

Single resistance training session leads to muscle damage without isometric strength decrease

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ABSTRACT

Here we demonstrated that a single resistance exercise session causes muscle damage, delayed onset muscle soreness (DOMS), higher creatine kinase (CK) and lactate dehydrogenase (LDH) activity, and increased IL-6 concentration without changes in muscle strength. Sixteen healthy untrained subjects performed five exercises consisting of three sets of 10 maximum repetitions for each exercise and 1 minute rest period between sets and exercises. Blood samples were taken after 30 minutes, 24, 48 and 72 hours and before exercise. Muscular performance was assessed by maximum isometric strength (MIS) before, 24h, 48h and 72h exercise session. We have concluded that the single resistance exercise session, performed on this study, led to muscle damage and this variable cannot be evaluated through maximal isometric strength. Among those markers, CK was more sensitive to muscle damage. This information might be important for adequate recovery between training sessions. **Key words:** CK, IL-6, LDH, DOMS, MAXIMAL ISOMETRIC STRENGTH.

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INTRODUCTION

For scientists and coaches, the assessment of muscular damage is important to control recovery and training periodization in resistance training (Halsón, 2014; Raeder et al., 2016). There are markers of muscle damage like Creatine Kinase (CK), Lactate Dehydrogenase (LDH) and Interleukin 6 (IL-6) that represent muscle membrane disruption and inflammation, however this represents a more expensive or invasive method for assessment (Brancaccio, Maffulli, & Limongelli, 2007; Lima & Denadai, 2015; Tartibian, Azadpoor, & Abbasi, 2009; Uchida et al., 2009). Because of low costs and non-invasive methods, the evaluation of damage (consequently recovery) in resistance exercise, coaches use dynamic strength tests like one-repetition maximum performance ($1RM_{test}$) (Halsón, 2014) to make decision about next training session. However dynamic strength tests could induce additional fatigue (Halsón, 2014). Another option used by coaches is to assess recovery through perceived pain, like delayed onset muscle soreness (DOMS), which is widely used to monitor fatigue and predict cellular damage (Schoenfeld & Contreras, 2013).

There is a positive correlation between muscle damage and strength decrease when resistance exercise is performed in isokinetic device (Raastad, Risoy, Benestad, Fjeld, & Hallen, 2003). However, this type of device differs from those used in training centers more often and the volume training sessions used in question are different from reality. There is a lack in studies about exercise inducing damage and recovery with a single resistance exercise session involving multiple sets (upper and lower limbs) performed in conventional machines leading to muscle damage. Resistance exercise can cause muscle damage (Newham, McPhail, Mills, & Edwards, 1983) and induce DOMS (Uchida et al., 2009). The DOMS is characterized by discomfort and soreness, reaching a peak of pain between 24 - 72 hours after the exercise practice (Tricoli, 2001). The muscle damage can trigger an inflammatory response, with changes in plasma cytokines, such as IL-6 (Petersen & Pedersen, 2006). Increased IL-6 by exercise is due to decreased muscle glycogen stores, reactive oxygen species (ROS) production and skeletal muscle cell contraction (Petersen & Pedersen, 2006). If these enzymes remain elevated, the integrity of the muscle cell is not restored. So, new training session is not recommended, especially for athletes that use strength and power in their sports because CK elevation has been associated with a failure of rhabdomyolysis treatment (Huynh et al., 2016).

We hypothesize that the assessment of maximal isometric strength (MIS) may be an optimal method to evaluate fatigue and muscular damage because it takes less time to apply, do not use expensive equipment, does not induce additional fatigue and it seems to have a protective effect (Chen, Chen, Pearce, & Nosaka, 2012; Halsón, 2014). Considering MIS a non-invasive measure to assess serum markers of damage, we propose a design for questioning some inconsistencies in scientific literature: i) exercise-induced damage used in most methods is different from a real training session; ii) DOMS seems to be inaccurate in predicting cell muscular damage; iii) MIS could be an alternative strategy to control training periodization and assess muscular damage.

MATERIALS AND METHODS

Participants

Sixteen sedentary volunteers, aged 21 ± 2 years; height 1.73 ± 0.1 cm; body fat $14.2 \pm 4.3\%$ participated on this study. All participants were informed of the procedures and potential risks before testing and signed the consent form. The study is in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and the local ethics committee ("World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects," 2013).

Experimental procedures

To resemble the volume training performed in training situations, the single resistance training session consisted of performing three sets of 10 maximum repetitions in five resistance exercises (bench press, shoulder press, parallel squat, leg curl and lat pulldown). Participants performed three sets with one minute of interval between sets and exercises.

