ABSTRACT

Purpose: Field measurement of core temperature typically requires rectal or other invasive, expensive core temperature methods. Infrared (IR) thermography uses a handheld camera to measure surface temperature at discrete locations. We attempted to validate IR thermography against core-temperature capsules for the tracking of core-temperature changes at rest, during exercise, and recovery.

Hypothesis: Infrared thermography is a noninvasive method to follow changes in core temperature during exercise.

Materials and methods: Twelve athletes swallowed an ingestible core-temperature (CorTemp) capsule 1-hour prior to exercise. Athletes refrained from drinking for 2 hours prior to or during the study. Temperatures were obtained using both the CorTemp capsule and IR thermography at 10-minute intervals for 30 minutes before exercise, during 30 minutes of moderate intensity aerobic exercise, and for 30 minutes of recovery. The temperatures were then averaged for each segment of data collection.

Study design: Prospective descriptive study.

Results: Infrared thermography results (rest = 34.7°C ± 0.49, exercise = 34.1°C ± 0.77, recovery = 34.6°C ± 0.46) were significantly lower than with the CorTemp capsules (rest = 37°C ± 0.55, exercise = 38.6°C ± 0.47, recovery = 37.7°C ± 0.47) throughout the data collection period. There were no significant correlations between the two measurement methods (rest = 0.22, exercise = 0.07, recovery = 0.59; all p > 0.05).

Conclusion: Infrared thermography is not a valid method to track core-temperature changes during exercise. In addition to IR thermography readings being consistently lower, temperature changes before, during, and after exercise showed wide and inconsistent variability.

Keywords: Core temperature, Heat illness, Infrared, Measurement, Thermography, Thermoregulation.

INTRODUCTION

In American high school athletics, heat stroke is the third most common cause of death behind cervical spine injuries and cardiac conditions.1 There are many factors that contribute to heat production and loss, including temperature, humidity, sun exposure, wind, fitness, age, equipment, body mass, and composition.

There are many devices currently used to measure core body temperature. Oral thermometer or tympanic measuring devices are commonly used but may not accurately determine the actual core temperature in exercising athletes.2 In recent years, numerous minimally invasive, easy to use temperature measurement devices have been developed to obtain core temperature readings. The CorTemp™ capsule, a swallowed thermistor, has been shown to be accurate, easy to use, and allows for easy repeat measurements.3 The capsule transmits temperature recordings wirelessly to a handheld data recorder and has been validated in previous studies.3,4

Infrared (IR) thermography is another technology that has been suggested as a way to measure body temperature. Infrared detects radiation in the IR range of the electromagnetic spectrum and then produces color images of that radiation. The amount of radiation emitted by an object increases with temperature and thermography visualizes variations in surface temperature. When viewed by a thermographic camera, varying temperatures are viewed as different colors and precise differences between small temperature changes can be detected. Infrared technology is not novel and has been used in the past for various uses, including surveillance in the military,5 search and rescue by police and firefighters, process control and energy audits in industry, breast cancer research, wound care follow-up, diagnosis of pneumothorax, and pediatric vascular malformations.6-10 Although not a direct measurement of core temperature, these surface temperature changes may mimic the changes found with other core measurement devices during exercise.

We hypothesized that IR thermography could be used as a noninvasive indirect method to follow changes in the
core temperatures of the exercising athlete. We undertook a validation study of IR thermography to determine if it could be used as an accurate, noninvasive measure of core body temperature change during exercise.

MATERIALS AND METHODS

The study sample included 12 recreational athletes (age 19–45) recruited from the local community via posted ads and word of mouth (9 males). Height ranged from 155 to 188 cm (average 175 cm) and weight ranged from 52 to 99 kg (average 76 kg). Inclusion criteria included the ability to swallow the telemetric capsule and being able to perform 30 minutes of continuous, moderate intensity aerobic exercise. Subjects were excluded if they could not swallow a capsule, had latex allergies (due to latex in capsule), were incapable of performing 30 minutes of continuous exercise, pregnant women, and those subjects less than 18 or older than 55 years. Prior to subject enrollment, our institutional review board approved this study and all subjects signed written consents prior to participation.

