USING SKIN TEMPERATURE AND MUSCLE THICKNESS TO ASSESS MUSCLE RESPONSE TO STRENGTH TRAINING

UTILIZANDO A TEMPERATURA DA PELE E A ESPESSURA DO MÚSCULO PARA AVALIAR A RESPOSTA AO TREINAMENTO DE FORÇA

USO DE LA TEMPERATURA DE LA PIEL Y EL ESPESOR DEL MÚSCULO PARA EVALUAR LA RESPUESTA AL ENTRENAMIENTO DE FUERZA

Original Article
Artigo Original
Artículo Original

Eduardo Borba Neves[1-3] (Fisioterapeuta)
Tiago Rafael Moreira[3] (Educador Físico)
Rui Lemos[3] (Educador Físico)
José Vilaça-Alves[3,4] (Educador Físico)
Claudio Rosa[3] (Educador Físico)
Victor Machado Reis[3,4] (Educador Físico)

1. Exército Brasileiro, Brasília, DF, Brasil.
2. Universidade Tecnológica Federal do Paraná, Curitiba, Paraná , Brasil.
3. Universidade de Trás os Montes e Alto Douro, Vila Real, Portugal.
4. Centro de Investigação em Desporto, Saúde e Desenvolvimento Humano, Vila Real, Portugal

Correspondence:
Exército Brasileiro, Quartel General do Exército, Setor Militar Urbano 4º Andar. 70630-901. Brasília, DF, Brasil.
borbaneves@hotmail.com

ABSTRACT

Introduction: Several studies already reported the response of many biomarkers after strength training, but studies using low cost diagnostic imaging tools are rare. Objective: To evaluate the usage of skin temperature and muscle thickness (MT) to monitor muscle response (until 96 hours after) to high-intensity strength training. Methods: This is a short-term longitudinal study with 13 trained, healthy male volunteers. Volunteers performed five sets of biceps bi-set exercise with their dominant arm with dumbbells, with load of 70% of one-repetition maximum (1RM). The ultrasound (US) and thermal images were acquired before and immediately after the last set, 24, 48, 72 and 96 hours after exercise. Results: The analysis was divided in two stages: acute muscle response (until 24 hours after training) and delayed muscle response (from 24 to 96 hours after training). The elbow flexors thickness showed the peak value immediately after the last set of training. Skin temperature (on elbow flexors) and the elbow flexors thickness grew continuously from 24 to 96 hours after strength training. There is a high correlation (r=0.941, p=0.017) between skin temperature and muscle thickness from the end of exercise until 96 hours after strength training. Conclusions: The US images showed high sensibility for muscle physiological changes on the first 24 hours after exercise. On the other hand, the thermal images had higher sensibility for muscle physiological changes than US images from 24 to 96 hours after training.

Keywords: musculoskeletal system, musculoskeletal physiological phenomena, ultrasonics, thermography, resistance training.

RESUMO

Introdução: Vários estudos já relataram a resposta de muitos biomarcadores após treinamento de força, mas os estudos que utilizam ferramentas de diagnóstico por imagem de baixo custo são raros. Objetivo: Avaliar o uso da temperatura da pele e da espessura do músculo (EM) para monitorar a resposta muscular (até 96 horas após) ao treinamento de força de alta intensidade. Métodos: Este é um estudo longitudinal de curta duração com 13 voluntários treinados e saudáveis do sexo masculino. Os voluntários realizaram cinco conjuntos de exercícios bi--set para bíceps com o braço dominante, com halteres, com carga de 70% de uma repetição máxima (1RM). As imagens de ultrassom (US) e térmicas foram obtidas antes e imediatamente após a última série, 24, 48, 72 e 96 horas após o exercício. Resultados: A análise foi dividida em duas etapas: resposta muscular aguda (até 24h após o treino) e resposta muscular tardia (de 24h a 96h após o treino). A espessura dos flexores do cotovelo mostrou o valor de pico imediatamente após o último conjunto de treinamento. A temperatura da pele (nos flexores do cotovelo) e a espessura dos flexores do cotovelo aumentaram continuamente de 24h a 96h após o treinamento de força. Existe uma alta correlação (r = 0,941, p = 0,017) entre a temperatura da pele e a espessura do músculo desde o final do exercício até 96h após o treinamento de força. Conclusões: As imagens de US mostraram alta sensibilidade para alterações fisiológicas no músculo nas primeiras 24 horas após o exercício. Por outro lado, as imagens térmicas apresentaram maior sensibilidade para alterações fisiológicas do que as imagens de US entre 24h e 96h após o treinamento.

