Abstract Mechanical stimuli have often been suggested to be the major determinant of resistance training adaptations; however, some studies suggested that metabolic changes also play an important role in the gains of muscle size and strength. Several resistance training methods (RTM) have been employed with the purpose of manipulating mechanical and metabolic stimuli; however, information about their physiological effects are scarce. The objective of this study was to compare the time under tension (TUT) and blood lactate responses among four different RTM reported in the literature. The four RTM were performed in a knee extension machine at 10 repetition maximum (RM) load by 12 recreationally trained young men. The RTM tested were: 10RM, super-slow (SL—subjects performed one 60-second repetition with 30 seconds for eccentric and 30 seconds for concentric phase), functional isometrics (FI—in each repetition, a five-second maximal isometric contraction was executed with the knees fully extended) and adapted vascular occlusion (VO—subjects performed a 20-second maximal isometric contraction with the knees fully extended and immediately proceeded to normal isoinertial lifts). According to the results, all RTM produced significant increases in blood lactate levels. However, blood lactate responses during FI (4.48 ± 1.57 mM) and VO (4.23 ± 1.66 mM) methods were higher than the SL method (3.41 ± 1.14 mM). The TUT for SL (60 s), FI (56.33 ± 6.46 s), and VO (53.08 ± 4.76 s) methods were higher than TUT for 10RM (42.08 ± 3.18 s). Additionally, the SL method was performed at a lower resistance than 6RM, which limits the comparison between mechanical stimuli.

Introduction

Resistance training has a fundamental role in physical activity programs, and has been recommended by many major health organizations in order to increase general health and fitness (American College of Sports Medicine; 1998; Fletcher et al., 1995; Kraemer et al., 2002; Pollock et al., 2000; U.S. Department of Health and Human Services, 1996). Two of the most common goals of resistance training are to obtain increases in muscle size and strength, for aesthetic, athletic or health purposes in chronic conditions such as sarcopenia and AIDS (Fairfield et al., 2001; Kotler et al., 2004; Yarasheski et al., 2003; Zinna et al., 2003). Mechanical stimuli have often been suggested to be the major determinant of the resistance training adaptations (Folland et al., 2002; Kraemer et al., 2002; McDonagh and Davies, 1984; Mikesky et al., 1989; Pincivero et al., 1997). However, some studies suggested that metabolic changes may play an important role in the gains of muscle size and strength (Kawada, 2005; Schott et al., 1995; Smith and Rutherford, 1995). With the purpose of manipulating metabolic and mechanical stimuli, several resistance training methods (RTM) have been developed; amongst them are super-slow, functional isometrics and modified vascular occlusion.

The super-slow (SL) method involves performing the exercise at slow velocities, taking 10 to 60 seconds to complete a repetition (Fleck and Kraemer, 2004). Hunter et al. (2003) compared the metabolic responses between SL (8 repetitions performed at ~28% of one repetition maximum - 1RM) and traditional resistance training (8 repetitions at 65% of 1RM) and reported higher blood lactate responses for the traditional training. On the other hand, Keogh et al. (1999) did not report significant differences in blood lactate response between one set of the SL method performed at 55% of 1RM and one set of 6 repetition maximum (6RM). With regard to time under tension (TUT), Keogh et al. (1999) reported that the SL method elicited greater TUT than 6RM. However, the SL method was performed at a lower resistance than 6RM, which limits the comparison between mechanical stimuli.
The Functional Isometrics (FI) method entails performing dynamic actions with an isometric contraction at the point of maximal effort in each repetition (Fleck and Kraemer, 2004). In a previous study, Keogh et al. (1999) did not find significant differences in the blood lactate response and TUT when comparing the FI method with 6RM. However, the isometric actions in the FI method lasted only two seconds while has often been suggested to perform the isometric actions for five to seven seconds (Fleck and Kraemer, 2004).

