1. at the beginning of the eccentric phase where short range stiffness occurred (Mecc1) and 2. at the end phase of the eccentric contraction where the eccentric action turns into concentric action (Mecc2).

Mechanical work, mechanical efficiency

From data recorded by the computer during stretch-shortening contraction negative and positive mechanical work (Wn and Wp), and mechanical efficiency (η) of the quadriceps femoris were calculated.

Integrated EMG

After the skin was shaved and alcohol-washed, Ag/AgCl electrodes (1 cm in diameter, 3 cm center to center inter-electrode distance) were placed on the belly of the vastus lateralis, rectus femoris and vastus medialis. The reference electrode was attached over the patella. The position of each electrode was marked with ink and kept constant across sessions. EMG data were sampled at 1000 Hz by a Noraxon telemetric EMG device (Noraxon U.S., Inc., Scottsdale, AZ). EMG signals were EMG signals were full-wave rectified, analogue filtered (low pass = 30 Hz, high pass = 300 Hz), smoothed (at 20-50 Hz window), and then integrated (iEMG in μV/s) and time normalized for 1 s stored on the computer's hard drive. EMG was recorded in a 200-ms-long window measured backwards from peak torque reached during isometric contraction. During eccentric contractions the interval of measurement was 50 ms before reaching Mecc1 and Mecc2. Values obtained from VL, VM and RF were summed and considered as iEMG value of the quadriceps muscle.

Serum creatine kinase (CK) activity

A 10-ml blood sample was drawn from the antecubital vein before each exercise test session in group E. There were only three blood drawings in group C (at T1, T4 and T6) (Table 1). Blood was centrifuged for 10 minutes to obtain plasma. CK activity was determined with spectophotography (Dinabot Co. Ltd., Tokyo, Japan). When using this methodology the normal reference range of CK was 45-135 $IU \cdot l^{-1}$.

Muscle soreness

Subjects were asked to report their perceived soreness during movement in the quadriceps muscle from the beginning of the training period. The subjective perception of muscle soreness was assessed by a questionnaire and was rated on a scale ranging from 0 (not sore at all) to 10 (very sore).

Statistical analyses

Descriptive statistics (means and standard deviations) were computed for the measured and calculated variables. Because of the limited sample size and according to the requirements of using parametric statistical procedures all variables were tested with Shapiro-Wilk's W test for normality. We determined the training effect across time in dependent variables such as *MTr, M0, Mecc1, Mecc2, iEMG* using a non-parametric Friedman ANOVA at 5% level of random error. This was performed due to the results of the normality test. To test differences among the variables Wilcoxon Matched Pairs Test was used for post-hoc analysis. As the baseline values for the two groups differed significantly in M0, Mecc1, Mecc2 and in all iEMG values, percentages of changes from T1 to T2…T7 were calculated and compared between groups by using Mann-Whitney U test. To test if increases in voluntary force are associated with increases in muscle activation, Spearman Rank Order Correlations were determined between percent change torque values and the corresponding percent change iEMG value. Friedman ANOVA was used to test the differences among the *CK* and *LDH* values at the different measurement times. For post-hoc analysis Wilcoxon Matched Pairs Test was used. Since *muscle soreness* was measured on ordinal scale therefore differences were determined using a non-parametric Mann Whitney U test. The probability level for statistical significance was set at $p<0.05$

3.2. Methods of the second experiment

Subjects

Sixteen healthy males volunteered for the experiment (age = 23.7 ± 5.9 years; bodyweight = 78.9 ± 891 kg; height = 177.5 ± 6.5cm) and were randomly assigned into two groups: group N (n=8) exercised at large range of motion, group K (n=8) exercised at small range of motion.

Experimental design

The training period consisted of six consecutive days containing six training bouts (E1-E7). Subjects performed the knee extension exercise with the right leg. Both groups performed 6 sets of 15 repetitions of isokinetic eccentric contractions. Group K performed eccentric contractions at 60 degrees of range of motion, between 20 and 80 degrees of anatomical knee joint angle, at $60° \cdot s^{-1}$ constant angular velocity. Group N carried out eccentric contractions in 120 degrees of range of motion between 10 and 130 degrees of anatomical knee joint angle at $120° \cdot s^{-1}$ constant angular velocity. Subjects had to exert torque against the lever and the driver automatically started to flex the knee (eccentric quadriceps contraction) when a 15 Nm of isometric target torque was reached. Subjects were encouraged to resist maximally against the rotating lever arm of the dynamometer. After finishing each trial the lever of the dynamometer returned to its starting position. There were two seconds rest between trials and two minutes between sets.

Averaged peak torques

The peak torque of each of the 90 contraction trials was determined and averaged (Mcs).

Serum CK activity

10ml of blood was drawn from the antecubital vein every time. Measurements were taken before, 24h, 48h, and 144 hours following the first bout. Procedures for measuring both CK activity and muscle soreness are identical with those described in the first experiment.

Statistical analyses

Descriptive statistics (mean and standard deviation) were calculated for all variables. Changes of these variables through time, and differences between groups were determined with the same procedure described in the first experiment.

IV. RESULTS

4.1. Results of the first experiment

Results of the experimental group

All subjects finished the experiment without any problem and injury. MTr increased 24% from Tr1 to Tr6 ($p<0.05$). The greatest improvement in MTr occurred at Tr7 (26%, $p<0.05$). During test contractions M0, Mecc1 and Mecc2 significantly decreased from T1 to T3 (15%, 8% and 16%, $p<0.05$), and this deficit was significantly greater in M0 and Mecc2 than in Mecc1. M0, Mecc1 and Mecc2 significantly increased from T3 to T5, T6 and T7 ($p<0.05$). Overall M0 increased from T1 to T7 ($p<0.05$). Wp decreased significantly from T1 to T7 ($p<0.05$). η decreased 9% from T1 to T7 ($p<0.05$).

