Video Article

The Use of Thermal Infra-Red Imaging to Detect Delayed Onset Muscle Soreness

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Abstract

Delayed onset muscle soreness (DOMS), also known as exercise induced muscle damage (EIMD), is commonly experienced in individuals who have been physically inactive for prolonged periods of time, and begin with an unexpected bout of exercise[1-4], but can also occur in athletes who exercise beyond their normal limits of training[5]. The symptoms associated with this painful phenomenon can range from slight muscle tenderness, to severe debilitating pain[1,3,5]. The intensity of these symptoms and the related discomfort increases within the first 24 hours following the termination of the exercise, and peaks between 24 to 72 hours post exercise[1,3]. For this reason, DOMS is one of the most common recurrent forms of sports injury that can affect an individual's performance, and become intimidating for many[1,4].

For the last 3 decades, the DOMS phenomenon has gained a considerable amount of interest amongst researchers and specialists in exercise physiology, sports, and rehabilitation fields[6]. There has been a variety of published studies investigating this painful occurrence in regards to its underlying mechanisms, treatment interventions, and preventive strategies[1-5,7-12]. However, it is evident from the literature that DOMS is not an easy pathology to quantify, as there is a wide amount of variability between the measurement tools and methods used to quantify this condition[6]. It is obvious that no agreement has been made on one best evaluation measure for DOMS, which makes it difficult to verify whether a specific intervention really helps in decreasing the symptoms associated with this type of soreness or not. Thus, DOMS can be seen as somewhat ambiguous, because many studies depend on measuring soreness using a visual analog scale (VAS)[10,13-15], which is a subjective rather than an objective measure. Even though needle biopsies of the muscle, and blood levels of myofibre proteins might be considered a gold standard to some[6], large variations in some of these blood proteins have been documented [6,16], in addition to the high risks sometimes associated with invasive techniques.

Therefore, in the current investigation, we tested a thermal infra-red (IR) imaging technique of the skin above the exercised muscle to detect the associated muscle soreness. Infra-red thermography has been used, and found to be successful in detecting different types of diseases and infections since the 1950's[17]. But surprisingly, near to nothing has been done on DOMS and changes in skin temperature. The main purpose of this investigation was to examine changes in DOMS using this safe and non-invasive technique.

Video Link

The video component of this article can be found at http://www.jove.com/video/3551/

Protocol

1. The Exercise

1. The muscle of interest for this experiment was the elbow flexors (Biceps Brachii).
2. Muscle strength was measured for each participant to be able to give each individual an appropriate resistance. This was determined by testing each participant for their resistance maximum (RM).
3. For testing the RM, we used a strain gauge device interfaced with a computer through a BioPac (DA-100C) bioelectric amplifier module (BioPac Systems, Goleta, CA) to measure muscle strength. The module was connected to an MP-100 analog to digital converter sampling at a frequency of 1,000 hertz per second, and at a resolution of 24 bits (Fig. 10).
4. The strain gauge device was fixed to a bench at a 45° angle. The subjects were instructed to sit behind the device and rest their elbows on the padded area, so that the exertion force is through their wrists. This was the best way to insure that the subject will not recruit any muscle other than the biceps (Fig. 11).
5. Strength was determined on 3 occasions with each contraction being 3 seconds in duration with approximately 45 seconds separating the contractions. The average of the 3 measurements was the RM.
6. After determining the RM for the biceps muscle of each participant, the intended session of exercise was carried out with 35% of their RM.
7. All the subjects underwent the same exercise using appropriate weighted dumbbells to induce the muscle soreness (DOMS). This was carried out by doing 4 sets of 25 repetitions of biceps concentration curls while seated on a chair, and with the elbows supported on their thighs (Fig. 12).

8. Each subject was given a 90 second resting period between each set. Subjects either did the full set of 25 repetitions, or were instructed to stop if they failed to steadily control the weight during the exercise.

