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RESEARCH

Indicators of strength, oxidative stress, and muscle damage in Paralympic powerlifting athletes undergoing variable resistance training

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Abstract

Introduction Variable resistance strength training (VRT) has been gaining notoriety in the physical preparation of Paralympic Powerlifting (PP) athletes. PP is a strength sport and training tends to increase levels of Oxidative Stress (OS) and Muscle Damage (MD).

Objectives This study aimed to analyze the use of chains as a training method with variable resistance (TRV) and the traditional method with invariable resistance (TRAD) on peak torque (PT), rate of torque development (RTD), biomarkers of oxidative stress (EO), and muscle damage (MD) after a PP training session.

Methods Fourteen PP athletes were analyzed, age (28.00 ± 5.64), body weight (82.00 ± 23.93), and 1RM (141.43 ± 47.43). The study was carried out in three consecutive weeks: in week (1), the familiarization and 1RM test occurred, and in weeks (2) and (3) in the pre- and post-training moments (immediately after, 24 h and 48 h after), the PT, RTD, EO, and DM were evaluated. The training consisted of five sets of five repetitions at 80% of 1 Repetition Maximum (1-RM) in the bench press.

Results For PT, there was an intraclass difference with the use of the chains between the moment before (462.73±94.23) and the moment after (368.48±119.47, "*a*" p=0.004), and between the moment after (368.48±119.47) and 48 h (444.96±111.25, "*b*" p=0.027, η2p=0.309, high effect). There was a difference at the moment after between traditional training (440.98±116.38) and with the use of chains (368.48±119.47, "*c*" p=0.022). There was also a difference between the traditional (500.99±103.67) and with chains (420.36±114.84, "*d*" p=0.004) at the 24 h time point. There was also a difference at the 48-h time point between the traditional (502.90±122.89) and chains (444.96±111.25, "*e*" p<0.001, η2p=0.561, very high effect). In the RTD, there was an intraclass difference, with chains, between the time point before (7721.21±4490.67) and the time point 24 h (12,101.89±5070.36, "*a*" p=0.005, η2p=0.132, moderate effect). And interclass difference, at 24 h, between the traditional (7915.32 ± 4486.39) and chains (12,101.89 ± 5070.36, "b" p = 0.002) and also at 48 h, where a difference was observed between the traditional (8187.01 ± 4903.53) and chains (12,133.42 ± 6399.98, "*c*" p = 0.016, η2p = 0.452, high effect). The traditional group showed a significant increase in sulfhydryl (SH) production between the pre- and post-moments, and between the post and 48 h after moments. In the LDH group, there was a significant difference only at 24 h after the use of chains and traditional training.

Conclusion The variable resistance training (VRT) promoted greater muscle fatigue when compared to traditional training (TRAD) when observing the strength indicators and the biomarkers of EO and DM were positively influenced by training, regardless of the method used.

Keywords Paralympic powerlifting · Variable resistance · Muscular strength · Oxidative stress · Muscle damage

Introduction

Variable resistance training (VRT), although an unconventional training technique, has become popular among high-level weightlifters and powerlifters as an alternative to the

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traditional method with invariable resistance (TRAD) [1]. Paralympic Powerlifting (PP) is a high-intensity strength sport characterized by the use of progressive overloads during its competitions and training [2]. High-intensity training aims to trigger adaptations necessary for sports performance, and the use of strategies using VRT in PP as a training method has had its effectiveness in terms of indicators of maximum strength, speed, and power scientifically verified over the years [1, 3]. A considerable part of the studies conducted with VRT are carried out with individuals who do not have any type of physical disability. The disability itself becomes a relevant factor regarding the way in which training should be conducted [4]. A growing research niche involving this type of sample can be evidenced with studies related to recovery methods [5, 6 and 2], warm-up methods [7–9], training methods [10, 11 and 12], among others.

The bench press performed in the PP causes several physiological responses, resulting from diverse metabolic adaptations [11, 12]. Such adaptations are associated with a possible decrease in muscle recovery and, consequently, the emergence of injuries, given the intensive characteristics of the training [5]. The pathophysiology inherent to such adaptations can lead to injuries, impairing tissue repair mechanisms and the immune system as a whole. This fact is observable through biomarkers of oxidative stress and muscle damage [2, 13], that can be used as parameters of effectiveness of physical training methods employed throughout a preparation.

Reactive oxygen species (ROS) are byproducts of energy metabolism that have the capacity to generate oxidative stress, especially after high-intensity exercise [13, 14]. In addition, muscle damage generated by intense physical exercise tends to contribute to changes in redox balance, either through an excessive increase in ROS production or a reduction in antioxidant capacity, thus inducing oxidative damage to biomolecules, such as lipids, proteins, and nucleic acids [13, 15].

