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ORIGINAL ARTICLE

One repetition maximum test increases serum indices of muscle damage and soreness in trained and untrained males

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KEYWORDS

1RM;
Creatine kinase;
C-reactive protein;
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Abstract

Introduction: The purpose of this study was to examine the effect of one repetition maximum test on muscle damage and soreness in trained and untrained males.

Methods: Ten trained (T) and 10 untrained (UT) males participated in this study. Subjects performed one repetition maximum (1RM) test for the back squat exercise and creatine kinase (CK) activity, C-reactive protein (CRP) concentration, and muscle soreness (quadriceps and hamstring) were assessed at pre, 24, 48 and 72 h post 1RM test.

Results: Significant increases in CK activity and muscle soreness were observed at 24, 48 and 72 h post 1RM test, and there were also significant differences between T and UT ($p < 0.05$). In the CRP concentration, both groups indicated significant increases above resting at 24, 48 and 72 h post 1RM test and 72 h compared to 24 h ($p < 0.05$). There were no significant differences between T and UT in the CRP concentration ($p > 0.05$).

Conclusion: In conclusion, the 1RM back squat test (high intensity and low volume) increases CK activity, CRP concentration in the plasma and muscle soreness in the T and UT. It can be observed that 1RM test can induce muscle damage, which would be a negative factor for athletes and individuals, since the muscle injury is associated with decreased performance.

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PALABRAS CLAVE

1RM;
Creatina quinasa;
Proteína C-reactiva;
Sentadillas;
Daño muscular

El test de una repetición máxima incrementa los índices séricos referentes a daño y dolor muscular en varones entrenados y no entrenados

Resumen

Introducción: El objetivo de este estudio fue examinar el efecto del test de una repetición máxima sobre el daño y el dolor muscular en varones entrenados y no entrenados.

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Métodos: En este estudio participaron diez varones entrenados y 10 no entrenados. Los sujetos realizaron un test de máxima repetición (1RM) para el ejercicio de sentadillas, evaluándose la actividad de la creatina quinasa (CK), la concentración de proteína C-reactiva (PCR) y el dolor muscular (cuádriceps e isquiotibiales) al inicio, y a las 24, 48 y 72 horas del test 1RM.

Resultados: Se observaron incrementos considerables de la actividad de CK y el dolor muscular a las 24, 48 y 72 horas del test 1RM, y también diferencias significativas entre los sujetos entrenados y los no entrenados ($p < 0,05$). En cuanto a las concentraciones de PCR, ambos grupos mostraron incrementos significativos en cuanto al descanso a las 24, 48 y 72 horas posteriores al test 1RM, y en cuanto al valor a las 72 horas en comparación al valor a las 24 horas ($p < 0,05$). No se produjeron diferencias significativas de concentración de PCR ($p > 0,05$), entre el grupo de sujetos entrenados y los no entrenados.

Conclusión: En conclusión, el test 1RM de sentadillas realizado (alta intensidad y bajo volumen) incrementa la actividad de CK, la concentración de PCR en plasma, y el dolor muscular en los varones entrenados y en los no entrenados. Puede observarse que el test 1RM puede inducir daño muscular, lo cual constituiría un factor negativo para atletas y demás personas, puesto que la lesión muscular se asocia a una disminución del rendimiento.

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Introduction

The resistance exercise intensity is usually determined by percent of one repetition maximum (1RM). Before design a resistance training program, coaches and trainers usually used 1RM test for the evaluation of muscle strength, because the 1RM test has several advantages, like easy implementation, low cost and ability to adapt to reality of various sports.¹

Many individuals such as athletes and general population used resistance training for promoting and maintaining health and quality of life,^{2,3} and designed the intensity of exercise based on 1RM. The 1RM test determine by raising the maximal weight possible in a single maximum effort and complete movement, aims to stimulate the maximum strength by the practitioner.⁴ But, physiological changes induced by the 1RM test have been poorly studied. It is noteworthy to data that no investigations are found about the muscle soreness and damage caused by the 1RM test in trained and untrained subjects. Numerous studies examined the effects of different type of exercises (e.g., plyometric exercise and resistance exercise [different intensity]) on muscle soreness and damage (e.g., creatine kinase [CK] and lactate dehydrogenase [LDH]) and found increases in muscle injury following these exercises.⁵⁻⁹

