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Brief Communication

Effect of air temperature on the rectal temperature gradient at rest and during exercise

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Abstract: The purpose of the current study was to determine the effect of air temperature on the rectal temperature gradient at rest and during exercise. It was hypothesized that the rectal temperature gradient would be exacerbated in cold environments and attenuated in warm environments both at rest and during exercise. Each subject completed three exercise bouts on a motor driven treadmill at approximately 55% of their previously determined maximal oxygen uptake. Three different air temperatures (10, 22, 39°C) were used for the exercise bouts. Rectal temperature was measured at rest and every 5 min during each exercise bout using 4 temperature sensors affixed at 4, 7, 10 and 13 cm past the anal sphincter. Readings obtained from the 4-cm depth were significantly ($p<0.05$) lower than those obtained at deeper insertion depths both at rest and during exercise for all three air temperatures. Furthermore, the results showed that the rectal temperature gradient was exacerbated in cold environments and attenuated in warm environments both at rest and during exercise.

Keywords: Thermoregulation, core temperature, physical activity

Introduction

Core body temperature is one of the most commonly measured parameters in the medical and physiological literature. Although a number of anatomical sites (e.g., rectum, axilla, esophagus, oral) can be used to measure core body temperature, it has been shown that rectal temperature (T_{re}) is higher, more reliable, more stable, and less prone to measurement error [1, 2]. In addition, T_{re} is generally considered to be independent of ambient air temperature [3-6].

However, a peculiarity of T_{re} is that a significant temperature gradient exists along the rectum [7-9]. For example, Lee et al [1] have recently reported that in healthy subjects in a thermoneutral environment (25°C) both resting and exercise T_{re} measured at a depth of 4 cm past the anal sphincter was significantly lower (0.3-0.5°C) than that measured at 13 cm. Although the exact cause for the rectal temperature gradient is not known, it is believed that readings taken from sensors placed shallower than 10 cm past the anal sphincter are not completely independent of the ambient air temperature [10]. If true, then it would be reasonable to hypothesize that the rectal temperature gradient would be exacerbated in cold environments and attenuated in warm environments. Unfortunately, most of the previous studies were conducted in temperate conditions and thus cannot test the above hypothesis. Therefore, the purpose of the current study was to determine the effect of air temperature on the rectal temperature gradient at rest and during exercise.

Methods

The subjects for this study were 7 healthy volunteers (2 males, 5 females). They had a mean (± SD) age, height, and weight of 32 ± 14 years, 168 ± 8 cm, and 67.7 ± 12.0 kg, respectively. The study was approved by the San Diego State University Institutional Review Board. All data collection on the female subjects was conducted during the follicular phase of their menstrual cycle, which was determined using a self-reported, menstrual cycle history.

