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SHORT COMMUNICATION

Dragan Brajkovic · Michel B. Ducharme
Paul Webb · Frank D. Reardon · Glen P. Kenny

Insulation disks on the skin to estimate muscle temperature

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Abstract This study examined the use of insulation disks placed on the skin to estimate muscle temperature in resting subjects exposed to a thermoneutral (28°C) ambient environment. The working hypothesis was that the skin temperature under each insulation disk would increase to a value corresponding to a specific muscle temperature measured by a control probe at 0.8 ± 0.2, 1.3 ± 0.2, 1.8 ± 0.2, 2.3 ± 0.2, and 2.8 ± 0.2 cm below the skin surface. Eight subjects sat for 120 min while lateral thigh skin temperatures and *vastus lateralis* muscle temperature were directly measured. Vastus lateralis temperature was estimated non-invasively using two 5 cm diameter foam neoprene disks which were placed on top of the skin temperature probes (from time 60 to 120 min) located at 15.3 and 26.3 cm superior to the patella. The disks at the two locations were 3.2 and 4.8 mm thick, respectively. The placement of the 3.2- and 4.8-mm disks on the thigh for a minimum of 15 and 20 min, respectively, resulted in an increase in skin temperature under the disks which corresponded to the lateral thigh muscle temperature measured directly and invasively at 0.8 ± 0.2 and 1.3 ± 0.2 cm, respectively, below the skin.

Keywords Non-invasive temperature measurement · Thigh temperature

D. Brajkovic (✉) · M. B. Ducharme
Human Protection and Performance Group,
Defence Research and Development Canada—Toronto,
1133 Sheppard Avenue West, M3M 3B9,
Toronto, Ontario, Canada
E-mail: dragan.brajkovic@drdc-rddc.gc.ca
Tel.: +1-416-6352000
Fax: +1-416-6352132

F. D. Reardon · G. P. Kenny · M. B. Ducharme
School of Human Kinetics, Laboratory for Human Bioenergetics and Environmental Physiology Research,
University of Ottawa, K1N 6N5, Ontario, Canada

P. Webb
370 Orton Road, Yellow Springs, OH, 45387 USA

Introduction

In the past, the zero-heat-flow (ZHF) method has been used to estimate bicep muscle temperature (Togawa et al. 1976). The ZHF probe placed on the surface of the bicep closely tracked (0.1 ± 0.08°C lower on average) the timeline response of intramuscular temperature.

However, a more recent study (Brajkovic and Ducharme 2005) found that the ZHF probe does not provide a good index of thigh muscle temperature up to 2 cm below the skin surface because the probe heats the muscle tissue in the process of estimating muscle temperature. They speculated that the ZHF probe may provide a better index of the muscle temperature near the limb core as opposed to more superficial or intermediate muscle temperatures.

The present study examined the effect of using insulated skin temperature to estimate muscle temperature. This was done by measuring thigh skin temperature under a passively insulated disk placed directly on the thigh. The skin temperature underneath the insulated disk was used as an index of the actual thigh muscle temperature. Taylor et al. (1998) recently found that measurements of insulated skin temperatures on the forehead or spinous process (T2–T4) provided good indices of esophageal temperature ($r = 0.86 - 0.94$), across an ambient temperature range of 25–40°C, during intermittent exercise in clothed subjects. Dollberg et al. (2000) also found that insulated skin temperature may be applied to continuously and non-invasively monitor core temperature in infants. Unlike these two studies which attempted to estimate core temperature, the goal of the present study was to use insulated skin temperature to estimate muscle temperature within a few centimeters of the surface of the skin. In addition, unlike the Togawa et al. (1976) study, the present study involved the use of a control skin temperature probe attached next to the insulation disk.

Temperature probes which measured thigh skin temperature were covered by a passive insulation disk and were compared to an invasive multicouple probe (uncovered control probe) which directly measured thigh muscle temperature.

