International Journal of EXERCISE SCIENCE

Original Research

Evaluation of Muscle Damage, Body Temperature, Peak Torque, and Fatigue Index in Three Different Methods of Strength Gain

NATALIE DE ALMEIDA BARROS†[1,2,3], FELIPE J AIDAR‡[1,2,4,5], DIHOGO GAMA DE MATOS†[6], RAPHAEL FABRÍCIO DE SOUZA‡[1], EDUARDO BORBA NEVES‡[7], BRENO GUILHERME DE ARAUJO TINOCO CABRAL‡[8], ENILTON APARECIDO CARMARGO‡[3,9], and VICTOR MACHADO REIS‡[6]

[1]Depatment of Physical Education, Federal University of Sergipe - UFS, São Cristovão, BRAZIL; [2]Graduate Program in Physical Education, Federal University of Sergipe - UFS, São Cristovão, BRAZIL; [3]Graduate Program in Health Science, Federal University of Sergipe - UFS, São Cristovão, BRAZIL; [4]Graduate Program in Physiological Sciences, Federal University of Sergipe, São Cristóvão, BRAZIL; [5]Group of Studies and Research of Performance, Sport, Health and Paralympic Sports - GEPEPS, Federal University of Sergipe - UFS, São Cristovão, BRAZIL; [6]Research Center in Sports Sciences, Health Sciences and Human Development – CIDESD, Tras os Montes e Alto Douro University, Vila Real, PORTUGAL; [7]Brazilian Army Research Institute of Physical Fitness (IPCFEx), Rio de Janeiro, BRAZIL; [8]Department of Physical Education, Federal University of Rio Grande do Norte, Natal, BRAZIL; [9]Department of Physiology, Federal University of Sergipe, São Cristovão, Sergipe, BRAZIL

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 13(3): 1352-1365, 2020. The aim of this study was to evaluate and compare three different strength training protocols for the lower limbs by using biochemical indicators of muscle damage, thermographic analysis, and neuromuscular performance. In total, 10 men (age: 22.50 ± 2.84 years; weight, 75.45 ± 6.86 kg) completed the study. All the athletes were subjected to three methods of resistance training (RT): traditional, tension, and occlusion training. Serum concentrations of creatine kinase, lactate dehydrogenase, aspartate aminotransferase, and alanine aminotransferase were used as indicators of muscle damage. To measure muscle strength, the peak force, and fatigue index were determined using a Kratos load cell. Images were captured using an infrared camera (FLIR T640sc). The vascular occlusion method demonstrated a 33% reduction in post-training peak torque ($p < 0.001$; η^2p: 2.74), which was recovered within 24 h ($p < 0.001$; η^2p: 1.08). The thermographic analysis revealed a reduction in skin temperature in both thighs after the tension (−9.37%) and vascular occlusion (−6.01%) methods. In conclusion, the occlusion training seems to provide additional benefits as compared to the other two methods of strength training.

KEY WORDS: Muscle damage, occlusion training, tension program, body temperature

INTRODUCTION

Resistance training (RT) at a load intensity from 70% to 100% of the one-repetition maximum (1RM) is commonly recommended to develop muscle strength (34). Traditional RT (TRAD) is associated with increase in metabolic stress. To overcome these disadvantages, different approaches that provide benefits in neuromuscular adaptation have been developed.

Manipulation of time under tension (TUT) with an emphasis on eccentric motion that increases muscle damage facilitates strength gains even with reduced overloads (21, 42). Additionally, partial occlusion (OCL) during RT at reduced intensities (20% of 1RM) and short-duration interventions increase muscle strength and volume (39). Further, both TUT and OCL training methods appear to lower metabolic and hormonal stress than TRAD (9). However, OCL training can impair the capacity to detect muscle fatigue. The inability to lift loads high enough because of the interrupted blood flow to the muscles compromises the hypertrophic response (13).

It is well established that RT induces functional and morphological adaptations in the skeletal muscle. However, whether these adaptations affect the results produced by RT on indicators of muscle damage and fatigue, such as peak torque and body temperature in the region of the exercised muscle, remain unclear. This implies a need for a study comparing the effects of RT with either an increase in TUT or vascular OCL on the aforementioned indicators. Such a study could further help understand how manipulating these RT variables impacts muscle physiology and functionality.

In this study, we aimed to evaluate and compare, during acute and recovery phases (24 and 48 h), three different RT methods (TRAD, TUT, and OCL) performed with the lower limbs by using biochemical indicators of muscle damage, thermal images, and neuromuscular performance.

METHODS

Participants

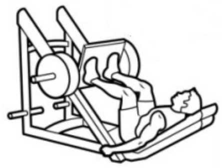
Interviews were conducted to screen participants for the study. Athletes following practices that could negatively affect their physical performance, such as use of inappropriate ergogenic supplements and involvement in a rapid weight-loss program, were excluded. The participants were subjected to medical authorization, and only 16 clinically healthy male athletes were finally recruited.

All athletes had about 12 months of prior experience in strength training. The mean age, height, body weight, and body fat percentage (BF%) of the athletes were 22.50 ± 2.84 years, 1.77 ± 0.05 m, 75.45 ± 6.86 kg, and 14.45% ± 3.36%, respectively. The athletes were subjected to three familiarization sessions of OCL, TUT, and TRAD, with a minimum rest interval of 72 h between the sessions. The order of sessions was randomized for each athlete. Of the recruited athletes, six who could not complete all stages of the study were excluded. The study design is presented in Table 1.