To the best of our knowledge, only one study examined the effect of 1RM test (bench press) on muscle injury and inflammation markers in recreationally athletic subjects. Barquilha et al.,⁵ found significant increases in the CK activity after 6 days of test, whereas C-reactive protein (CRP) concentration increased 24 and 48 h post 1RM bench press test.⁵

Although, previous study attempted to assess the muscle injury following 1RM test,⁵ the data is no clear and information this aspect is very limited. In this study, we wanted to assess the muscle damage induced by 1RM test for the back squat exercise, because of this exercise recruit or require large amount of muscle mass and typically used in resistance training programs.¹⁰ Moreover, the other aim of this study was to evaluate the muscle damage responses to 1RM

test for the back squat exercise in trained and untrained males. Thus, the purpose of the present study was to examine the effects of 1RM back squat test on CK activity and CRP concentration, and muscle soreness (quadriceps and hamstring muscles) in trained and untrained males. This approach was used to demonstrate, using back squat exercise: (a) changes in CK and CRP in the plasma, (b) changes in muscle soreness for the quadriceps and hamstring muscles, in trained and untrained males. We hypothesized that (a) 1RM back squat will produce increases in the muscle soreness and damage; (b) the untrained subjects will produce greater increases than trained subjects in the muscle damage.

Materials and methods

Experimental approach to the problem

Two groups of trained and untrained subjects were used to make comparisons of muscle soreness and damage when 1RM back squat test was performed. Subjects performed 1RM back squat test in the morning, and CK activity, CRP concentration and muscle soreness for the quadriceps and hamstring muscles were assessed before the 1RM test, and 24, 48 and 72 h within recovery.

Subjects

Ten trained (T) and 10 untrained (UT) males volunteered to participate in the present study. T had been undertaking a continual resistance weight training program at least three times a week for more than 2 years exercise. UT were familiar with resistance weight training (especially back squat exercise), but they did not perform resistance weight training during the previous year. Subjects were free from any musculoskeletal or neurological problems, and instructed to not use nutritional supplementation, anabolic steroids and or any other anabolic agents known to increase performance. All subjects abstained from any

Table 1 Subjects' characteristics (mean \pm SD).

	Trained ($n = 10$)	Untrained ($n = 10$)
Age (y)	20.7 \pm 2.4	20.6 \pm 2.5
Height (cm)	175.9 \pm 5.7	174.6 \pm 4.7
Weight (kg)	75.8 \pm 6.1*	70.3 \pm 4.5

* Significant difference ($p < 0.05$) between groups.

resistance exercise or physical activity for at least 7–10 days before and during the experimental period. Subjects were informed of the purpose and experimental risks of this study and signed an informed consent form before the investigation. The Institutional Review Board for Human Subjects of the University approved the research protocol. Subject's characteristics are presented in [Table 1](#).

Study design

The subjects were familiarized with the back squat testing procedure during a control day about 1 week before the start of study. During familiarization session, subject's characteristics such as, age, height and weight were obtained. The 1RM testing lasted from 9:00 to 11:00 AM. The 1RM testing was performed in a counterbalance order by all 20 participants. One blood sample was drawn in the morning after 12 h of fasting and approximately 8 h of sleep for determination of basal serum CK and CRP. Three blood samples were also drawn at 24, 48, and 72 h within recovery period at the same time of the day. Also, muscle soreness (palpation) for the quadriceps and hamstring muscles were determined at pre, and 24, 48 and 72 h post 1RM back squat test. Moreover, after 1RM test, rating of perceived exertion was determined using the Borg CR15 scale¹¹ for the determination of perceived exertion in T and UT subjects.

One repetition maximum testing

The 1RM back squat testing was performed according to method previously described by Kraemer and Fry.¹² In the back squat (1RM), the shoulders were in contact with a bar, and the starting knee angle was 90°. On command, the subject performed a concentric extension of the leg muscles starting from the flexed position to reach the full extension of 180° against the resistance. The trunk was kept as straight as possible. The participants performed a warm-up set of 8–10 repetitions at a light weight (~50% of 1RM). A second warm-up consisted of a set of 3–5 repetitions with a moderate weight (~75% of 1RM), and third warm-up included 1–3 repetitions with a heavy weight (~90% of 1RM). After the warm-up, each subject was tested for the 1RM by increasing the load during consecutive trials until the participants were unable to perform a proper lift, complete range of motion and correct technique. The 1RM test was determined by ~5 sets of one repetition, with 3- to 5-min of rest among attempts¹⁰. Spotters were present to provide verbal encouragement and safety for the subjects. The values of 1RM were 104 \pm 17 kg for T and 70 \pm 11 kg for UT.