Palavras-chave: *sistema musculoesquelético, fenômenos fisiológicos musculoesqueléticos, ultrassom, termografia, treinamento de resistência.*

RESUMEN

Introducción: Varios estudios ya relataron la respuesta de muchos biomarcadores después de entrenamiento de fuerza, pero los estudios que utilizan herramientas de diagnóstico por imagen de bajo costo son raros. Objetivo: Evaluar el uso de la temperatura de la piel y del espesor del músculo (EM) para monitorear la respuesta muscular (hasta de 96 horas después) al entrenamiento de fuerza de alta intensidad. Métodos: Este es un estudio longitudinal de corta duración con 13 voluntarios entrenados y saludables del sexo masculino. Los voluntarios realizaron cinco conjuntos de ejercicios bi-set para bíceps con el brazo dominante, con pesas, con carga de 70% de una repetición máxima (1RM). Las imágenes de ultrasonido (US) y térmicas fueron obtenidas antes e inmediatamente después de la última serie, 24, 48, 72 y 96 horas después del ejercicio. Resultados: El análisis fue dividido en dos etapas: respuesta *muscular aguda (hasta 24 horas después del entrenamiento) y respuesta muscular tardía (de 24 a 96 horas después del entrenamiento). El espesor de los flexores del codo mostró el valor de pico inmediatamente después del último conjunto de entrenamiento. La temperatura de la piel (en los flexores del codo) y el espesor de los flexores del codo aumentaron continuamente de 24 a 96 horas después del entrenamiento de fuerza. Existe una alta correlación (r = 0,941, p = 0,017) entre la temperatura de la piel y el espesor del músculo desde el final del ejercicio hasta 96 horas después del entrenamiento de fuerza. Conclusiones: Las imágenes de US mostraron alta sensibilidad para alteraciones fisiológicas en el músculo en las primeras 24 horas después del ejercicio. Por otro lado, las imágenes térmicas presentaron mayor sensibilidad para alteraciones fisiológicas que las imágenes de US entre 24 y 96 horas después del entrenamiento.*

Palabras clave: *sistema musculoesquelético, fenómenos fisiológicos musculoesqueléticos, ultrasonido, termografía, entrenamiento de resistencia.*

DOI: http://dx.doi.org/10.1590/1517-869220152105151293 Artigo recebido em 26/06/2015 aprovado em 03/08/2015.

INTRODUCTION

During the performance of physical exercise, there is an increased metabolic rate and therefore increased internal heat[1]. This changes the heat balance and activates the mechanism responsible for heat loss mediated by hypothalamic complex feedback system. This system controls the redistribution of blood flow from the inactive areas for the active ones during exercise[2]. Later, with the continuity of the exercise, occurs the redirection of blood flow to the skin, in order to exchange heat with the environment[2].

Among subjects physically active, most of them aim to muscle hypertrophy, which can be obtained through the so-called strength training (ST). This method is usually accomplished with the use of extracorporeal load and leads to stimulation of satellite cells and metabolic stress[3]. All this makes the exercised muscle develop some level of inflammation that is repaired during the recovery period[4].

The muscle inflammation resulting from strength training reflects the muscle damage (destruction of muscle fibers and liberation of metabolites) that occurs during muscle contraction performed with high loads[5]. This process also involves volume changes in muscle fibers, the release of several biochemical markers and local heat production[6]. There are many methods that can be used to assess the extent post--exercise muscle damage: creatine kinase[4], magnetic resonance imaging (MRI)[7], thermography[1] and ultrasonography[6].

Thermography is a harmless, non-invasive, non-ionizing able to measure the skin temperature, at a distance, with high precision and displaying high resolution images. This technique quantifies the information in real time, differentiating temperature differences smaller than 0.05°C[1]. The use of thermal imaging in fusion with MRI images has been recommended for the diagnosis and monitoring of muscle damage due to high sensitivity to physiological changes (temperature) in muscle level[7].