The subjects were asked not to consume any liquids or solids for 2 hours prior to participation in the study. Each subject swallowed one CorTemp™ capsule (HQ Inc.; Palmetto, Florida, USA) 1 hour prior to data collection. Core temperature was then measured telemetrically with a handheld recorder held at the patient’s chest. Infrared surface temperature was measured by a single technician using a Micron 7,800 IR camera (Infrared Systems; Reno, Nevada) from a position directly in front of the subject from a distance of 3 feet. Single shot pictures were taken at each measure time and recorded on the camera. Only the subject’s face was included in the measurement. Temperature was measured at 10-minute intervals beginning 30 minutes prior to exercise, continuing throughout 30 minutes of moderate intensity aerobic exercise, and during 30 minutes of passive recovery. The subjects self-selected an exercise intensity that was below lactate threshold and above a conversational pace. No fluids were consumed for 2 hours prior to the study, during, or after the exercise bout, or during the recovery period. All exercise was done in the temperature-controlled Student Recreation Center using self-chosen modes (treadmill, cycle ergometer, or rowing ergometer).

DATA ANALYSIS

Infrared recordings were transferred to a computer and analyzed individually. The IR maximum temperature (T-max) and IR temperature at the left medial canthus were recorded for each subject at each measurement point. The medial canthus is defined as the angle formed by the union of the upper and lower eyelids medially. Our temperature measurements were recorded just medial to that point at the base of the nose. Data were summarized using routine descriptive statistics. Differences by method and time were determined using a two-factor repeated measures analysis of variance. Results for the three distinct periods (rest, exercise, and recovery) were averaged and used as the unit of analysis. Pearson correlations were used to assess the relationship between the IR and CorTemp™ readings.

RESULTS

The measured temperatures for all three time periods are summarized in Tables 1, 2 and Graphs 1, 2. The IR temperatures were lower than the CorTemp™ measurements across all three measurement times. The average of the three preexercise temperature readings for the CorTemp™ capsule was 36.9°C, the average medial canthus temperature was 34.8°C (p < 0.05; r = 0.22, p = Not significant). The averaged results for IR during exercise
were significantly below the CorTemp™ (34°C vs. 38.5°C, respectively; p < 0.05; r = 0.07, p = Not significant). Finally, the averaged IR measured temperature for recovery was 34.6°C vs. 37.7°C for the CorTemp™ (p < 0.05; r = 0.59, p = Not significant).

The measured temperature changes from preexercise to the end of exercise for the CorTemp™ capsule increased by +1.7°C (±0.73). Using the IR method, the temperature for four subjects increased, while eight subjects showed a temperature drop during exercise (Graph 3). Overall, the IR method measured an average temperature change of 0.2°C (±0.6).

DISCUSSION

Early recognition of heat illness is made possible by quick and precise temperature measurements taken from exercising athletes. The measurement of core-temperature changes during exercise can have safety and performance issues for those athletes. Core temperature readings need to be accurate and precise to be useful in monitoring heat illness (Fig. 1). This study shows that using facial measurements via IR thermography are not accurate enough to be a useful measure of core body temperature changes in exercising athletes.

Ideal sites for core temperature measurements are convenient, unaffected by environmental factors, and accurately reflect the changes in core temperature that occur with exercise. The “gold standard” location to measure core temperature, which is accepted as accurately reflecting the hypothalamic temperature, is the blood temperature in the pulmonary artery.11 Esophageal temperature measurements taken at the level of the left atrium have also been shown to provide sensitive measurements in exercise studies.12 Both of these methods are impractical in the exercising athlete. Rectal temperature measurements are easier to perform, less invasive, and are much more widely used; however, they can be difficult to assess on the sideline during competition. Additionally, rectal temperatures in athletes have been shown to react slowly during exercise and are better used during steady state exercise.13

Infrared thermography uses cameras (Fig. 2) to detect radiation in the IR range of the electromagnetic spectrum and produces images of that radiation. The amount of radiation emitted by an object increases with temperature. Thermography allows easy identification of variations in object surface temperatures. This technology.
Infrared Thermography: Not a Valid Method to Track Changes in Core Temperature in Exercising Athletes


has been used in a variety of other applications and we hypothesized it might be a method to measure the change in core temperature accurately, reliably, and noninvasively.

