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LENGTH OF REST INTERVAL BETWEEN RESISTANCE EXERCISE SETS: PERFORMANCE AND INTER-INDIVIDUAL VARIABILITY OF CK ACTIVITY

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ABSTRACT

Purpose: To determine how the rest interval (RI) lengths of 30 and 90 s between sets of biceps curl exercise affect the total volume of work performed and serum CK activity, and to verify the relationship between inter-individual variability of CK activity and total volume performed when the resistance exercise bout is conducted with 30 or 90 s **Methods:** Twenty-seven healthy sedentary men (18–20 years old) volunteered to participate in this study and were divided into two groups: 30RI ($n = 16$) or 90RI ($n = 11$), based on the RI length of 30 or 90 s between the sets of a resistance exercise protocol. The one repetition maximum (1RM) assessment of the elbow flexion was carried out and then a resistance exercise protocol which constituted five sets of biceps curl at 85% of 1RM with 30-s

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(30RI group) or 90-s (90RI group) RI length between sets was performed. Each bout was performed to voluntary fatigue and the number of repetitions and workout volume completed were calculated. Subjects provided blood samples prior to resistance exercise, and at 48, and 96 h following exercise to evaluate serum CK activity. The inter-individual serum CK activity along the 96 h after exercise was analyzed. **Results:** The results demonstrated that the longer RIs provided greater workout volume as expected, but there were no differences in serum CK activity between the groups. Additionally, it was possible to identify two high responder subjects, one from each RI group, who showed a great inter-individual serum CK activity variability. **Conclusion:** Exercising with short RIs does not appear to present any additional muscle microtrauma to untrained subjects. Further studies are necessary to evaluate if the inter-individual variability of the serum CK activity is influenced by the inter-set RI length.

Keywords: Recovery time; Exercise volume; Muscle damage; Muscular stress; Biochemical markers.

INTRODUCTION

When designing a program for resistance training, inter-set rest interval (RI) length is one of the variables used among others such as intensity, order of exercise, velocity of execution etc. The manipulation of the RI length variable is closely linked with volume workout and with the key objective proposed in resistance training programs. Despite many studies about this subject,[19,35,38] the findings been largely unsubstantiated.[6] Previous studies have examined the impact of inter-set RI lengths of 1 to 5 min between sets for single and multiple exercises.[22,25,26,30,31,39–41] These studies demonstrated that, the shorter the RI length, the smaller will be the volume of work performed during a training session when it is done until volitional fatigue.

It is well-established that resistance exercise causes transient damage to muscle fibers.[8,10] Quantifying post-exercise muscle damage provides vital information to the researchers and clinicians interested in evaluating resistance exercise protocols and the subsequent skeletal muscle response and adaptation. Assessment of the biomarker creatine kinase (CK) is widely used for indirectly evaluating muscle damage after resistance exercises in part because of its large expected increase from baseline and because it is relatively simple and inexpensive to quantify.[4,17,27] Interestingly, conflicting results appear in the literature when comparing the serum CK activity after resistance exercises when they are performed with different RI lengths. Mayhew *et al.*[24] evaluated the serum CK activity in men after ten sets of 10 repetitions of leg press [65% one repetition maximum (1RM)] using either a 1- or 3-min rest between sets. The group which executed the sets with a RI of 1 min had a higher CK elevation than the group who performed with longer intervals (3 min). However, Rodrigues *et al.*,[33] Machado *et al.*[21] and Ribeiro *et al.*[32] observed no differences in CK activity between research groups after completing a session of resistance exercise with different intervals lengths. Conflicting results can be attributed to great inter-individual variability on serum CK activity.[7] For example, Machado and Willardson[22] verify differences in serum CK activity following resistance exercise sessions with 1- or 3-min RI lengths when high responder (HR) subjects (i.e. subjects who had a great post-exercise serum CK activity peak) were separated from each group, while the analysis of groups without stratification (i.e. having both high and normal responders) demonstrated no differences between RI lengths.

Additionally, it is described that exercise with shorter than 1-min inter-set RIs length results in a

significant increase in epinephrine, norepinephrine, cortisol, growth hormone and insulin-like growth factor-I.[2,5,18,23] All these hormones play a role in the immunological response that occurs following heavy resistance exercises,[29] as demonstrated by concomitant elevations in prostaglandin E2 (PGE2), tumor necrosis factor-α (TNF-α), interleukin 1b (IL-1b), interleukin 6 (IL-6) and interferon-α (INFα),[1,37] which may influence the muscle response to resistance excercises.[1,18,19,37]

Based on previous findings we hypothesized that shorter inter-set RI length would manifest greater alterations in serum CK activity following an exercise session when compared to longer inter-set RI length. Therefore, the present study aims to determine how the RI lengths of 30 and 90 s between sets of biceps curl exercise can affect the total volume of work performed and the serum CK activity. Additionally, we also aim to verify the relationship between inter-individual variability of CK activity and total volume performed when the exercise is conducted with RI length of 30 or 90 s.