Before resistance training session participants had blood samples collected from median cubital vein. Were taken at four moments: 30 minutes after exercise and 24, 48 and 72 hours too, from CK, LDH and IL-6 analysis.

Before the training session, the subjects performed a warm-up, which consisted of three sets of 12 submaximal repetitions with approximately 50% of the estimated load chosen by subjects. After the warm-up and immediately before the training session, participants were tested for the ability to generate maximal isometric strength (MIS) of the right leg knee extensors (dominant). The MIS test was performed on a leg extension machine instrumented with a load cell (Lider Scales, Araçatuba-SP). During testing, participants were seated with the knee flexed to 90 degrees and hip to 75° (0° degree was equal to the hip fully extended). The participants were requested to place the distal part of the leg in a horizontal padded rod and, after a signal, to push it as hard and as fast as possible and relax after 4 seconds. Other undesirable movements were restricted by belts positioned around the thigh and trunk and fixed on the machine. The knee rotation axis was aligned with the leg extension machine rotation axis. The rod was positioned just above the ankle. The MIS was considered the high strength obtained among three trials (Brown & Weir, 2001).

Determination of the concentration of CK, LDH and IL-6

The CK and LDH activity were measured according to methods established by Oliver (Oliver, 1955) and Zammit (Zammit & Newsholme, 1976). The plasma activity of CK and LDH was analyzed using a commercial kit (Bioclin®, São Paulo, Brazil). The IL-6 plasma level was determined using the ELISA method with the R&D Systems commercial kit (Quantikine®, R & D Systems, Minneapolis, MM, USA), according to the kit guide (Cavaglieri et al., 2003).

Analysis and data processing of maximal strength of knee extensors

Besides the assessment of maximal isometric strength of knee extensors in the pre-test before the training session, participants were assessed 24, 48 and 72 hours after the exercise session. Isometric maximum strength was performed after the blood sample collection. The strength data from the load cell were acquired at 1000 values per second, transformed from analog to digital by an A/D board (National Instruments®), converted into Newtons and filtered by a Butterworth digital filter with frequency and low pass threshold of 20 Hz. The strength temporal series record and analysis were made via a computational routine written in graphic language (LabView, National Instruments®). The attempt which the subject reached the MIS on each test session (pre, 24, 48 and 72 hours) was considered for further analysis (Taylor, Christou, & Enoka, 2003).

DOMS evaluation

For DOMS evaluation a visual analogue scale (VAS) was used (Uchida et al., 2009). Before the experiment, the scale was introduced and explained to the participants. This scale was made on a paper that contained two markers at opposite ends, separated by a distance of 100 mm. At one end was marked "no pain" and at the other end "maximum pain". To quantify the pain, the quadriceps muscle was stretched by the knee flexion movement to their maximum amplitude for 5 seconds. The VAS was presented to the subjects before, 24, 48 and 72 hours after the exercise session, to allow an evaluation of the possible changes in the pain scale.

Statistical analysis

Shapiro-Wilk test was used to examine the normality distribution of data. Variance analysis for repeated measures (ANOVA) was performed to test the effect of the test time on concentration of CK, LDH and IL-6, maximal strength and DOMS. Possible degrees of violation in sphericity of data were corrected by Mauchly W test. Analysis of variance with repeated measures (ANOVA) followed by Bonferroni post-hoc was applied for comparison between sets. Alpha level of $P \leq 0.05$ was accepted. To calculate Effect Size (ES) the Hedge's g (Berben, Sereika, & Engberg, 2012) was used. To classify the ES we used a qualitative scale developed by Cohen adapted by Rosenthal (Rosenthal, 1996) and to estimate the probability of the superior outcome of one treatment over another we used the common language effect size statistic (Grissom & Kim).

RESULTS

To show a sensibility of different markers (biochemical, psychophysiological and performance) of muscle damage we analyzed the time effects acutely to 72-h after single session of resistance training in sedentary subjects. It was observed (figure 1) for CK concentrations [$F(4,56)=2.9; P<0.005$], LDH [$F(4,56)=3.9; P<0.05$], VAS [$F(3,48)=0.8; P<0.05$] and IL-6 cytokine [$F(4,56)=4.1, P<0.05$] that we had a time effect showing that these markers are sensible to indicate muscle damage after a single resistance training session, but there was no time effect for MIS [$F(3,48)=0.05, P>0.05$] (Table 1) demonstrating that it is a poor marker of muscle damage and cannot be used to assess muscle damage and monitor training periodization.