The medial canthus was the site on the face we chose to track core temperature changes during exercise. We selected a location that would be available to measure in all athletes regardless of the equipment used. From the study by Zaproudina et al, the forehead showed a small side to side temperature difference and this was supported by Gatt and Sickles who showed a high degree of thermal symmetry in facial measurements. Although the face is subject to sweating and evaporative cooling, we hypothesized there would be limited evaporative cooling occurring at the medial canthus and that this may give us an accurate representative measure of core-temperature change. A prior study by Park and Tamur showed that both vapor pressure and evaporation rate changed very little at the forehead as ambient temperature. We found no prior studies that isolated the medial canthus as the measurement location; however, we believed that this area might give the most accurate reflection of changes in core temperature. In addition to the medial canthus, we also measured the T-max on the face in order to compare these values with each other and identify if there was a different more suitable site for these measurements. Due to the potential confounding data that may result from helmets, we did not elect to use the forehead directly for our measurements. Football is a sport where tracking heat illness would be important and we believe that the pressure from the forehead pads in football and other helmets may lead to erroneous results.

Other prior research has described the relationship between skin and core temperatures showing that the relationship between them is highly dependent on the individuals sweat rate, the amount of movement (convective heat transfer coefficient), and several climatic factors influencing evaporation. Additionally, skin temperature tends to level off when sweating starts, while core temperature keeps increasing.

Our data showed that 27% of the measured T-max readings were not from the medial canthus of the subjects. However, the difference in the values remained small across the entire test population as shown in Table 1. With the exception of subject 12 in which the medial canthus was never the T-max, nearly all of the other results were in line with our proposed hypothesis. Additionally, the differences in means between the T-max values and the values from the medial canthus were not statistically significant at any data point measured.

From prior thermography data, we presumed that our IR readings would be lower than “true” core temperature, but we intended to see if we could identify similar changes in the values when exercising compared with the CorTemp™ values. Our results showed that the IR readings were consistently lower than the CorTemp™ temperatures (Graphs 1 and 2), but they did not support the underlying hypotheses that the two measures would trend similarly with exercise (Graph 3). In this study, the IR temperature readings were unpredictable. Of the 12 postexercise values used, 4 changed in the positive direction (relative to preexercise values) and 8 in the negative in the IR group, whereas in the CorTemp™ group all 12 subjects showed an increase in core temperature as would be expected with sustained aerobic exercise.

There are many possible reasons why the two devices used in this project were not correlated. The IR temperature readings may have been affected by the evaporative cooling of the sweat on the subject’s faces as described earlier. Despite attempting to choose a suitable location for IR measurements, the face may not be the ideal location for IR measurements during exercise. Both the presence of sweat on the face and the ambient air temperature may have led to erroneously low-temperature measurements in the exercising athlete. Additionally, if there were heating and cooling vents not identified above the exercising athletes, this air movement may have created a cooling effect on the face and thus affected the IR measurements. Another confounder might be the different body compositions of the athletes. Frim et al showed that changes in surface temperature may be affected by skinfold thickness. Precisely how body fat differences affect the body’s core temp readings is not clear. We have observed, in our unpublished data, a difference in core temperature measurements in athletes with varying body mass indices depending on the ambient air temperature where larger athletes in air temperatures above 92°F (33.3°C) had increased core temperature compared with those with a lower body mass index.

*Fig. 2: Thermography camera*
LIMITATIONS

The primary limitation of this study was the subjective selection of exercise intensity. During the exercise portion of the study, we allowed subjects to exercise at an intensity described as moderate; however, there was no monitoring used to determine what intensity this was or how well they stayed within this range. Additionally, as we only measured IR recording from the face, there are possibly other areas of the body that may prove to be a more accurate representation of core temperature change as measured by thermography during exercise.

CONCLUSION

Infrared thermography, measured at the medial canthus, had poor concurrent validity with intestinal temperature using ingested thermistors (CorTemp™) during exercise and should not be used to follow changes in core temperature.

ACKNOWLEDGMENTS

The authors acknowledge Micron for donating the IR camera for research purposes and to Donald T. Kirkendall for his help in preparing the manuscript.

REFERENCES