ORIGINAL ARTICLE

The thermal response of biceps brachii to strength training

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ABSTRACT

BACKGROUND: This study aimed to determine the relationships among exercise volume and the time/intensity of thermal response during biceps brachii exercise and on subsequent days.

METHODS: A short-longitudinal study has been carried out, involving 28 healthy male volunteers. The volunteers were randomized into two groups: the 3BS group (N.=15) and the 5BS group (N.=13). The 3BS group performed three sets with 16 repetitions of biceps bi-set exercise (eight repetitions of biceps curls and another eight of biceps hammer curls, with dumbbells) with load of 70% of 1RM. The thermal images were made in the following moments: before the exercise and immediately after each set (three images for the 3BS group and five for the 5BS group) and at 24, 48, 72 and 96 hours after the exercise.

RESULTS: The main findings of this study were that: 1) the temperature in the regions of interest decreased in both groups during the first minute of exercise; 2) the temperature of the control group tended to decrease and the temperature of the exercise group tended to increase, during exercise performance; 3) the temperature of control biceps followed the values of the exercise biceps on the following days; 4) the observed time and intensity of thermal response seems to be related with exercise volume, during and following exercise; 5) the thermal effects lasted for over 4 days in the group with higher volume of exercise; 6) the thermal response did not show significant statistical correlations with delayed onset muscle soreness scores.

CONCLUSION: The main findings of this study were that there are strong relationships among exercise volume and the time/intensity of thermal response after biceps brachii exercise. Also, the temperature of contralateral arm go along with the exercise arm temperature at the subsequent days after exercise, and the thermal effects last for more than four days after high exercise volume.

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The knowledge of thermal physiology has been developed in the last decade and being applied in the medical and in sports medicine area. Thermography has been used for diagnosis of temporomandibular dysfunction,[1] carpal tunnel syndrome,[2] overuse injuries of the knee in skiers,[3] sports injuries [4] and injuries after strength training.[5]

A study published in 2012 [5] on Brazilian athletes who were divided into two groups, one with low intensity training and another with high intensity training, indicated the possibili-

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ty of using thermographic images to determine the location and intensity of muscle injuries after high intensity workout. Also in 2012, another study [6] demonstrated the applicability of thermography in preventing injuries in football. The used protocol pointed what activity should be practiced by the athlete: normal training, a lighter training or physical therapy, according to the analysis results of thermograms. This protocol significantly reduced the incidence of muscle injuries in the considered team during the 2009 season.

These applications have led the authors [4, 7] to advocate the application of this tool in planning the training, based on the idea that exercise causes an inflammatory response that is part of the muscle recovery process. This inflammatory response may be accompanied by delayed onset muscle soreness (DOMS) or not.[8] It is known that intense training without an appropriated recovery time could lead to muscle damage and subsequent inflammation, muscle soreness, swelling, prolonged loss of muscle function.[9] Once that muscle recovery involves an inflammatory process, and this produces local heating, the thermography could be used for the monitoring of muscle recovery.

Some studies [10-12] have discussed about the number of sets for resistance training (dose) to optimize muscular strength development (response). These discussions involved a lot of physiological markers but not cite the blood flow or the thermal response. And obviously, this variable is as important as all of others studied in cited studies. Thus, this study aimed to determine the relationships among exercise volume and the time/intensity of thermal response during biceps brachii exercise and at subsequent days.

Materials and methods

Study design and sample

A short-longitudinal study has been carried out, involving 28 healthy male trained volunteers. The volunteers were selected among customers of two bodybuilding gyms of Guimarães city, Portugal. The anthropometric characteristics of the sample were presented formatted as average ± standard deviation (SD): age of 24.92±2.76 years; weight of 75.52±7.78 kg, height of 1.77±0.07 meters. The inclusion criterion was the agreement of volunteer to stay without physical activities during data collection period (three weeks). All volunteers signed the terms of free and informed consent and the study protocol was approved by Human Research Ethics Committee of Campos de Andrade University Center under CAAE no. 28901414.3.0000.5218.

