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Original Research

Comparison of the Local Temperature, Lactate and Glucose After Three Different Strength Training Methods

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ABSTRACT

International Journal of Exercise Science 14(4): 1408-1420, 2021. This study aimed to evaluate the local temperature, lactate, and blood glucose in three strength training methods. The study included 12 male subjects; (22.15 ± 5.77 years, 76.85 ± 9.15 kg, 1.72 ± 0.09 m), with minimum of 12 months of strength training experience, and all participated in the three training methods: the occlusion training (Kaatsu); the tension training (Tension); and the traditional training (Traditional). The Kaatsu training consisted in 3 sets of 10RM with occlusion device in both arms inflated to a 130% occlusion pressure. In addition, the tension method was performed with 30% of 1RM and the traditional training, consisted in 10 repetitions with 80% RM. Regarding the temperature variation, differences were observed between the Kaatsu and Traditional methods in relation to Tension ($p = .049$, $\eta^2p = 0.187$). While for blood glucose ($p = .351$, $\eta^2p = 0.075$) and lactate ($p = .722$, $\eta^2p = 0.022$) there were no differences between the methods. Regarding the temperature (°C) measured by thermography and asymmetry, the right side showed a decrease in the post-test, in relation to the pre-test, in all methods ($p < .05$, $\eta^2p > 0.150$). The left ($p = .035$, $\eta^2p = 0.301$) and right ($p = .012$, $\eta^2p = 0.324$) sides showed a decrease in temperature, in the post-test in relation to the pre-test, in the Kaatsu and traditional method. In asymmetry, the three methods showed an increase in the post-test in relation to the pre-test ($p = .042$, $\eta^2p = 0.158$). In conclusion, tension method seems to stimulate greater heat production than the other methods. This information can help coaches to choose among these training methods according to the desired physiological response.

KEY WORDS: Strength training, temperature, blood lactate, kaatsu training

INTRODUCTION

In humans, body temperature is controlled through physiological responses that maintain the production, absorption, and loss of heat by the body at safe levels. These thermoregulatory mechanisms are responsible for temperature homeostasis at rest and during exercise, keeping the body temperature at approximately 37 °C to avoid dangerous levels of hyperthermia and hypothermia (31, 33). Several techniques are used to measure and record body temperature. Body temperature assessments can be made through thermography, thermal sensation, conduction through body contact, and thermometers (31, 32). These show that the human body undergoes circadian variations in temperature over a 24-h period. Indeed, body temperature is one of the core markers used to identify daily circadian variations, which result from the internal systems anticipating and preparing for daily changes (25). However, these variations in body temperature have been found to differ in their normal ranges depending on the anatomical site and type of technique employed (4).

Strength training tends to result in microlesions within the muscle itself and triggers inflammation, which increases the local temperature due to increased local metabolism (4, 28). In this context, this inflammatory process can be monitored through thermal imaging (26, 32). Thus, the thermal response due to exercise has gained relevance in academia (7, 29). Establishing the normal temperature response to strength training would help coaches, physical trainers, and physical therapists to select the best time intervals for certain interventions, based on certain exercises being indicated or not depending on the variation in skin temperature (31). Thermography provides a noninvasive method to measure temperature gradients and thermal patterns in the body and the thermal radiation (heat) emitted, which makes it suitable for assessing the lesions caused by training (4, 32).

In this sense, it is believed that the hemodynamic changes that are caused by the restriction of blood flow can be assessed by thermography, since the skin temperature is related to the level of blood flow (12). Furthermore, it is possible to hypothesize that the blood flow restriction increases the amount of blood on the muscle, and therefore the skin temperature increases. On the other hand, some studies have found differences in the effects of exercise in skin temperature depending on the physical fitness level of the participant (1). Participants with longer training experience (more than 12 months of training, three times a week) could present a higher capacity of heat loss due to sweat rate and the tendency to have less body fat (36). A higher temperature of the skin reduces the temperature gradient between the skin and the core and thus leads to reduced performance in yield situations (9). It is possible that due to the lower heat loss capacity, untrained people lead to high skin temperatures easily.