Thus, we identified as a problem the lack of consensus between the effects after a strength training session with variable and invariable resistance, in relation to biochemical and strength indicators. Therefore, we aimed to analyze the effect of traditional training (TRAD) and training with variable resistance using chains (TRV) on strength indicators and biomarkers of oxidative stress (EO) and muscle damage (MD), correlating them with static strength indicators, such as Peak Torque (PT) and Rate of Torque Development (RTD), before, after, 24 and 48 h after a training session.

Our hypothesis is that variable resistance training using chains (VRT) will promote a significant increase in biomarkers of oxidative stress and muscle damage compared to the traditional method (TRAD) at post-intervention moments.

Materials and methods

Design

This study used a randomized, cross-over, counterbalanced design to analyze the effects of two different training methods (traditional resistance and variable resistance using chains attached to the ends of the bar) on the performance of Paralympic weightlifting (PP) athletes through dynamic strength tests. This was a quadruple-experimental study with a convenience sample. Participants were randomized to two experimental conditions: traditional training and training using chains. The study duration was 3 weeks. All tests were performed at the same time of day (between 9:00 AM and 12:00 PM), at temperatures ranging from 23 to 25 °C, with a relative humidity of ~60%. All tests were performed using an adapted bench press.

In the first week, a familiarization session with the chains and traditional (unvariable resistance) training methods was conducted, and a one-repetition maximum (1RM) test was performed to determine the training load. In the second and third weeks, the athletes were randomly assigned to the two types of training: chains and traditional. Thus, the sample was equally divided with the same number of participants (50%) in each week.

During weeks 2 and 3, strength indicators (peak torque, rate of force development) and biomarkers of oxidative stress and muscle damage were assessed at four time points: before, immediately after, 24 h after, and 48 h after the intervention. The intervention consisted of five sets of five repetitions (5 × 5) at 80% of 1RM. During the intervention, strength indicators were assessed before the first (Set1) and after the last set (Set5), as illustrated in Fig. 1.

Sample

The study sought to analyze 14 male Paralympic weightlifting (PP) athletes who competed at national and international levels and met the criteria established by the World Para Powerlifting Organization [16]. The participants had various disabilities: five had malformations (arthrogryposis), three had spinal cord injuries below the eighth vertebra due to trauma, three had polio sequelae, and three had amputations (Table 1). The sample size was determined using the open-source software G*Power® (version 3.0; Berlin, Germany), adopting an "*F* family statistic (ANOVA)" with a standard $\alpha < 0.05$, $\beta = 0.80$, for the rate of force development (RFD) in Powerlifting athletes. This allowed for an estimated sample power of 0.80, with a minimum of eight individuals per group, suggesting that the sample is adequate. The observed power in blood