Muscle soreness

Each subject determined soreness of the leg by self-palpation of the quadriceps and hamstring muscles. Perceived soreness was rated on a scale from 1 (no soreness) to 10 (very, very sore).^{6,8} This scale has been used in other muscle soreness studies.^{6–8} The muscle soreness scale was modified by inserting a picture of each specific muscle. Subjects were instructed to write the rate of soreness of each individual muscle in muscle soreness questionnaire. Reliability coefficient for repetitive measurements in muscle soreness was 0.98.

Blood markers

Blood samples were drawn (10 cc) from the antecubital vein into plain evacuated test tubes. The blood was allowed to clot at room temperature for 30-min and centrifuged at 1500 \times g for 10-min. The serum layer was removed and frozen at -20°C in multiple aliquots for further analyses. Serum CK activity was determined spectrophotometry in duplicate using a commercially available kit (Pars Azmun co, Tehran, Iran) with CV <5%. The normal reference range of CK activity for men using this method was 35–175 U/L. The CRP (DBC, SLT Spectria Instrument, Austria) was determined using enzyme-linked immunosorbant assay (ELISA) method. The intra-assay coefficient of variance was 4.7% and inter-assay coefficient of variance was 6.4% for CRP.

Statistical analyses

Data are presented as mean \pm SD. Data normality was verified with the 1-sample *Kolmogorov–Smirnov* test; therefore, a nonparametric test was not necessary. Data were analyzed through 2-way (group \times time) repeated measures ANOVA with planned contrast on different time point. When a significant effect was found, post hoc analysis was performed through the *Bonferroni* test. Pearson product-moment correlations coefficient was used to determine relationship between peak CK activity and peak muscle soreness. A criterion α level of $p < 0.05$ was used to determine statistical significance. All statistical analyses were performed through the use of a statistical software package (SPSS®, Version 16.0, SPSS., Chicago, IL).

Results

The 1RM test increased CRP concentration at 24, 48 and 72 h post test in the T and UT. Also, both groups showed significant increases at 72 h than 24 h post 1RM test ($p < 0.05$) ([Fig. 1](#)). CK activity was increased significantly at 24 h until 72 h of recovery in the T and UT ($p < 0.05$) ([Fig. 2](#)). Muscle soreness (quadriceps and hamstring) was increased at 24, 48 and 72 h post 1RM test ([Fig. 3](#)), likewise there were significant differences between T and UT in the muscle damage and soreness after 1RM back squat test (except CRP concentration) ($p < 0.05$). There was no significant correlation between peak CK activity and peak soreness of quadriceps muscle ($r = 0.24$, $p > 0.05$) ([Fig. 4](#)). However, a weak but significant correlation was found between peak CK activity

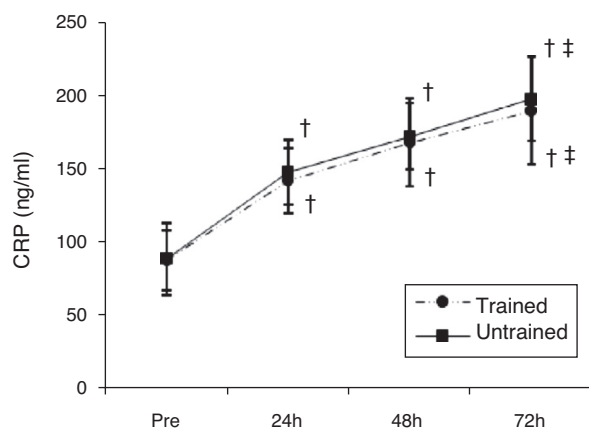


Figure 1 Changes in the CRP concentration at pre, 24, 48 and 72 h after 1RM back squat test. Values are means \pm SD. \dagger Significant difference ($p < 0.05$) with baseline. \ddagger Significant difference ($p < 0.05$) with 24 h.