High Intensity training was defined as “single set to failure protocol”, with the use of high loads, or with the use of lower loads combined with occlusion (40). On the other hand, there is now an increase in evidence suggesting that low-intensity exercise (20-40% of 1RM) combined with restriction of blood flow has produced a series of positive increments in some training-related variables, such as synthesis of proteins (39), hypertrophy (23) and muscle strength (13). However, some factors remain to be elucidated. Among these factors, we can highlight lactate, which can exert a great influence on the metabolic processes related to training with high intensities, especially in testosterone synthesis (22). According to Reeves et al., (37), lactate appears to be directly involved in the secretion of Growth Hormone (GH) and Testosterone. In addition, it is possible to observe that strength training tends to improve the rate of glucose elimination, increase glycogen storage capacity, increase GLUT 4 receptors in the muscle, increase insulin sensitivity and normalize glucose tolerance.

On the other hand, exercise with occlusion tends to promote gains in strength and muscle hypertrophy (34), and this type of training can induce muscle damage (44). In this sense, three factors tend to promote more muscle hypertrophy, mechanical tension, metabolic stress and muscle damage (19), where training with increased tension time tends to promote a increased muscle thickness (17). Thus, the present study hypothesized that thermography may be a form of control aimed at hypertrophy in different training methods.

Therefore, the aim of this study was to compare the local temperature, lactate, and blood glucose after elbow flexion exercises, measured by thermography, between three strength training methods, traditional method, with occlusion or tension method.

METHODS

The study was carried out during five weeks. In the first and second weeks, the volunteers started the familiarization, 1-RM testing and adjustment of the loads in each type of intervention, with a minimum of 48 hours rest between the familiarization and testing sessions. In the following three weeks, volunteers were assigned to one of the intervention methods, with 1/3 of the individuals participating in each intervention per week, and this order was randomized (by draw). Figure 1 exemplifies the experimental design of the study.

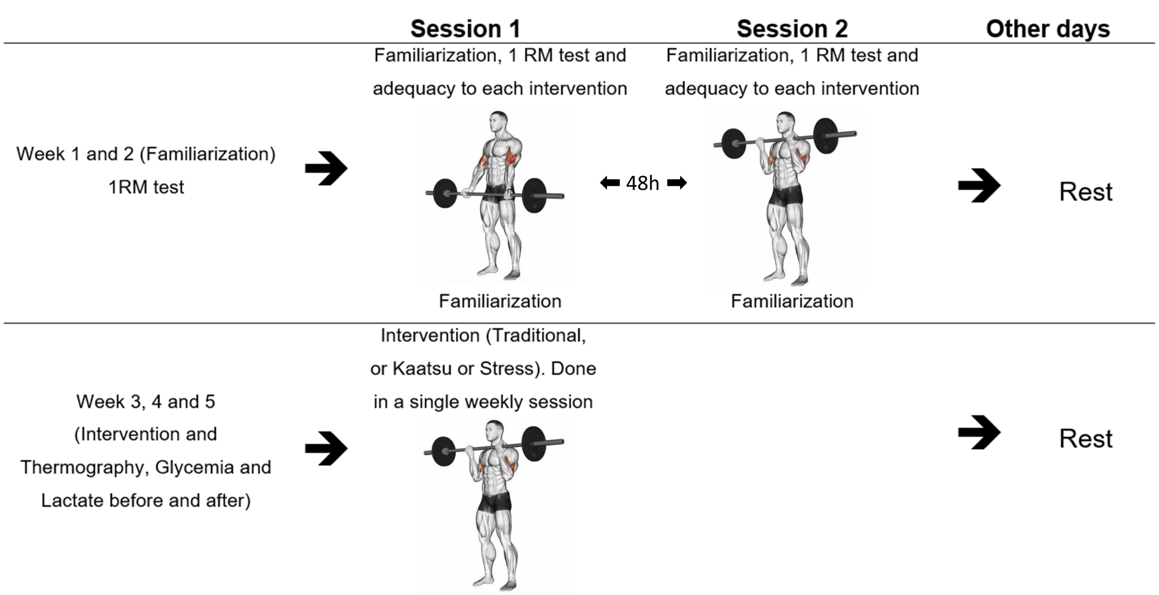

Figure 1. Experimental design - Weekly testing schedule

Participants
Based on our pilot study (*N* = 5), we performed a representative analysis to determine the appropriate sample size based on asymmetry, which is an important indicator for the risk of injury. To achieve 80% statistical power to detect differences between conditions, the sample size of eight participants would be necessary to show an increase in asymmetry from 0.4° C, (normal condition) to 0.8° C (preventive condition), throughout the experiment (24). This variable was selected for the calculations because it presented the greatest variation among the other variables measured in our study. A more detailed description is presented in the subsection on thermal asymmetry. Considering the nature of our study, we estimate a sample loss of 30%.