Several studies have found that the utilization of vascular occlusion has a positive effect on muscle strength and hypertrophy (Burgomaster et al., 2003; Shinohara et al., 1998; Takarada et al., 2000). This strategy has been shown to increase blood lactate concentration (Takarada et al., 2000) and was proposed to induce a preferential activation of the fast twitch (FT) fibers and to increase the amplitude of the changes from hypoxia to hyperoxia during exercise (Kawada, 2005; Moritani et al., 1992; Takarada et al., 2000). According to this evidence, some weight trainers have employed a maximal isometric contraction prior to normal dynamic lifts in order to simulate vascular occlusion (Gentil, 2005). The rationale for this practice lies in the finding that isometric actions interrupt blood flow and leads to metabolites accumulation, as shown by Koba et al. (2004) and Hietanen et al. (1984). However, it is not known if this practice would have any benefit in accumulating metabolites or providing higher mechanical stimuli than traditional resistance training with maximum repetitions. Thus, due to the contradictions in the literature with regard to the SL method, as well as the lack of studies comparing physiologic stimuli among other RTM, the purpose of the present study was to compare the blood lactate responses and TUT among four different RTM.

Methods

Experimental procedures

Twelve subjects were tested in all situations. Blood lactate concentrations were measured in order to assess metabolic stress, similar to previous studies (i.e., Kraemer et al., 1990; Keogh et al., 1999; Hunter et al., 2003). Blood was collected from the right ear lobule immediately before and three minutes after each RTM. Therefore, a 4x2 (RTM x time) within-within design was employed. Due to the unique characteristics of the RTM tested (controlled velocity at the SL method and isometric moments at the FI and VO methods), it would be difficult to compare total work volume for the RTM. Hence, as load was kept constant, TUT was used as an estimate of the mechanical load imposed to the muscle. Additionally, previous studies have found a strong correlation between TUT and skeletal muscle adaptations (Mikesky et al., 1989).

Subjects

Twelve recreationally weight-trained men with experience in all the RTM tested volunteered to participate in this study. The minimum overall resistance training experience required to enter the study was two years. All subjects were informed of the risks and benefits of the experiment and signed a consent form before participating in the study. The experiment was approved by the University of Brasilia Institutional Review Board. The characteristics of the subjects are presented in Table 1.

Testing procedures

Tests were conducted using a leg extension machine (HN1030, Righetto Fitness Equipment, São Paulo-Brazil). During the week before the experiment, the 10RM load for each subject was assessed according to the procedures reported by Simão et al. (2005). Data were analyzed by Pearson product moment correlations to estimate day-to-day 10RM reliability (r=0.96).

All subjects executed the four RTM in a randomized order with at least 24 hours between each one. Subjects were instructed to avoid any type of resistance training involving the quadriceps muscles 72 hours prior to the beginning of tests.

In all RTM, except the SL method and the specific isometrics moments during the FI and VO methods, subjects were instructed to maintain a constant velocity of two seconds in the concentric phase and two seconds in the eccentric phase, with no pause between phases. The concentric phase started at 100° of knee flexion and ended with the knees fully extended. A metronome was used to control contraction velocity.

Resistance training methods (RTM)

All RTM were performed with the same knee extension machine used during the load tests. The four RTM were performed with the load equivalent to 10RM. SL was the exception, here the RTM were performed until concentric failure, characterized when the subject was not able to

<table>
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<th>Table 1</th>
<th>Characteristics of the subjects (Mean±SD)</th>
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<tr>
<td>Characteristic</td>
<td>Values</td>
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<tr>
<td>Age (years)</td>
<td>24.83±3.27</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78.94±13.13</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177.83±5.96</td>
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<tr>
<td>10RM load (kg)</td>
<td>109.58±16.58</td>
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<tr>
<th>Table 2</th>
<th>Time under tension and number of repetitions performed during different resistance training methods (Mean±SD)</th>
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<tr>
<td>RTM</td>
<td>Repetitions</td>
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<tr>
<td>10RM</td>
<td>10.33±0.49*</td>
</tr>
<tr>
<td>Super-slow (SL)</td>
<td>1.00±0.00</td>
</tr>
<tr>
<td>Adapted vascular occlusion (VO)</td>
<td>7.17±1.11*</td>
</tr>
<tr>
<td>Functional isometrics (FI)</td>
<td>6.58±1.00*</td>
</tr>
</tbody>
</table>