Informed consent was obtained from all the participants (free, informed, and consented), in accordance with the resolution 466/2012 of the National Commission of Ethics in Research—CONEP, National Health Council, and ethical principles expressed in the Declaration of

Helsinki (1964, restated in 1975, 1983, 1989, 1996, 2000, and 2008) of the World Medical Association. The study was approved by the ethics committee of the Federal University of Sergipe (CAAE 51976315.1.0000.5546). This research was conducted in accordance with the ethical standards specified in the *International Journal of Exercise Science* (27).

Table 1: Design of the procedures performed in the study weeks

Study weeks "1", "2" and "3"				
Session 1 Pre Test	Session 1 Training	Session 1 Post Test	Session 2 24 Hours	Session 3 48 Hours
Peak Torque Fatigue Index Blood sample Thermal Imaging Pain	 Tension or, Oclusion or, Traditional (Cross Over)	Peak Torque Fatigue Index Blood sample Thermal Imaging Pain	Peak Torque Fatigue Index Blood sample Thermal Imaging Pain	Peak Torque Fatigue Index Blood sample Thermal Imaging Pain

Protocol

Equipment: A 45° leg press (Physicus, Brazil), a chronometer (HS-50W, Casio, Japan) for counting the 90-s rest time between the series, and a metronome (Willner, Isny, Germany) for determining the time expended in the concentric and eccentric phases of the exercise were used.

A digital platform scale (Filizola 2002, Filizola, Brazil), calibrated from 0 to 150 kg, with an accuracy of 0.1 kg, was used to measure the athlete's weight in kilograms (kg). A compact stadiometer (Trena ES2040, Sanny, Brazil) fixed to a wall, with a capacity of 2.0 m and an accuracy of 0.1 cm, was used to measure height in triplicate in order to calculate the mean value.

A scientific adipometer (Sanny, Brazil) was used to measure body density, which was calculated using the quadratic equations of three skinfolds for men (18). The %BF was calculated using the equation of Siri (38).

Strength training with the OCL: A sphygmomanometer cuff with aneroid manometer (18-cm wide and 80-cm long) was used to measure the blood pressure. The sphygmomanometer was placed on the distal arm of the participants and inflated to a 130% occlusion pressure for systolic blood pressure while they, wearing occlusion bands on the thighs, performed the leg press exercises (40). The mean occlusion pressure was systolic pressure at rest, which was maintained at 130% throughout the exercise session (130–160 mmHg) and were performed in 3 sets of 8–12 repetition (40). The athletes performed a 10-min warmup on a cycle ergometer, followed by localized warm up with exercises, leg presses, and bending the knee with a load of 50% for 1RM. The occlusion pressure was maintained throughout the workout, even during the rest intervals, and only released at the end.

Strength training with TUT: Athletes performed a 10-min warmup on a cycle ergometer, followed by localized warmup with knee extension exercises at a 30% load for 1RM. The metronome was set to beep each second. The tension was maintained throughout the TUT session, involving 3 sets of 8–12 repetitions (3 × 8–12) with 6 s of the concentric phase and 6 s for the eccentric phase (6).

Strength training with TRAD: The athletes performed a 10-min warmup on a cycle ergometer, followed by a localized warmup with knee extension exercise with a load of 70%–85% for 1RM (14). In the TRAD, 3 sets of 8–12 repetitions (3 × 8–12) were performed with an execution speed of 1 s in the concentric phase and 2 s in the eccentric phase, with a 90-s interval between the sets.

Dynamic strength assessment: The 1RM assessment was performed to determine the maximum dynamic strength. A progressive test was implemented until the maximal load was reached. Each athlete started with a weight that could be lifted only once, at maximal effort. After resting for 3–5 min, another repetition was performed after adding some weight. This process was repeated until the maximum load was reached. If the athlete failed to perform a repetition, 2.5% of the load used was subtracted for the next attempt (14). The 1RM load was determined a week before the other assessments using a Righetto mark (Righetto, Brazil).

The relative dynamic strength was defined as the percentage of the 1RM load, which were 30%, 50%, and 70%–85% for TUT, OCL, and TRAD methods.

A digital thermo-hygrometer (HTH-240, Hikari, China) was used to measure the body temperature.

Intensity control: To control for the intensity of the planned activities, we used the Omni-Res scale of subjective perception of effort. The athletes were properly acquainted with the scale, and the Omni-Res perception was maintained between 6 and 8 (22).

Muscle damage: Serum concentrations of creatine kinase (CK), lactate dehydrogenase (LDH), aspartate aminotransferase (AST), and alanine aminotransferase (ALT) were considered as indicators of muscle damage. For these measurements, blood samples (8.0 mL) were obtained from the antecubital fossa vein before, immediately after, at 24 h, and at 48 h of the intervention and stored in tubes containing an coagulant gel (Vacuette®, Greiner Bio-One, Brazil) until use. Biochemical measurements were performed using the Vitros® 5600 film system (Ortho-Clinical Diagnostics, Johnson & Johnson, USA). The LDH, AST, and ALT levels were measured using the kinetic multiple point technique, whereas CK level was measured using the multiple point rate technique.

Blood Lactate: Lactate levels were assayed to identify the intensity level of the sessions. Blood lactate measurement was performed using an electrochemical blood lactate test strip (Accu-Chek, Roche, Brazil). Blood (25 µL) was collected 1–3 min after the intervention from the left digital pulpa using heparinized and calibrated glass capillary tubes. The collected blood was immediately stored in 1.5-mL Eppendorf tubes containing 50 µL of 1% NaF solution. The tubes were then stored in a cooler containing ice and taken to the laboratory for determining blood lactate concentrations. Blood lactate was determined using an electrochemical analyzer YSL Model 1500 STAT (Yellow Springs, OH, USA).

