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The Integrated Use of Thermography and Ultrasonography as Predictive Load Control Model of Muscle Injuries in Soccer Athletes

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1. Abstract

High-intensity efforts represent 25% of the distance in a soccer match. This demand can result in fatigue, that could be assessed by load monitoring. Ultrasonography (US) is gaining popularity for clinical evaluation in soccer clubs and Infrared Thermography (IRT) presents skin temperature (ST) in real-time. There are no studies of their combined use in soccer. 28 male soccer players participated in this study (age 18.0±2 years, bodyweight 74.3±7.3kg). All athletes who participated in 75% of the total minutes or had some pain during the games were referred for evaluations involving IRT, biomarkers and VAS scale. Athletes who presented VAS pain ≥ 6 and Thermograms with unilateral hypothermic changes in the same limb and anatomical region were referred for evaluation by US. Data normality was verified using the Shapiro-Wilk test. Differences between the maximum, mean, and minimum temperature of the affected and healthy sides were analyzed using the T-test for independent groups. A $\alpha<0.05$ was adopted as the level of significance. The US images of the contralateral were not diagnosed with injuries and no temperature reductions were found within the ROIs. In all, there were seven diagnoses of edema and three grade I injuries.

2. Introduction

Soccer is a sport in which performance depends on physical, technical, tactical, and psychological factors [1], characterized by intermittent and high-intensity efforts [2]. High-intensity actions consist of sprints, accelerations and decelerations come to represent 25% of the distance covered in a match [3]. Such physical demand can cause skeletal muscle damage, which induces a decrease in neuromuscular performance and extravasation of cellular proteins into the bloodstream, as a consequence, it takes longer than three days for the musculoskeletal system to recover from muscle soreness and performance [4-6]. Nevertheless, players compete in a busy calendar of games [7,8], the interval being insufficient for full recovery between matches, which can result in both acute and chronic fatigue [9-11]. Considering this scenario, data collection and analysis for load monitoring purposes has become a usual practice that allows assessing fatigue and subsequent adaptations, examining performance, and minimizing the risk of injury [12]. Training load control can reduce the possibility of negative adaptation to training, such as excessive fatigue leading to injuries and absences [13]. Despite greater knowledge and the injury prevention strategies applied around non-contact injuries in soccer, the rate of these types of injuries continues to increase [14]. In professional soccer, it is common for the sports science and medicine team to monitor several variables throughout the training program and the matches in order to help understand prescribing the correct load to maximize adaptation and minimize the risk of injury [15]. However, there are some limitations with the monitoring process, including the high cost of equipment, the invasive methods, unrealistic logistics, and a large number of athletes in soccer, in addition to uncertainties regarding the meaning and interpretation of collected parameters related to fatigue and its functional relevance and applicability in the field [16,17]. Given the above and the need for more specific monitoring models for muscle health, with predicting capacity to prevent high-degree myofibrillar disorganization injuries, conventional techniques for monitoring degenerative changes and in vivo screening tools were recently reviewed, among them the Ultrasonography (US), in particular, is gaining popularity for clinical evaluation in outpatient routines of soccer clubs, since it is a safe, portable imaging modality, relatively simpler in settings and cost-effectively adjusted to reality when compared to MRI [[18]. To quantify these changes in ultrasounds (US), the average echo intensity of a region of interest (ROI) of the image widely used in research applied to the area of physical exercise to evaluate DOMS in response to muscle damage [19-22]. Ultrasonography (US) is a diagnostic imaging method that provides real-time information on the architecture of abdominal and pelvic organs. Despite the numerous benefits, the ultrasound exam diverges in the interpretation of its findings due to the subjective and individual analysis, making it relevant to use techniques that quantify echogenicity and echotexture [23]. The literature suggests that the leakage of material from the sarcomere structures, when the muscle is injured and inflamed, alters the brightness of the US image [24,25], making the grayscale image closer to white [26]. In addition to the US, another imaging resource is the Infrared Thermography (IRT), characterized as an innocuous, non-ionizing, and non-invasive exam with sensitivity to the spectrum of infrared radiation [27,28]. This spectrum of infrared radiation has equivalents with absolute temperature, according to the length of electromagnetic waves, as demonstrated by Planck's Law [29,30]. Through IRT, it is possible to present the skin temperature (ST) in real-time in the generated thermal images [31], and these images are called Thermograms [32]. From the Thermograms, qualitative and quantitative analyzes are performed, with the possibility of anatomically identifying thermal changes when comparing Thermograms from different moments [33,34]. Infrared thermal imaging can provide physiological or functional information by dynamic and non-invasive measurement of body regions of interest, without physical contact or risk to the subject and is related to the heat radiated by the skin. Changes in ST are primarily a result of perspiration, core temperature, and ambient temperature, except for body contact with another surface or exposure to convection currents. This technology is widely used in medicine in the diagnosis of diseases due to the relationship between body temperature and various pathological conditions where inflammatory or degenerative processes are present, as well as abnormal changes in the peripheral circulation (Davie & Amoore, 2010). Despite the practical advantages of thermal imaging, to date, there are few validation studies on its use when compared to other modern imaging techniques, such as musculoskeletal ultrasound. Although IRT and US have been evaluated as individual imaging techniques in load control, [35,36]. There are no studies of their combined use as load control in soccer. The potential advantage of combining both techniques is that the different sets of image data derived from each of these two techniques can complement each other, and this is the foundation of our hypothesis that the image combination may allow a more comprehensive overall assessment when compared to the use of each imaging technique alone. The literature suggests that the extravasation of material from the sarcomere structures, when the muscle is injured and inflamed, alters the brightness of the US image [37]. Leaving the image in shades of gray closer to white [38], the same behavior occurs in Thermographic images due to the reduction of the radiated power by thermal absorption promoted by the edema [39]. In this study, we present an investigation of the combination of Thermographic and Ultrasound assessments for the early detection of muscle injury in soccer athletes.

