

TISSUE TEMPERATURE PROFILE IN THE QUADRICEPS MUSCLE DURING BILATERAL ISOLATED KNEE EXTENSIONS

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INTRODUCTION

A number of studies have investigated the effect of thermal stress on the temperature profile of muscle tissue during rest and exercise. To our knowledge, Saltin, et al. (5) is the only study that measured intramuscular leg temperature following low to intense exercise (25 to 75% $\text{VO}_{2\text{max}}$) performed in a range of ambient temperatures (10 to 30°C). Although they graphically represented quadriceps muscle temperature changes during post-exercise rest, they did not specifically address the post-exercise period. Their data demonstrate that post-exercise esophageal and muscle temperatures decreased progressively during recovery to pre-exercise resting values within 10 to 15 min (except following intense exercise at 30°C).

In contrast, we have previously shown that esophageal temperature remains elevated by $\sim 0.5^\circ\text{C}$ for at least 65 min after exercise (6). It was subsequently shown that the quadriceps muscle temperature remained elevated 2.8°C above esophageal temperature for the duration of the 30-min recovery (3). The discrepancy in these data supports the need to further investigate the mechanism(s) of local tissue heat balance following different conditions of exercise.

More recently, evaluation of tissue temperature transients during thermal stress at rest under steady state (1) and transient (2) conditions have demonstrated the significant role of the convective heat transfer by the blood on local tissue heat balance. However, few studies have investigated the direct effect of local endogenous heat loads and the role of convective heat transfer by the blood on the thermal stability of tissue. We have recently demonstrated that single-knee extension produces an increase in the resting contralateral muscle temperature comparable to esophageal temperature suggesting that convective heat transfer by the blood to inactive tissue may significantly affect the rate of change in esophageal temperature (T_{es}) during and following exercise (4). As such, the following study was designed to evaluate the effect of localized endogenous heating on muscle tissue and core thermal stability following exercise.

METHOD

Subject Selection

Six males and 1 female participated in the study. They were physically active, although none engaged in daily or intensive training programs.

Instrumentation

T_{es} was monitored as an index of core temperature. Skin heat flux and temperature (T_{SKavg}) were measured from 12 sites by combined thermal flux transducer/thermistors and the area-weighted mean was calculated. Heart rate was monitored continuously. Oxygen consumption was measured continuously by an open-circuit method from measurements of expired minute volume and inspired and mixed-inspired gas concentrations sampled from a mixing box. Forearm blood flow was measured by laser-Doppler flowmetry.

Muscle temperature (T_{mu}) was measured by a multisensor temperature probe inserted into the vastus medialis (left thigh) under ultrasound guidance, such that the temperature sensors were located at ~10, 25 and 45 mm (i.e., T_{mu10} , T_{mu25} and T_{mu40}) from the femur and deep femoral artery. The implant site was about midway between, and medial to, a line joining the anterior superior iliac spine and the superior aspect of the center of the patella.

Experimental Protocol

Subjects were required to perform an incremental isotonic test on the KIN-COM isokinetic apparatus (angular velocity of 59 sec^{-1}) to determine their maximal oxygen consumption during bilateral-knee extension. The results of the test were used to establish the work level for the experimental trial.

Experimental trials were conducted in the morning. Following the insertion of the intramuscular probe, subjects rested in a semi-recumbent position for 60 min in an ambient condition of 22°C . During this period, the subject was instrumented appropriately and then remained seated for a minimum period of 30 min. Subjects then performed 15 min of bilateral-knee extensions against a dynamic resistance corresponding to 60% of maximal oxygen consumption. Exercise was followed by 60 min of seated rest.

Analysis of Results

Statistical analyses for T_{es} , T_{sk} and T_{SKavg} were performed by ANOVA for repeated measures to compare values for pre-exercise, end-exercise and at 10-min intervals during post-exercise recovery. Data are presented as means \pm SE.

RESULTS

Baseline T_{es} and T_{sk-avg} were $36.86 \pm 0.1^\circ\text{C}$ and $31.93 \pm 0.3^\circ\text{C}$, respectively. Resting muscle temperature was significantly lower than esophageal temperature (i.e., 36.56 ± 0.1 , 36.54 ± 0.1 and $36.28 \pm 0.1^\circ\text{C}$ for T_{mu10} , T_{mu25} and T_{mu40} , respectively) (Figure 1). Following the onset of exercise, T_{es} remained stable for the initial -5 min of exercise after which it increased at a rate of $0.05^\circ\text{C}\cdot\text{min}^{-1}$ that was significantly reduced in the final 5 min ($P < 0.05$). In contrast, T_{mu} increased at a rate