2. Infra-Red Camera Preparation & Setup

1. The room where the infra-red imaging takes place was set at a constant temperature to minimize any external bias from differences in room temperature, which could lead to false thermal readings. For the purpose of this experiment we had a temperature controlled room which was maintained at approximately 23°C (+/- 0.5°C).
2. The camera was set at a distance of 1 meter away, and at a perpendicular angle to the skin being measured (Fig. 9a)*.
3. After the required distance was set up, the subjects were advised to stand still until the image has been taken. This shouldn't take more than a couple of seconds, but it is very critical to minimize movement to insure the accuracy of the taken image.
4. It is preferable that the room has darker colored paint, rather than lighter colors, to minimize any infra-red interference.
5. Lighting is also critical when dealing with infra-red images, because light source that emit infra-red waves like fluorescent or tungsten lighting could give false high readings. The best lighting option would be a room equipped with uniform LED lights, as LED lights hardly produce any infra-red interference (Fig. 9b)*.

* A series of tests were done at our labs using the FLIR 660 IR Camera (Fig. 8), where we compared images of the skin at different angles (0 (perpendicular), 15, 30, 45, and 60 degrees), and at different distances (1, 2, and 5 meters) from the skin, to accurately detect the temperature of the skin. All images were compared to calibrated thermocouples, and the best correlation between the images and the thermocouple readings was at a perpendicular angle and at a distance of 1 meter away from the skin (r = 0.93). The different angles and distances caused a pixilation loss, and decreased the overall correlation between the images and the thermocouple readings.

3. Image Acquirement

1. For the purpose of this experiment, the image of the exercised muscle was taken before the exercise, and at 24, and 48 hours post exercise.
2. Body heat from sources other than the target could disrupt the thermal image and give false readings. For this reason, no one should be standing beside or behind the intended target.
3. In this investigation, pictures of both the exercised and non-exercised arm were taken for comparison purposes. We exercised one of the arms, as was mentioned previously, and the other arm was used as a control (Fig. 4 and 5).
4. Image numbers from the IR camera were recorded immediately on a separate spreadsheet, as it could be difficult to identify which image belongs to whom.

4. Image Processing & Analyses

1. The acquired IR images were processed using the "ThermoVision ExaminIR" software Version: 1.10.2.
2. After selecting the required image for analysis, four regions of interest were identified on the acquired image of the arm using statistical boxes on the software interface (Fig.6).
3. When the required regions across the arm have been located, the software shows the Means and Standard Deviations of the temperatures for each of the selected regions. We can then either cross compare each region individually or obtain an average temperature of the whole arm (Fig. 7).

5. Visual Analog Scale & Blood Analysis

1. A visual analog scale (VAS) was used to assess subjective soreness of the arm. The scale had a 10 cm (100mm) long line marked "no pain" at one end, and "extremely sore" at the opposite end. Each participant was directed to make a mark along the 10 cm line to indicate their response to soreness.
2. The VAS's were administered to the subjects before the exercise, 24 hours after the exercise, and at 48 hours.
3. Peripheral blood was collected from the subjects to measure myoglobin concentration levels in the blood.
4. The blood was drawn from the subjects antecubital vein before the exercise, 30 minutes after the exercise was over, and at 48 hours.
5. The blood was centrifuged at 4000 rpm for 10 min to separate the serum from the cells. The samples were then stored at -80°C until the analyses of myoglobin was done.
6. Myoglobin was measured using a TOSOH "AIA-360" Automated enzyme Immunoassay Analyzer (TOSOH Corp., Tokyo, Japan). The myoglobin Assay kits (Myo 025297, ST AIA-PACK Myoglobin) were used according to the manufactures instructions.

6. Representative Results

The results of IR thermal images taken during this investigation are clearly represented in figure 1. Images taken at the 3 time periods (pre-exercise, 24 hours post-exercise, and 48 hours post-exercise) for the exercised arms of the 41 subjects, showed a noticeable increase in temperature on day 2 (24 hours post-exercise) when compared to pre-exercise temperatures, and temperatures taken at 48 hours. As shown in figure 1, the average skin temperature was 32.80 +/- 1.03 °C for day 1 (pre-exercise), and 33.96 +/- 1.46 °C for day 2 (24 hours post-exercise), and 32.82 +/- 1.29 for day 3 (48 hours post-exercise). This difference in skin temperature from day 1 to day 2 was significant (ANOVA p < 0.01).