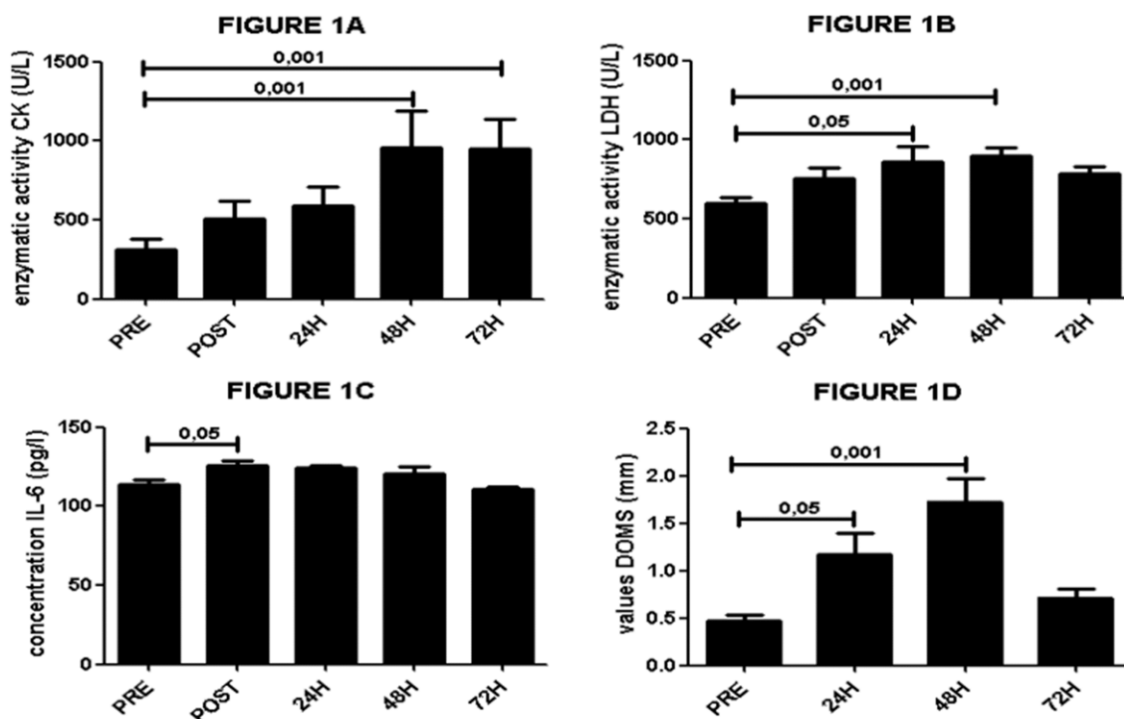


Figure 1. Average and standard errors on CK (Figure 1A), LDH (Figure 1B) and IL-6 concentrations (Figure 1C) before exercise (pre), 30 minutes after exercise (post), 24, 48 and 72 hours after exercise. The DOMS (Figure 1D) was performed only before exercise (pre), 30 minutes, 24, 48 and 72 hours after exercise. P values are shown in the figure.

Table 1. Average and standard errors before and after exercise. MIS: Maximal Isometric

	Strength			
	PRE	24H	48H	72H
MIS (N)	740.5±197.9	718.3±191.9	723.0±195.3	725.9±197.9

The ES for all variables is described in table 2 with values of Confidence Intervals (IC). All post values of MIS were small when compared with pretest. The IL6 shows a large ES when compared pretest with 72h posttest. All other variables showed a very large ES.

Table 2. Effect size of all variables comparing pre tests with 24h, 48 and 72h later. CK, LDH and IL6 compared pre test with post test, 24h, 48h and 72h later.

Effect Size (Hedger's g; n=16)								
	Pre X Post	IC	Pre X 24h	IC	Pre X 48h	IC	Pre X 72h	IC
MIS	---	---	-0,1	-67.4 to 67.6	-0.08	-68 to 68.2	-0.07	-68.6 to 68.4
DOMS	---	---	4.6	4.6 to 4.7	8.2	8.1 to 8.2	2.9	2.9 to 3
CK	2.4	-25 to 29.7	3.4	-23.8 to 30.8	3.5	-56.5 to 63.6	4.5	-42.9 to 51.9
LDH	3	-15.2 to 21.1	3.3	-23.4 to 30	6.1	-10.3 to 22.6	4.2	-10.6 to 19
IL6	3.2	1.9 to 4.5	3.8	2.8 to 4.8	1.8	0.4 to 3.2	-0.9	-1.8 to 3

DISCUSSION

To determine if the assessment of muscular isometric strength (MIS) may be an optimal method to evaluate fatigue and muscular damage, we submitted sedentary subjects to a single session training of resistance exercise and measured biochemical, psychophysiological and muscular performance up to 72 hours post session. There were no changes on muscle strength in the present study with small ES. It differs from other studies that found muscle damage with strength decrease (Byrne & Eston, 2002; Byrne, Eston, & Edwards,