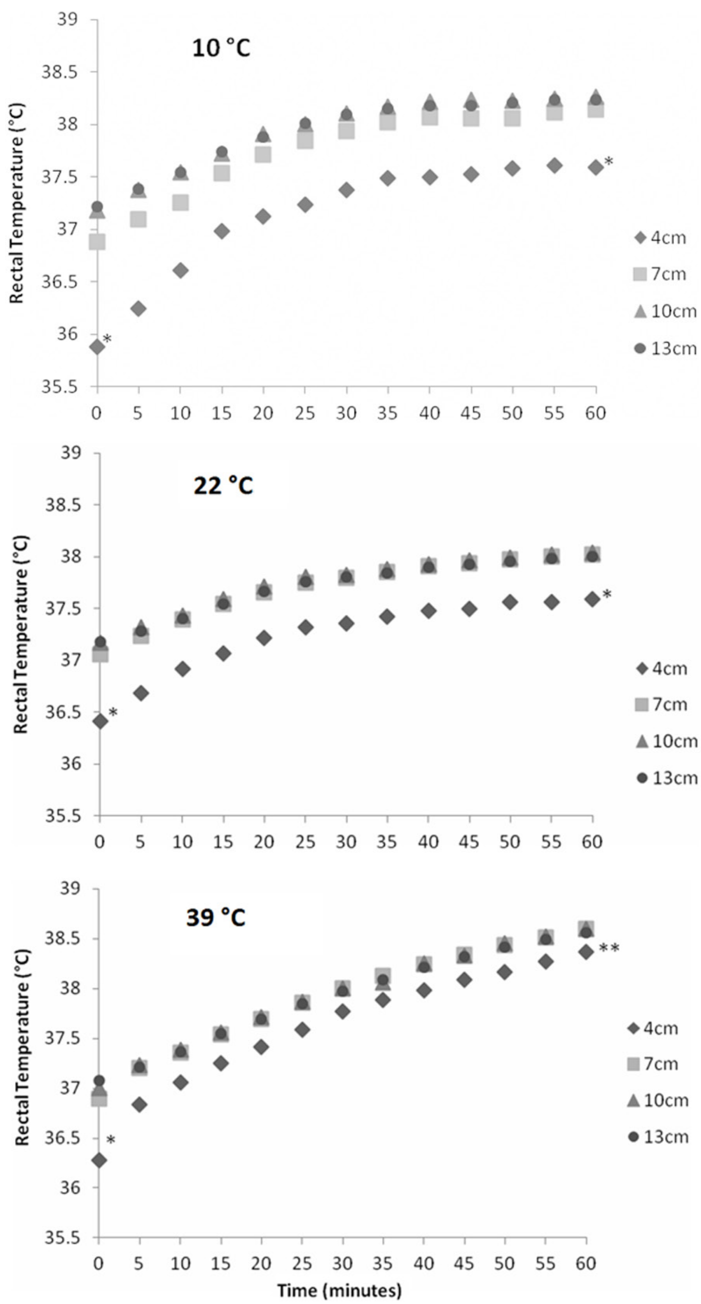

Figure 1. The mean rectal temperature during rest and every 5 min of exercise at all 4 measured depths (4, 7, 10, and 13 cm). The top panel was collected at 10°C, the middle panel at 22°C, and the bottom panel at 39°C. *indicated the 4 cm data was significantly ($p<0.05$) different than the other 3 depths at that time point. **indicated the 4 cm data was significantly ($p<0.05$) different that the 10 cm data at that time point.

Each subject completed three exercise bouts on separate days on a motor driven treadmill at 50-60% of their previously determined maximal oxygen uptake. This was verified by measuring oxygen uptake for each subject at approximately min 15 of exercise. The speed and grade remained the same for each subject for all three exercise bouts. Each exercise bout was 60 min in duration and subjects wore shorts and a t-shirt. Three different air temperatures (10, 22, 39°C) were used for the exercise bouts and controlled via an environmental chamber. The order of the three different air temperatures was randomized for each subject.

Prior to each exercise bout a urine sample was collected from each subject. To ensure that the subjects were not dehydrated, they had to have a urine specific gravity of <1.020. Additionally water was allowed ad libitum during each trial. T_{re} was measured at rest and every 5 min during each exercise bout using a multi-sensor rectal probe. The probe was approximately 5 mm in diameter, semi-rigid to prevent probe curling within the rectum during insertion [9] and had four temperature sensors affixed at 4, 7, 10 and 13 cm. A raised bead of silicone was place on the exterior of the probe to ensure that it was placed at the proper depth into the rectum and that it remained in position during the 60 min exercise bout. The four sensor temperature probe was calibrated against a mercury thermometer.

The resting and end-exercise T_{re} for the three different air temperatures were compared using a repeated measures analysis of variance and Tukey's post-hoc comparisons. After reviewing the previous work of Lee et al [1] on the topic, large variability in the data was expected, thus, significance was set at the $p<0.10$.