Force measurements: Load cells (Model CZC500, Kratos, Brazil) integrated to the 45° leg press equipment enabled the carabiner (HMS Spider, Simond; Chamonix, France) with a rupture card of 21 KN, approved by the Union International des Associations d'Alpinisme (UIAA) for climbing, to measure peak torque and fatigue index (FI). A 10 × 35 × 30 mm^3 steel chain with a rupture load of 2,300 kg was used to fix the load cell to the apparatus. The perpendicular distance between the load cell and the center of the joint was determined and used to calculate the peak torque and FI, according to the procedure of Bento et al. (3).

The isometric peak torque (Pt) was measured using the maximum torque generated by the muscles of the lower limbs (3). The Pt was determined by the product of the isometric force peak with the length of the segment, provided by the distance between the attachment point of the load cell cable and the leg press apparatus. The Pt was measured using a fleximeter (Sunny apparatus, Model FL6010, Sunny, Brazil), with a 135° knee angulation. The isometric force was determined by a load cell attached to an inextensible cable, which was then attached to the leg press. The Pt was evaluated when the athletes performed a single maximum movement to attain knee extension as soon as possible. To evaluate FI, the same exercise was performed with the athletes maintaining the maximum contraction for 1 min.

Perception of pain: Athletes revealed their perception of pain using the 10-point visual analog pain scale, with 0 indicating no pain; 1–3 indicating low-intensity pain; 4–6 indicating moderate-intensity pain; 7–9 indicating severe pain; and 10 indicating pain of unbearable intensity, according to the method of Carvalho and Kowacs (8).

Perception of exertion: Perceived exertion was measured using the OMNI Subjective Effort Perception Scale, according to the procedure of Lagally and Robertson (22) and Gearhart et al. (15). Perception of exertion helps assess the safety of the exercising individual.

Acquirement of thermal images: To assess the localized body temperature, thermal images were captured using an infrared camera. Images were obtained in a room with no natural light or airflow directed to the site of image. Ambient temperature was maintained around 24°C and relative humidity around 50% using an air conditioner and monitored by a hygrometer (HIGHMED, model HM-01, USA) (26, 41).

The athletes were instructed not to perform vigorous physical activity in the previous 24 h, consume alcohol or caffeine in the previous 6 h, or use any type of cream or lotion on the skin in the 6 h prior to the evaluation. To obtain the thermograms, the athlete had to remain standing and not make sudden movement, cross the arms, or scratch for at least 10 min for acclimatization (25).

FLIR T640sc (FLIR, Stockholm, Sweden), with temperature range of −40°C to 2000°C, accuracy of 2%, sensitivity of <0.035, infrared spectral band of 7.5–14 µm, refresh rate of 30 Hz, and resolution of 640 × 480 pixels, was used to capture the images. The FLIR TOOLS (FLIR, Stockholm, Sweden) software was used to analyze the thermal images. The regions of interest evaluated were the anterior and posterior faces of the thigh (35). The thermal images are presented in Figure 1.

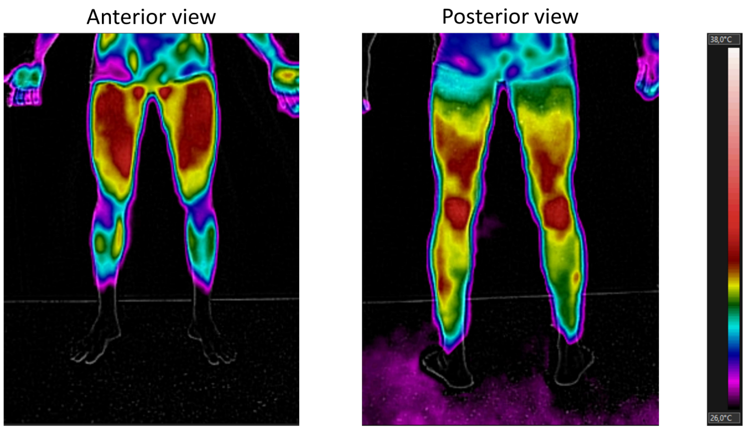


Figure 1: Illustration of the thermal images

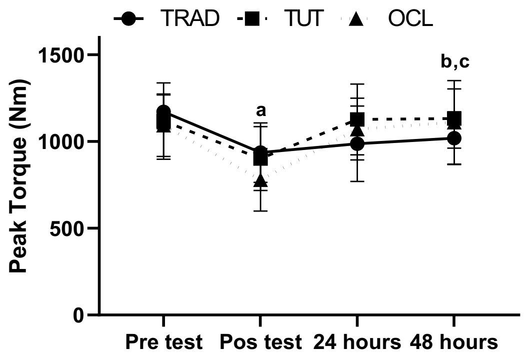
Statistical Analysis

All statistical analyses were performed using the SPSS version 22.0 software. Data are presented as mean ± standard deviation. Considering the sample size, the Shapiro–Wilk test was used to verify the normality of variables. The analysis of variance (3 × 4) (condition and moment) test, with post hoc Bonferroni correction, was used to verify the possible differences in the indicators of strength, fatigue, muscle damage, and skin temperature. Paired t-tests were used to compared pain and subjective perception of effort (OMNI-Res). The partial eta squared (η_p^2), adopting values of low effect (≤0.05), medium effect (0.05–0.25), high effect (0.25–0.50), and very high effect (>0.50), was used to verify the effect size (16). Significance was defined as a p value of <0.05.