However, for the un-exercised arm, changes amongst the 3 time periods were not evident. Figure 1 shows that the average skin temperature was 33.08 +/- 0.83 °C for day 1 (pre-exercise), and 32.79 +/- 1.42 °C for day 2 (24 hours post-exercise), and 33.17 +/- 0.95 for day 3 (48 hours post-exercise). This difference in skin temperature over the 3 days was not significant (ANOVA p = 0.38).

The results of the pain readings from the VAS are shown in figure 2. As seen in figure 2, the reported pain had a dramatic increase on days 2 and 3. Pain levels of the exercised muscle increased from 3.6 +/- 6.1 on day 1, to 36.3 +/- 22.8 on day 2, and 37.5 +/- 25.3 on day 3. This increase from day 1 was significant (ANOVA p < 0.01).

The results of the myoglobin concentration levels are shown in figure 3. As seen in this figure, there was hardly any change between the 2 myoglobin concentrations on day 1 (pre, & 30 minutes post exercise). But on day 3, the increase in myoglobin was very large. This increase on day 3 was approximately 147 nanograms per milliliter (ng/mL) of blood when compared to the first 2 concentrations on day 1. Myoglobin

concentrations were 30.12 +/- 7.66 ng/mL at baseline, 31.66 +/- 11.89 ng/mL 30 minutes post exercise, and 178.96 +/- 249.51 ng/mL on day 3. This increase on day 3 was highly significant (ANOVA p < 0.01).

A correlation analysis was done between the skin temperatures obtained from the IR images, and the VAS soreness levels. It was found that there was a considerable correlation between the VAS readings on day 2, and the skin temperature measurement on day 2. This correlation was significant (r = 0.312, p < 0.05). However, there was no evident correlation between the VAS readings and the skin temperatures on day 3. This correlation was insignificant (r = 0.047, p = 0.77).

Figure 1. A representative graph of the differences in skin temperature in the exercised arms (Diamonds), and un-exercised arms (Squares) of the 41 subjects over the 3 day time period.
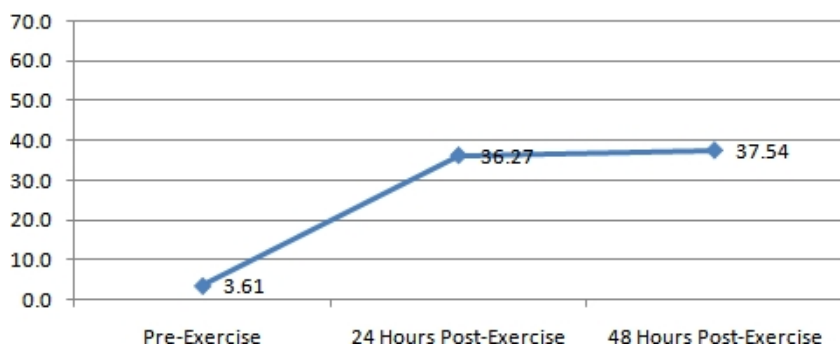

Figure 2. A representative graph of the differences in perceived muscle soreness measured with the VAS over the 3 day time period for all the 41 subjects.
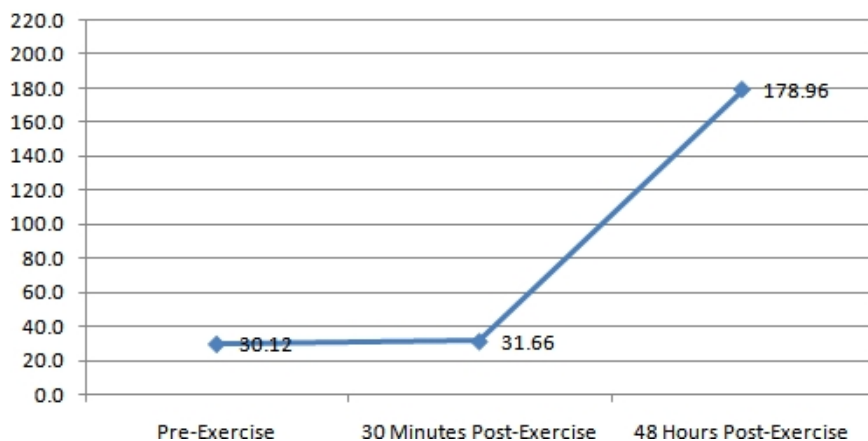