Experimental protocol

The volunteers were randomized into two groups called 3BS group (N.=15) and 5BS group (N.=13) to perform two different volumes (dose) of strength training. The one-repetition maximum (1RM) was determined seven days before the experimental day. The 1RM test was performed with three to five attempts for the bi-sets exercise,[13] using the protocol described by Kraemer and Fry.[14] All volunteers performed two sessions of 1RM test with interval of one week between sessions. No exercise was performed between the 1RM tests.

The 3BS group performed three sets with 16 repetitions of biceps bi-set exercise [13] with dominant arm (eight repetitions of biceps curls and another eight of biceps hammer curls, with dumbbells) with load of 70% of 1RM. The 5BS group performed five sets of the same exercise and load. The volunteers were instructed to maintain a constant velocity of 1 second in the concentric phase and 1 second in the eccentric phase, without any pause between phases. A metronome was used (60 bpm). The rest time between sets was 90 seconds.

The experimental day begin with the volunteers remaining for 15 minutes in an acclimatized room with temperature of 24±0.3 °C for reaching thermal balance before the images acquisition.[4] At the experimental day, the thermal images were made in the following moments: before the exercise and immediately after each set (three images for the 3BS group and five for the 5BS group).

At the four following days, were recorded both thermal images and DOMS's visual analog scale at the same time of the day as when the exercise in the experimental day finished (at 24, 48, 72 and 96 hours after the exercise). All day, after the record of thermal image and before marking the VAS for DOMS (printed with 100 mm), the volunteers were asked to carry out the execution of three repetitions of the biceps curl exercise with the same load that they had used on the main exercise (70% of 1RM).

Instrumentation and data acquisition

Thermal images were acquired from both arms (biceps brachii). It was used a term digital hygrometer to monitor the temperature and humidity of the room, a thermographic camera (FLIR Systems Inc. Model SC2000), and a computer (with specific software for acquisition and processing of thermographic images ThermaCam™ Researcher Pro 2.9). The thermographic camera used has a high resolution (320 × 240 pixels), which measures temperatures ranging from -20 °C to +120 °C. This camera has a sensitivity to detect differences of less than 0.1 °C temperature and provides accuracy of ±1 °C of the absolute temperature.

The first part of thermal images acquisition protocol was the region of interest (ROI) delineation using tapes (which reduces the emission of infrared radiation where the ribbon is attached and allows recognizing the markers in the thermal image).[7]

The ultrasonographic images were performed at the midpoint of biceps brachii using an Aloka SSD 500V real time scanner equipped with a linear probe of 7.5 MHz. This measurement was performed to evaluate the skinfold thickness.[15]

Data processing and statistical analysis

All acquired image were analyzed by FLIR ThermaCam™ Researcher Pro 2.9 software. The software was set to treat the image with background temperature of 22°C and emissivity of 0.98 [7] and in the color palette midgreen.[16] The average temperature of regions-of-interest

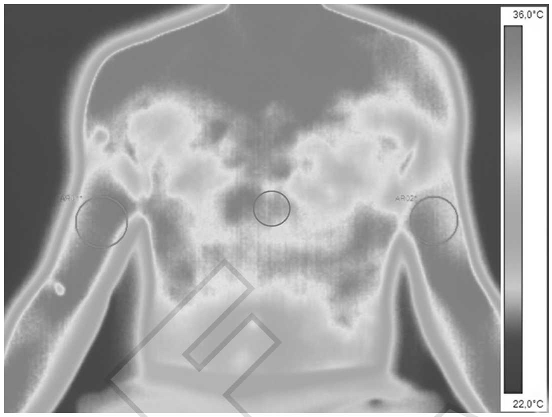

Figure 1.—Illustration of thermal images analysis where the circles indicate the ROIs.

(ROI) in biceps brachii (BB) and in the xiphoid appendix of the sternum was considered, as illustrated in Figure 1. The xiphoid appendix temperature was measured as a reference which is not influenced by arm circulation.