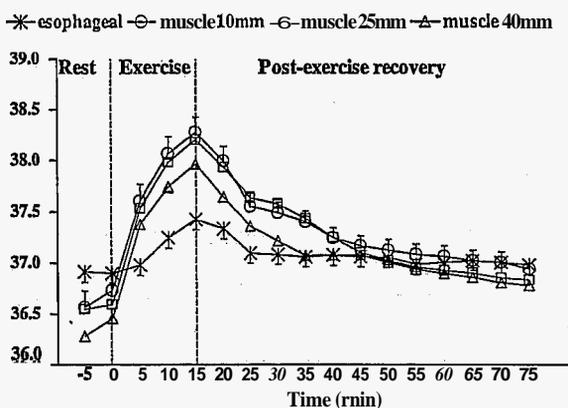


Figure 1. Mean (\pm SE) esophageal and muscle (non-exercising leg) temperatures during baseline resting, exercise and post exercise recovery ($n=6$)

of $0.21^{\circ}\text{C}\cdot\text{min}^{-1}$ during the initial 5 min and was subsequently reduced for the duration of exercise ($0.07^{\circ}\text{C}\cdot\text{min}^{-1}$). The decrease in the rate of T_{mu} increase paralleled the attenuation of T_{es} during the late stages of exercise. T_{SKavg} increased continuously following initiation of exercise to an end-exercise value of 32.92°C that was significantly elevated above baseline rest ($P < 0.05$). The increase in T_{SKavg} was paralleled by an increase in heat loss (Figure 2). Exercise resulted in a T_{es} increase of 0.51°C (37.42°C) above pre-exercise rest ($P < 0.05$). Muscle temperature increased by 1.71°C (38.27°C), 1.66°C (38.20°C) and 1.68°C (37.96°C) for $T_{\text{mu}10}$, $T_{\text{mu}25}$ and $T_{\text{mu}40}$, respectively ($P < 0.05$). T_{es} decreased rapidly ($-0.034^{\circ}\text{C}\cdot\text{min}^{-1}$) during the initial 10 min of recovery to an elevated value of 0.2°C above baseline rest. This was followed by a more gradual decrease of T_{es} ($-0.002^{\circ}\text{C}\cdot\text{min}^{-1}$) for the dura-

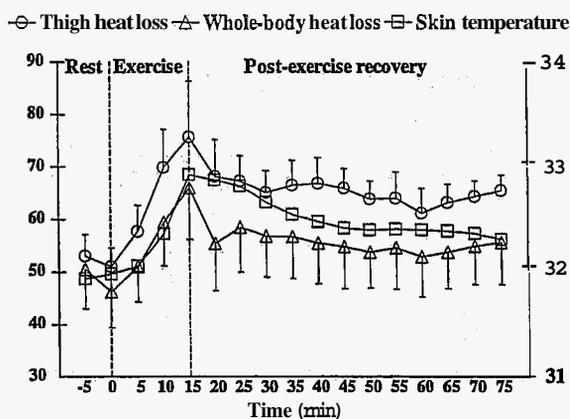


Figure 2. Mean (\pm SE) heat flux of the inactive thigh and whole body and average skin temperature during baseline rest, exercise and post-exercise resting ($n=6$)

tion of recovery. T_{mu} decreased rapidly during the initial 30 min of recovery ($-0.04^{\circ}\text{C}\cdot\text{min}^{-1}$) and was reduced for the duration of recovery ($-0.01^{\circ}\text{C}\cdot\text{min}^{-1}$). T_{SKavg} decreased to baseline resting values within -20 to 25 min of recovery.

CONCLUSION

These data demonstrate that the rate of tissue heat production, by bilateral-knee extensions, was sufficient to result in a significant increase in T_{es} above pre-exercise resting. Previous studies have shown that the rate of temperature increase in muscle during exercise is paralleled by a subsequent change in T_{es} (5). Of interest, however, is the post-exercise change in both esophageal and muscle rates of temperature change. In the present study, T_{es} achieved an elevated value, $\sim 0.2^{\circ}\text{C}$ above baseline rest at about the same time muscle temperature demonstrated a significant reduction in the rate of temperature decrease. The rate of heat loss (for the whole body and thigh) remained elevated above baseline resting for the full duration of recovery that paralleled the sustained elevation in muscle temperature. Despite employing a single muscle group (i.e., quadriceps) during exercise (as compared to treadmill running), we demonstrated a sustained post-exercise elevation of T_{es} $\sim 0.2^{\circ}\text{C}$ above baseline rest. Thus, more intense exercise would likely result in an increase in the magnitude of the post-exercise T_{es} . These results show that the transfer of residual heat from previously active musculature may contribute to the sustained elevation in post-exercise T_{es} .

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