Our working hypothesis was that the skin under the insulation disk would increase to a value corresponding to a specific muscle temperature measured by the control probe. Therefore, the temperature of the insulated skin alone could be used as an indicator of the muscle temperature at a specific depth below the skin.

Methods

Subjects

Eight male subjects with the following characteristics were recruited (mean ± SD): age 30.5 ± 5.7 years, height 177 ± 0.03 cm, weight 80.4 ± 14.0 kg, body surface area 1.97 ± 0.14 m^2, body fat 13.7 ± 3.4% (see Brajkovic and Ducharme 2005 for method), and lateral thigh skin and subcutaneous fat thickness of 4.9 ± 1.4 mm. Skinfold measurements of the lateral thigh were done 15 cm superior to the patella using skinfold calipers. Thigh circumferences at 15, 20.5, and 26 cm superior to the patella were 53 ± 3, 57 ± 3, and 58 ± 3 cm, respectively.

All subjects were informed of the experimental protocol before being asked for their written consent. The experimental protocol was approved by the DRDC Toronto Human Research Ethics Committee.

Experimental protocol

The subject arrived to the laboratory at 08:00 h and lay down on a stretcher. A sterile control multicouple muscle temperature probe (CMTP) (Ducharme and Frim 1988) was inserted into the *vastus lateralis* muscle to a depth of 2.6–3.0 cm at a distance of 20.5 cm superior to the top of the patella (see Fig. 1). To insert the CMTP, the procedure described in a previous study (Brajkovic and Ducharme 2005) was used, with the exception of the depth of the probe insertion. The actual depth of the CMTP was determined after each session by carefully withdrawing the CMTP with two fingers (which were flush against the skin of the thigh) and then measuring the distance between the tip of the probe and the tip of the fingers.

The objective was to insert the probe to a depth of 2.5 cm below the skin, however, in all cases the probe was unintentionally pushed slightly deeper (range of 2.6–3.0 cm) when Tegaderm™ surgical tape (3M Medical, St. Paul, MN, USA) was applied over the CMTP to hold it in place against the thigh. Therefore, the thermocouple junctions actually measured tissue temperature 0.8 ± 0.2, 1.3 ± 0.2, 1.8 ± 0.2, 2.3 ± 0.2, and 2.8 ± 0.2 cm below skin surface.