3. Materials and Methods

3.1. Participants

28 male soccer players with previous experience (7 ± 3 years) participated in this study (mean ± standard deviation (SD)); age: 18.0 ± 2 years, bodyweight: 74.3 ± 7.3 kg, height: 178.1 ± 6.6 cm, VO2max: 56.3 ± 3.1 mL kg-1•min-1) (Table 1). All participants are from the under-20 category in clubs in the first division of Brazilian soccer.

Before the beginning of the study, the subjects were informed of the possible risks and benefits, signed a free and informed consent form, and were informed that they could stop participating in the study at any time without prior justification. This study was approved by the local Ethics Committee on Human Research (CAAE: 69253417.1.0000.5149) and respected all the norms established by the National Health Council (Resolution 466/12) involving research with human beings. The local Ethics Committee approved the study and the procedures were carried out under the Declaration of Helsinki.

Table 1: Sample characterization.

Variables	Average ± SD	Minimum	Maximum
Age (years)	18±2	16	20
Weight (kg)	74.3±7.3	58	90.8
Height (cm)	178.1±6.6	165.5	189.1
% Body Fat	10.3±2.2	6.43	14.8
VO^2máx ($mL.kg^{-1}.min^{-1}$)	56.3±3.1	51.9	62.5
Previous Experience (years)	6±2	4	8