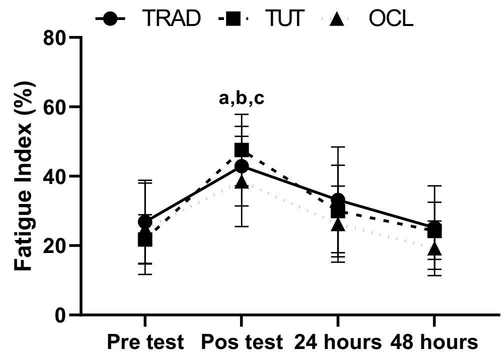
RESULTS

As is presented in Figure 2, the vascular OCL method revealed a 33% reduction in the post-test peak torque ($p < 0.001$; η^2p: 2.74), which was recovered within 24 *h*. All the training methods demonstrated an increase in post-intervention FI ($p < 0.05$), but only the OCL method presented an increase in CK ($p < 0.001$; η^2p: 1.08) and LDH ($p < 0.001$; η^2p: 1.56).

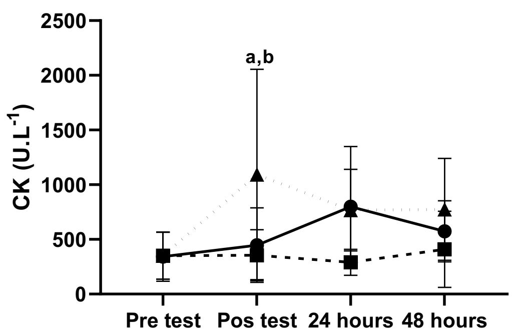
As is presented in Table 2, post-training blood lactate concentration was significantly increased compared with the pre-training values in all the training methods analyzed. The TRAD induced a lower sensation of pain than the TUT (21.87%; $p < 0.05$; η^2p: 4.63) and vascular OCL (16.66%; $p < 0.05$; η^2p: 3.31) methods. However, there were no differences between the methods for perceived exertion.



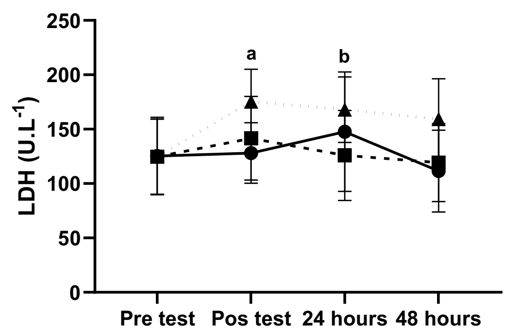
a: OCL post test vs OCL, TRAD, TUT (pre test, 24, 48 hours), p<0,05; b: TRAD 48 hours vs TUT and OCL (48 hours), p<0,05; c: OCL 48 hours vs OCL (post test), p<0,05



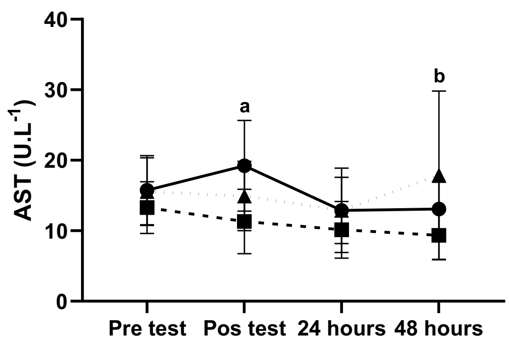
a: TRAD post test vs OCL, TRAD, TUT (pre test), p<0,05; b: TUT post test vs OCL, TRAD, TUT (pre test, 24, 48 hours), p<0,05; c: OCL post test vs OCL, TRAD and TUT (48 hours), p<0,05



a: OCL post test vs OCL, TRAD, TUT (pre test, 24, 48 hours), p<0,05; b: OCL post test vs TRAD, TUT (post test); p<0,05



a: OCL post test vs OCL, TRAD, TUT (48 hours), p<0,05; b: OCL 24 hours vs TRAD, TUT (24, 48 hours), p<0,05



a: TRAD post test vs OCL, TRAD, TUT (pre test), p<0,05; b: OCL 48 hours vs TRAD, TUT (48 hours), p<0,05

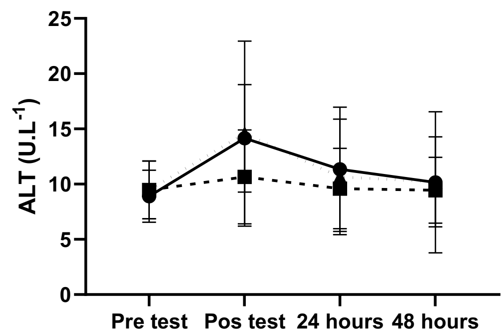


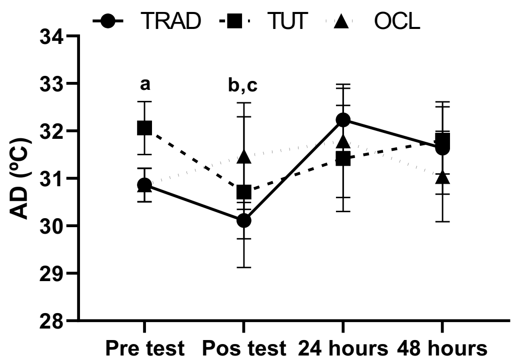
Figure 2: Strength, fatigue and muscle damage (mean ± standard deviation) after traditional, tension and occlusion methods interventions. TRAD = Traditional method; TUT = Tension method; OCL = Vascular occlusion method; PT = Peak torque, FI = Fatigue index, CK = Creatine kinase, LDH = Lactate dehydrogenase, AST = Aspartate aminotransferase, ALT = Alanine aminotransferase

Table 2: Blood Lactate, Perceived pain and subjective perception of effort (mean ± standard deviation) before and after traditional methods intervention, with increased tension time and occlusion.