# significantly higher than adapted vascular occlusion (p<0.05)
† significantly higher than super-slow (p<0.05)
‡ significantly higher than functional isometrics (p<0.05)
* significantly higher than 10RM (p<0.05)
completely extend the knees during two consecutive repetitions. The mean number of repetitions performed during each RTM are presented in Table 2.

The four RTM analyzed in this study were:
1) Ten maximum repetitions method (10RM): Normal isoinertial lifts were performed until concentric failure at the load obtained during the 10RM test.
2) Functional isometrics method (FI): In each repetition, a five-second maximal isometric contraction was executed with the knees fully extended.
3) Adapted vascular occlusion (VO): subjects performed a 20-second maximal isometric contraction with the knees fully extended and immediately preceded to normal isoinertial lifts.
4) Super-slow method (SL): subjects performed one 60-second repetition consisting of 30 seconds for the eccentric phase and 30 seconds for the concentric phase. To control for muscle contraction velocity, time was given every five seconds.

Blood lactate measurements

A small sample of blood (25 µl) was taken from the right ear lobule immediately before (T0) and three minutes (T3) after the completion of each RTM. Blood from these incisions was allowed to flow into a Brand NH4 heparinized capillary tube. From the capillary tube, the blood was added to a labeled Eppendorf tube filled with buffer (1% sodium fluoride) at a ratio of 1 : 3 (blood to buffer). These samples were then placed in refrigeration at approximately 4°C to be transported to the laboratory and then put in a refrigerator. Blood samples were analyzed using the YSI 1500 Lactate Analyzer (Yellow Springs Instrument Co., Yellow Springs, OH).

Time under tension

Time under tension (TUT) was defined as the total time in which the muscles were applying force to the implement. The same pair of investigators recorded the times of all tests using a digital chronometer. Data were analyzed by Pearson product moment to estimate the correlations between the measurements of the two investigators (r=0.98). The mean of the two measures was used in the analysis.

Statistical analyses

Standard statistical methods were used for the calculation of means and standard deviations (SD). Before parametric analyses were done, the normality of distribution of the data was assessed with Kolmogorov-Smirnov tests. Differences in blood lactate responses during the RTM were assessed using a two way ANOVA 4×2 (RTM×time). TUT and repetitions among the RTM were compared with one-way ANOVA. Multiple comparisons with adjustment of confidence interval by the Bonferroni method were used for post-hoc comparisons. The p<0.05 criterion was used for establishing statistical significance.

Results

Table 2 shows the values of TUT and repetitions performed during the different RTM. The total number of repetitions performed were significantly different among RTM [f (3,33)=441.136, p<0.001]. Repetitions performed during the 10RM were higher than those in the SL, FI and VO methods (p<0.01). Repetitions performed during the FI and VO methods were higher than during the SL method (p<0.01). Repetitions performed during the VO method were higher than during the FI method (p<0.05).

There were significant differences in TUT among RTM [f (3,33)=43.670, p<0.01]. TUT for the SL, FI and VO methods were higher than 10RM (p<0.01). TUT for the SL method was higher than that for the VO method (p<0.01).

There was a significant effect of time on blood lactate [f (1,11)=40.048, p<0.01]. When all RTM were considered, the blood lactate concentrations at T3 were significantly higher than at T0 (p<0.01).

There were significant differences in blood lactate responses among RTM [f (3,33)=7.466, p<0.01]. Blood lactate

Fig. 1 Blood lactate level in different RTM, expressed as means and standard deviation. Analysis were done before (T0) and three minutes after the end (T3) of each RTM. 10RM, SL (super-slow), FI (functional isometrics), VO (adapted vascular occlusion).