The study included 12 subjects, (age 22.15 ± 5.77 years, body weight 76.85 ± 9.15 kg, height 1.72 ± 0.09 m and body fat percentage 14.7 ± 4.8), of the male with experience minimum of 12 months of experience in strength training (bodybuilding and powerlifting) Participation in the study was preceded by a medical clearance and only clinically healthy subjects were included. The exclusion criteria included muscle and joint injuries, high blood pressure or a heart problem in the previous five months.

This study was granted by local ethics committee. The participants were informed of the study protocol and the associated risks and they signed a consent form in accordance with Resolution 196/1996 of the Japan National Health Council and the ethical principles of the Declaration of Helsinki (1964, revised in 1975, 1983, 1989, 1996, 2000, 2008, and 2013), and the World Medical Association. The participants also signed a consent form in accordance with Resolution 466/2012 of the National Committee of Ethics in Research-CONEP, the National Health Council. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (30).

Protocol
The subjects underwent four pre-testing sessions over a two-week period; two sessions to assess 1-RM and two sessions for familiarization with the training methods, with a minimum rest interval of 48 h between sessions. The activities started with 10 to 15 minutes of warm-up consisting of five minutes on the cycle ergometer and later performed shoulder rotation with 20 movements. Then, they performed 20 barbell curls movements with the barbell without weights, and finally performed the warm-up with about 50% of the load corresponding to the 8-12 repetition maximum (8-12RM), consisting of two sets of 15 to 20 repetitions.

The materials used included a barbell with washers and bar (Righetto, São Paulo, Brazil), a metronome (Brand Willner, Isny, Germany), and a venous occlusion apparatus (Riester, Jungingen, Germany), a width of 9 cm (21), with the rest duration between the sets determined by a stopwatch (HS-50W; Casio, Tokyo, Japan). The subject's height was measured using an anthropometric tape (Sanny®, São Paulo, Brazil), with an accuracy of 0.1 cm. Body weight was measured on a digital scale (G-tech®, Zhongshan, China) with an accuracy of 100g. For these evaluations, subjects were wearing only thermal shorts suitable for long-term running made from lightweight fabrics while standing, barefoot, with his feet together, in inspiratory apnea and with his head oriented according to the Frankfurt plan.

One week before the tests, to adjust the load for each type of intervention, 1RM (barbell bicep curl test) assessed. The intensity of the activities was controlled using the OMNI Resistance Exercise Scale (OMNI-Res) of subjective perception of effort (20). The subjects were familiarized with the scale, and the OMIN-Res perception was maintained between 6 and 8 (out of 10) during the exercises.

The one-repetition maximum (1RM) test is widely recognized as the reference standard for evaluating muscular strength (3). This technique requires an individual to lift the heaviest load possible a single time through a full range of motion. The occurrence of injury is low among experienced weight trainers, but novice exercisers are at a greater risk of injury when unaccustomed to handling heavy loads, and apprehension about lifting these heavy loads could compromise their performance, underestimating their actual strength (3).

In this study, the 1RM test was preceded by a warm-up set (8–12 repetitions) at approximately 50% of the load to be used at the first attempt of the test. After a rest of 2 min, the 1RM test started with a weight the subject believed he could lift a single time using maximum effort. Weight increments were then added until the actual maximum load that could be lifted once was reached. If the subject could not perform a single repetition at a given weight, the load was reduced by 2.4%–2.5% (3). The subject rested for about 3–5 min between the attempts. All the subjects underwent three sessions of 1RM tests to evaluate their muscle strength, with intervals of 48–72 h between the sessions. Movement technique used in each exercise was standardized and continuously monitored in an effort to ensure data quality.

On the subsequent 3 weeks, the volunteers performed randomly the three intervention methods. Every training method involved exercise to failure, aiming at a maximum of 12 and a minimum of 8 repetitions per set.

The occlusion method (Kaatsu training) is widely used in Japan and involves gentle or moderate exercise while wearing a pressurized occlusion cuff that reduces blood flow to the exercised muscle, which has been shown to have various physiological benefits. The subject did the warm-up exercises above mentioned before occlusion cuff placement. In this study, a sphygmomanometer aneroid blood pressure unit with occlusion total was used. Occlusion cuffs were applied to both of the subject's arms; the sphygmomanometer was placed in the distal arm and the cuffs were inflated to an occlusion pressure of 130% of resting systolic blood pressure (40), in the proximal portion of the arm. Subjects performed three sets of 8-12RM with 50% of 1RM (40) of elbow flexion, with 90s of interval among sets. The occlusion pressure was maintained throughout the workout, including the rest intervals, and was released at the end. The participants were instructed to perform the exercise in the 2x2" cadence (two seconds for the concentric phase and two seconds for the eccentric phase).