Ultrasonography has lately been used in research as a way to assess muscle damage and the muscle volume[6,8]. Studies have applied this technique both in trained subjects as untrained by the assessment of muscle thickness, which variation was associated with the occurrence of edema in the post-workout period[9,10].

Several studies[1,11-13] already reported the response of many biomarkers after strength training, but studies using low cost diagnostic imaging tools (as ultrasonography and thermography) are rare. authors[14] have reported a high correlation in the diagnosis of handle repetitive strain injuries (RSI) and work-related musculoskeletal disorders (WMSD) between the assessment by ultrasound and thermography, however, although there are studies evaluating muscle recovery through ultrasound[9,10] or by thermography[1,4] in isolation but there is no known correlation between the results of these assessment tools in the post-workout period or the best period to use one or another. Thus, the aim of this study was to evaluate the usage of skin temperature and muscle thickness (MT) to monitoring the muscle response (until 96 hours) to high-intensity strength training.

METHODS

This work is a short-longitudinal study made with 13 trained male apparently healthy volunteers. All volunteers (age of 24.92±2.7 years; weight 75.52±7.78 Kg; and height 1.77±0.07 m) were selected by the inclusion criterion: a) were used to strength training for at least 3 month; b) did not had any physical activities during the data collection period (three weeks); c) signed the Free and informed Consent term that has been approved by the Human Research Ethics Committee of Centro Universitário Campos de Andrade (UNIANDRADE) under number 28901414.3.0000.5218.

Experimental Protocol

The muscle group selected was the elbow flexors (biceps brachii and brachialis). This muscle group was chosen because it has a low subcutaneous fat layer, which allows a good heat transfer from muscle to skin[15,16].

The sample (13 volunteers) made one-repetition maximum test (1RM) seven days before the beginning of the tests. The 1RM was determined using the Kraemer and Fry protocol[17], with three to five attempts for bi-set exercise. No exercise was performed between the 1 RM tests.

The first experimental day began with the acclimatization of the volunteers during 15 minutes in a room with controlled temperature of 24ºC ± 0.3ºC before the thermal images acquisition and after that the US images were acquired.

Volunteers performed five sets of biceps bi-set exercise with dominant arm (eight bicep curl repetitions and eight biceps hammer curls each set) with dumbbells. The load of exercise was 70% 1RM, with constant velocity of 1 second in the concentric phase and 1 second of eccentric phase (60bpm) controlled by a metronome. The rest time between sets was 90s.

The thermal images were acquired before the exercise and immediately after the last set, sitting the volunteer in a chair 1.5m from the thermal camera on anatomic position. The US images were obtained after the thermal images acquisition applying the US probe parallel to the muscle fiber orientation, in the middle distance of acromion process and lateral epicondyle of humerus, before and after volunteers perform all the practice protocol.

At the four following days, were obtained the thermal and US images exactly 24, 48, 72 and 96 hours after exercise. All days, were recorded thermal image after 15 minutes acclimatization, following the US image.

Instrumentation and Data Acquisition

The first part of thermal images acquisition protocol was the muscle delineation using tapes (which reduces the emission of infrared radiation) in order to help identify the region of interest (ROI). Thermal images were acquired from both arms (figure 1) with thermographic camera (FLIR® Systems Inc. Model SC2000, United States of America (USA)), and a computer (with specific software for acquisition and processing of thermographic images: ThermaCam™ Researcher Pro 2.9 from FLIR®). To monitor the temperature and humidity of the room was used a term digital hygrometer. The thermographic camera used has a high resolution (320 x 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 actual temperature (figure 1).

Ultrasonographic images are an established method of assessing muscle thickness[11]. The ultrasonographic images were acquired at the midpoint of biceps brachii, as illustrated in figure 2, using an Aloka SSD 500V real time scanner equipped with a linear probe of 7.5 MHz. This measurement was performed to evaluate the muscle thickness in all studied moments.