Descriptive statistics (means and SD) were used to summarize the characteristics of the study sample, Shapiro-Wilk test was performed to test the variable distributions, Pearson's (ρ) correlation analysis was used for evaluation of associated between DOMS's score and Biceps temperature variation at 24, 48, 72 and 96 hours. Student's *t*-test for paired sample was used to compare both arms of each volunteers in all moments measured. Student's *t*-test for independent sample was used to compare the variables that ensure the comparability of the two groups studied. The one-way analysis of variance (ANOVA) was applied to verify the difference of each variable among the moments evaluated. The Statistical analyses were performed with Statistical Package for Social Sciences (SPSS, v.21.0). The statistical significance level was defined as $P<0.05$.

Results

After performing the Shapiro-Wilk test, all variables showed Gaussian distribution. The results of Student's *t*-test for independent sample for four important variables that ensure the comparability of the two groups studied were presented in Table I.

Table I.—*Results of Student's t-test for variables that ensure the comparability of the two study groups.*

Variable	Group	N.	Average	SD	P value
Age	3BS	15	25.000	2.076	0.881
	5BS	13	24.833	3.486	
Skinfold thickness (mm)	3BS	15	3.733	1.208	0.298
	5BS	13	4.231	1.268	
Average load (kg)	3BS	15	12.600	2.530	0.713
	5BS	13	12.923	1.977	
Total volume (kg) (reps × sets × load)	3BS	15	604.800	121.432	<0.001
	5BS	13	1033.846	158.195	

When applied Pearson's correlation test to evaluate the relationship between the exercise volume and the temperature variation of exercise arm in the all moments evaluated, it was observed significant correlations at 48 (ρ=0.568, P=0.002) and 72 hours (ρ=0.534, P=0.003) after exercise, and non-significant correlations for immediately after last set on experimental day (ρ=0.182, P=0.353), at 24 hours (ρ=-0.154, P=0.434) and at 96 hours (ρ=0.111, P=0.642). The results of the biceps temperature (in the ROI) during the exercise, and in the four following days, were presented in Figures 2, 3 (for the 3BS and the 5BS group, respectively).

Figure 4 presents the temperature of xiphoid appendix of the sternum during all days of study. This result suggests that the body temperature in the subsequent days also may had been influenced by the biceps exercise performed at experimental day.

Muscle soreness developed on subsequent days after exercise. It increased significantly (P<0.05) at 24 and 48 hours for the 3BS group and at 48 and 72 hours for the 5BS group. In both groups, the peak of DOMS was 48 hours after exercise (Figure 5). Table II shows the comparison between groups for DOMS's VAS score and temperature variation (considered moment – before exercise) during all day of study.