In the tension method, a lower load is applied and the time under tension is increased in every repetition. The subject the standard warm-up and then started the execution of three sets of 8-12RM, with 30% of 1RM, with 90s of interval among sets. A metronome was used and subjects were instructed to perform the elbow flexion slowly, taking 6.0s for the concentric phase and 6.0s for the eccentric phase (5).

In the traditional method, the load was higher and the movement cadence faster. The subject performed the same standard warm-up and then proceeded to three sets of 8-12RM, with 70-80% of 1RM, with 90s of interval among sets. A metronome was used and subjects were instructed to perform the elbow flexion taking 1.0s for the concentric phase and 1.0s for the eccentric phase.

Pre- and post- every session, thermal images were captured in a room without natural light, with the ambient temperature maintained at around 24 °C and relative humidity around 50% by means of an air conditioner, which was monitored by a hygrometer (HM-01; HIGHMED, USA) (10). No airflow was directed to the collection site.

The subjects were instructed not to perform vigorous physical activity in the previous 24 h, nor to consume alcohol or caffeine, or use any type of cream or lotions on the skin in the 6 h immediately prior to the evaluation. While the thermograms were acquired, the subject remained in the standing position without any sudden movements and with the arms uncrossed. In addition, the subject was not allowed to scratch for a period of at least 10 min for acclimatization (24).

The images were captured with a FLIR T640sc infrared camera (FLIR, Stockholm, Sweden) with measuring range of −40 °C to 2000 °C, accuracy of 2%, sensitivity < 0.035, infrared spectral band of 7.5–14 μm, refresh rate of 30 Hz, and resolution of 640 × 480 pixels. The image analysis was performed using FLIR Tools (FLIR, Stockholm, Sweden). The region of interest evaluated included the anterior face of the arm (the portion corresponding to the brachial biceps muscle) and the portion between the ulnar fossa and the axillary line in the anterior view (32).

The thermal images were collected before the intervention, where the subjects stayed 10 minutes in an air-conditioned room between 22º and 24º C, after the images were collected the subjects were submitted to the intervention. After the end of the exercise, they did a new acclimatization of 10 minutes before the new thermographic evaluation. The 10 minutes were for acclimatization of the subjects both in the pre and in the post test (10).

Temperature asymmetry was based on differences in local skin temperature between the regions of a contralateral center of pressure radial study, and was categorized according to the classification of Marins et al., (24). The five categories are summarized in Table 1.

Table 1. Temperature asymmetry classification

Level of attention	Asymmetry
Normal	≤ 0.4 °C
Monitoring	≥ 0.5-0.7 °C: it is advisable to reassess and verify whether there is an influence from an external factor
Prevention	0.8–1.0 °C: it is recommended that the load should be reduced or even the training suspended, and medical and/or physiotherapeutic evaluation sought
Alarm	1.1–1.5 °C: training should be immediately suspended and/or medical or physiotherapeutic evaluation sought
Severe	≥ 1.6 °C: suggests an asymmetry with pathological characteristics or an important lesion; medical and/or physiotherapeutic evaluation is recommended

Marins et al., (24)

Pre- and post- every session blood Lactate was assayed to identify the intensity of the sessions. Blood lactate measurement was performed using an electrochemical blood lactate test strip (Accu-Chek, Roche, Basel, Switzerland). Blood (25 µL) was collected 1–3 min after the intervention from the left digital pulp 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).

For the verification of blood glucose, samples were collected from the subjects' index finger in the environment of the exercise sessions. The collection took place at the same time and with the same lactate evaluation technique. A clinical glucometer (Accu-Check Active, Roche, São Paulo, Brazil) was used, which provides the reading of the glycemic level in about 5 seconds and a lancet indicated for the referred glucometer (Accu-Check - Multiclix, São Paulo, Brazil).

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 (ANOVA) for repeated measures, in three types of training for blood glucose, temperature and blood lactate with post hoc Bonferroni. It was using a two-way ANOVA for repeated measures (2×3) (moments and training) test, for thermography in each side and asymmetry temperature, with post hoc Bonferroni, was used to verify the possible differences. The partial eta squared ($\eta^2 p$), 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 (8). Significance was defined as a $p < .05$.

RESULTS

Figure 2 shows an example of thermal images taken: before, after tension method, after Kaatsu method and after traditional method. Table 2 summarizes the differences between the temperatures and glucose and lactate levels measured before and after the subjects performed each of the training methods.