METHODS

Subjects

The study consisted of twenty-seven healthy sedentary men aged between 18 and 20 years. They indicated that they were not currently using medical drugs, dietary supplements or anabolic steroids, and were without joint, muscular or cardiovascular diseases. The experimental conditions were conducted in accordance with the norms of the Brazilian National Health Council, under Resolution No. 196, promulgated on 10 October 1996, referring to scientific research on human subjects and Helsinki Declaration (1964, reformulated in 1975, 1983, 1989 and 1996) of the World Medical Association (http://www.wma.net/e/policy/17-c_e.html), and all the subjects participated voluntarily.

Table 1 Characteristics of Subjects.

	30RI ($n = 16$)	90RI ($n = 11$)
Age (years)	18.5 ± 0.5	18.6 ± 0.5
Height (cm)	178.8 ± 7.1	178.6 ± 6.7
Body Mass (Kg)	68.3 ± 9.8	70.0 ± 14.5
Bíceps Curl 1RM (Kg)	39.8 ± 6.4	38.8 ± 4.7

Design

Subjects were divided according to a computer generated randomization process into the 30RI ($n = 16$) or 90RI ($n = 11$) according to the RI length between sets of each group (i.e. 30 or 90 s). Comparisons of both groups in terms of age, height, body mass and dynamic strength were done prior to initial resistance exercise protocol and significant differences between groups were not found ($p > 0.05$). Descriptive characteristics of the subjects are showed in Table 1.

Methodology

The dynamic strength of the elbow flexor muscles was assessed through 1RM on a standard preacher curl bench on two different occasions separated by 72 h. The same investigator measured 1RM for all subjects and verbally instructed subjects to perform one full range of motion repetition, extending the elbow to 170° and curling the weight back up to the shoulder with the weight at 100% of estimated maximum. If the lift was unsuccessful, a 5-min rest was taken and the weight decreased slightly. If the lift was successful, a 5-min rest was taken and the weight increased. The procedure was repeated until subjects failed to complete a full range of motion lift. Weights were chosen so that the 1RM could be determined in three to five attempts. Maximum weight lifted was recorded in kilograms as the greatest amount of weight successfully lifted one time. The same investigator measured 1RM and provided verbal encouragement during each 1RM attempt for a given subject.

To increase the reliability of 1RM assessments, the following strategies were used: (a) the 1RM was measured on two nonconsecutive days that were separated by 72 h, (b) exercise technique was monitored and corrected as needed, and (c) all subjects received verbal encouragement. The highest 1RM load measured during the two sessions was used during the experiment. The 1RM assessment procedures demonstrated high reliability (intraclass $r = 0.98$).

The exercise experimental protocol constituted of five sets of biceps curl at 85% of 1RM with a 30-s (30RI group) or 90-s (90RI group) RI length between the sets. The subjects were instructed to extend the elbows from an elbow flexed (50°, 0.87 rad) to an extended position (170°, 2.97 rad) and then to return to the flexed position in 3 s (~1 s to concentric and ~2 s to eccentric phase). The repetition cadence for each exercise was controlled with a digital sound signal (Beat Test & Training, CEFISE, Nova Odessa, Brazil) that was adjusted so that each repetition was completed in 3 s (~1 s concentric and ~2 s eccentric). Each bout was performed to concentric failure and the numbers of repetitions per set were recorded. The warm up consisted in two sets with 10 repetitions of same exercise with 30% 1RM.

Blood Samples Analyses

Blood samples were obtained from the subject while in a seated position from antecubital vein. Samples were placed into plain evacuated tubes. Samples were collected before exercise, after an 8 h overnight fast prior to exercise bout, and at 48, and 96 h following exercise. Immediately following collection, blood samples were centrifuged at 1600 × g for 20 min. The serum was removed and the serum CK activity was analyzed with an enzymatic method at 37°C (CK-UV NAC-optimized; Biodiagnostica, Pinhais, Brazil) in a Cobas Mira Plus analyzer (Roche, Basel, Switzerland). The CK assessment procedures demonstrated high reliability on quality control standards (intraclass $r = 0.97$).