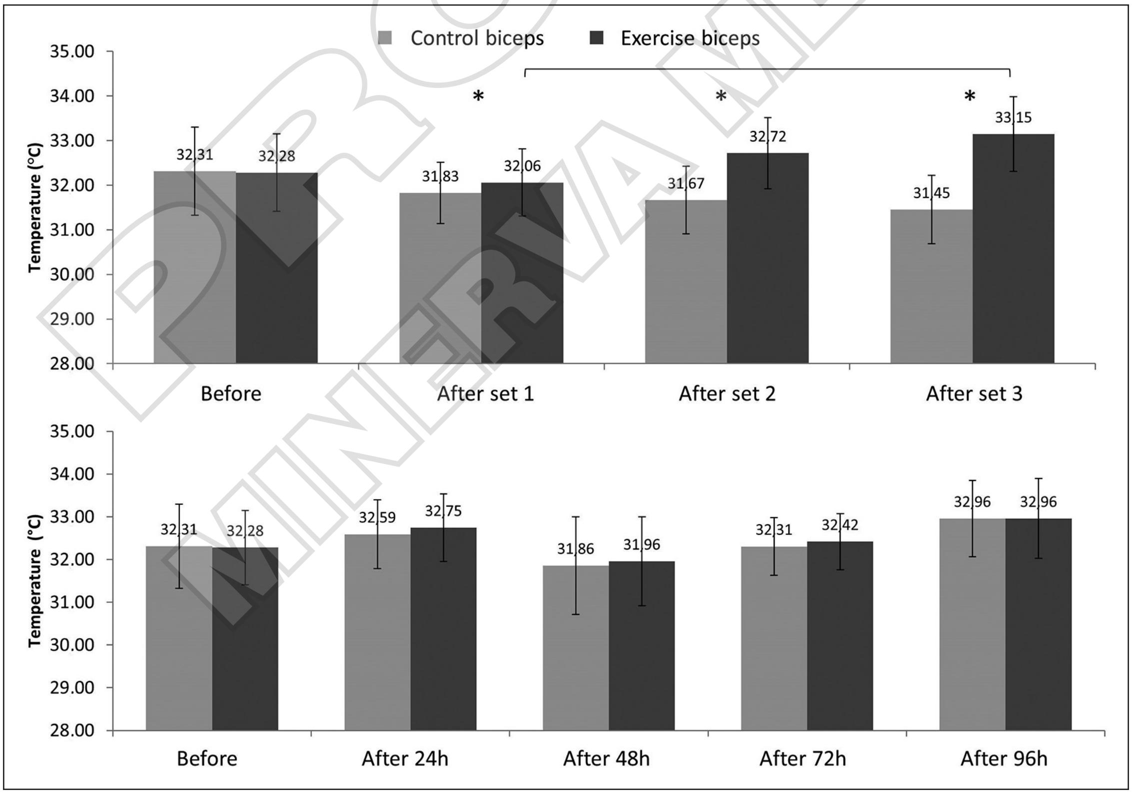

Figure 2.—Results of the biceps temperature (in the ROI) during the exercise and 24, 48, 72 and 96 hours after three sets of biceps bi-set exercise (3BS group, N.=15). *Statistical difference (P<0.05) by Student's *t*-test for paired sample; ⌐¬ means statistical difference (P<0.05) by ANOVA one-way with Bonferroni *post-hoc* test.