Figure 3. A representative graph of the differences in myoglobin concentrations for all the 41 subjects over the 3 time periods.
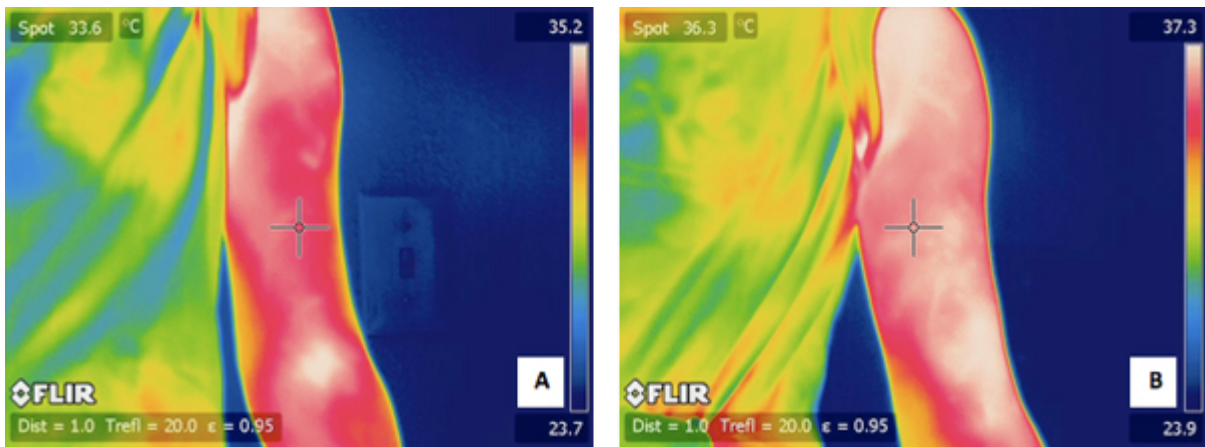
Figure 4. A) a typical IR image of a subject's **exercised** arm before the exercise. B) an IR image of the same subjects arm 24 hours after the exercise.
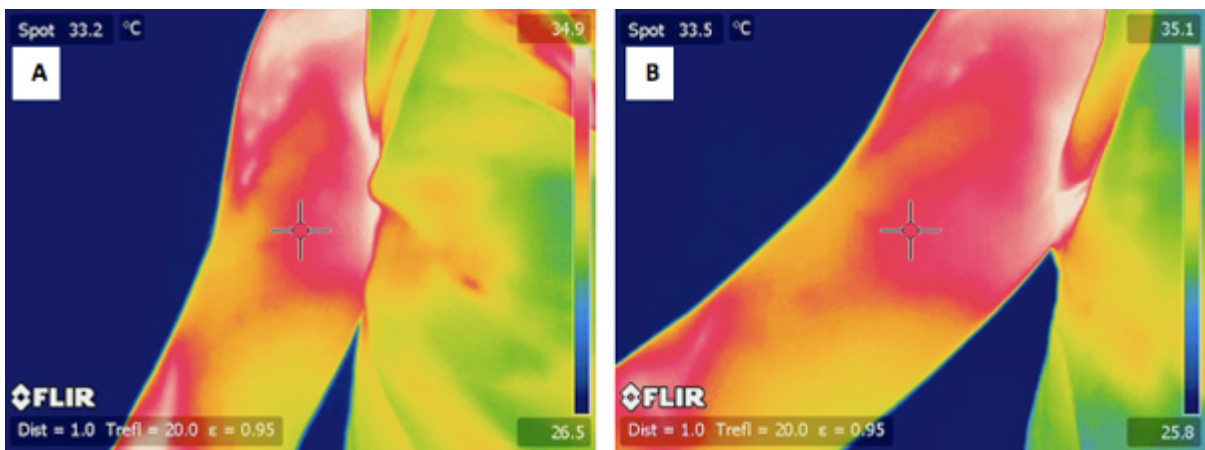