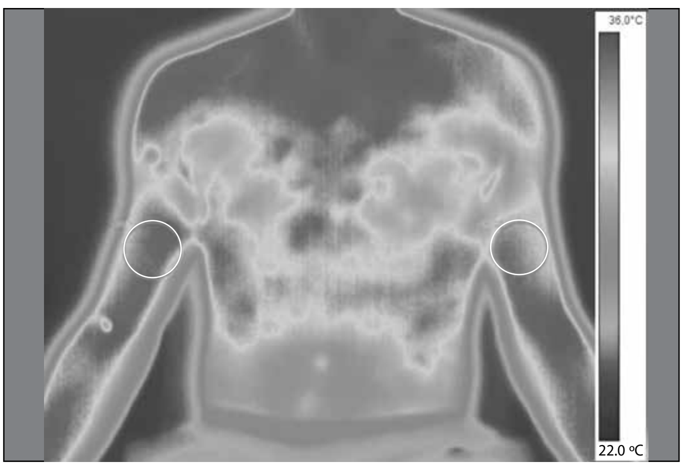

Figure 1. Illustration of thermal images analysis. The circles indicate the ROIs.

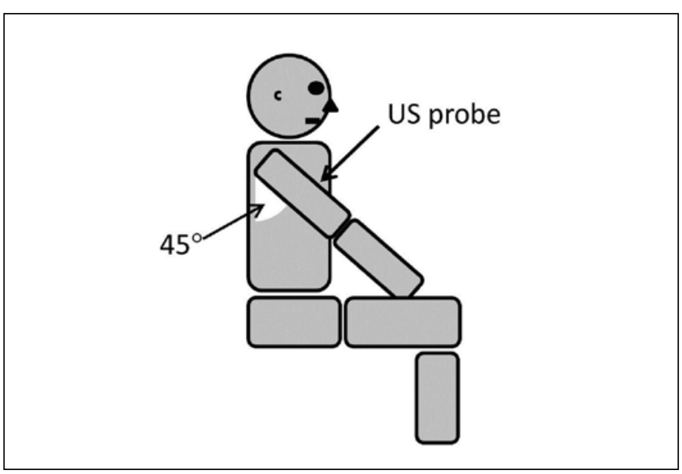

Figure 2. Illustration of ultrasonographic images acquisition.

Statistical Analysis

Shapiro-Wilk test was performed to test the variable distributions and descriptive statistics (means and SD) were used to summarize the characteristics of the study sample. Pearson correlation coefficient (r) was used for quantify the association between ultrasound images and skin temperature (on elbow flexors) at the following moments: before, immediately after, 24h, 48h, 72h and 96h after exercise. The paired t test was used to compare the skin temperature between both arms, and one-way analysis of variance (ANOVA) was used to evaluation the difference of MT and Skin temperature, among all moments evaluated. The Statistical analyses were performed with significance level of 95% ($p < 0.05$) using Statistical Package for Social Sciences (SPSS, version 21.0, USA).

RESULTS

All variables showed Gaussian distribution after performed Shapiro-Wilk test. The studied sample can be characterized by variables showed in table 1.

After exploratory data analysis and considering the time course of physiological events related to high-intensity exercise, it was decided to divide the analysis of the results in two stages: Muscle acute response (until 24h after training), showed in figure 3, and muscle delayed response (from 24h to 96h after training), showed in figure 4. Muscle thickness showed the peak value immediately after the last set of training.

It was also analysed the correlation between the thermal response and the muscle thickness (table 2). In this table was presented the Pearson correlation coefficient (r) for some situations of analysis. It can be pointed out that the correlation for delayed response of exercise biceps temperature and biceps muscle thickness (moments showed in figure 4) was 0.941 ($p = 0.017$).

Table 1. Descriptive statistics for sample characterization (N=13 male volunteers), Vila Real, Portugal, 2014.

Variables	Minimum	Maximum	Average	SD
Age (years old)	20.00	33.00	24.77	3.35
Weight (kg)	57.00	94.00	75.38	9.12
Height (m)	1.60	1.80	1.73	0.06
Control biceps temperature before training (°C)	30.40	33.10	31.75	0.81
Exercise biceps temperature before training (°C)	30.20	33.20	31.51	0.78
Biceps muscle thickness before training (mm)	27.00	36.00	30.70	2.70

SD: standard deviation.