Statistical Analysis

Data are presented as means [± Standard Deviation (SD)]. Comparisons of characteristics between groups were performed with Student's t test. To compare repetitions and volume, a 2 (groups) by 5 (sets) Analysis of variance (ANOVA) were utilized. To compare serum CK activity, a 2 (groups) by 3 (CK) ANOVA were utilized. The alpha level was set at less than 0.05 for a difference to be considered significant. Significant effects were further analyzed using pair wise comparisons with Tukey's *post hocs*. The reliability of the CK activity assessments were assessed with the intraclass correlation (ICC) and the reliability was described as 'excellent' for ICC values in the range of 0.8−1.0 and 'good' for 0.6−0.8, whereas values below 0.6 were considered 'poor'.[36] The relationship between peak CK activity and total volume completed was performed using Pearson correlation. Statistical procedures were carried out with software package SPSS® (15.0) for Windows.

RESULTS

The number of repetitions per set and the volume for work performed is shown in Table 2. Number of repetitions and volume per set decreased significantly along the sets for both groups, but the 30RI group displays a greater reduction when compared to 90RI group. Total number of repetitions ($p = 0.0001$), as well as total volume ($p = 0.0072$) was lower in 30RI when compared to 90RI.

The 2 × 3 ANOVA revealed no significant interaction between RI length and measurement time for CK activity ($p = 0.6040$). However, CK

Table 2 Repetitions, Volume of Work Per Set and Their Total for Each Group.

Set	Repetitions		Volume (Kg)	
	30RI	90RI	30RI	90RI
1st	9.1 ± 1.1	9.7 ± 0.7	237.1 ± 59.6	244.4 ± 30.9
2nd	4.7 ± 1.1^{a}	$6.7 \pm 1.6^{a,f}$	124.1 ± 46.7^{a}	$167.6 \pm 35.2^{a,f}$
3rd	$3.1 \pm 0.9^{a,b}$	$4.7 \pm 1.5^{a,b,f}$	$82.3 \pm 30.8^{a,b}$	$119.0 \pm 38.5^{a,b,f}$
4th	$1.4 \pm 0.7^{a,b,c}$	$3.5 \pm 1.1^{a,b,d,f}$	$38.5 \pm 21.9^{a,b,c}$	$88.0 \pm 25.9^{a,b,f}$
5th	$1.1 \pm 0.8^{a,b,c}$	$2.3 \pm 1.8^{a,b,c,e,f}$	$27.7 \pm 19.9^{a,b,c}$	$61.1 \pm 52.4^{a,b,c,f}$
Total	19.4 ± 3.4	26.9 ± 4.5^{f}	509.7 ± 153.1	680.1 ± 141.4^{f}

[a]Different from the 1st Set for the same RI group ($p < 0.001$). [b]Different from the 2nd Set for the same RI group ($p < 0.001$). [c]Different from 3rd Set for the same RI group ($p < 0.001$). [d]Different from the 3rd Set for the same RI group ($p < 0.05$). [e]Different from the 4th Set for the same RI group ($p < 0.05$). [f]Differences between RI groups on same Set ($p < 0.01$).

activity increased significantly at 48 h ($p < 0.001$ for RI30; $p < 0.032$ for RI90) when compared to pre-exercise measure in both groups (Table 3).

As expected all subjects reach a peak CK activity at 48 h after exercise protocol. No significant relationships were found between peak CK activity and total volume for 30RI ($r = 0.0053$) or 90RI ($r = 0.0151$). Neither of these correlation coefficients were significant ($p = 0.8454$ and $p = 0.9649$ respectively) (Fig. 1).

The volunteers showed a great serum CK activity inter-individual variability [Figs. 2(a) and 2(b)]. It is possible to identify two HR subjects, one from each group.

DISCUSSION

This study examined whether a standardized five-set elbow flexion/extension resistance exercise at 85% of 1RM could influence differently the performance and the serum CK activity response to the exercise carried out with different RI lengths. Besides, the inter-individual relationship between these variables was studied. Our main findings were that the performance, examined through number of repetitions and volume completed (i.e., load × sets × repetitions), was significantly reduced along the five sets of exercise protocol for both inter-set RI lengths, with greatest reduction for the shorter RI length. Additionally, the serum CK activity response after the exercise

Table 3 Serum CK Activity at Different Times of Collection.

	PRE	48 h	96 h
30RI	189.7 ± 67.6	$949.8 \pm 1107.9^{a,b}$	506.4 ± 164.3^{c}
90RI	199.4 ± 70.6	$743.8 \pm 815.7^{a,b}$	403.8 ± 158.3

[a]Different from PRE for the 30RI group ($p < 0.001$). [b]Difference from the PRE for the 90RI group ($p < 0.05$). [c]Different from 48h for the 30RI group ($p < 0.05$).