Figure 5. A) a typical IR image of a subject's **un-exercised** arm before the exercise. B) an IR image of the same subjects arm 24 hours after the exercise.
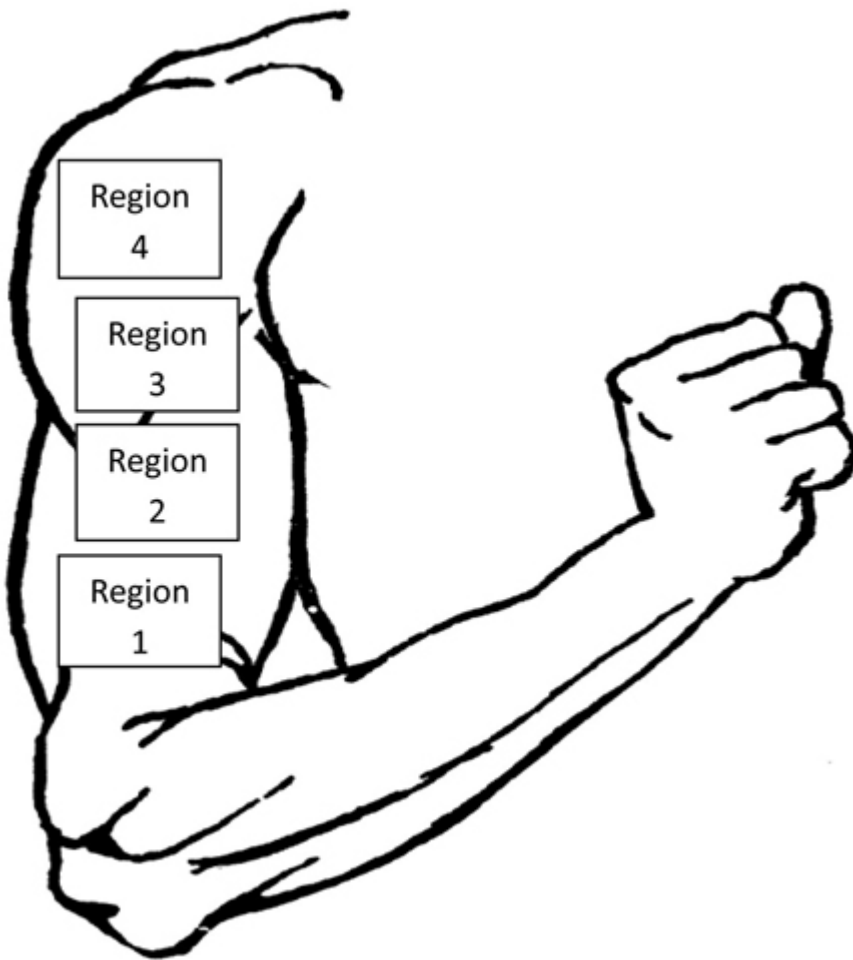
Figure 6. An illustration of the 4 regions of interest for analyzing the thermal image of the arm.
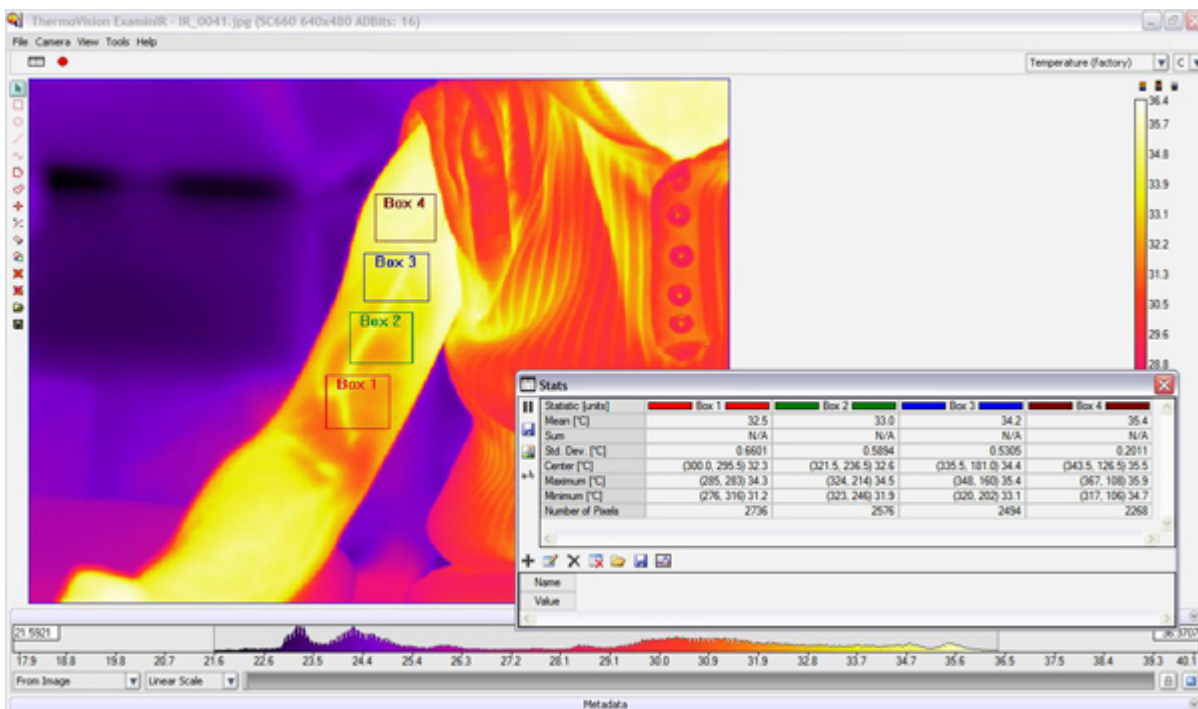