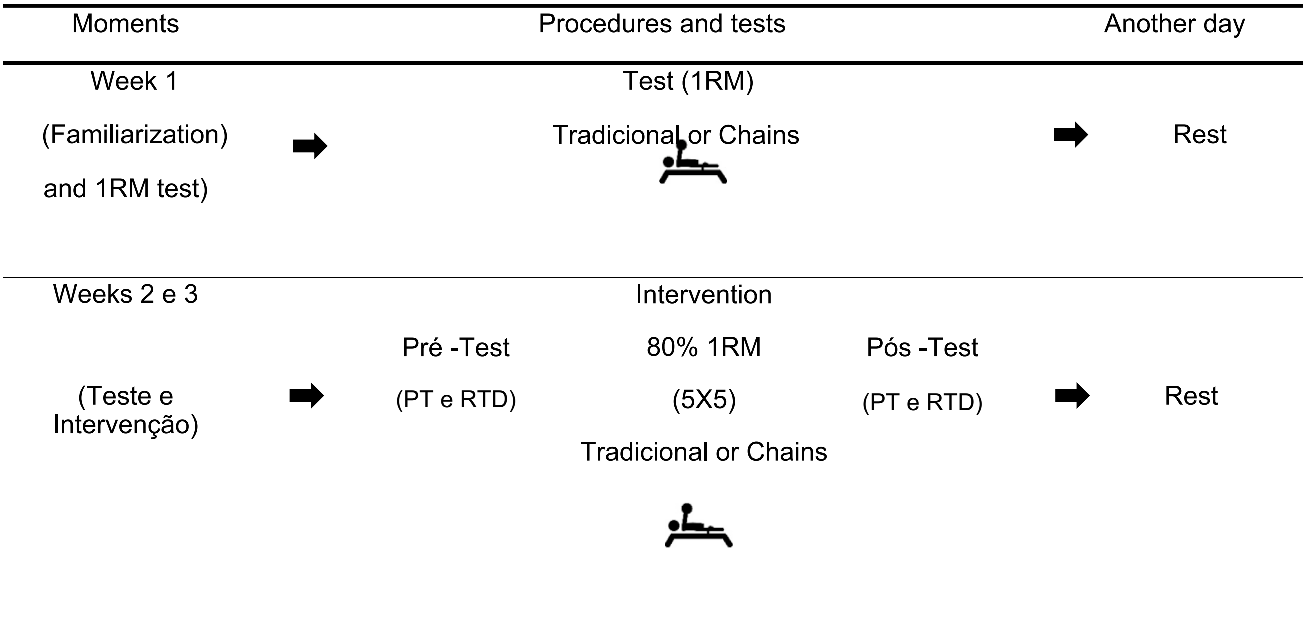

Fig. 1 Experimental design—weekly training schedule. *PT* peak torque, *RTD* rate of force development, *RM* maximum repetition, *Traditional* training with invariable resistance, *Chains* training with variable resistance, *5X5* five sets of five maximum repetitions each

Table 1 Sample characterization (n=14)

Variable	(Mean ± standard deviation)
Age (Years)	28.00±5.64
Body mass (kg)	82.00±23.93
Experience (Years)	3.54±1.11
1RM test (bench press) (kg)	141.43±47.43
1RM test/body mass (kg)	1.82±0.61*

1RM one maximal repetition, *kg* kilogram

*Athletes with values above 1.4 in the bench press (1RM/body weight) would be considered elite athletes [17]

indicators and static strength indicators was greater than 0.80. Corroborating this, other studies that worked with similar indicators and with a population of Paralympic athletes used similar samples [18, 19]

All athletes voluntarily participated in this study and provided written informed consent in accordance with Resolution 466/2012 of the National Research Ethics Committee (CONEP) of the National Health Council and following the ethical principles of the Declaration of Helsinki (1964, revised in 2013) of the World Medical Association. This study was approved by the Research Ethics Committee of the Federal University of Sergipe (ID-CAAE: 67,953,622.7.0000.5546), technical opinion number 6,523,247, dated November 22, 2023.

Instruments and procedures

A digital electronic scale specialized for wheelchair users (Mic Welcair model; Michetti, São Paulo, Brazil) was used to weigh the athletes. The scale dimensions were 1.50 × 1.50 m with a maximum capacity of 300 kg. The bench press exercise was performed on an official 210 cm flat bench with a 220 cm bar and weights, all manufactured by Eleiko (Sweden) and approved by the International Paralympic Committee (IPC) [20].

The chains used for variable resistance overload measured between 1.00 and 1.50 m. The chains were added to the training loads, representing 20% of the total load. Thus, in traditional training, the load was 80% of 1RM exclusively with weight plates. In training with chains, 80% of 1RM was used, with the training load (80%), 20% of this load being with the use of chains, and the remainder with weight plates. Thus, as an example, if we had the training load at 100 kg (80% 1RM), 20 kg would be chain (20%) and 80 kg would be weight plates (80%). The weight of the chain was determined using the average distance of the chain and measured with a digital dynamometer (Data Weighing Systems, Wood Dale, IL, USA) with a maximum weight of 150 kg and a resolution of 0.05 kg. The chains weighed 7.0, 3.5, and 3.0 kg.

The training session consisted of five sets of five repetitions (5 × 5) [10], with full range of motion. The difference between the training sessions was the use of chains attached to the bar (variable resistance) or fixed resistance (invariable resistance). All athletes had previous experience in training with chains and fixed resistance.

In weeks 2 and 3, before the interventions, the athletes performed a warm-up targeting the main muscle groups involved in upper limb movement. Three exercises were used (shoulder abduction with dumbbells, elbow extension on the pulley, and shoulder rotation with dumbbells), with three sets of 10–20 RM for approximately 10 min. Subsequently, a specific warm-up was performed on the bench press, with 30% of the 1RM load, consisting of 10 slow and 10 fast repetitions. During the tests, the athletes were verbally encouraged to perform their best.

During the interventions, the athletes performed 5 sets of 5 repetitions (5 × 5), with chains fixed to the bar or fixed resistance (weights only). The evaluations were performed before, immediately after, 24 h after, and 48 h after the training session.

Maximum load test (1RM)

A one-repetition maximum (1RM) test was conducted to establish training load for both traditional and variable resistance training methods. This test was performed in week 1. Each participant selected a starting load that they believed they could lift, and incremental weights were added until their maximum lifting capacity was reached. Whenever an athlete was unable to lift the load, the weight was reduced by 2.5%. Participants rested for 3–5 min between attempts [10].