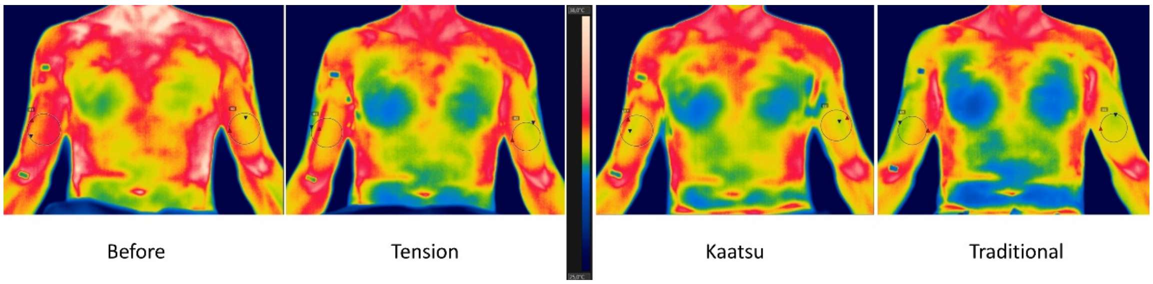

Figure 2. Illustrative images taken before the exercise, after tension method, after Kaatsu method, and after traditional method (thermal scale in the center of the image shows that temperature increase from blue regions to red-white ones)

Table 2. Changes in blood glucose levels, temperature, and blood lactate following elbow flexion training using the Kaatsu, traditional, and tension methods

Parameter	Tension	Kaatsu	Traditional	p	η^2p
Blood glucose (mg/dl)	− 1.70 ± 7.63	− 3.30 ± 10.26	− 3.60 ± 14.02	0.351	0.075[b]
Δ Temperature (°C)	− 0.68 ± 0.17	− 1.47 ± 0.13*	− 1.76 ± 0.34*	0.049	0.187[b]
Blood lactate (mmol/L)	3.06 ± 1.15	3.38 ± 0.84	3.29 ± 1.55	0.722	0.022[a]

Data are the differences between measurements made before and after the exercise, expressed as mean ± standard deviation. *Statistically significant difference compared with the tension method ($p < 0.05$ by one-way ANOVA with Bonferroni post hoc tests). Effect Size: "a" low effect (≤0.05) and, "b" medium effect (0.05–0.25)

The Table 2 shows that blood glucose was not different between the three methods, though the traditional method presented greater variations in blood glucose. At temperature, there was a greater variation of the traditional and Kaatsu methods compared to the tension method, with no significant differences between the Kaatsu and traditional methods, and the last showed larger variations. The effect size on the temperature was medium. In lactate, there were no significant differences in the variation between the three methods.

Table 3 shows the temperature values measured on the left and right sides, and the asymmetry between them, before and after the three training methods.

Table 3. Temperature (°C) measured by thermography and asymmetry before and after the three training methods

	Tension	Kaatsu	Traditional	p	η^2p
Right side, before	31.65 ± 0.59	31.70 ± 0.30	31.65 ± 0.34		
Right side, after	30.94 ± 0.51#	30.26 ± 1.12#	29.69 ± 0.37#	0.012	0.324[b]
Left side, before	31.83 ± 0.55	31.54 ± 0.37	31.50 ± 0.40		
Left side, after	31.18 ± 0.55	30.04 ± 1.11*	29.94 ± 0.29*	0.035	0.301[b]
Asymmetry, before	0.18 ± 0.03	0.16 ± 0.03	0.15 ± 0.02		
Asymmetry, after	0.24 ± 0.03#	0.22 ± 0.13#	0.25 ± 0.03#	0.042	0.158[a]

Data are expressed as mean ± standard deviation. $p \leq .05$ (two-way ANOVA with Bonferroni post hoc testing). * intraclass difference, # interclass difference. Effect Size: "a" medium effect (0.05–0.25), "b" high effect (0.25–0.50).

The right side on Table 3 it is presented a decrease in post-test, compared with pre-test, in all the methods. The left side shows a decrease in the temperature, in the post-test in relation to pre-testing, both in Kaatsu and in traditional methods. There was no significant differences with the tension method. In the asymmetry, the three methods showed increases at the post-test.