Figure 7. Software interface for the "ThermoVision ExaminIR" showing the 4 boxes of interest on an IR image of an exercised arm. Also shown are the statistical interpretations for each box.

Figure 8. The IR thermal camera used for this investigation (FLIR 660).
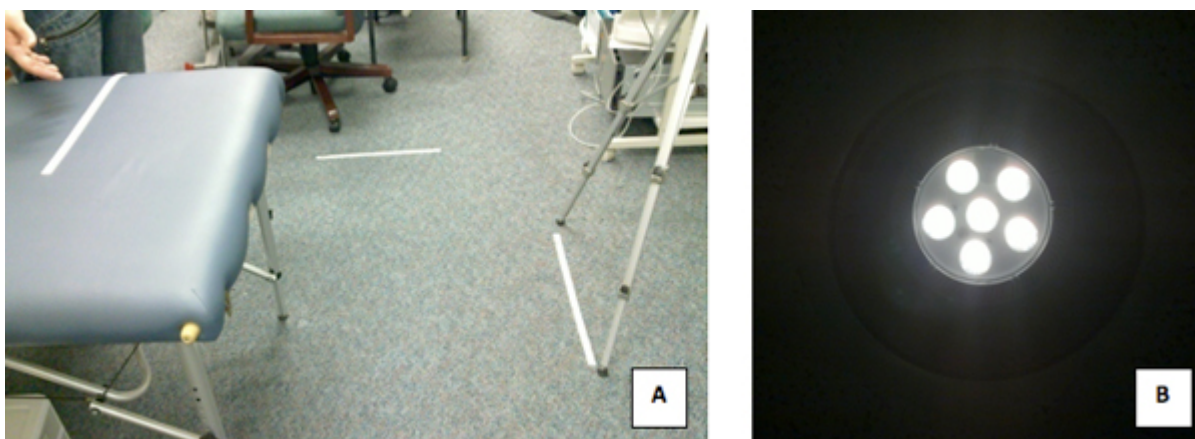