Results

The mean temperature and relative humidity for the hot, temperate, and cold trials were 39°C and 40%, 22°C and 50%, and 10°C and 42%, respectively. The mean exercise intensity for the three exercise bouts was 55 ± 8% of

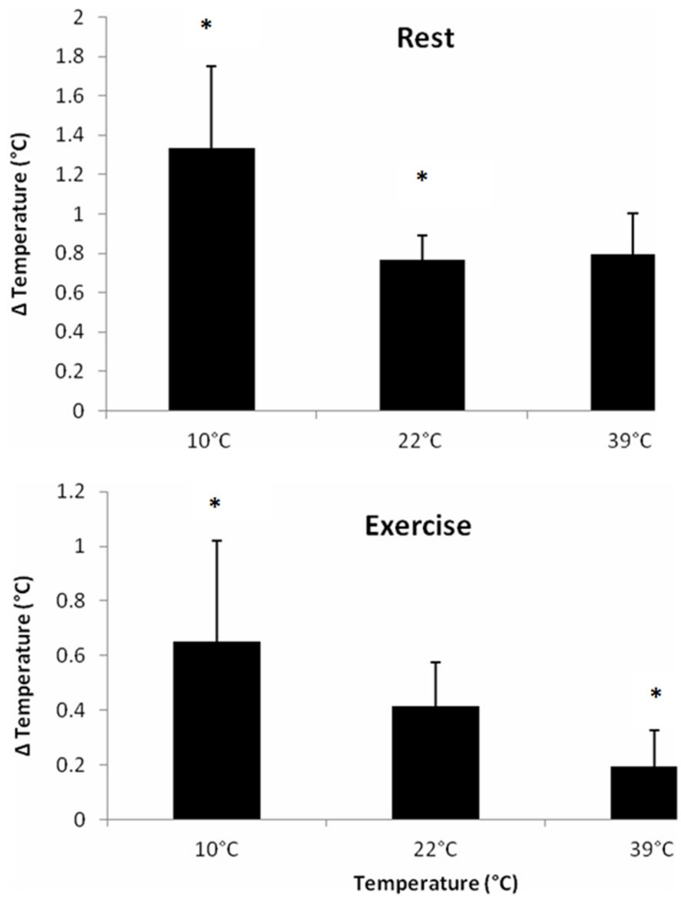

Figure 2. The mean (± SE) Δ core temperature, which was determined as the difference between the readings obtained from the 13 cm and 4 cm probes, during the 3 different environment conditions. The top panel was obtained at rest and the bottom panel was obtained at the end of 60 min of exercise. *indicates the data were significantly ($p<0.10$) different from each other.

maximal oxygen uptake. **Figure 1** shows the mean rectal temperature during rest and every 5 min of exercise at all four measured depths (4, 7, 10, and 13 cm). The top panel was collected at 10°C, the middle panel at 22°C, and the bottom panel at 39°C. Readings obtained from the 4-cm depth were significantly ($p<0.05$) lower than those obtained at deeper insertion depths both at rest and during exercise for all three air temperatures. **Figure 2** shows the mean (± SE) Δ rectal temperature, which was determined as the difference between the readings obtained from the 13 cm and 4 cm probes, during the three different environment conditions. Readings shown on the top panel were obtained at rest and those in the bottom panel were obtained at the end of 60 min of exercise. The results showed that at rest the rectal temperature gradient was significantly larger in the 10°C trial compared to the 22°C condition. In addition, during exercise the mean Δ rectal temperature was significantly different between the 10 vs. 39°C trials.