* significantly higher than SL.
concentrations at T0 were not significantly different among RTM ($p>0.05$). However, blood lactate concentrations at T3 were higher for the VO and FI methods than for the SL method ($p<0.05$). The results of the lactate concentrations are presented in Fig. 1.

**Discussion**

There is a consensus that mechanical load is crucial for gains in muscle size and strength (Kraemer et al., 2002; McDonagh and Davies, 1984). Based on this paradigm few would have been predicted that healthy subjects could obtain gains in muscle strength and hypertrophy after three weeks of walking, as was recently reported by Abe et al. (2006). There are several reports showing that metabolic stress results in increases in muscle size and strength (Schott et al., 1995; Kawada and Ishii, 2005). Some authors suggested that the recommendation of high load to induce hypertrophy may be derived from an association between load and metabolic stress (Meyer, 2006).

It has been recognized that intracellular metabolic changes may be an important signal for muscle hypertrophy, but the mechanisms by which acute changes in lactate or other metabolites are linked to the hypertrophic signaling cascade is unknown. In the present study lactate was not used based on a cause-effect relationship. However, although lactate may not be a direct promoter of muscle adaptations it may be used as a marker of metabolic stress. This assumption was based on previous findings that reported elevated responses of lactate and other metabolites in interventions that promoted increases in muscle size and/or strength (Kawada and Ishii, 2005; Schott et al., 1995; Takarada et al., 2000; Tanimoto and Ishii, 2005).

Previous studies have reported positive effects of tourniquet vascular occlusion in muscle strength and hypertrophy (Abe et al., 2006; Burgomaster et al., 2003; Shinohara et al., 1998; Takarada et al., 2000). However, direct vascular occlusion is a very specialized procedure that should be used with careful monitoring of occlusive pressure and blood flow, therefore, other strategies should be used as alternatives. According to Tanimoto and Ishii (2005), exercises with sustained force generation would be one of these alternatives.

With regard to the SL method, the present findings showed that blood lactate response to this RTM was similar to 10RM, and lower than the VO and FI methods. Previous studies comparing blood lactate response between traditional resistance training and the SL method have yielded conflicting results. Keogh et al. (1999) compared the stress profile of one set of six different RTM with traditional resistance training (6RM) during the bench press exercise in 12 resistance-trained men and reported no significant differences in blood lactate response between the SL method and 6RM.

However, Hunter et al. (2003) found opposite results when comparing the metabolic effects of a resistance training session involving the SL method or traditional resistance training in seven resistance-trained men. The SL session involved one set of eight repetitions at $\sim 28\%$ of 1RM, performed in a slow cadence (10 seconds for concentric and 5 seconds for eccentric muscle actions). The traditional resistance training session consisted of two sets of eight repetitions at 65\% of 1RM, taking approximately 30 seconds to complete each set. Contrary to the present study’s findings, the authors reported a $\sim 50\%$ higher blood lactate response during the traditional resistance training session.

The discrepancy between the present results and those of Hunter et al. (2003) could be due to methodological differences. The load used during the SL method in the experiment of Hunter et al. (2003) was less than half the load used during traditional resistance training ($28\%$ vs. $65\%$ of 1RM), while the present study equated the loads in both conditions. Moreover, Hunter et al. (2003) compared resistance-training sessions with multiple sets, and traditional resistance training involved twice the number of sets than the SL session of the present study which compared the effects of a single set of each method.

According to our results, blood lactate responses were higher for the VO and FI methods than the SL method, but no significant differences were found between the VO and FI methods and 10RM. In a previous study, Keogh et al. (1999) did not report significant differences in blood lactate responses between the FI method and maximum repetitions (6RM), which does not conflict with the present results. With regard to the VO method, it is difficult to compare our results with previous findings because similar studies could not be found in the literature. During the FI and VO methods, isometric contractions were performed as an attempt to induce ischemia. However, it is not known if these RTM would obtain chronic results comparable with those obtained by means of constant vascular occlusion as reported by Takarada et al. (2000), Burgomaster et al. (2003) and Shinohara et al. (1998).