Figure 9. A) The Setup of the IR Camera 1 meter away from the subjects arm. B) The LED lights used in the lab where the images were taken.
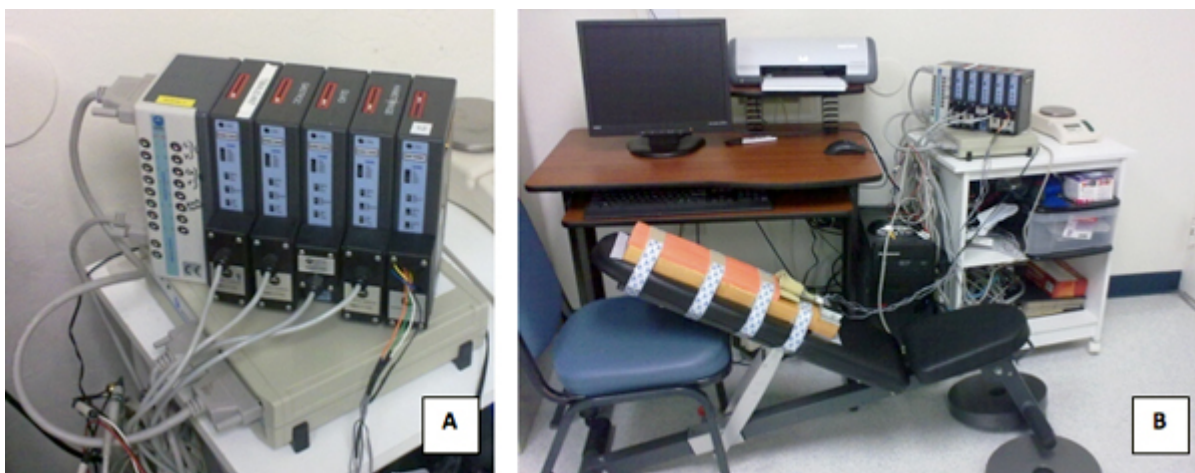

Figure 10. A) The BioPac Modules used for measuring the muscle strength. B) The strain gauge device fixed to a 45° angled bench and hooked to the BioPac system.

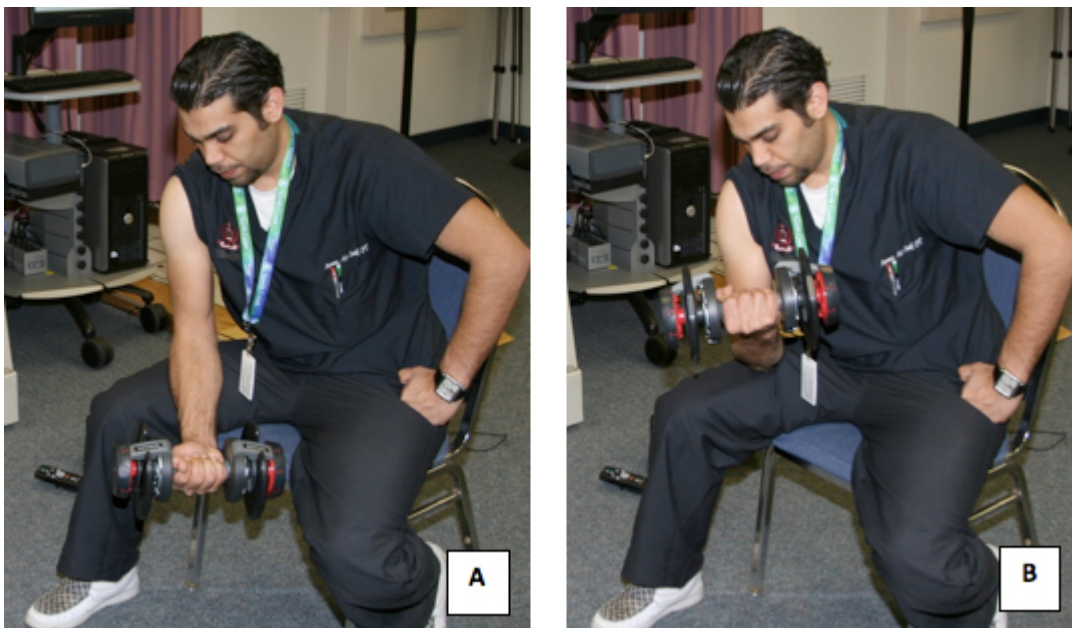**Figure 11.** A typical subject exerting force on the strain gauge device.