Discussion

The results of the current study confirm the existence of a significant temperature gradient along the rectum; with shallower depths having significantly lower temperatures than deeper depths both at rest and during exercise. In the current study we found that in a temperate environment (i.e., 22°C), the mean resting T_{re} measured at 4 cm past the anal sphincter was significantly less than that measured at deeper depths (7, 10, and 13 cm) by 0.7°C. This agrees with the recent results of Lee et al [1] who reported that mean resting T_{re} measured 4 cm past the anal sphincter was 0.5°C less than that measured at a depth of 13 cm. In addition, both the current study and Lee et al [1] are in agreement that the rectal temperature gradient is reduced during exercise in a temperate environment. The cause for the reduced temperature gradient during exercise is that T_{re} measured at the 4 cm depth increases significantly faster during the initial stage of exercise (i.e., first 10 min) compared to deeper regions (**Figure 1**). Specifically, during the first 10 min of exercise the mean T_{re} recorded at 4 cm increased at a rate of 0.06°C per min for the three trials compared to 0.03°C for the 10 cm and 13 cm probes; or essentially twice as fast. Interestingly, the mean rate of rise for the 4 cm probe (0.06°C per min) in the current study is similar to that previously reported for the rate of rise in esophageal temperature during the initial stage of similar intensity (50-60% maximal oxygen uptake) sub-maximal exercise [11-13] and immediately following hot water immersion [14]. Such results suggest that measuring Δ rectal temperature at shallow insertion depths (e.g., 4 cm) during the initial stage of exercise may be a valid surrogate for Δ esophageal temperature. Clearly this important topic warrants further investigation, because if ultimately shown to be valid it would potentially address two current methodological concerns in the literature; namely the slow response time for T_{re} measured at deeper depths at the start of exercise [2, 6] and subject discomfort associated with esophageal probe insertion [15, 16].

No significant differences were found in T_{re} at rest or during exercise, between the 7, 10, and 13 cm probes. Such results support previous reports that have recommended temperature probe insertion depths of at least 7 cm to obtain valid readings [16]. Likewise the current results support previous findings that insertion depth greater than 7 cm is unnecessary [5]. Lastly, the current results, however, do not support previous studies that have recommend probe insertion depths of 4 cm or less [15, 17] for obtaining valid steady-state rectal temperature.

The most important new finding of the current study, as shown in **Figure 2**, was that cold ambient air temperature exacerbated the rectal temperature gradient at rest and during exercise while hot air temperature attenuated it only during exercise. As can be seen in **Figure 1**, air temperature had essentially no effect on readings obtained from probes inserted 10 and 13 cm. Thus, they were independent of air temperature, as previously reported in the literature [3-6].

However, the readings obtained from the 4 cm probe were significantly biased by air temperature, as evidenced by the fact that the mean resting T_{re} was 35.9°C, 36.4°C and 36.3°C in the 10, 22 and 39°C environments, respectively. It is well known that the rectum is well insulated and thus has a low heat loss to the environment [6, 8, 18]. The current results suggest that at rest there is greater heat loss at the shallower insertion depths in cold environments and thus the T_{re} at 4 cm is significantly lower than that recorded at deeper depths. Conversely, in hot environments, where the air temperature is greater than core temperature, there appears to be little effect on resting T_{re}, but during exercise the 4 cm reading is increased, approaching the values seen at deeper depths. Thus, the T_{re} gradient at rest and during exercise is exacerbated in cold environments and attenuated in warm environments; however different mechanisms appear to be at work. Specifically, cold air increases the T_{re} gradient by decreasing the temperature reading from the 4 cm probe while in hot environments, the T_{re} gradient is attenuated by rapidly increasing the temperature reading from the 4 cm probe during exercise. Such results suggest that cold air increases heat loss from the shallow regions of the rectum, probably due to lower insulation, while hot air reduces it.

In conclusion, the results of the current study confirm the existence of a significant T_{re} gradient up to 7 cm past the anal sphincter and that the magnitude of the T_{re} gradient is affected by air temperature and exercise. Such results may help to explain the rather large range in resting T_{re} that has been reported in the literature over the last 60 years [19]. They also stress the importance of standardizing probe insertion depth and the need to prevent probe slippage [1] during exercise. Lastly, the rapid rate of rise in ΔT_{re} seen during the start of exercise in shallow rectal probes mimics that seen for Δ esophageal temperature and certainly warrants further study.

Disclosure of conflict of interest

None.

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