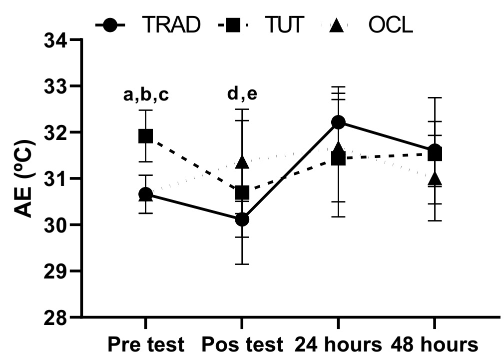
Ind/Mom	TRAD	TUT	OCL	TRAD	TUT	OCL	p	η²p
		Pre training			Post training			
Lactato (mmol ·L⁻¹)	3.60±0.57	3.80±0.47	3.80±0.47	13.60±0.86*	14.90±0.77*	14.20±0.89*	0.004	0.186**
Pain (a.u.)	---	---	---	7.50±0.50#	9.60±0.40	9.00±0.40	0.013	0.041*
OMNI (a.u.)	---	---	---	8.00±0.40	9.60±0.40	9.00±0.40	0.123	---

* p≤0.05 (Two-way ANOVA and Post Hoc Bonferroni test).
# p≤0.05 (ANOVA oneway and Post Hoc Bonferroni Test).
TRAD: Traditional Method; TUT: Method Tension; OCL: Occlusion Method; OMNI: Subjective Effort Scale; a.u. = arbitrary unity

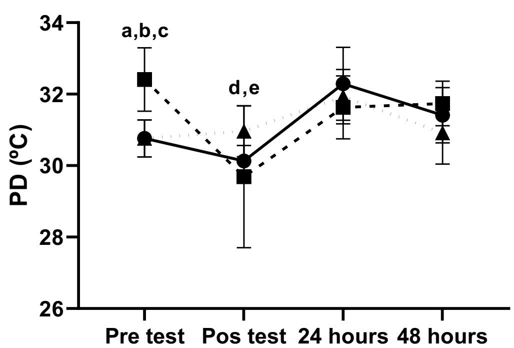
Thermographic results revealed a reduction in skin temperature in both thighs after TUT (−9.37%; $p < 0.05$; η^2p: 3.11) and vascular OCL (−6.01%; $p < 0.05$; η^2p: 2.89) trainings. The temperature before, immediately after, at 24 h, and at 48 h of the training is presented in Figure 3.



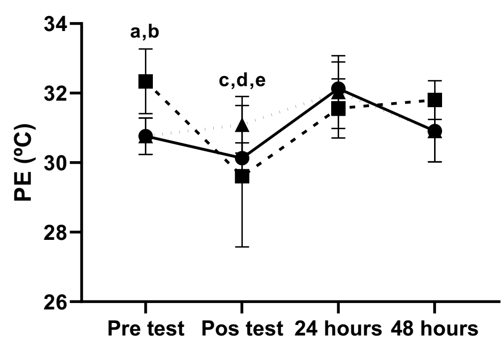
a: TUT pre test vs TRAD, OCL (post test), p<0,05; b: TRAD post test) vs TRAD, OCL (24, 48 hours), p<0,05; c: TUT post test vs TRAD 24 hours, p<0,05



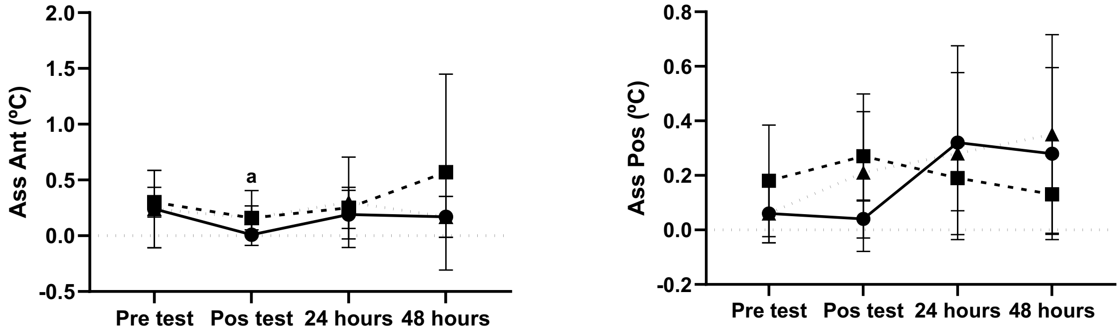
a: TRAD pre test vs TRAD 48 hours, p<0,05; b: TUT pre test vs TRAD post test, p<0,05; c: OCL pre test vs TRAD 48 hours, p<0,05; d: TRAD post test vs TRAD, OCL (24 hours), TRAD 48 hours, p<0,05; e: TUT post test vs OCL 24 hours, p<0,05



a: TRAD vs TUT (pre test), TRAD 24 hours, p<0,05; b: OCL vs TUT (pre test) and TRAD 24 hours, p<0,05; c: TUT pre test vs TRAD, TUT, OCL (post test), OCL 48 hous, p<0,05; d: TRAD post test vs TRAD, TUT, OCL (24 hours), TUT 48 hours, p<0,05; e: TUT pos test vs TRAD, TUT, OCL (24 hours), TRAD, TUT (48 hours), p<0,05