Upper limb muscle strength

Peak Torque (PT) and Rate of Torque Development (RTD) were determined by a Chronojump load cell (Chronojump®, BoscoSystem, Madrid, Spain), fixed to the Bench Press, using HMS Simond Spider carabiners (Chamonix, France), with a breaking load of 21 kN, approved for climbing by the Union International des Associations d'Alpinisme (UIAA). Steel chains with a breaking load of 2300 kg were used to fix the load cell to the bench. The perpendicular distance between the load cell and the center of the joint was determined and used to calculate the joint torques.

Peak isometric torque (PT) was measured by the maximum torque generated by the muscles of the upper limbs. The PT was determined by the product of the peak isometric force, measured between the attachment point of the load cell cable and the adapted bench press, which was adjusted, so that there was an angle close to 90° at the elbow, at a distance of 15 cm from the starting point (chest to bar), verified with a device for measuring angular amplitude, Model FL6010 (Sanny®, São Bernardo do Campo, Brazil). Participants were instructed to perform a single maximum movement until elbow extension (as quickly as possible) and then relax, to assess the PT.

The Rate of Torque Development (RTD) was determined using the ratio between Peak Torque and the time until reaching Peak Torque (RTD = ΔPeak Torque/ΔTime), in 300 ms (9).

Chains use

Participants were placed lying on an Eleiko Paralympic bench (Eleiko, Halmstad, Sweden). They held the barbell in two positions, with their elbows extended and the barbell in contact with their chest. This distance was measured to ensure that only the resistance produced by the chains was measured. The athletes then replaced the barbell on the support, and the resistance produced only by the chains in the upper and lower positions was measured. The average resistance of the chains throughout the range of motion was as close as possible to 20% of the working load [21]. The athletes performed training sessions in which five sets of five RM (5X5 with 80% 1RM) (80% = 20% 1RM Chains + Weight on the bar) were performed with chains (variable resistance) fixed at the end of the bar with a quantified load as close as possible to 20% of 1RM, during the range of motion [21] (Fig. 2).

Blood sample collection

Blood samples were collected from the antecubital vein of the forearm and immediately transferred to EDTA tubes. Blood collection (10 mL) was performed by a health care professional (nursing technician). The samples were placed in vacuum blood collection tubes, centrifuged, and sent to the Enzymology Laboratory of the Federal University of Sergipe (São Cristóvão, Sergipe, Brazil), where biochemical analyses were performed by a laboratory biochemist.

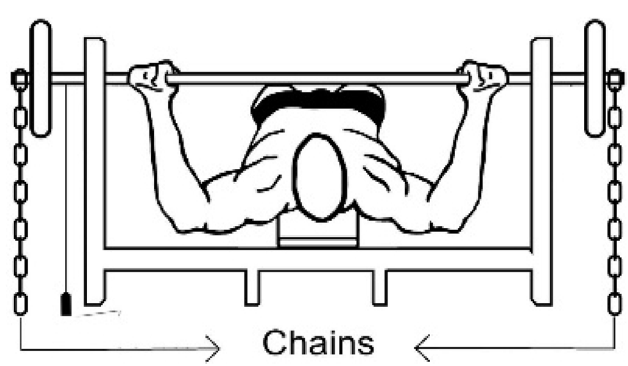

Fig. 2 Representation of the placement of chains for training with variable resistance

Oxidative stress

For oxidative stress, tubes were centrifuged (3000× g for 10 min), and plasma and serum were then aliquoted and stored at 4 °C for later analysis. To avoid loss of volatile compounds, plasma ammonia was immediately measured using a spectrophotometric assay (Randox®, Crumlin, UK). Blood was centrifuged at 800× g for 15 min at 4 °C, and serum was stored at −80 °C.

In plasma, markers of oxidative stress were assessed. Lipid peroxidation was determined by measuring thiobarbituric acid-reactive substances (TBARS) according to the method described by Lapenna et al. [22]. For TBARS, 200 µL aliquots of blood samples were added to a 400 µL mixture consisting of equal parts of 15% trichloroacetic acid (TCA), 0.25N HCl, and 0.375% TBA, plus 2.5 mM butylated hydroxytoluene (BHT) and 40 µL sodium dodecyl sulfate (SDS) 8.1%, and heated for 30 min at 95 °C in an incubator. The pH of the mixture was adjusted to 0.9 with concentrated HCl. BHT was used to prevent lipid peroxidation during heating. After cooling to room temperature and adding 4 mL of butanol, the material was centrifuged at 800× g for 15 min at ±4 °C, and the absorbance of the supernatant was measured at 532 nm. The molar extinction coefficient used was 1.54 × 105 M −1 cm −1 and the TBARS result was expressed in nmol Eq MDA/mL for the plasma samples.