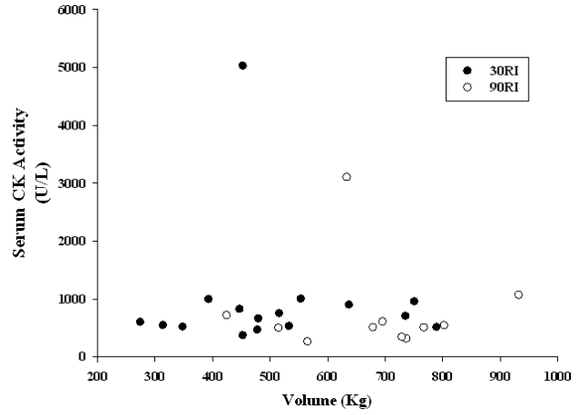

Fig. 1 Relationship between peak CK activity and total volume (sets × repetitions × load). Black = 30RI; White = 90RI.

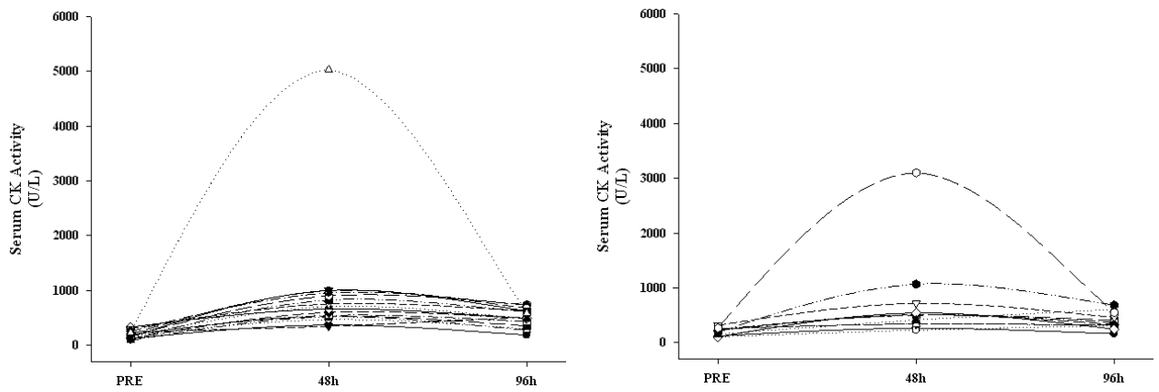

Fig. 2 Inter-individual variability of serum CK activity following resistance exercise. (a) 30RI subjects; (b) 90RI subjects.

was maintained significantly increased for a long time (i.e. at least 96 h after the exercise protocol) when the exercise was conducted with short inter-set RIs, but without differences between short (30RI) and long (90RI) inter-set RI lengths. The inter-individual relationship between performance and serum CK activity was not different for the 30RI and 90RI groups, demonstrating that these inter-set RIs induce similar muscle damage.

Many studies have examined the effect of inter-set RI length on performance of single and multiple exercises.[11,21,24,32,33] Our findings about the performance were consistent with previous reports that compared the number of repetitions and the volume completed of a single exercise protocol, which is lower as when the inter-set interval length is shorter.[39–41] Short inter-set RI lengths (i.e. lesser than 1 min) have been used in hypertrophy programs because it can induce a great metabolic stress, leading to an increased hormonal release, especially the release of the growth hormone.[2,3,13]

Resistive exercise often triggers an increase in circulating levels of total CK via disruption of the sarcolemma. This disruption provides a pathway for the release of CK from the cytoplasm to the extracellular fluid, where it is transported to the lymphatic system before entering the circulation. Total CK protein concentration in the circulation represents the balance between enzyme entry rate into the circulation versus clearance by the reticuloendothelial system.[4,17,27] Serum CK activity can be elevated for 24–48 h following exercise bouts, with a gradual return to the basal levels in 72–96 h.[9,34] The current study corroborates with previous investigations on this trend, where the serum CK activity was significantly elevated above pre-exercise levels at 48 h post-exercise. Our results represent a typical resistance response where the subjects tend to be submitted to a standard exercise, unlike from many studies where isokinetic exercises are used.[7,28] Thus, the present results obtained with this design display findings which could be used by researchers, clinicians, coaches and fitness professional in day-to-day exercise prescription and evaluation.