3.2. Procedures

Body mass (kg) and height (cm) were measured with a digital scale and an attached stadiometer (Filizola®, São Paulo, Brazil). Body fat percentage was determined by measuring and summing skinfold (subscapular, triceps, pectoral, mid-axillary, suprailiac, abdominal, and thigh) (Jackson and Pollock, 1978; Siri, 1961), using a Lange® plicometer (Beta Technology Inc., Maryland, USA). VO^2_{MAX} was quantified from the performance in the "Yo-Yo Intermittent Recovery Test Level2" [40]. The ST was collected in a room properly equipped with artificial fluorescent lamps, and the ambient temperature was maintained through a heating/cooling air conditioner (Hitachi, Hi-wall Split, Sao Paulo, Brazil). The average temperature remained at 22.8±0.6°C, and the relative humidity was 72.4±12.1%; both measurements were recorded by Thermo-Hygrometer (Instrutherm® HT-260, São Paulo, Brazil). The participants were previously instructed to avoid alcoholic beverages, caffeine, large meals, ointments, cosmetics, and showering for 04h before the assessment. A time of 10 min in a standing position was used for acclimation [41]. The participants remained in anatomical position in front of the imager at a mean distance of 1.5 meters. Two Thermograms (anterior and posterior regions of the body) were recorded with an infrared imager, with a measurement range from -20 to +120°C accuracy of 1%, sensitivity ≤0.02 °C, spectral band of infrared from 7.5μm to 13μm, 60Hz refresh rate, autofocus and FULL HD resolution (FLIR®, T1020, Stockholm). The camera was turned on 30 minutes before the test to allow sensor stabilization following the manufacturer's guidelines and the images were recorded perpendicular to the region of interest. Images were selected and visualized in software (APOLLO® version 1.2, Brazil) for analysis by the thermopixelgraphy method (TPG) [42-44]. The emissivity value adopted for human skin was 0.98 and a black background was used [45-47]. The US images were obtained by a B-mode US (ButterflyiQ+), 7.5MHz linear operating frequency, and a 38mm long transducer. Images were taken within the ROIs with wave frequency, used for a transverse scan. The ultrasound images were captured with a gain of 90dB and magnification, which allows a depth of 42mm. A water-based gel was used for acoustic coupling of the transducer, causing a reduction of its pressure on the tissue.

3.3. Experimental Design

This study fits into descriptive-exploratory research due to its characteristic of observing, classifying, and describing phenomena related to the inflammatory process in soccer athletes. All subjects in this study were selected from a standard methodological protocol for assessing muscle fatigue after official games. All athletes who participated in 75% of the total minutes or had some pain during the games were referred between 20 and 24 hours after the games to the physiology department for evaluations involving IRT, biomarkers, and subjective assessment of pain using the VAS scale. Athletes who presented VAS pain ≥ 6 and Thermograms with unilateral hypothermic changes in the same limb and anatomical region were referred to the Medical Department with markings using a demographic pen, in the region of interest (ROI), for evaluation of muscle condition by US in the delimited region. Clinical and US examinations was performed by the same club doctor, the ROI target region of the affected limb and the healthy contralateral limb were evaluated at the same time, and the images were classified according to the magnitude of the injury [48]. ROIs were created and standardized for area and region using APOLLO® version 1.2 software Brazil between the body parts and the mean, maximum and minimum values were recorded and the delta was calculated for the limb with the highest temperature.

3.4. Statistical Treatment

Data were expressed as mean ± standard deviation. Data normality was verified using the Shapiro-Wilk test. Differences between the maximum, mean, and minimum temperature of the affected and healthy sides were analyzed using the T-test for independent groups. In all analyses, $\alpha<0.05$ was adopted as the level of significance. SPSS version 21.0 statistical software was used.

4. Results

The differences and values between the maximum, mean, and minimum temperatures of the affected and healthy limbs are shown in Table 2. 10 subjects were selected from a total of 224 evaluations that met the criteria for collection and referral for US exams, Thermograms on the side diagnosed with injury showed a reduction in temperature in the ROI region of interest compared to the unaffected contralateral region. The US images of the contralateral were not diagnosed with injuries and no temperature reductions were found within the ROIs (Fig. 1). In all, there were seven diagnoses of edema and three grade I injuries (Table 4) based on British athletics muscle injury classification [49]. Differences between the maximum, mean, and minimum temperature of the affected and healthy sides are shown in Table 3.