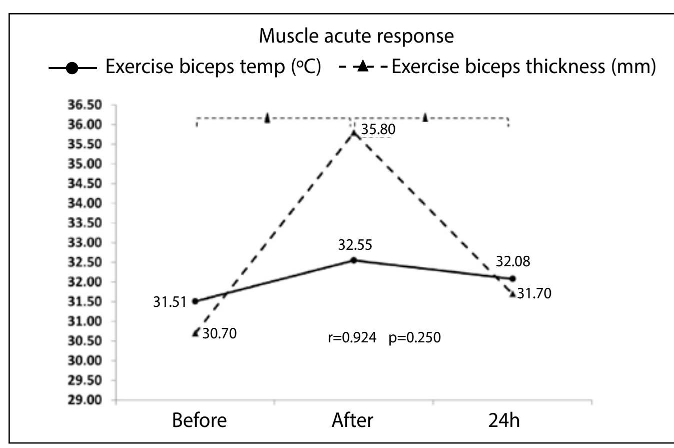

Figure 3. Acute response of exercise biceps temperature and biceps muscle thickness until 24h after strength training, where - ▲ - means statistical difference ($p<0.05$) by ANOVA one-way with Bonferroni post hoc test.

DISCUSSION

The aim of this study was to evaluate the usage of skin temperature and muscle thickness (MT) to monitoring the muscle response (until 96 hours) to high-intensity strength training. The values of MT found before training (30.70 ± 2.70mm) agree with those found by Fukunaga et al,.[18] who evaluated a sample of 160 university male students and reports an average of 30.00 ± 3.30mm. In the same direction, the temperature

Table 2. Pearson correlation coefficient (r) between exercise biceps temperature and biceps muscle thickness (N=13 male volunteers), Vila Real, Portugal, 2014.

Variable A	*vs*	Variable B	Number of moments	Period interval	r	*p* value
Exercise biceps temperature	x	Biceps muscle thickness	6	All moments	0.569	0.239
Exercise biceps temperature	x	Biceps muscle thickness	5	From before to 96hs, without immediately after	0.941	0.017
Exercise biceps temperature	x	Biceps muscle thickness	4	From 24h to 96h	0.847	0.153
Exercise biceps temperature	x	Biceps muscle thickness	3	From Before to 24h	0.924	0.250

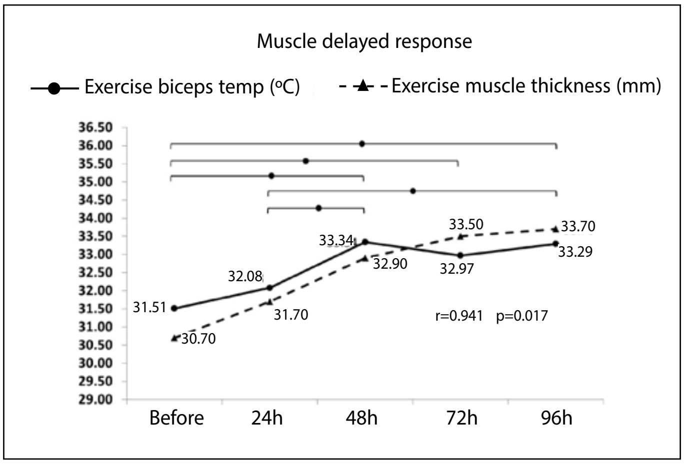

Figure 4. Delayed response of exercise biceps temperature and biceps muscle thickness until 96h after strength training, where —●— means statistical difference ($p<0.05$) by ANOVA one-way with Bonferroni post hoc test.

of the biceps before training agrees with that found by Neves et al.[15] where the mean skin temperature of the biceps was 31.10 ± 0.80°C.

Regarding to the first stage of muscle response to a strength training (until 24h), in the present study, significantly increases of MT were observed immediately after exercise (16.61% more than the before exercise values) with posterior decreasing at 24h (3.26%). This result agrees with those found by Flores et al.[12] that monitored MT of elbow flexors after a session of exercise performed by eight sets with 10 maximum repetitions of load. They observed significantly increases immediately after exercise (11.94%), decreasing at 24h (7.44%). And it also agrees with Nosaka et al.[13] that investigated the muscle response to electrical stimulation at elbow flexors in eccentric contraction and reported the same behavior of MT: rising significantly immediately after exercise and decreasing at 24h after exercise.