The determination of sulfhydryl groups (SH) was performed according to the methodology described by Faure and Lafond [23]. A 50 µL aliquot of plasma was mixed in 1 mL of Tris–EDTA buffer (1 mM), and the first reading was taken at 412° (reading A1). After this reading, 20 µL of 10 mM 5,5'-dithiobis-2-nitrobenzoic acid (DTNB) diluted in methanol were added. A new reading was taken after 15 min at room temperature. The Blank contained only DTNB and Tris–EDTA buffer. The final unit was expressed in mM. The total sulfhydryl groups were calculated according to the molar absorption coefficient = 13,600 cm −1 M −1: (A2 − A1 − B) × 1.57 mM [23].

Muscle damage

For the analysis of muscle damage markers creatine kinase (CK) and lactate dehydrogenase (LDH), commercial kits (Labtest®, Santa Lagoa, Minas Gerais, Brazil) were used, in which the blood plasma of the sample studied was homogenized in specific reagents at 37° C and read at a wavelength of 340 nm in a spectrophotometer, with the result expressed in IU/L (BioespectroModel SP-22 UV/Visible, Minas Gerais, Brazil).

Statistics

The measures of central tendency, mean and standard deviation (X±SD), and 95% confidence interval (95% CI) were used. Considering the sample size, the Shapiro–Wilk test was performed to verify the normality of the data. The two-way ANOVA (Moment X Condition), for repeated measures, and Bonferroni post hoc were used. The effect size was evaluated with the partial eta squared (η2p), considering magnitude: low <0.05, medium of 0.05 and <0.25, high of 0.25 and <0.50, and very high ≥0.50 (72,73). The statistical analysis was performed in the Statistical Package for Social Sciences (SPSS), version 24. For all analyses, the significance level of p <0.05 was adopted (IBM, New York, USA).

Results

Figure 3 shows the results in relation to peak torque, expressed in N.m, and the rate of torque development rate, expressed in N.m.s-1 in the pre, post, after 24 h and after 48 h moments, under traditional training conditions and with the use of chains.

Regarding PT, there was an intraclass difference with the use of chains between the moment before (462.73±94.23) and the moment after (368.48±119.47, "a" p=0.004), and there was also a difference between the moment after (368.48±119.47) and 48 h (444.96±111.25, "b" p=0.027, η2p=0.309, high effect). Regarding the interclass difference, there was a difference at the moment after between traditional training (440.98±116.38) and with the use of chains (368.48±119.47, "c" p=0.022). There was also a difference between the traditional (500.99±103.67) and with chains (420.36±114.84, "*d*" p=0.004) at the 24 h time point. There was also a difference at the 48-h time point between the traditional (502.90±122.89) and chain (444.96±111.25, "e" p<0.001, η2p=0.561, very high effect).

In the Torque Development Rate (RTD), there was an intraclass difference, in the method with chains, between the time before (7721.21±4490.67) and the time point 24 h (12,101.89±5070.36, "*a*" p=0.005, η2p=0.132, moderate effect). And there was an interclass difference, at 24 h, between the traditional (7915.32±4486.39) and chains (12,101.89±5070.36, "*b*" p=0.002) and also at 48 h, where a difference was observed between the traditional (8187.01±4903.53) and chains (12,133.42±6399.98, "*c*" p=0.016, η2p=0.452, high effect).

Table 2 shows the results related to oxidative stress and muscle damage evaluated at different times with traditional training and with the use of chains.

A significant increase in SH production was found in traditional training when comparing the pre (161.76±106.18) and post (433.66±318.76) moments. A significant difference