a: TRAD vs TUT (pre test), p<0,05; b: OCL vs TUT (pre test), p<0,05; c: TRAD post test vs TRAD, TUT, OCL (24 hours), p<0,05; d: OCL vs TUT (post test), p<0,05; e: TUT pos test vs TRAD, TUT, OCL (24 hours), TRAD, TUT (48 hours), p<0,05



a: TRAD post test vs TUT 48 hours, p<0,05

Figure 3: Temperature acquired through thermography (mean□standard deviation) after traditional and occlusion methods intervention. TRAD: Traditional Method, TUT: Tension Method, OCL: Vascular occlusion method, Pre: Moment prior to intervention, Post: Moment after intervention. 24 h: 24 h after intervention, 48 h: 48 h after intervention, AD - Thigh temperature right anterior view, AE - Thigh temperature left anterior view, PD - Thigh temperature right posterior view, PE - Thigh temperature left posterior view, As Ant - Asymmetry anterior view, As Pos - Asymmetry posterior view.

DISCUSSION

In the present study, we evaluated and compared the biochemical indicators of muscle damage, thermographic images, and neuromuscular performance after the athletes performed TRAD, TUT, and OCL methods with the lower limbs. We found that the muscle torque peak decreased, serum CK and LDH levels increased, and post-intervention skin temperature decreased in the OCL training method. The results also revealed greater post-intervention pain sensations in TUT and OCL training methods.

Peak torque: In this study, the OCL training method presented a significant reduction in the muscle peak torque, similar to the results of the study by Shin and Sung (36). Those authors demonstrated that repeated muscle contractions while performing RT were responsible for inducing a temporary decrease in muscle strength and electromyographic activity. Similarly, Brown et al. (5) reported a temporary decrease in strength and muscular power in women performing specific exercises of repeated sprints. Sieljacks et al. (37) also observed a temporary reduction in the maximum muscle contraction in healthy young men after performing an eccentrically reinforced training session with vascular OCL.

RT consists of repeated concentric and eccentric muscle contractions, usually resulting in muscle damage, which may be characterized by ultrastructural changes in the muscle tissue and clinical signs and symptoms (e.g., reduced muscle strength and range of motion; increased pain and muscle swelling and flow of myocellular proteins) (31). Thus, we can attribute the reduction of muscle torque peak observed in the OCL method to the greater induction of muscle damage generated by this method.

A possible mechanism for this loss of muscular force induced by muscle damage is that mechanical stress during RT causes excessive and non-uniform stretching of sarcomeres, in addition to overlapping of the filament, leading to the “rupture of sarcomeres.” These changes probably directly reduce the production of force and overload the structures of the sarcolemma and T-tubules. In turn, these events can cause the opening of activated channels by stretching, membrane rupture, and dysfunction of the coupling–excitation–contraction mechanism. Additionally, Ca^{2+} entering the cytosol through stretch-activated channels and/or permeable sections of the sarcolemma may stimulate the calpain enzyme to degrade contractile proteins and proteins involved in the coupling–excitation–contraction mechanism, resulting in loss of muscle strength (17).

Corroborating the hypothesis that the loss of peak muscle torque is related to the greater induction of muscle damage generated by the OCL method, it was also observed that this method caused a significant increase in plasma concentrations of muscle damage indicators. Among the RT-induced bloodstream metabolites, CK, and LDH are indicators of great specificity in the diagnosis of muscle damage (10, 19).

Muscle damage: As such, Damas et al. (12) observed an acute increase in serum CK concentrations in healthy young men who underwent a week of RT. Nazari et al. (28) also found an increase in the plasma concentration of CK and LDH after the performance of RT by young women aged between 20 and 30 years. Another study that also observed increases in CK and LDH concentrations after RT was performed by Ammar et al. (1), who studied trained individuals after an RT session, with the objective of evaluating its effect on acute responses of muscle damage indicators. Additionally, Sieljacks et al. (36), who studied healthy young men performing eccentrically reinforced RT sessions, with and without vascular OCL, observed that RT with vascular OCL induced a higher plasma concentration of CK.

CK and LDH are described as two of the best indirect markers of tissue damage in the skeletal muscle, especially after performing RT or exercises that require predominantly eccentric actions (20). The increase in circulating levels of plasma CK occurs when there is damage to the sarcolemma and Z disks, resulting in increased membrane permeability (20). LDH is an enzyme that exudes from the cytosol when there is muscle damage generated by increased mechanical stress in the muscle (23).

Thus, the increase in CK and LDH concentrations induced by the OCL method may be associated with higher mechanical stress caused by RT and with the higher metabolic breakdown generated by the restriction of blood flow used in this method (31).

Skin temperature: The thermographic evaluation revealed a reduction of temperature on the anterior and posterior faces of the thighs after the OCL method and only in the posterior face of the thigh after the TUT. This monitoring refers to the thermoregulatory effect, primarily induced by a redirection of blood flow from the skin to the active muscles, which reduces the skin temperature above the muscles (29, 30).

At 24 h after the exercise, a consequence of the onset of muscle inflammation (TUT and OCL methods) was observed in our study, although not statistically significant. This result reinforces the use of thermography in the assessment of muscle damage as a preventive measure against injury in athletes (2).