Although these studies found little differences among the variations of muscle thickness immediately after exercise, the US images seem to be sensible to identify the physiological changes occurred at the muscle among these moments. But the same is not true with the thermal images analysis. The results of thermal images analysis did not show statistical differences in this period (figure 3).

On the other hand, considering the delayed muscle response (figure 4), it can be seen that the MT presented a continued rising from the moment before exercise to 96h after exercise, increasing at 24h (3.26%), 48h (7.17%), 72h (9.12%), and 96h (9.77%). This result disagrees with those found by Flores et al.[12] which decreased from 24h to 96h after exercise. However, it agrees with Nosaka et al.[13] that reported a continuous rising of MT from 24h to 96h after exercise. Nosaka et al.[13] also presented the plasma creatine kinase (CK) and aspartate aminotransferase (AST) activities that showed the same behavior observed in the figure 4 of the present study (continuous rise considering the moments of delayed response). The CK and AST are known markers of muscle damage[1, 13]

In delayed muscle response period (from 24h to 96h), the muscle thickness did not show statistical significance in the present study. On the other hand, in this period, thermal images analysis showed a rise of skin temperature highly correlated with the MT variation ($r=0.941$, $p=0.017$) and with statistical differences among the moments 48h, 72h, and 96h and the reference values (before exercise). Authors[1, 4] have already reported the use of thermal images in the evaluation of muscle damage and monitoring of muscle recovery.

In the present study, thermal images seem to have more sensibility than US images because the last one has not shown statistical differences among the delayed muscle response moments, and the first one did it. On the other hand, at the acute muscle response, the US images were more sensible.

In the present study, it was observed a high correlation between exercise arm temperature and control arm temperature during delayed muscle response (figure 5). Although the explanation for the increase in temperature is a local inflammation, which in this case should occur only in the arm exercise, other authors[19, 20] have reported that the application of localized vascular stimulus can cause a systemic endothelial adaptation. This could explain the increase of temperature in the control arm during the late response.

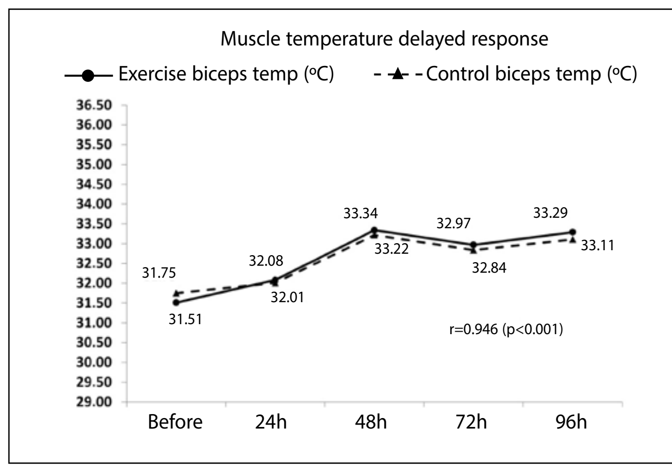

Figure 5. Biceps temperature delayed response after strength training (N=13 male volunteers). We did not find a statistical difference ($p<0.05$) by paired t test between both arms analyzed.

CONCLUSIONS

We may conclude that the skin temperature (on elbow flexors) and the elbow flexors thickness grew continuously from 24h to 96h after strength training. There is a high correlation between skin temperature and muscle thickness during the 96h after strength training. The US images showed higher sensibility for muscle physiological changes than thermal images on the first 24h after exercise. On the other hand, the thermal images had higher sensibility for muscle physiological changes than US images from 24h to 96h after training.

ACKNOWLEDGEMENTS

We would like to thank Exército Brasileiro and CNPq for important funding and financial support.

All authors have declared there is not any potential conflict of interests concerning this article.

