

# THE EFFECT OF SINGLE LEG KNEE EXTENSIONS ON THE CONTRALATERAL QUADRICEPS MUSCLE TEMPERATURE

G.P. Kenny<sup>1</sup>, M.B. Ducharme<sup>3</sup>, M.L. Reardon<sup>2</sup>, W. Zaleski<sup>2</sup> and F.D. Reardon<sup>1</sup>

University of Ottawa, <sup>1</sup>Faculty of Health Sciences and <sup>2</sup>Faculty of Medicine, Ottawa, Canada, K1N 6N5 and <sup>3</sup>Defence and Civil Institute of Environmental Medicine, Toronto, Canada, M3M 3B9.



## INTRODUCTION

We have previously shown that esophageal temperature remains elevated by  $\sim 0.5^{\circ}\text{C}$  for at least 65 min after exercise (8). In a subsequent study, we demonstrated that successive exercise/recovery cycles performed at progressively increasing pre-exercise esophageal temperature levels resulted in further and parallel increases of the esophageal temperature threshold for cutaneous vasodilation during exercise and the post-exercise elevation in esophageal temperature (4).

In recent studies, the exercise-related effect on the post-exercise threshold of cold (i.e., vasoconstriction and shivering) (5) and warm (i.e., cutaneous vasodilation and sweating) (6) thermoregulatory responses were evaluated. Results indicated that exercise exerts a residual effect on thermal responses by increasing ( $\sim 0.3$  to  $0.5^{\circ}\text{C}$ ) the post-exercise resting threshold for cold and warm thermal responses. This residual effect is not a result of the exercise-induced elevation of whole body heat content (3), but most likely due to exercise-related factors such as cardiovascular (either central or peripheral), metabolic, endocrine or neurochemical (i.e., interleukin-1,  $\alpha$ -interferon, dopamine, etc.) changes during exercise that alter hypothalamic temperature regulation (7).

However, recent evidence favors a baroreceptor-mediated influence, in that a post-exercise hypotensive effect has been observed following acute bouts of exercise likely due to a persisting peripheral tissue vasodilation (1). It has been suggested that the resultant peripheral vasodilation following exercise may cause a pooling of the warmed blood, thus entrapping the residual heat of muscle, thereby temporarily increasing local tissue heat content. This may result in a time-dependent transfer of the residual heat of muscle to the core.

It has been demonstrated that local tissue heat content is mainly determined by convective heat transfer with blood (2). Therefore, in the absence of an increased heat loss response (i.e., cutaneous vasodilation and sweating) (5,6), core temperature would remain elevated as long as the heat content of muscle remains higher than that of the core and/or the post-exercise hypotensive effect is removed. This study was designed to evaluate the role of nonactive tissue in the retention and dissipation of heat during and following intense isolated muscle activity.

## METHODS

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

**Instrumentation.** Esophageal temperature ( $T_{es}$ ) 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 determined 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 of the non-exercising leg was measured by a thermocouple temperature probe inserted into the vastus medialis under ultrasound guidance. 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 to determine their maximal oxygen consumption for one-legged knee extension. The results of the test were used to establish the work level for the experimental trial.

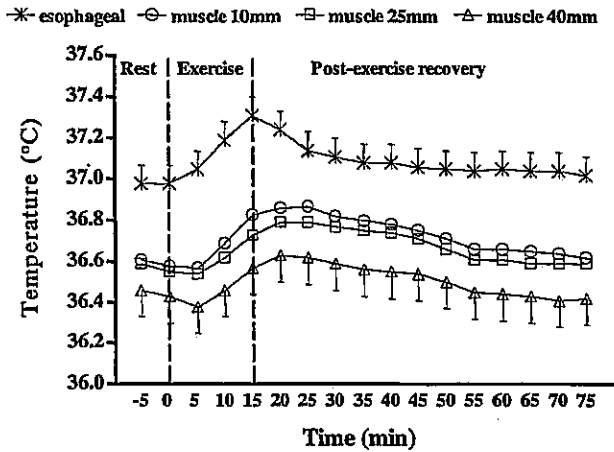
Experimental trials were conducted in the morning. Following the insertion of the intramuscular probe (i.e., in the non-exercising leg), subjects rested in a semi-recumbent position for 60 min in an ambient condition of 22°C. During this period, the subject was instrumented appropriately and then remained seated for a minimum period of 30 min. Subjects then performed 15 min of one-legged right 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  $T_{es}$ ,  $T_{SKavg}$  and  $T_{mu}$  were performed by ANOVA for repeated measures to compare values for baseline (average of final 5 min), end-exercise and at 10-min intervals post-exercise. Data are presented as means  $\pm$  SE.