2001). This conflict may be due to the different exercise protocols used in those studies. Our data shows that while inflammatory, muscle damage and pain markers are elevated, the isometric muscle strength does not change. Therefore, isometric muscle strength does not appear to be suitable for assessing the recovery period between training sessions. One hypothesis that could support this finding is that the strength training protocol used does not damage the same group of fibers used in MIS evaluation. There is a difference between activation pattern during an isometric and anisometric (shortening and lengthening) twitch. During an isometric twitch there is a lower neuromuscular activation (based on EMG), and based on a size principle, it may explain different motoneuron and consequently different fibers utilization during the MIS (Altenburg, de Ruyter, Verdijk, van Mechelen, & de Haan, 2009). Due to a lack of studies that found the same results, there is a need for future studies to understand this unknown mechanism.

Here we show that just after (30 minutes) of a single session of high-intensity resistance training, the muscle damage and inflammatory markers were increased and remained elevated up to 72 hours. DOMS increased reaching the higher value in 48 hours (ES= 8.2) and remained high about 72 hours (ES= 2.9) compared to pre-exercise. If we follow the MIS, this data can lead us to a wrong interpretation that muscle is able to be exercised again 24h later, but when carefully examined we can see that DOMS, CK, LDH and IL-6 remain elevated (table 2), showing that the next exercise session should occur after the 72 hours. Future researches are needed to detect the optimal moment for the next exercise session.

The CK and LDH enzymes concentrations were elevated in plasma when the muscle fiber was damaged (Brancaccio et al., 2007). The peak concentration occurs between 9 hours and 4 days after strength exercise (Friden & Lieber, 2001; Raastad et al., 2003; Uchida et al., 2009). Here, the peak concentrations were found from 48 hours (LDH) to 72 hours (CK). This difference can be explained by the different exercise protocols, since one study (Uchida et al., 2009) did not find increases of CK for several days due to using lower volumes of training compared to our protocol and other studies (Friden & Lieber, 2001; Raastad et al., 2003). One important data is that 30 minutes after training session the CK and LDH concentrations were high (ES of 2.4 and 3.0 respectively), it shows us that muscle damage can be detected acutely. This data suggests that training based on monitoring these enzymes values for load adjustments is necessary to adjust the time of recovery.

Releasing IL-6 after a stressful situation - such as the training protocol used - represents the proinflammatory role of this cytokine in response to muscle damage (Pedersen et al., 2004; Petersen & Pedersen, 2006). In this study, an increase in IL-6 was found immediately after the training session (equivalent to our training volume). This increase (ES of 3.8) is associated with a satellite cell proliferation about 24h after the training protocol and differentiation of satellite cell already proliferated during resting period (between 24h and 48h) (Guerci et al., 2012; Peake, Della Gatta, Suzuki, & Nieman, 2015). If the coach does not know how to monitor the training loads, executing a new exercise session in the wrong period may decrease the tissue recovery and start a overreaching process. An indirect marker of muscle damage used on this study was DOMS. The present study demonstrated the pain peak 48 hours and very large ES after the activity, similar to others studies (Uchida et al., 2009). In practice, DOMS can be used to control when a person could exercise again without muscle discomfort and injury risks. However, caution is needed with this application of DOMS, because here, we demonstrated that enzymes activity remains elevated even with the decrease of pain sensation (DOMS) at 72h after the training session. Even with a high ES compared with pre-values, DOMS was less sensitive for muscle damage than CK, LDH or cytokines activity because its values were lower about 72 hours while enzymes and cytokines remained elevated⁹. CK and LDH activity remain elevated 72 hours after resistance exercise session indicating that muscle damage is not repaired, and further time is

needed before training again. Furthermore, DOMS can be influenced by other variables like training experience and trained muscular group.

CONCLUSIONS

The volume-training often used in gyms and training venues - that we used in this research - may lead to a muscular damage. Noninvasive methods like maximal isometric strength test and DOMS are not a good measure to assess muscular damage, consequently, the recovery. Muscle damage can be detected after a single session of high-intensity resistance exercise and, based in our training protocol, the recovery needs to be over 72 hours to complete muscle regeneration, therefore, the monitoring of training loads is necessary for an optimal periodization.

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AUTHOR CONTRIBUTIONS

Joel conceived, designed the experiments and collected the data; Silvestre, Motoyama and Azevedo wrote and made the statistical approach, reviewed and made the intellectual contribution.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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