According to Bandeira et al. (2), the thermographic camera is capable of evaluating an increase in metabolic activity and the compensatory response after a catabolic period, naturally modified according to the protocol, volume, and intensities. Additionally, the thermographic results of the OCL method can be corroborated by the increase in the biochemical values of the muscle damage, CK, and LDH levels, reduction in the mechanical performance of the peak torque before and after training (Figure 3), and increased pain as compared to the TRAD (Table 2).

Pain: When comparing the three training protocols used in the present study, the TUT and OCL training methods induced the greatest sensation of pain in the athletes evaluated. Similarly, Wirtz et al. (43) observed increased muscle pain sensations in men with RT experience who underwent RT sessions with additional electrostimulation. Raeder et al. (33) also observed an increase in the perception of muscle pain after 6 days of intensive RT by athletes. Magoffin et al. (24) reported that RT with eccentric actions promoted increased sensations of muscle pain in trained athletes after 300 maximal eccentric contractions.

The perception of muscle pain due to RT, especially late-onset muscle pain, may be a consequence of the interaction of several factors such as connective tissue degradation, muscle damage, enzyme extravasation, and inflammation (7). Conolly et al. (11) suggested that muscle pain is associated with a series of events in which exercise causes damage to the cell membrane, initiating an inflammatory response leading to the synthesis of E2 prostaglandins and leukotrienes. The E_2 prostaglandins directly cause pain, whereas the leukotrienes increase vascular permeability and attract neutrophils to the lesion site. Neutrophils can generate free reactive oxygen species that can exacerbate muscle cell damage. Additionally, the swelling of the cells resulting from the movement of fluid from the bloodstream to the interstitial space could also contribute to the sensation of pain (7).

Accordingly, during RT, the increase in mechanical tension induced by the increased TUT method and/or the increase of the metabolic stress induced by the OCL method could result in a greater induction of muscle damage, initiating a cascade of reactions that could explain the increased muscle pain in our study. Importantly, the increase in muscle pain sensation observed in the group of athletes who performed the OCL method was accompanied by an increase in muscle damage indicators and a reduction in peak torque.

The fact that these athletes were relatively inexperienced in the three different training methods can be considered as a limitation of this study.

Conclusion: The results of the present study revealed that an RT session with restriction of blood flow (OCL method) increases the plasma levels of CK and LDH, elevates the subjective perception of muscle pain, and decreases the peak muscle torque and skin temperature.

Considering the different possible methodological delineations, it is necessary to investigate the responses of these types of training in relation to the aforementioned variables so that interventions using these methods, especially the OCL method, are guided to ensure the efficacy and safety among practitioners of strength training.

ACKNOWLEDGEMENTS

This work received funding from the Portuguese Foundation for Science and Technology – FCT (UID04045 / 2020).

REFERENCES

1. Ammar A, Chtourou H, Boudaya M, Driss T, Ayedi F, Souissi N. Acute and delayed responses of steroidal hormones, blood lactate and biomarkers of muscle damage after a resistance training session: time-of-day effects. J Sports Med Phys Fitness 58: 980-989, 2018.

2. Bandeira F, Moura M, Souza M, Nohama P, Neves E. Can thermography assist in the diagnosis of muscular injuries in soccer athletes? Braz J Sports Med 18: 246-51, 2012.

3. Bento P, Pereira G, Ugrinowitsch C, Rodacki A. Peak torque and rate of torque development in elderly with and without fall history. Clin Biomechanics 25: 450–454, 2010.

4. Bishop P, Martino M. Blood lactate measurement in recovery as an adjunct to training. Sports Med 16: 5-13, 1993.

5. Brown MA, Howatson G, Keane K, Stevenson EJ. Exercise-induced muscle damage following dance and sprint-specific exercise in females. J Sports Med Phys Fitness 56: 1376-1383, 2016.

6. Burd N, Andrews R, Little JP, Cochran A, Hector A. Muscle time under tension during resistance exercise stimulates differential muscle protein sub-fractional synthetic responses in men. J Physiol 590: 351-362, 2012.

7. Candia-Luján R, De Paz Fernández J, Costa-Moreira O. Are antioxidant supplements effective in reducing delayed onset muscle soreness? A systematic review. Nutr Hosp 31: 32-45, 2014.

8. Carvalho D, Kowacs P. Pain intensity assessment. Mig Cefal 9: 164-168, 2006.

9. Cintineo H, Freidenreich D, Blaine C, Cardaci T, Arent S. Acute physiological responses to an intensity-and time-under-tension-equated single-vs. multiple-set resistance training bout in trained men. J Strength Cond Res 32: 3310-3318, 2018.

10. Clarkson PM, Hubal MJ. Exercise-induced muscle damage in humans. Am J Phys Med Rehabil 81: S52-S69, 2002.

11. Connolly DA, Sayers SP, McHugh MP. Treatment and prevention of delayed onset muscle soreness. J Strength Cond Res 17: 197-208, 2003.

12. Damas F, Phillips S, Tricoli V, Roschel H, Ugrinowitsch C. Resistance training-induced changes in integrated myofibrillar protein synthesis are related to hypertrophy only after attenuation of muscle damage. J Physiol 594: 5209-5222, 2016.

13. Dankel S, Buckner S, Jessee M, Mouser J, Loenneke JP. Correlations do not show cause and effect: Not even for changes in muscle size and strength. Sports Med 48: 1-6, 2018.

14. Fleck SJ, Kraemer W. Designing resistance training programs, 4th ed. Champaign, IL: Human Kinetics; 2004.

15. Gearhart RF, Lagally KM, Riechman SE, Robertson RJ. Strength tracking using the OMNI resistance exercise scale in older men and women. J Strength Cond Res 23: 1011-1015, 2009.