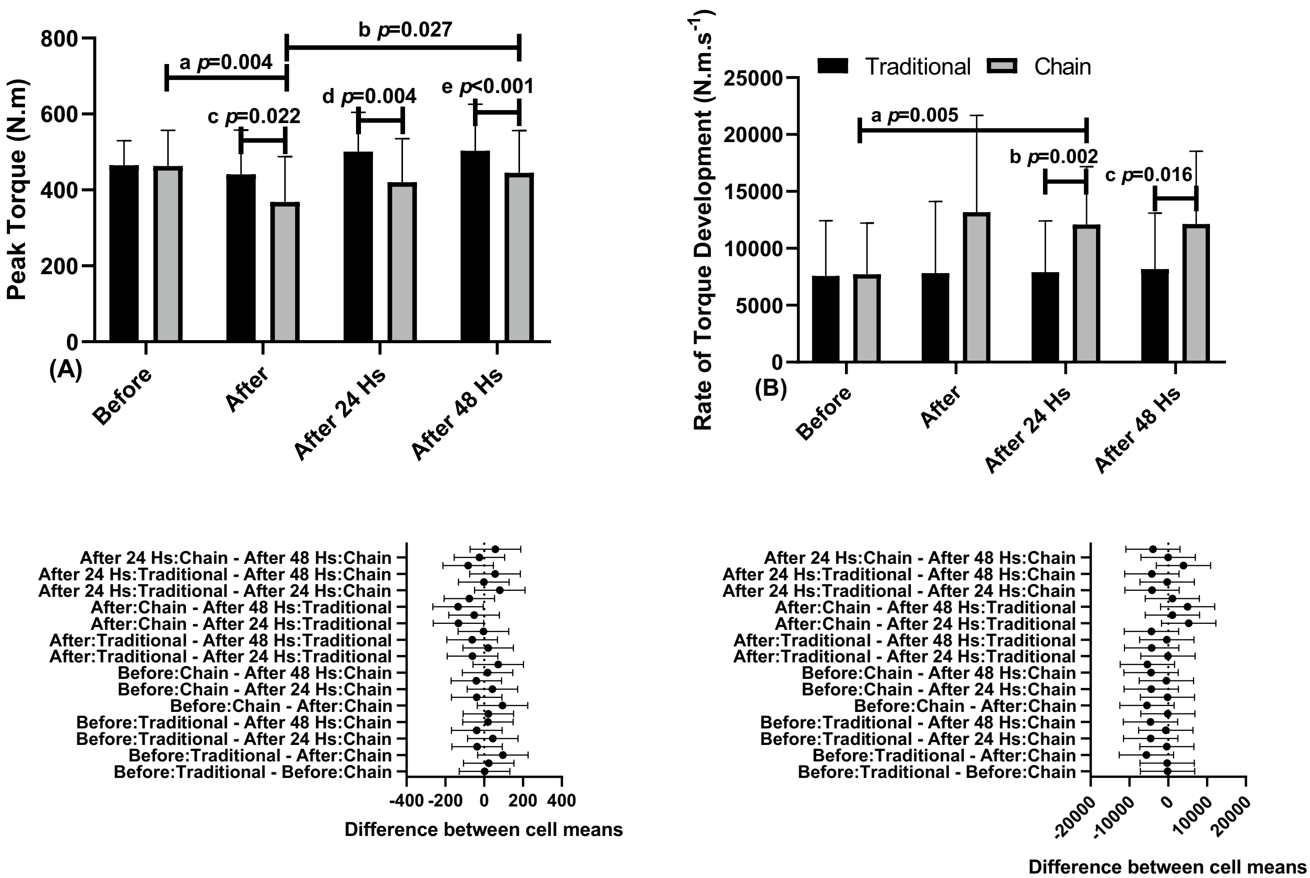

Fig. 3 **A** Peak Torque (PT) and **B** Rate of Torque Development (RTD) at different times, under traditional training conditions and with variable resistance (use of chains)

was also observed between the post and 48 h after moments (182.19±105.29) in traditional training. In the comparison of the LDH group, a significant difference was detected between the moments 24 h after using chains (95.95±28.59) and 24 h after using traditional training (71.09±17.22).

In the other comparisons, no relationships of interference of the methods and collection moments in the markers of oxidative stress and muscle damage were observed in this study.

The baseline values of the sample at the moments before for both groups demonstrate the reliability and control of the collection, as no significant variations were observed in the intergroup values.

Discussion

It is important to emphasize that there are few studies using the methodology adopted here on Paralympic weightlifting or powerlifting athletes; therefore, our discussion will also focus on research involving other sports, different from our sample.

The results regarding the strength indicators obtained in our study showed significant differences between peak torque and torque development rate in the two conditions studied (traditional vs. use of chains) as well as in the moments analyzed (before/pre, immediately after/post, 24 h after and 48 h after training session).

As shown in Fig. 3, in item (A), a greater PT was evidenced when TRAD was used as a training method, characterizing a greater recruitment of motor units for this method. However, the literature has shown that the intervention time is a preponderant factor in strength development when using TRV as a training method [21, 24]. Although VRT promotes a greater amount of stimuli, resulting in greater neural adaptation [25], on the other hand, the use of variable resistance for a longer period of time would influence the result. We emphasize that our study was conducted acutely with only one training session [26]. In this sense, variable resistance training has been shown to be an effective training method when applied over the long term (≥ seven weeks), with positive effects on several strength indicators [26].