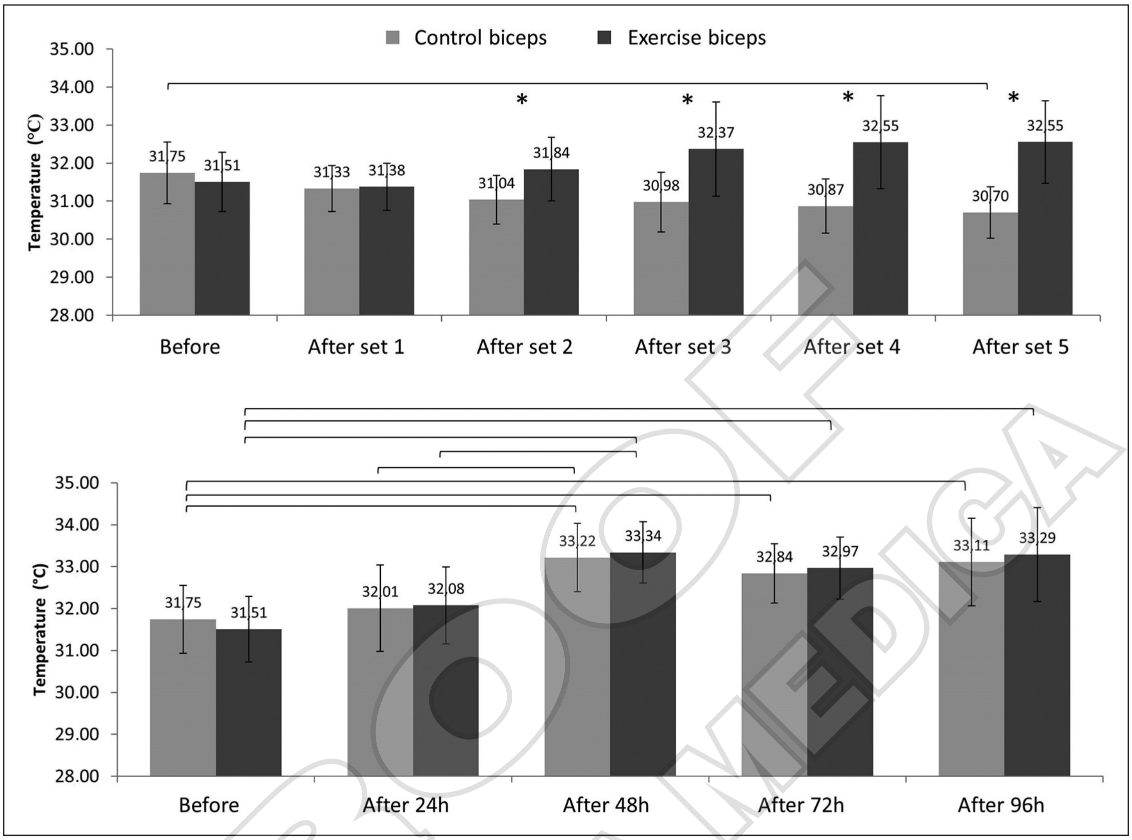

Figure 3.—Results of the biceps temperature (in the ROI) during the exercise and 24, 48, 72 and 96 hours after three sets of biceps bi-set exercise (5BS group, N.=13). *Statistical difference (P<0.05) by Student's *t*-test for paired sample; ⌐¬ means statistical difference (P<0.05) by ANOVA one-way with Bonferroni *post-hoc* test.

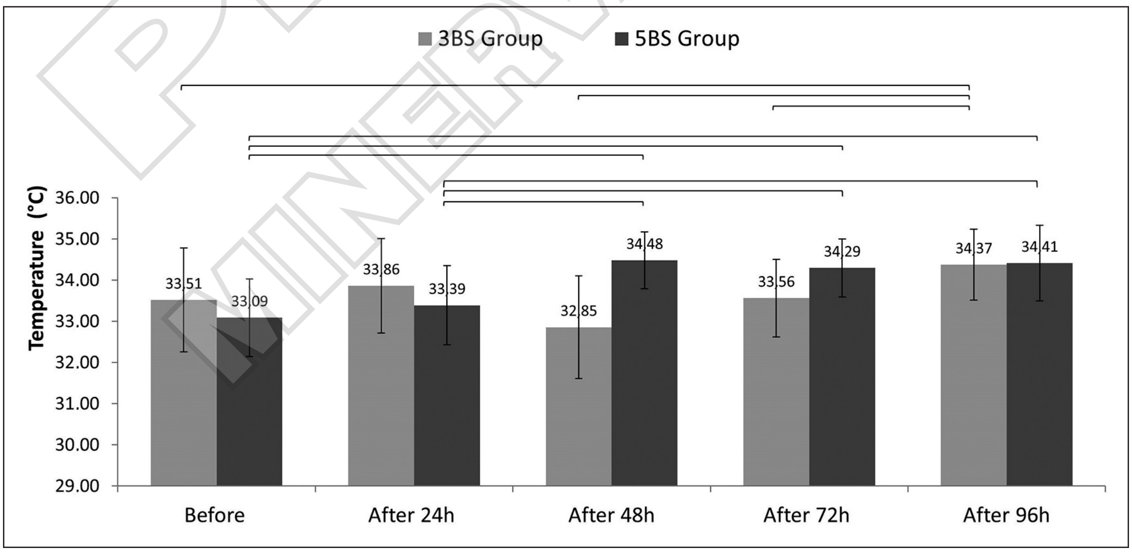

Figure 4.—Results of the xiphoid appendix temperature (in the ROI) at moments: before, and 24, 48, 72 and 96 hours after biceps bi-set exercise for the both groups. ⌐¬ means statistical difference (P<0.05) by ANOVA one-way with Bonferroni *post-hoc* test.

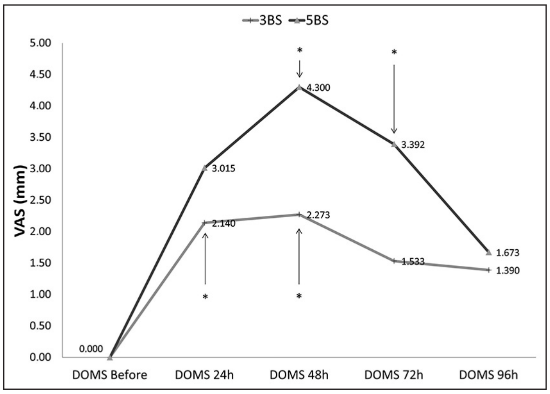

Figure 5.—DOMS variation during subsequent days after biceps exercise determined by a visual analogue scale (VAS). *Statistical difference (P<0.05) between considered moment and score before exercise (ANOVA one-way with Bonferroni *post-hoc* test).