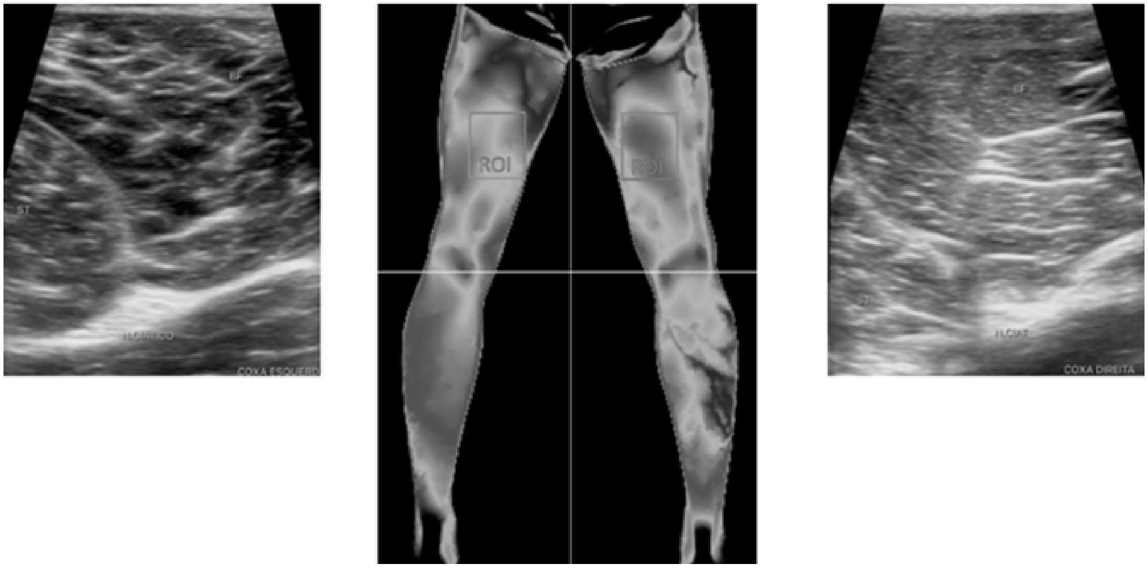

Figure 1: Thermogram with delimited ROI and corresponding US images.

Table 2: Group Descriptives.

Group		N	Mean (ºC)	Median (ºC)	SD	SE
Maximum	Affected	10	31.9	32.0	1.28	0.403
	Healthy	10	33.5	33.5	1.40	0.442
Mean	Affected	10	30.9	30.7	1.39	0.441
	Healthy	10	32.5	32.7	1.35	0.426
Minimum	Affected	10	30.0	29.4	1.57	0.497
	Healthy	10	31.5	31.5	1.42	0.449

Table 3: Independent Samples T-Test.

		Statistic	df	p
Maximum	Student's T	-2.68	18.0	0.015
Mean	Student's T	-2.55	18.0	0.020
Minimum	Student's T	-2.28	18.0	0.035

Table 4: Measurement data in ROIS.