The differences in blood lactate responses among the RTM may not be explained solely by mechanical factors (TUT, repetitions or work). If it is assumed that repetitions or total work was the sole determinant of blood lactate responses, it would be expected that 10RM would produce the highest blood lactate response among the RTM tested, however, this was not observed. On the other hand, if TUT exerted a major influence on blood lactate, SL would be related to the higher blood lactate responses rather than VO and 10RM. Therefore, it is suggested that the differences observed in the present study were probably caused by the unique characteristics of the RTM tested, specifically, the isometric moments at the FI and VO methods.

In a study of Moritani et al. (1992), the subjects performed repeated contractions at 20% of MVC (maximal voluntary contraction) for 2 seconds followed by 2 seconds of rest for 4 minutes. Vascular occlusion was induced between the first and second minute by a pressure cuff inflated to 200 mmHg. According to their findings, blood lactate concentrations showed a large increase shortly after the release of arterial occlusion and it remained significantly elevated during the
following contractions. Therefore, it is possible that the isometric contractions at VO and FI may have caused a temporary vascular occlusion that resulted in a higher lactate concentration when blood flow was reestablished.

According to the stimulus-tension theory, the intensity (\%RM) and duration of the muscular tension are responsible for neural and morphological adaptations (Crewther et al., 2005). As load was kept constant across RTM, TUT was used to provide an insight into this parameter. Additionally, some authors consider TUT an important factor for strength and hypertrophic adaptation, especially when associated with high loads (Crewther et al., 2005; Mikesky et al., 1989). In the present study, the SL, FI and VO methods provided higher TUT than 10RM, despite using the same load. Therefore, it is feasible to suggest that the VO, FI and SL method could be used with the purpose of increasing muscle adaptations. However, one should be cautious when prescribing SL to promote increases in muscle power due to the velocity specificity (Kanehisa et al., 1983; Neils et al., 2005).

Previous studies have reported that the FI method was superior to traditional strength training programs for increasing muscle strength (Jackson et al., 1995; O’Shea and O’Shea, 1989), especially in stronger subjects (Giorgi et al., 1998). In addition to strength gains in specific joint angles (Fleck and Kraemer, 2004) and a higher level of concentric force (Keogh et al., 1999), this could be caused by the higher TUT achieved with this RTM when compared with traditional approaches (10RM), as observed in the present study.

The findings that some RTM are more effective in promoting metabolic stimuli is of particular interest, because metabolic stress may be associated with increases in muscle strength and size (Schott et al., 1995; Smith and Rutherford, 1995). In this regard, the FI and VO methods have shown to be superior to the SL method. Another point of interest is the exposure of muscle to mechanical overload. Since resistance was kept constant across RTM, a greater TUT would mean that muscle was more mechanically stimulated. According to the present findings, the SL, FI and VO methods provided greater mechanical stress than 10RM; and the SL method provided greater TUT than the VO method.

In conclusion, our results showed that the FI and VO resistance training methods may provide more metabolic stress than the SL method. Moreover, the SL, FI and VO methods grant higher mechanical stimuli than the 10RM method, and the SL method appeared to be superior to the VO method. Future studies should use other methods to measure both physiologic (i.e., muscle protein synthesis and specific RNAm of proteins of interest) and mechanic characteristics of the RTM. Additionally, long-term studies are needed to evaluate the chronic adaptations of different RTM to test if the acute differences in selected physiological parameters reflect an increase in muscle size and/or strength.

References
Abe T, Kearns CF, Sato Y (2006) Muscle size and strength are increased following walk training with restricted blood flow from the leg muscle, Kaatsu-walk training. J Appl Physiol 100: 1460–1466


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