DISCUSSION

The objective of this study was to compare the skin temperature in the elbow flexors, using thermography, after three different methods of strength training. The main findings of the study were significant differences in the skin temperature over the brachial biceps muscle (specifically the short head) and coracobrachialis muscle with the traditional and Kaatsu methods when compared to the tension method. Previous studies have reported that the Kaatsu method of blood flow occlusion contributes to increasing strength and hypertrophy (2, 41) through generating local hypoxia and reducing the venous return because of the occlusion, leading to the accumulation of metabolites in the muscular tissue (35).

The analysis of training through thermography presents itself as a complex physiological analysis, related to training load, and to the exercised muscle groups (6). The temperature can change due to stress and physical effort, where the thermoregulation is expressed due to the increase in temperature (18). These changes would be explained due to the redirection of blood flow to the exercised location, causing peripheral vasoconstriction in the muscles (16).

The skin surface temperature correlates inversely with the thickness of the skin of the thigh fold, confirming that subcutaneous fat provides good insulation against the heat flow (33). Indeed, McArdle et al., (27) reported that fat has relatively low thermal conductivity, making it an excellent thermal insulator. It is also known that the skin temperature depends upon the amount of heat that reaches it (15); a small amount of body heat is continuously moved to the skin by conduction (one of four ways to dissipate body heat), which occurs through the direct transfer of heat from one molecule to another (27).

Despite of the difference in the magnitude of the reduction in the temperature after the three different methods (with a medium effect size), it was observed a decrease in skin temperature after all method evaluated. This result is in agreement with Uchôa et al., (43) and with Neves et al., (31). Uchôa et al., (43) studied the acute effect of the two resistance training volumes, organized in the drop-sets, on task of the Elbow Flexors with 17 Caucasian men who performed the exercise (10 repetitions per set, with 80%, 60% and 40% of the 10RM). In the same direction, Neves et al., (31) studied the thermal response to the traditional exercise of elbow flexors with untrained women. These authors performed a short longitudinal study with 31 untrained women who were randomized into two groups: biceps group, with 15 women, and quadriceps group with 16 women. The results showed that during and after completion of the exercise session, there was a significant reduction in skin temperature on the active muscles in both groups, with similar thermal responses for the two intensities studied (70% and 85%) until 15 minutes of recovery.

However, others studies reported an increase on skin temperature immediately after traditional exercises of elbow flexors (32). This disagreement may be explained by the difference of the body composition among the samples (33); by the volume and intensity of the exercise performed (32); and by the time of thermal imaging capture, after the exercise, because in the present study, the sample takes 10 minutes of acclimation after the end of exercise, and on the others studies the protocol of acquisition was immediately after the exercise.

No statistically significant differences between the methods were observed for the changes in blood glucose and lactate, although the change with the Kaatsu method was greater than that of the other two methods. These findings are consistent with previous studies, which reported that the Kaatsu vascular occlusion method leads to a series of metabolic changes (including in lactate levels). The accumulation of metabolites and the occurrence of other events contribute to the promotion of an environment conducive for muscular hypertrophy and a consequent gain in strength (42).

No significant changes related to the tension method were observed in this study. However, this method has been reported as one suitable for strength training and its benefits sum up in mechanical stress (38). Studies have reported similar levels of muscle activation between this type of method and methods that trained at high intensity (single set to failure protocol), with further indications by the Kaatsu method (42). Furthermore, Burd et al., (5) demonstrated that increasing the duration of tension (here amounting 12s per repetition; 6s for the concentric phase and 6s for the eccentric phase), with a 30% of 1 RM load, improved protein synthesis.

The study had some limitations. The accumulated load (total repetitions x absolute load) was not equalized across all the methods. In addition, the rest interval between sets was longer than that in a previous report, which found that a 30- or 60-s rest between sets was sufficient for major metabolic changes related to strength training (14). These factors may have contributed to the lack of significant differences in lactate accumulation between the methods. Future studies should include assessment of different body zones, with different strength training exercises and with different recovery intervals between sets of exercise. In addition, other training methods commonly used in strength training are yet to be analyzed under this approach, such as the pre-exhaustion method and drop-set method.

Conclusion: In conclusion, there were no differences between methods in blood glucose and in blood lactate. Regarding the variation in skin temperature, the tension method here applied to the elbow flexors resulted in a lower variation on skin temperature post-training, when compared with the traditional and occlusion methods. Considering that the skin temperature tended to decrease, this suggests that the tension method seems to stimulate greater heat production than the others method, in the active muscle after exercise. Therefore, it is possible that this training method enables a higher metabolic stress which in turn may affect muscle adaptations. This information can help coaches to choose between these training methods, according to the desired physiological response.

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