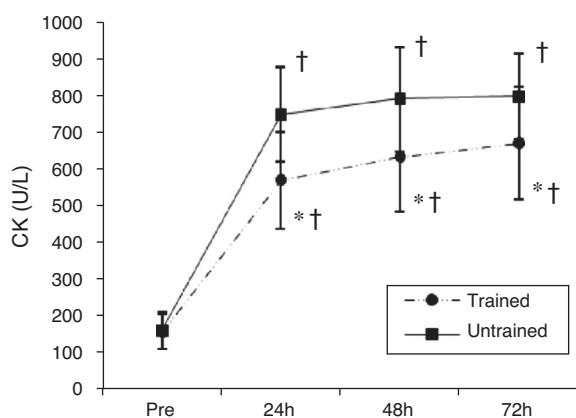


Figure 2 Changes in the CK activity at pre, 24, 48 and 72 h after 1RM back squat test. Values are means \pm SD. \dagger Significant difference ($p < 0.05$) with baseline. *Significant difference ($p < 0.05$) between groups.

and peak soreness of hamstring muscle ($r = 0.45$, $p < 0.05$) (Fig. 4). There were significant differences between T and UT in the RPE after 1RM back squat test; 14.9 ± 1.3 vs. 16.7 ± 1.4 , $p < 0.05$.

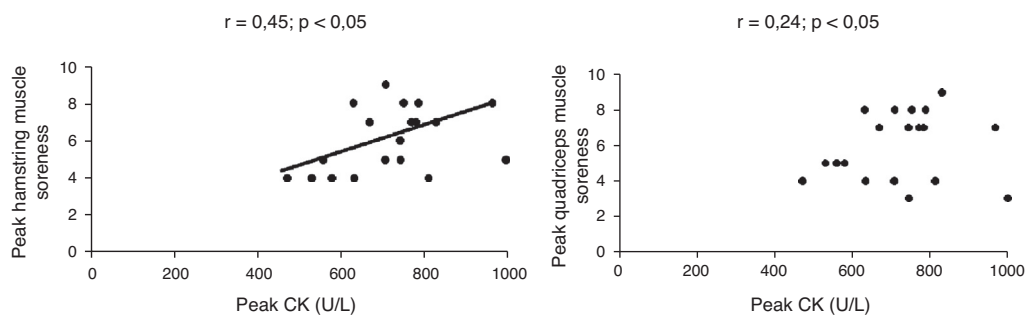


Figure 4 Correlation between peak CK activity and peak muscle soreness for the hamstring or quadriceps ($n = 20$).

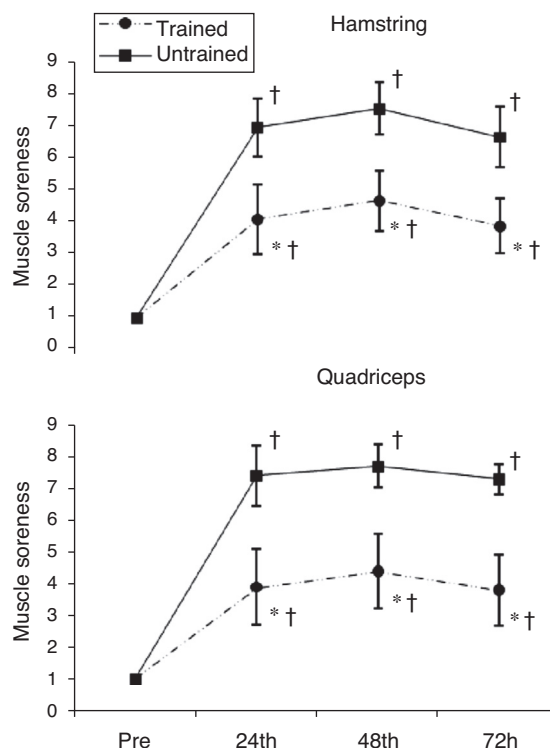


Figure 3 Changes in the muscle soreness for the hamstring and quadriceps at pre, 24, 48 and 72 h after 1RM back squat test. Values are means \pm SD. \dagger Significant difference ($p < 0.05$) with baseline. *Significant difference ($p < 0.05$) between groups.

Discussion

Little is known about the effects of 1RM test on muscle damage and soreness, for this goal we examined the effects of 1RM back squat test (high intensity and low volume) on CRP, CK, RPE and muscle soreness (quadriceps and hamstring) in the T and UT subjects. In the present study, we found increases in CRP, which peaked at 72 h after the 1RM test in T and UT. There were no significant differences between T and UT, but CRP increased 72 h post test compared with 24 h. Increases in CRP have previously been reported to be associated with exercise induced muscle damage, with evidence linking the stress and intensity of exercise to the subsequent magnitude of response of this marker within the circulation.^{8,13} It has been reported that triathlon race