IEMG measured during Mecc1 was significantly higher at T6 and T7 compared with T1 ($p<0.05$). IEMG measured during Mecc2 was significantly higher at T7 than at T1 ($p<0.05$). IEMG measured at M0 was significantly higher at T5, T6 and T7 compared with T1 ($p<0.05$).

CK activity was the highest at T3 (779 ± 332 U/l). Values at T3, T4, T5, T6 and T7 were significantly higher than at T1 (202 ± 140 U/l, $p<0.05$), but these values decreased from T3 to T6 and from T6 to T7 ($p<0.05$).

Perceived muscle soreness developed 24h after Tr1 ($p<0.05$). With further trainings soreness diminished but four days after Tr1 it was still significantly higher than the baseline ($p<0.05$). By the end of the experiment in some of the subjects soreness disappeared.

Results of controls

M0, Mecc1 and Mecc2 significantly decreased from T1 to T3 (7%, 6% and 9%, $p<0.05$), but there was no improvement in any of these variables by the end of the experiment. IEMG measured during Mecc1 and Mecc2 increased from T1 to T5 ($p<0.05$). IEMG measured during M0 increased from T1 to T7 ($p<0.05$). Wn was significantly greater at T6 and T7 compared with T1, and Wp was significantly greater at T4 and T7 than at T1 ($p<0.05$). η increased 12% from T1 to T7 ($p<0.05$). 24h after Tr1 muscle soreness developed ($p<0.05$) but it disappeared later.

Differences between groups

Percent changes of M0 and Mecc1 from T1 to T2 and from T1 to T7 was significantly greater in E than in C ($p<0.05$). Percent change of iEMG (measured at M0) from T1 to T5 was greater in E than in C ($p<0.05$). Muscle soreness was significantly higher in E at 24h, 48h, 72h and 4d after Tr1 ($p<0.05$). CK activity was higher in E at T4 and T6 test times ($p<0.05$)

4.2. Results of the second experiment

Mcs significantly decreased in both groups at E2 (25% for N, 14% for K, $p<0.05$). In N Mcs further decreased at E3 (40% compared with E1) and this did not return to baseline. In K Mcs increased 11% from E1 to E6. Percent changes of Mcs from E1 to E3, E4, E5 and E6 were significantly different between groups ($p<0.05$).

Twenty-four hours after E1 CK activity increased in both groups ($p<0.05$). In N CK elevated to 5216 IU/l ($p<0.05$) by the last day of the experiment (144h). At this point CK was significantly different between groups ($p<0.05$).

V. CONCLUSIONS

Based on the result of the experiments our conclusions are the followings:

- In both experiments the first training bout induced muscle damage supported by indirect markers. Maximal voluntary torque production acutely decreased, CK activity and soreness elevated.
- In the first experiment muscle damage was not extracerbated by further trainings. Indicators stabilized and voluntary torque production increased in the experimental group.
- During regeneration electric activity of the quadriceps femoris increased already 72h after the first training bout.
- In contrast with increase in isometric torque production mechanical efficiency of the muscle decreased throughout the study
- Increase in electric activity was not associated with increased in isometric torque
- Eccentric training at large range of motion induced greater muscle damage and strength loss compared with training at small range of motion.

It is possible that during consecutive training comprising high force eccentric actions the following mechanisms are going on:

- Damage of the motor units recruited during the first training bout.
- Regeneration of these motor units.

- With further trainings new motor units are recruited or the previously working motor units increase their firing rate.
- Damage of the newly recruited motor units.

The extent to which these mechanisms are present and compensate each other will probably determine how voluntary torque production changes during a training protocol. It is also possible that with damaging eccentric training stiffness of the muscle increases and this facilitates torque production during short stretches, as indicated by the little change of Mecc1 in our experiment. From sport specific point of view it might have importance that damaging exercises induces greater loss in isometric torque versus torque during stretch-shortening contraction. Results of the controls are somewhat surprising. In agreement with previous literature it is obvious that already few unaccustomed muscular contractions (test contractions) may induce muscle damage and if these exercise are repeated myoelectric activity increases. This may be explained with motor learning rather than training specific adaptation.

It is also surprising that in contrast with increased isometric torque mechanical efficiency gradually decreased during the training program, which is one of the most important outcomes of the present work. In previous investigations mostly changes of isometric force was observed but this type of strength may not accurately reflect dynamic sport performance. Scientists must pay attention to what type of exercise tests they use to evaluate effects of muscle damage. From our results we conclude that our training protocol induced significant fatigue in reactive force production that may regenerate with further, lower intensity training bouts. This is what should be considered for example when in practice periodized training programs are designed with alternating between high and low intensity weeks.

Though it is not directly part of question in our work, it is important to mention that electric activity during the eccentric phase of the stretch-shortening contraction is similar, or even higher compared with that of isometric contraction. It is possible that during high velocity stretch-shortening exercises a special cortical activation strategy enhances electric activity during the eccentric phase in order to increase mechanical power during the concentric phase.

From the results of our second experiment it is concluded that consecutive eccentric knee extensor training performed at either small or large range of motion induced different degradation and regeneration processes. After training at large range of motion, with greater stretch of the muscle force deficit is greater compared with training at small range of motion. High velocity exercises performed at large range of motion may induce severe damage and pain in muscle even in antigravitational muscles.

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