Table II.—*Results of Student's t-test for paired sample for DOMS's score and temperature variation (considered moment – before exercise) during studied days.*

Variable	Group	Average	SD	P value
Thermal asymmetry after end of exercise (exercise biceps – control bicep) (°C)	3BS	1.700	0.364	0.094
	5BS	2.092	0.784	
DOMS at 24 h	3BS	2.140	1.656	0.280
	5BS	3.015	2.506	
DOMS at 48 h	3BS	2.273	2.036	0.070
	5BS	4.300	3.538	
DOMS at 72 h	3BS	1.533	1.926	0.076
	5BS	3.392	3.306	
DOMS at 96 h	3BS	1.390	1.397	0.752
	5BS	1.673	2.449	
Temperature variation at 24 h in control biceps (°C)	3BS	0.307	0.803	0.908
	5BS	0.262	1.224	
Temperature variation at 24 h in exercise biceps (°C)	3BS	0.467	0.745	0.780
	5BS	0.569	1.161	
Temperature variation at 48 h in control biceps (°C)	3BS	0.033	1.170	<0.001
	5BS	1.885	0.977	
Temperature variation at 48 h in exercise biceps (°C)	3BS	-0.100	1.216	<0.001
	5BS	1.962	0.941	
Temperature variation at 72 h in control biceps (°C)	3BS	0.640	0.810	0.002
	5BS	1.800	0.994	
Temperature variation at 72 h in exercise biceps (°C)	3BS	-0.300	0.701	<0.001
	5BS	1.131	0.780	
Temperature variation at 96 h in control biceps (°C)	3BS	1.620	1.451	0.329
	5BS	2.210	1.164	
Temperature variation at 96 h in exercise biceps (°C)	3BS	-0.090	1.571	0.110
	5BS	1.160	1.745	

It was not found significant correlations between DOMS's score and temperature variation at 24, 48, 72 or 96 hours after experimental day (Table III).

Table III.—*Results of Pearson's correlation test between DOMS's score and temperature variation at 24, 48, 72 or 96 hours after exercise.*

Variables	3BS (N.=15) (ρ/P value)	5BS (N.=13) (ρ/P value)	Total (N.=28) (ρ/P value)
DOMS 24 h x temperature variation in exercise biceps 24 h	-0.228/0.414	0.404/0.171	0.202/0.303
DOMS 48 h x temperature variation in exercise biceps 48 h	0.127/0.653	-0.116/0.706	0.240/0.218
DOMS 72 h x temperature variation in exercise biceps 72 h	0.036/0.899	-0.137/0.656	0.195/0.320
DOMS 96 h x temperature variation in exercise biceps 96 h	-0.042/0.907	-0.197/0.586	-0.090/0.705

Discussion

Regarding to thermal physiology, the main findings of this study were that: 1) the temperature in the ROI decreased in both groups during the first minute of exercise; 2) the temperature of the control group tended to decrease and the temperature of the exercise group tended to increase, during exercise performance; 3) the temperature of control biceps followed the values of the exercise biceps on the following days; 4) the observed time and intensity of thermal response seems to be related with exercise volume, during and following exercise; 5) the thermal effects lasted for over 4 days in the group with higher volume of exercise; 6) the thermal response did not show significant statistical correlations with delayed onset muscle soreness scores.

According to Figures 1 and 2, the thermal response at the ROI in the first moment (after set 1) was a non-statistical significant decrease when compared with the values obtained before the exercise. This result agrees with the findings of Neves and Vilaça-Alves [17] who analyzed, in time domain, the skin temperature variations during high-intensity biceps exercise of two male adults. The results showed that the temperature decreases during the first minute (between the start and the end of the first set of exercise). Another study [18] that monitored the thermal variation during aerobic exercise on a treadmill (60% of VO_{2max} speed) found a temperature decrease during the first five minutes of experiment. This initial reduction of skin temperature occurs due a redirect of blood flow to the active muscles, generated by a reflex cutaneous vasoconstriction.[17, 19, 20]

One curious finding of this study, also observed in Figures 1 and 2, was that the temperature of control arm tended to decrease while the temperature of exercise arm tended to increase, during exercise performance. This response occurred in both groups. The only study [17] that has compared the arm exercise with the contralateral (control) observed that the temperature of the contralateral arm followed the warming of the arm exercise. However, the cited study was conducted with just two volunteers. Others authors [18, 21] studied the thermal response during aerobic exercises where both limbs worked, but did not study one limb in comparison with contralateral limb during the exercise.