REFERENCES

1. Bandeira F, Neves EB, Moura MAMd, Nohama P. A termografia no apoio ao diagnóstico de lesão muscular no esporte. Rev Bras Med Esporte. 2014;20(1):59-64.
2. Charkoudian N. Mechanisms and modifiers of reflex induced cutaneous vasodilation and vasoconstriction in humans. J Appl Physiol. 2010;109(4):1221-8.
3. Wolinski PA, Neves EB, Pietrovski EF. Análise das repercussões hemodinâmicas e vasculares do treinamento Kaatsu. ConScientiae Saúde. 2013;12(2):305-12.
4. Bandeira F, Moura MAMd, Souza MAd, Nohama P, Neves EB. Pode a termografia auxiliar no diagnóstico de lesões musculares em atletas de futebol? Rev Bras Med Esporte. 2012;18(4):246-51.
5. Pournot H, Bieuzen F, Louis J, Fillard J-R, Barbiche E, Hausswirth C. Time-course of changes in inflammatory response after whole-body cryotherapy multi exposures following severe exercise. PLoS One. 2011;6(7):e22748.
6. Radaelli R, Wilhelm E, Botton C, Bottaro M, Cadore E, Brown L, et al. Effect of two different strength training volumes on muscle hypertrophy and quality in elderly women. J Sports Med Phys Fitness. 2013;53(Suppl. 1 to No. 3):6-11.
7. Sanches IJ, Gamba HR, de Souza MA, Neves EB, Nohama P. Fusão 3D de imagens de MRI/CT e termografia. Rev Bras Eng Bioméd. 2013;29(3):298-308.
8. Pinto RS, Correa CS, Radaelli R, Cadore EL, Brown LE, Bottaro M. Short-term strength training improves muscle quality and functional capacity of elderly women. Age. 2014;36(1):365-72.
9. Gomes PSC, Meirelles CdM, Leite SP, Montenegro CAB. Reliability of muscle thickness measurements using ultrasound. Rev bras med esporte. 2010;16(1):41-5.
10. Matta TT, de Salles BF, Spineti J, Simão R, Oliveira LF. Índice de tensão específica dos flexores do cotovelo em homens treinados e não treinados. Rev Bras Cineantropom Desempenho Hum. 2010;12(1):62-7.
11. Yasuda T, Loenneke JP, Thiebaud RS, Abe T. Effects of blood flow restricted low-intensity concentric or eccentric training on muscle size and strength. Plos one. 2012;7(12):e52843.
12. Flores DF, Gentil P, Brown LE, Pinto RS, Carregaro RL, Bottaro M. Dissociated time course of recovery between genders after resistance exercise. J Strength Cond Res. 2011;25(11):3039-44.
13. Nosaka K, Newton M, Sacco P. Responses of human elbow flexor muscles to electrically stimulated forced lengthening exercise. Acta Physiol Scand. 2002;174(2):137-45.
14. Magas V, Neves EB, Moura MAMd, Nohama P, editors. Avaliação da aplicação da termografia no diagnóstico de LER-DORT de punho. XXIII Congresso Brasileiro em Engenharia Biomédica; 2012; Porto de Galinhas - PE, Brazil: SBEB.
15. Neves EB, Vilaça-Alves J, Krueger E, Reis VM. Changes in skin temperature during muscular work: a pilot study. Pan Am J Med Therm. 2014;1(1):11-5.
16. Neves EB, Bandeira F, Ulbricht L, Vilaça-Alves J, Reis VM, editors. Influence of Muscle Cross-sectional Area in Skin Temperature. BIOIMAGING 2015 - 2nd International Conference on Bioimaging, Proceedings; Part of 8th International Joint Conference on Biomedical Engineering Systems and Technologies, BIOSTEC 2015 2015; Lisboa: SCITEPRESS.
17. Kraemer W, Fry A. Strength testing: development and evaluation of methodology. In: Maud P, Foster C, editors. Physiol Asses Hum Fit: Human Kinetics; 1995. p. 115-38.
18. Fukunaga T, Miyatani M, Tachi M, Kouzaki M, Kawakami Y, Kanehisa H. Muscle volume is a major determinant of joint torque in humans. Acta Physiol Scand. 2001;172(4):249-55.
19. Goto C, Higashi Y, Kimura M, Noma K, Hara K, Nakagawa K, et al. Effect of different intensities of exercise on endothelium-dependent vasodilation in humans role of endothelium-dependent nitric oxide and oxidative stress. Circulation. 2003;108(5):530-5.
20. de Moraes DU. Efeitos Sub-Agudos de uma Única Sessão de Exercício sobre o Fluxo Sanguíneo, Modulação Autonômica e Pressão Arterial na Insuficiência Cardíaca. Porto Alegre - Rio Grande do Sul: Universidade Federal do Rio Grande do Sul; 2007.