Athlete	Age	Thermography	Injury classification	Muscle	EVA	Side	Affected ROI				healthy ROI				Delta ROI			
							Maximum	Mean ±	dp	Minimum	Maximum	Mean ±	dp	Minimum	Mean ±	Maximum	dp	Minimum
1	18	Hypothermic	Edema	Biceps Femoris	6	Right	33,20	32,39	1,62	31,58	34,15	33,565	1,17	32,98	-0,95	-1,18	0,45	-1,40
2	18	Hypothermic	Edema	Rectus femoris	7	Left	32,56	31,56	2,00	30,56	33,69	32,58	2,22	31,47	-1,13	-1,02	-0,22	-0,91
3	18	Hypothermic	Edema	Biceps Femoris	6	Left	30,40	29,49	1,83	28,57	31,47	30,86	1,22	30,25	-1,07	-1,38	0,61	-1,68
4	16	Hypothermic	Edema	Biceps Femoris	6	Right	32,50	30,79	3,43	29,07	34,68	33,075	3,21	31,47	-2,18	-2,29	0,22	-2,40
5	17	Hypothermic	Grade I	Biceps Femoris	7	Right	31,56	30,62	1,88	29,68	33,14	32,85	0,58	32,56	-1,58	-2,23	1,30	-2,88
6	18	Hypothermic	Edema	Adductor magnus	8	Right	30,78	29,72	2,12	28,66	32,16	31,15	2,02	30,14	-1,38	-1,43	0,10	-1,48
7	20	Hypothermic	Edema	Adductor magnus	5	Left	30,56	29,50	2,13	28,43	33,37	31,9	2,94	30,43	-2,81	-2,41	-0,81	-2,00
8	19	Hypothermic	Edema	Adductor magnus	6	Left	32,74	32,11	1,27	31,47	34,82	33,605	2,43	32,39	-2,08	-1,50	-1,16	-0,92
9	19	Hypothermic	Grade I	Biceps Femoris	7	Right	33,98	33,47	1,03	32,95	35,69	34,78	1,82	33,87	-1,71	-1,32	-0,79	-0,92
10	17	Hypothermic	Grade I	Biceps Femoris	6	Right	30,59	29,73	1,72	28,87	31,73	30,635	2,19	29,54	-1,14	-0,90	-0,47	-0,67

5. Discussion

We demonstrated that the use of US combined with IRT has high accuracy in detecting injuries in early stages (subclinical) in agreement with other studies with mathematical modeling studies using multilayer tissue models. The combination of Thermography and Ultrasonography in assessments for early detection of injury and pathologies is documented in the literature with articles that studied pressure sore ulcers, [50,51], Breast cancer [52,53]. Skin cancer [54]. Systemic sclerosis [55,56]. States that there is no single tool that provides excellent predictability on the detection of breast cancer and points to a sensitivity of 83% of Thermography, but the values rise to 95% when used in conjunction with Mammography. The investigation of this study, therefore, suggests new criteria for early detection of muscle tissue injury based on IRT and US evaluation. The temperature reductions in the ROIs can be explained by the edema extravasation forming a transient mechanical barrier, a fact that would lead to an increase in the resistance to the passage of heat based on the concentric cylindrical model founded on the Fourier theory of multilayers and Beer-Lambert law regarding the alteration of absorbance and transmittance of the infrared spectrum [57-59]. The staging of muscle health as understood by myofibrillar disorganization helps to explain the apparent inconsistent data in thermographic measurements of previously published results [60,61]. The temperature reductions in ROI and US-diagnosed edema may be explained by, in response to the variation of thermal energy within a tissue differential control volume, determined by the rate of net heat leaving and entering the control volume by heat conduction, blood perfusion, and metabolic heat generation explained by thermophysical properties such as local tissue density (kg / m3), specific heat (J / kg·K), thermal conductivity (W / m·K), rate of metabolic heat generation (W/m3) and tissue temperature, tissue blood perfusion rate (1/s), blood density (kg/m3), blood specific heat (J/kg·K) and arterial blood temperature (°C) present in the equation 1 of transient heat conduction from bio heating well established by Pennes (1948). Given the magnitude of these temperature differences, thermographic imaging can be used to identify early inflammation and ischemic changes associated with impending injury. Using the combined techniques will help clinicians relate thermographic findings to main physiological changes, to identify patients at risk at an early stage of injury, and provide the necessary intervention for prevention.