However, when analyzing the RTD in item (B) of Fig. 3, a higher prevalence of VRT was noted to the detriment of

Table 2 Muscle damage and oxidative stress (Mean±SD; 95% CI) at different times with traditional training and using chains in Paralympic powerlifting

	Sulfhydryls (SH) (nmol.mg^{-1})	Thiobarbituric acid-reactive substances (TBARS) (nmol Eq MDA/ml)	Creatine kinase (CK) (UI/L)	Lactate dehydrogenase (LDH) (UI/L)
Before traditional	**161,76±106,18 a (100,46–223,07)**	182,96±62,49 (146,88–219,04)	55,76±41,10 (32,03–79,49)	69,65±23,71 (55,96–83,34)
Before chains	165,48±117,02 (97,91–233,05)	185,26±29,99 (167,94–202,58)	56,13±31,13 (38,15–74,10)	67,90±31,56 (49,67–86,12)
After traditional	**433,66±318,76 a,b (249,61–617,70)**	167,07±47,66 (139,55–194,58)	55,38±41,91 (31,18–79,58)	74,85±22,65 (61,77–87,93)
After CHAINS	353,59±332,39 (161,67–545,50)	179,65±62,10 (143,80–215,51)	86,07±71,29 (44,90–127,23)	71,67±14,23 (63,46–79,89)
24hs traditional	230,46±128,57 (156,23–304,69)	180,15±65,68 (142,23–218,07)	55,38±32,67 (36,51–74,24)	**71,09±17,22 a (61,15–81,03)**
24hs chains	569,57±663,27 (186,61–952,53)	180,37±54,68 (148,79–211,94)	55,38±47,35 (36,51–74,24)	**95,95±28,59 a (79,44–112,45)**
48hs traditional	**182,19±105,29 b (121,40–242,99)**	175,51±66,58 (137,07–213,95)	60,39±68,12 (21,06–99,72)	77,12±33,34 (57,87–96,37)
48hs chains	181,00±145,05 (97,25–264,75)	154,73±51,67 (124,90–184,56)	73,15±42,32 (48,72–97,59)	77,45±27,02 (61,85–93,05)
p	a p=0.038* b p=0.033*	p=0.274	p=0.173	a p=0.006#
F	5.474*	0.711#	1244#	2.193 #
η2p	0.296*	0.052#	0.087#	0.144#

SH sulfhydryls, *TBARS* thiobarbituric acid reactive substances, *CK* creatine kinase, *LDH* lactate dehydrogenase

$p \leq 0.05$ (ANOVA two way and Post Hoc de Bonferroni). η2p = partial eta square (small effect ≤0.05, medium effect 0.05 to 0.25, high effect 0.25 to 050, and very high effect (> 050)

*Intraclass, #Interclass. The repeated letters (a–a, b–b), and in bold, represent where the statistical differences are

TRAD. Training with variable resistance allows for a greater demand in terms of muscle force generation throughout the range/development of the movement [27], which tends to generate additional stress in comparison with invariable resistance methods [28].

Furthermore, Soria-Gila and collaborators [26], in a meta-analysis on the subject, found that training with variable resistance combined with training with fixed loads proved to be an effective method when considering longer training plans. Thus, the combination of variable resistance with invariable resistance is significantly superior in terms of strength development when compared to just using fixed loads [24, 28], this is due to the increase in neural action that promotes greater recruitment of motor units when using variable resistances [26, 29].

The following two studies also compared strength indicators in rugby athletes using the traditional training method (TRAD) and with variable resistance (VRT). Small improvements were observed in all variables for VRT and lower values for TRAD using a 20% increase in variable load in the form of elastic bands [21].

Approaching the methodology of the present study using chains as VRT, Godwin and collaborators [30] did not observe greater power production compared to the constant load condition, although they found a significantly positive difference in the condition with the use of chains. Although power production was greater with the use of chains, these values did not show a significant difference in relation to the constant load condition.

The impact of exercise on oxidative stress in PP athletes has only recently been brought to light. Regarding oxidative stress, the results found here demonstrated that there was intense participation of antioxidant defense mechanisms. One way to perform this analysis is through biomarkers, which determine the evolution of these adverse conditions resulting from training, as well as attest to the results of the training strategies that should be adopted [2, 31 and 32].

It is known that intense physical exercise promotes an increase in reactive oxygen species (ROS) that result in oxidative stress and can be measured by analyzing oxidative damage in the blood [31, 33]. However, it is important to remember that regular physical exercise favors the regulation of the enzymatic antioxidant system and the modulation of oxidative damage, influencing the cellular redox state through the regulation of metabolism in an intensity-dependent manner and/or through the direct activation of ROS-generating enzymes [34].