The analysis of inter-individual variability of serum CK activity along 96 h after exercise demonstrated that two subjects, one from each RI group, had a great post exercise serum CK activity peak. According to Chen[7] these subjects can be classified as HR, because of their CK induced by exercise variation. Recent studies have demonstrated that the variation of CK induced by exercise is great among the population and may

depend on age, sex, and the fact that there are subjects who present disproportional alteration of serum CK activity.[15,22] The evaluation of this exercise-induced response is important because it is proposed that HR subjects are more susceptible to develop rhabdomyolysis, an undesirable condition that occurs in response to strenuous physical activity where the exercise induces stress on the muscle causing damage to the muscle fibers.[9,14]

Another possible factor that has been attributed to responder status is the force application at long muscle lengths. It has been shown that subtle force applications at long muscle lengths can alter a participant's high or low response to the exercise.[7] Because a force-angle curve was not determined during muscle actions in this study, it is possible that "responder" consistency was due to the manner in which participants performed the exercise, as well as the behavioral factors (i.e. the speed of muscle actions during RI30 and RI90 or whether the participants had participated in physical activity in the past) which may partially account for the consistent response in this study. We try to minimize these effects with control of the cadence and including only subjects without resistive training experience for at least 6 months before the study.

It is interesting to note that the serum CK activity in HRs before, and at 96 h after, exercise protocol is similar to the other participants, corroborating previous findings.[22] There is no known explanation for this fact, and so it is necessary to develop further studies to elucidate whether the highest serum CK activity after exercise is related to the direct muscle damage or, a different kinetics to wash out the CK from the serum.

We did not identify differences in serum CK activity between groups which corroborates with the findings of others.[21,32,33] However, the present result does not agree with the findings of Mayhew *et al.*[24] In Mayhew's study the subjects performed leg press exercises and the total work had been equalized between short and long RI conditions, whereas in this study each group performed bicep curls to volitional fatigue for each set (intervals modulate the number of repetitions and the total volume) during the biceps curl exercise. In addition, Saka *et al.*[34] demonstrated that the lower body exercise results display lower CK activity variation when compared with upper body, which can explain some of the differences between our results and the results from Mayhew *et al.*[24] Because of the different architecture of arm and leg muscles,[20] it is probable that mechanical stress per muscle unit differs between these two muscle groups when doing exercises of the same intensity. This can be one of the reasons for different muscle damage responses. In addition, Jamurtas *et al.*[16] proposed that submaximal eccentric actions during daily activities, like downhill walking and going down stairs, is a routine training stimulus for lower body muscles. It is well documented that, following repeated bouts of eccentric exercise, the muscles adapt themselves to protect against further damage,[9] lending support to the proposition of other investigators.[16,34]

Buresh *et al.*[5] proposed that the differences caused by exercise with short versus long RIs will depend less on the RI employed and more on the total volume (sets $\times$ repetitions per set $\times$ load) of work completed. We tested this by examining the correlation between the total volume (sets $\times$ repetitions per set $\times$ load) and the peak of serum CK activity. Our results showed a weak correlation ($r = 0.0053$ and $r = 0.0151$, for 30 and 90 s RIs, respectively) between cited variables. With regard to endurance-based exercises, a relationship is described between greater volume and serum CK activity magnitude variations,[4] but this data apparently is not repeated in resistance exercises.[11] Friden *et al.*[12] demonstrated that following eccentric exercises, myofibril

damage was more pronounced in type II muscle fibers. Following a bout of eccentric exercise, type II muscle fibers are more likely to be damaged than type I muscle fibers and, therefore, show greater serum CK activity. Resistance exercise recruits more type II fibers than endurance exercise; we postulate that CK response is less related to volume and more related to intensity or other physiological mechanism.

A mechanism of CK equal response in different inter-set RIs can link with hormonal profile or response. We did not examine a hormonal profile and its influence on CK variability, but many studies[2,3,5,18,23] have shown augments in anabolic hormones [growth hormone (GH), insulin-like growth factor-1 (IGF-1) and testosterone] after resistance training with very short inter-set RIs. These augmentations are higher when the intervals were shorter, and the higher effect of metabolic membrane and protein degradation, and higher mechanical load can be compensated by acute augmented anabolic response. Despite little empirical evidence about the influence of acute rises in GH, IGF-1 and testosterone on muscle hypertrophy,[6] we do not neglect the short term effect of these and other hormones on the maintenance of structural muscle architecture, but further studies should be developed to evaluate this topic.

CONCLUSION

The results from the current study add to the growing body of knowledge regarding acute responses to resistance training with different inter-set RIs. Results showed that if sufficient time is available, instituting longer RIs (e.g. 90 s) allows for greater repetitions and total workout volume compared to a shorter RI (e.g. 30 s). There might be a point of diminishing returns at which the RI between sets would become excessive, and yield no further increases. This last point, however, needs to be invested further. Differences in serum CK activity modulation was not observed when 30- and 90-s inter-set RIs are compared.

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