and an ultramarathon can cause significant increases of this protein.^{14,15} Recently, Barquilha et al.⁵ examined the effects of 1RM bench press test on muscle injury and inflammation markers and found significant increases in CRP concentration above resting at 24 and 48 h post test. However, the levels of inflammatory cytokines (e.g., interleukin 2, IL-2, IL-8, IL-1 β , tumoral necrose factor- α -TNF- α) were not increased.⁵ It seems that high intensity and low volume exercise can lead to increases in CRP without differing in training status (T vs. UT); because we did not find significant differences between T and UT subjects. However, we did not assess the cytokines IL-6 and TNF- α ; it is well known that these factors can stimulate the production of acute phase proteins, such as CRP.^{14,16} C-reactive protein rise has been associated with monocyte activation and adhesion molecules synthesis that recruit leukocytes.¹⁷

The present study detects significant increases in CK activity and muscle soreness after 1RM back squat test with significant differences between T and UT. Previous studies have shown that eccentric exercise induced increases in muscle damage and soreness.⁶⁻⁸ The CK activity in the blood and muscle soreness scale are the most frequently used indices of muscle damage, and were significantly increased after eccentric exercise, which is in accordance with the data from previous studies.⁶⁻⁸ Resistance exercise, which also has a strong eccentric component, has been shown to increase CK activity and muscle soreness in most studies in men.^{5,9,18}

Uchida et al.,⁹ conducted a study which aimed to investigate muscle damage in different intensities in bench press exercise. The intensities were 50%, 75%, 90% and 110% of 1RM. The CK activity increased significantly in all groups after bout, with no significant differences among groups, probably because the total volumes were similar among them. Paschalis et al.¹⁸ compared two different protocols of resistance exercise, one with a moderate and one with high intensity, and found significant increases of CK in both protocols. Also, Barquilha et al.,⁵ found that intense exercise (1RM bench press test) increased CK activity above resting up to 6 days after the test. Increases in CK activity and muscle soreness following eccentric exercise (e.g., resistance exercise) can be negative phase of eccentric activation, which produces higher tension per cross-sectional area of active muscle mass, resulting in significant structural muscle damage.^{6,19,20} The differences between T and UT in the muscle damage and soreness can be related to training status or previous experience. It is well known that previous experience with exercise training has a prophylactic effect on muscle damage.²¹ Changes in muscle recruitment patterns or ultrastructural changes within the muscle may be due to other mechanisms for the differences between T and UT subjects.²²

A weak correlation between peak soreness of hamstring muscle and CK activity was observed, but no correlation was found between peak soreness of quadriceps muscle and peak CK activity. Nosaka et al.,²³ reported a weak correlation between muscle soreness and plasma CK activity after eccentric exercise of the elbow flexion. Uchida et al.,⁹ reported no significant correlation between peak CK activity and peak muscle soreness following different intensities of bench press exercise. Malm et al.,²⁴ have documented that muscle soreness may not be directly associated with

damage and inflammation of muscle fibers, but is due to inflammation of connective tissue. It may be that damage to connective tissue was not substantially intensity of back squat exercise. Further studies are necessary to address such speculation.

Rating of perceived exertion was greater in UT than T after 1RM back squat test. There were strong linear relationships between RPE and exercise intensity during resistance exercises. These mean that during a resistance movement, corollary discharges from the motor cortex are concurrently sent to both the recipient muscle and the somatosensory cortex. The higher intensity with low volume results in greater tension and increased motor unit recruitment and firing frequency.^{10,11} The significant differences between T and UT in the RPE may increase in motor unit recruitment, muscle recruitment pattern or muscle fiber synchronization in trained subjects.²²

In conclusion, the 1RM back squat test (high intensity and low volume) rendered increased CK activity, CRP concentration in the plasma and muscle soreness in the T and UT. Also, the muscle damage was greater for UT than T. These results suggest that indeed there was muscle damage following 1RM test. The results of the present study confirm that 1RM testing can induce muscle damage and soreness up to 72 h post test. Therefore, coaches and trainers must attend to time the start of training session after testing session. Also, with regard to induction of muscle soreness and increasing muscle injury indices in non-athletes, it will be better using strength measurements such as numbers of RM (e.g., 3-6RM) and 1RM prediction equations. No muscle function measure was used in the present study to assess muscle damage. Future research should include a muscle function measure to confirm the results of the present study. It can be also interesting to correlate between muscle damage and inflammation with imaging tests such as MRI that can demonstrate the existence of intra and inter muscular edema following 1RM test.

Conflict of interests

Authors declare that they don't have any conflict of interests.

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