Regarding the analysis of oxidative stress parameters, the levels of sulfhydryl (SH) and thiobarbituric acid-reactive substances (TBARS) were used. No increased levels of TBARS were observed, which suggests a reduction in lipid peroxidation. In addition, we observed that there was a significant difference in SH levels immediately after training compared to before training. Considering the increased SH levels immediately after training, we can deduce that there is a tendency for increased antioxidant activity, preventing the manifestation of oxidative stress evidenced by the control of TBARS levels [35].

These results highlight the role of exercise in promoting antioxidant defense systems, corroborating studies that have shown that physical training can promote a decrease in oxidative stress, in addition to increasing the antioxidant system [36]. It is known that any level of adaptation to exercise improves the ability of the cellular antioxidant defense system to neutralize the increase in OS, improving the metabolic state, resulting in a redox balance [2, 35 and 14].

In addition to the fact that the level of training tends to positively influence the immune system [5] and that the longer the time under tension, the greater the oxidative stress [37]. It is worth highlighting at this point the high level of training of the researched sample, a fact that may presuppose a greater removal of ROS and the consequent non-manifestation of OS, according to the results found [17].

For tissue damage, we used the analysis of biomarkers such as creatine kinase (CK) and lactate dehydrogenase (LDH), which together estimate the potential for injury due to exercise. The results revealed no differences in creatine kinase (CK) levels between the time points following training.

The only observation related to muscle damage found was due to the LDH enzyme being increased 24 h after VRT. This fact corroborates the aforementioned specificities of chains training. The evidence that the lactate dehydrogenase (LDH) enzyme can remain increased after strength training is due to its function in anaerobic metabolism [32, 38 and 39], which aims at the rapid supply of energy leading to the production of lactate. In studies that analyzed acute and chronic responses of muscle enzymes, including LDH, after strength training sessions, an increase in enzymatic activities was evidenced, indicating a physiological adjustment of anaerobic metabolism, mainly in energy production during intense efforts [32],A [15, 35].

The lack of significant observation of the cellular damage markers analyzed here may refer to what we mentioned previously regarding the training level of the sample and its adaptation to the training methods used in this study. It is worth noting that the study had limitations in the control of diet, intake of supplements, or other ergogenic resources by the athletes. As well as the lack of control over the activities of daily life, work, and history of pain and injuries in the joints involved in performing the bench press exercise.

The study presents the following limitations. The athletes' diets were not monitored, nor were the potential implications regarding their sleep evaluated. However, the study aimed to assess the training while attempting to keep the athletes' dietary and sleep routines unchanged. Furthermore, the study evaluated a single training session—comparing a traditional workout with one emphasizing the eccentric phase—to determine whether incorporating such a session into a training microcycle might affect fatigue and strength loss. Consequently, evaluating training regimens with these characteristics over longer periods could yield different results.

Conclusion

We can conclude that both traditional training (TRAD) and variable resistance training (VRT) have distinct effects on strength, oxidative stress, and muscle damage. TRAD was more effective at peak torque (PT), suggesting that there was greater motor recruitment during VRT, which in turn obtained better performance in the rate of torque development (RTD), promoting greater force demand throughout the range of motion.

Regarding oxidative stress, training increased antioxidant activity, without evidencing significant damage to cells (lipid peroxidation), as indicated by stable TBARS levels. In addition, a positive adaptation of the antioxidant system was evidenced with an increase in sulfhydryl (SH) immediately after training, suggesting an efficient response to oxidative stress. Regarding muscle damage, there were no significant increases in creatine kinase (CK), but the increase in lactate dehydrogenase (LDH) at the time point 24 h after VRT corroborates the literature and partially confirms our hypothesis.

Our findings reinforce the importance of well-structured training periodizations, which consider the body's adaptation to stimuli and long-term physiological responses, maximizing the benefits of training while minimizing the risks of excessive muscle damage or oxidative stress, especially when adapting and inserting training methods with variable resistances.

In this regard, it appears that eccentric training induces additional fatigue, a factor that coaches must monitor to ensure proper training control when employing this type of training.

Author contributions E.L.M.V.: Investigation, Implementation of experiments, Methodology and Preparation and review of manuscripts;

F.J.A.: Research, Implementation of experiments; G.B., C.B.: Research, Implementation of experiments; J.U.O.: Research, Implementation of experiments; G.F.S.F.: Implementation of experiments; E.L.M.V., C.B., G.B., S.B., J.L.S., E.A.M: Methodology and Manuscript preparation and review; F.J.A: Methodology and Preparation and review of manuscripts, Implementation of experiments; G.F.S.F.J.L.S.,.: Methodology and Preparation and review of manuscripts, Supervision, Validation, Project administration. All authors reviewed the manuscript.

Data availability The data supporting this study's findings are available from the corresponding author upon reasonable request.

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