Another finding was the thermal response of control biceps followed the exercise biceps temperature at the subsequent days after exercise. Hani and Jerrold [8] studied the use of thermal images of biceps brachii to detect the associated muscle soreness. The subjects carried out 4 sets of 25 repetitions of biceps concentration curls exercise with 35% of their RM. The results showed a significant increase in temperature of exercise arm at 24 hours after exercise when compared to pre-exercise temperatures, and temperatures taken at 48 hours. However, the temperature of control arm did not follow the values of exercise arm as observed in this study.

As observed in Figures 3 and 4, the thermal effects last for more than four days after exercise. This is most easily seen for the 5BS group (with higher volume of exercise). It may be due to the several biosynthetic processes that contribute to homeostatic recovery at a local level, including elevated rates of mitochondrial and myofibrillar protein synthesis and glycogen resynthesis.[9] After exercise, macrophages are present in muscle from 24 hours to 14 days. They contribute to the degradation of damaged muscle tissue and may also produce pro-inflammatory cytokines.[22] In the same sense, Kanda and Sugama [23] studied the time course of serum Mb concentration as a marker of muscle damage and they reported that was observed a significant rise in Mb concentration at 72 hours after exercise.

This physiological response appears not to be restricted to the arm that held the exercise because also was observed an increase in contralateral arm temperature and in xiphoid appendix temperature, along four days after exercise. This rise may be due to a systemic endothelial adaptation induced by exercise. It was known that vascular conductance in skeletal muscle is also regulated by the sympathetic nervous system which, in rest periods, keeps the symmetrical blood flow level to the upper limbs.[4] Studies [24, 25] report that exercise can induce a systemic endothelial adaptation, which means that the effects produced by exercise are not restricted only to the blood vessels of the exercised muscle groups, but can also be observed in blood vessels not directly involved in performed exercise. In present study, the results reinforce this idea.

The warming of ROI in the arm exercise seems to be related with exercise volume, during and in following days after exercise, because the group that performed more sets (5BS) presented a higher thermal response during exercise ($P=0.094$) than the 3BS group. Also, the same was observed in delayed response in 48 hours ($P<0.001$), 72 hours ($P<0.001$), and 96 hours ($P=0.110$). Some authors [18] found similar results during exercise when they monitored the thermal variation during aerobic exercise on a treadmill with thermocouples. This reinforces the possibility of the use of thermography for measurement of the intensity (dose) of performed exercise, as proposed by Neves and Reis.[7]

Regarding the delayed thermal response, there were not found studies that monitored the volunteers during such a long period. Thus, using exercise physiology, it is known [9] that after exercise, the metabolic rate declines but remains slightly elevated for up to 24 hours, as observed in 5BS group of this study at 48, 72 and 96 hours ($P<0.05$). The extent of this excess post-exercise metabolic rate is proportional to the metabolic stress and determined by the intensity, duration, and type of exercise.[9]

Regarding the DOMS's results, the same authors [8] found a low correlation ($\rho=0.312$, $P<0.05$) between the VAS and biceps temperature measured 24 hours after exercise and non-significant correlation at 48 hours after exercise ($\rho=0.047$, $P=0.77$). In this study, no significant correlations between the thermal response (proposed as marker of muscle damage) and the DOMS's scores has been observed. This may be explained because the thermal response can shows a behavior similar to others biomarkers that occur at different time of muscle soreness peak.[26, 27]

Conclusions

It can be concluded that there is a strong relationships between exercise volume and the time/intensity of thermal response after biceps brachii exercise. Also, the temperature of contralateral arm go along with the exercise arm temperature at the subsequent days after exercise, and the body thermal effects last for more than four days after high exercise volume.

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