16. Cohen J. Statistics: a power primer. Psychol Bull 112:155-159, 1992.

17. Hyldahl RD, Hubal MJ. Lengthening our perspective: morphological, cellular, and molecular responses to eccentric exercise. Muscle Nerve 49: 155-170, 2014.

18. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. Br J Nutr 40: 497-504, 1978.

19. Kim HJ, Lee YH, Kim CK. Biomarkers of muscle and cartilage damage and inflammation during a 200 km run. Eur J Appl Physiol 99: 443–447, 2007.

20. Koch AJ, Pereira R, Machado M. The creatine kinase response to resistance exercise. J Musc Neuronal Interact 14: 68-77, 2014.

21. Lacerda L, Martins-Costa HC, Diniz R, Andrade A, Tourino F. Variations in repetition duration and repetition numbers influence muscular activation and blood lactate response in protocols equalized by time under tension. J Strength Cond Res 30: 251–258, 2016.

22. Lagally KM, Robertson RJ. Construct validity of the OMNI resistance exercise scale. J. Strength Cond Res 20: 252-256, 2006.

23. Machado M, Koch A, Willardson J, Motta M, Pereira R, Monteiro N. Effect of varying rest intervals between sets of assistance exercises on creatine kinase and lactate dehydrogenase responses. J Strength Cond Res 25: 1339-45, 2011.

24. Magoffin RD, Parcell AC, Hyldahl RD, Fellingham GW, Hopkins JT, Feland JB. Whole-body vibration as a warm-up before exercise-induced muscle damage on symptoms of delayed-onset muscle soreness in trained subjects. J Strength Cond Res 34(4): 1123-1132, 2018.

25. Marins J, Fernández-Cuevas I, Arnaiz-Lastras J, Sillero-Quintana M. Applications of infrared thermography in sports: A review. Revista Inter Med Ciencias Activ Física Depor 15: 805-824, 2015.

26. Matos F, Neves E, Rosa C, Reis VM, Saavedra F, Silva S. Effect of cold-water immersion on elbow flexors muscle thickness after resistance training. J Strength Cond Res 32: 756-63, 2018.

27. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1-8, 2019.

28. Nazari M, Azarbayjani M, Azizbeigi K. Effect of exercise order of resistance training on strength performance and indices of muscle damage in young active girls. Asian J Sports Med 7: e30599, 2016.

29. Neves E, Cunha R, Rosa C, Antunes N, Vilaça-Alves J. Correlation between skin temperature and heart rate during exercise and recovery, and the influence of body position in these variables in untrained women. Infrared Phys Tech 75: 70-76, 2016.

30. Neves EB, Vilaça-Alves J, Antunes N, Reis VM. Different responses of the skin temperature to physical exercise: A systematic review. Engineering in Medicine and Biology Society (EMBC), 37th Annual International Conference of the IEEE, 2015.

31. Peake JM, Neubauer O, Della-Gatta PA, Nosaka K. Muscle damage and inflammation during recovery from exercise. J Appl Physiol 122: 559-570, 2017.

32. Pearson SJ, Hussain SR. A review on the mechanisms of blood-flow restriction resistance training-induced muscle hypertrophy. Sports Med 45: 187-200, 2015.

33. Raeder C, Wiewelhove T, Meyer T, Pfeiffer M, Ferrauti A. Assessment of fatigue and recovery in male and female athletes after 6 days of intensified strength training. J Strength Cond Res 30: 3412-3427, 2016.

34. Ratamess NA, Alvar BA, Evetoch TK, Housh TJ, Kibler WB, Kraemer WJ. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. Med Sci Sport Exerc 41: 687–708, 2009.

35. Salamunes A, Stadnik A, Neves E. The effect of body fat percentage and body fat distribution on skin surface temperature with infrared thermography. J Therm Biol 66: 1-9, 2017.

36. Shin MS, Sung YH. Effects of massage on muscular strength and proprioception after exercise-induced muscle damage. J Strength Cond Res 29: 2255-2260, 2015.

37. Sieljacks P, Matzon A, Vissing K, Overgaard K. Muscle damage and repeated bout effect following blood flow restricted exercise. Eur J Appl Physiol 116: 513-525, 2016.

38. Siri WE. The gross composition of the body. In: Advances in biological and medical physics (CA Tobias and JH Lawrence eds). New York, NY: Academic Press; 1956.

39. Slysz J, Stultz J, Burr J. The efficacy of blood flow restricted exercise: A systematic review & meta-analysis. J Sci Med Sport 19: 669-75, 2016.

40. Takada S, Okita K, Morita N, Horiuchi M. Blood flow restriction exercise in sprinters and endurance runners. Med Sci Sports Exerc 44: 413-419, 2012.

41. Uchôa P, Matos F, Neves E, Saavedra F, Reis VM. Evaluation of two different resistance training volumes on the skin surface temperature of the elbow flexors assessed by thermography. Infrared Phys Tech 93: 178-83, 2018.

42. Watanabe Y, Tanimoto M, Ohgane A, Sanada K, Miyachi M, Ishii N. Increased muscle size and strength from slow-movement, low-intensity resistance exercise and tonic force generation. J Aging Phys Act 21: 71–84, 2013.

43. Wirtz N, Wahl P, Kleinöder H, Achtzehn S, Mester J. Acute metabolic, hormonal, and psychological responses to strength training with superimposed EMS at the beginning and the end of a 6 week training period. J Musc Neuronal Interact 15: 325-332, 2015.