(1) $$\rho c \frac{\partial T}{\partial t}\partial = \nabla.(K.\nabla T) + \omega_b \rho_b c_b (T_{b-} T) + q$$

Modern medical imaging technologies offer the potential and promise of major advances in medicine. The area of digital image processing and analysis is one of the most important fields of medical science due to the rapid and continuous progress in medical image visualization and advances in computer-assisted diagnostic methods and image-guided therapies. This area has been essential for early detection, diagnosis, and assessment of response to treatment. Images from digital cameras and/or for the internet, in general, are formed by files that are characterized by having a resolution of 8 bits per channel, encoded in RGB (red, green and blue). This typical structuring is different for most types of medical images, whose "channels" simply represent a physical measurement, such as radiographic density. The contrast resolution, in this case, is determined by the number of gray shades that are represented in the image. In this case, in an 8-bit encoding, the total amount of shades varies on a scale from 0 to 256, with 0 being conventionally black and 256 being the maximum white. Even so, more advanced equipment, since the 2000s at least, converts the variation of real shades of gray in scales with even greater sensitivity, in contrast resolutions of 10, 12 and, currently, up to 16 bits (1024, 4096 or over 65,000 different levels of gray respectively). Musculoskeletal ultrasound allows anatomic structures to be easily identified (Pillen, 2011). When the US pulse encounters tissues with different acoustic impedances (product of the density of the tissue and the speed with which the sound propagates), part of the wave is reflected, producing echoes that are captured by the receiving transducer and transformed into a temporal sequence of the scale of gray, forming the B-mode image from juxtaposed vertical lines [62,63]. Structures that do not reflect sound appear black on the screen and are called hypoechoic. The tissue interfaces with the greatest difference in acoustic impedance produce echoes of greater amplitude, generating the brightest points (higher values in the grayscale). The tissues whose internal structure has spreaders create a pattern of texture that presents as regions populated with dots of various shades of gray (grainy appearance). Tissues that have a large number of scatters generate a pattern called hyperechoic [60]. The healthy skeletal muscle of an untrained volunteer, in general, appears darker in tone due to the hypoechoic structure, in addition to being constituted by little fibrous tissue and little spreading [61,22]. Thus, some studies suggest that if the evaluated site is injured at milder levels, the leakage of material from the sarcomere structures would change the tone of the acquired image, making it closer to lighter gray tones [55,56]. One of the most studied acute secondary effects of strength training is temporary muscle damage (TMD). TMD refers to a set of acute microstructural changes in muscle tissue caused by mechanical stimuli of high intensity or volume in physical exercise and lasting for approximately one week (Clarkson and Tremblay, 1988; Friden and Lieber, 2001; Clarkson and Hubal, 2002). TMD is thought to be caused by a disruption in the sarcoplasmic reticulum and transverse tubules, as well as myofibrils and cytoskeletal structures such as the Z line, alpha-actin, and desmin (Friden and Lieber, 2001). Studies in humans have contributed to the understanding of TMD through different forms of evaluation and analysis. The most applied acute interventions for the study of TMD are long-distance downhill running [50], stretching exercises [51], and mainly, eccentric strength exercises [53,54]. To assess local TMD, Ultrasound analysis has been widely used in scientific research since it is a non-invasive and relatively low-cost tool when compared to other image acquisition instruments. One application of this technique is the determination of edema by a transverse image, considered an indirect marker of local TMD. In addition to edema, B-mode Ultrasonography can assist in the analysis of muscle image texture, thus being considered a structural and local marker. In conclusion, when analyzing the results obtained under the conditions of this study, Thermography showed a correlation with Ultrasound and medical clinic, being an option as a screening tool in the detection of musculoskeletal injuries in early stages. Future studies with larger sample size and mathematical modeling are recommended to explain the hypothermic pattern associated with the appearance of edema.

6. Acknowledgments

IRT and US could be used together in soccer clubs by Medical and Physiology teams to add informations in an early diagnosis. To detect as soon as possible the presence of edema or the beginning of a muscle tear could help to reduce the absence of training sessions and matches during a season. Thus, IRT and US also could help the staff to prevent that the athletes have severe injuries, reducing the time-loss in case of minor injuries.

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