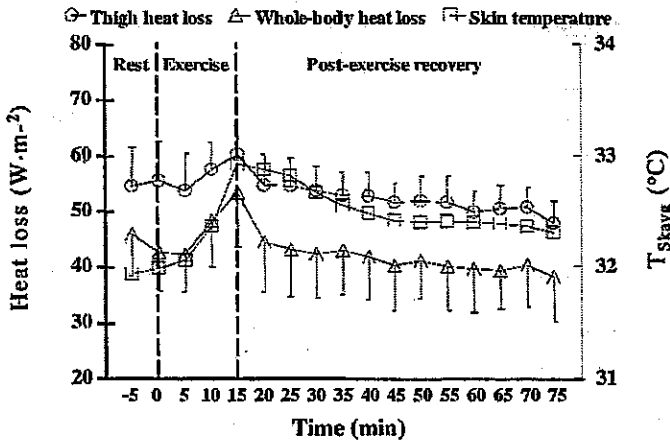
## RESULTS

Baseline  $T_{es}$  and  $T_{SKavg}$  were  $37.03 \pm 0.1$  °C and  $31.81 \pm 0.3$  °C respectively. Resting muscle temperature was significantly lower than esophageal temperature (i.e.,  $36.60 \pm 0.1$ ,  $36.58 \pm 0.1$  and  $36.45 \pm 0.1$  °C for  $T_{mu10}$ ,  $T_{mu25}$  and  $T_{mu40}$ , respectively) (Figure 1). Following the onset of exercise, both  $T_{es}$  and  $T_{mu}$  increased for the duration of exercise.  $T_{SKavg}$  demonstrated a slight decrease at the onset of exercise followed by a gradual increase, ~5 min into exercise, to an end-of-exercise value of 32.18°C (N.S.). The increase in  $T_{SKavg}$  was paralleled by an increase in the rate of heat loss (Figure 2).

Exercise resulted in a  $T_{es}$  and  $T_{SKavg}$  increase of 0.27°C and 0.37°C, respectively, above pre-exercise rest ( $P < 0.05$ ). Muscle temperature ( $T_{mu}$ ) increased



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



**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 ( $n = 6$ ).

0.22, 0.14 and 0.11°C for  $T_{mu10}$ ,  $T_{mu25}$  and  $T_{mu40}$ , respectively ( $P < 0.05$ ).  $T_{es}$  continued to increase for  $\sim 2$  min following cessation of exercise after which  $T_{es}$  decrease to baseline values within  $\sim 20$  min. In contrast,  $T_{mu}$  continued to increase for  $\sim 10$  min post-exercise reaching a peak value of  $36.86 \pm 0.1$ ,  $36.78 \pm 0.1$  and  $36.62 \pm 0.2$ °C for  $T_{mu10}$ ,  $T_{mu25}$  and  $T_{mu40}$ , respectively ( $P < 0.05$ ). While  $T_{es}$  decreased to baseline values within  $\sim 20$  min of end-exercise,  $T_{mu}$  reached pre-exercise resting values following  $\sim 40$  min of recovery.

## CONCLUSION

These data show that the rate of tissue heat production of the active muscle was sufficient to result in a significant elevation of esophageal temperature and a subsequent increase in the contralateral (i.e., inactive leg) muscle temperature. Although muscle heat loss, of the inactive leg, increases above resting during mid-exercise, it actually decreased to resting values before peak muscle temperature was reached (i.e., at ~10 min of post-exercise rest). Our results may support the importance of convective heat transfer by blood to inactive muscle tissue in reducing the rate of core temperature increase during exercise. In addition, the sustained increase in muscle temperature (i.e., inactive leg) during the early stages of recovery, in contrast to the decrease of esophageal temperature and rate of heat loss, demonstrates the potential role of inactive muscle tissue as a heat sink during recovery. Although the transfer of heat to the cooler tissue regions may act as a heat sink during exercise, thereby reducing the thermal stress, it results in a significant residual heat load during subsequent recovery. This may in fact increase recovery time required to re-establish normal resting temperatures.

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Support: Natural Sciences and Engineering Research Council of Canada and University of Ottawa, Faculty of Health Sciences Research Fund.