Figure 12. A subject undergoing the exercise protocol for inducing the muscle soreness.

Discussion

The primary purpose of this investigation was to assess the usefulness of thermal IR imaging in detecting and measuring muscle soreness after strenuous exercise, and our results suggest that IR imaging could be a valid technique for detecting DOMS, especially within the first 24 hours of exercising. This is not surprising, as Pennes[18] provided a very detailed model of heat flow from muscle to skin in limbs. This model predicts that heat in deeper tissues such as muscles can be dissipated into blood and into the skin through conductive heat exchange. When muscles exercise, obviously, tremendous heat is developed in the muscle due to frictional forces of the muscle fibers and because of the increased metabolism. Increased blood flows to the muscle would also contribute to the increased heat in the muscle after exercising. Because muscle is a shell tissue, the temperature is usually 32 to 33 °C, however when blood flow is increased to the exercised muscle it approaches the temperature of the core tissues which is 37°C [18,19]. This increased blood flow should go back to normal within a couple of hours after the exercise termination. But when temperatures are still elevated at 24 hours post exercise, this shows that damage has happened to the exercised muscle. This damage in the muscle causes additional heat transfer from the muscle to the overlying skin, which causes a detectable hot spot under the skin.

IR imaging has been used to detect and diagnose many diseases[17,19-24]. Changes in the human body's temperatures have always been indicators of dysfunction, where increased heat is mainly associated with some sort of inflammation or infection[17]. Thus, the elevated skin temperatures found 24 hours post exercise in all subjects is possibly the result of higher blood flows in muscle due to inflammation, and tissue damage repair [2]. Also, no noticeable increases in the skin temperature of the un-exercised arm occurred during the 3 days of the study. Therefore, if muscle blood flow remained elevated in the exercised arm, the warmer blood would keep the muscle warm and hence the overlying skin would stay warm. As a result, breast tumors in women and skin cancer can be easily detected by IR imaging because of the increased blood flows to the affected lesion site[20,21].

The elevated soreness levels (VAS) on day 2 and 3, and the increased myoglobin concentrations on day 3 are both indicators of DOMS. This shows that the subjects did get sore after the exercise session. As was seen in the results, there was a relationship between the increased skin temperatures on day 2, and the increased soreness levels on that same day. Myoglobin concentrations were still elevated on day 3, while skin temperatures were returning back to normal. This delayed release of myoglobin into the blood, could be due to the muscles slower response to inflammation and damage that occurs in the muscle fibers after exercise [25,26].

However, 3 to 5 days later, there can still be minor tissue repair and reconstruction, even though the blood flow maybe close to normal. That's why on the 3rd day we did not see a correlation between skin temperature and soreness levels, because the damage was already done. Therefore, we believe that this is predictive of soreness, because it shows that if you get sustained 24 hours increase in tissue blood flow, then you know that you've got damage to the tissue. This damage was verified by the VAS readings, and the myoglobin concentrations in the blood. Thus, the higher the skin temperature readings 24 hours post exercise, the sorer the subject would be later on.

Hence, IR thermal imaging would be of great value in detecting DOMS in its early stages. It would also be an interesting, and painless way of looking at muscles that have been exercised and are sore, hours after the exercise is over. In a sports setting, this early detection of DOMS could help in lowering the incidence of injuries from over-exercising sore muscles on days following the initial exercise.

Disclosures

No conflicts of interests declared.

Acknowledgements

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