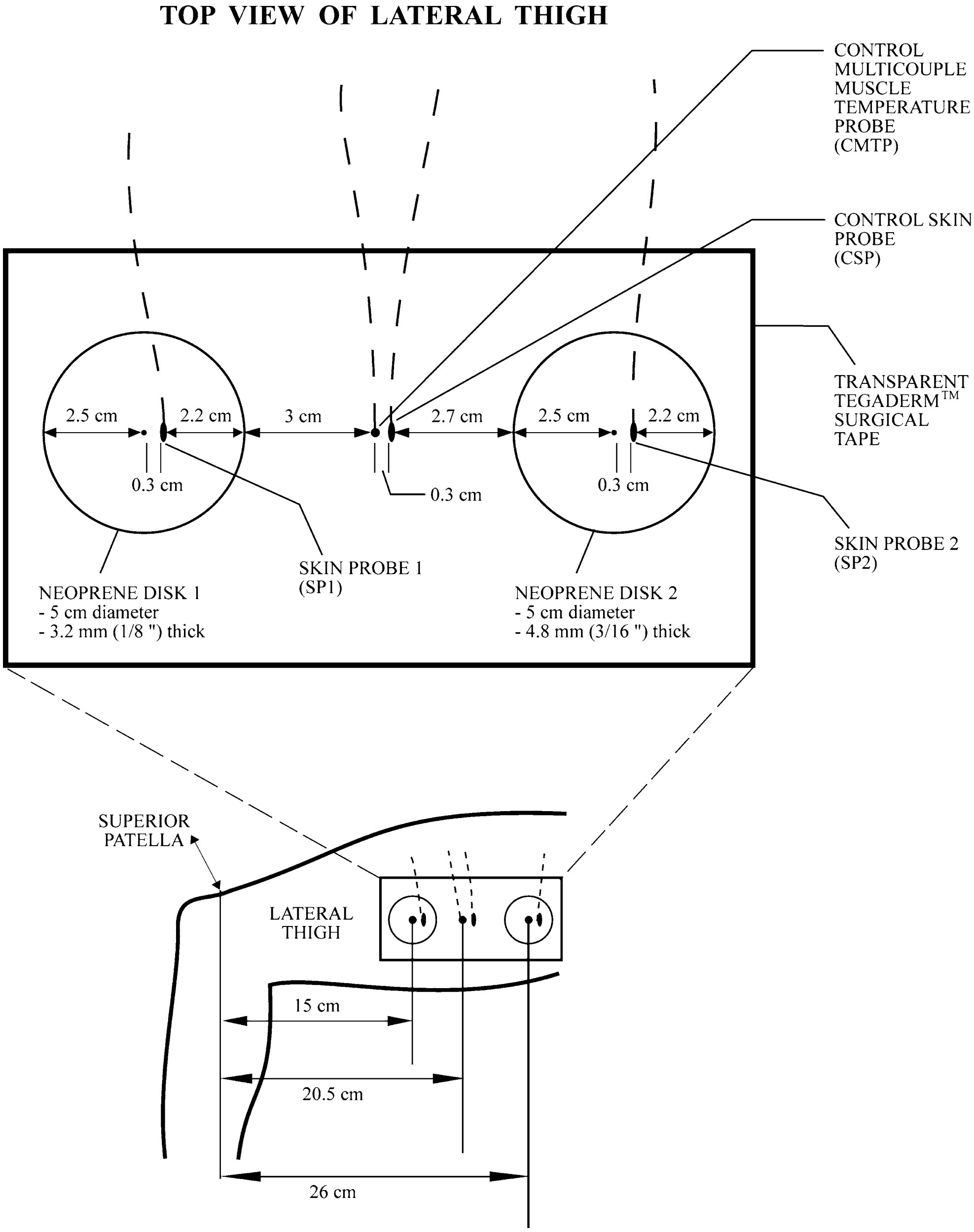
The Tegaderm™ prevented the CMTP from sliding out of the puncture site. The same piece of Tegaderm™ tape was used to hold three, cylinder-shaped (9 mm×1.5 mm) skin thermistors (Size 12 Fr. Mon-a-therm general purpose temperature probe without protective sheath covering, Mallinckodt Inc., St. Louis, MO, USA) in place on the left lateral thigh. The skin thermistors were located 15.3 cm (Skin Probe 1, designated as SP1), 20.8 cm (Control Skin Probe, designated as CSP), and 26.3 cm (Skin Probe 2, designated as SP2) superior to the patella (see Fig. 1). A piece of Transpore™ surgical tape was then applied over each sensor and across the thigh to ensure that the CMTP and three skin probes would not come out. After the CMTP and skin probes were in place, the subject entered a climatic chamber (28 ± 1°C air, RH 30 ± 5%) and sat in a chair for 180 min.

During the first 60 min inside the climatic chamber, SP1 and SP2 were not covered by the neoprene insulation disks. This 60-min period was used as a control period to compare the thigh skin temperatures without being disturbed by the disks. After 60 min in the climatic chamber, two open cell foam neoprene insulation disks were placed directly on top of SP1 and SP2, respectively. Each disk was 5 cm in diameter, however, disk 1 was 3.2 mm (1/8 in.) thick and disk 2 was 4.8 mm (3/16 in.) thick. We chose to vary the disk thickness instead of decreasing the diameter below 5 cm because of edge effects. That is, the skin temperature at the outer edge of the disk would be lower as a result of being influenced by the lower skin temperature next to the disk. The disks were fastened to the skin using double-sided tape (Double-stick discs, 3M Medical), followed by a piece of Transpore™ surgical tape placed over each disk. The CMTP was inserted into the thigh muscle in between disks 1 and 2 and was 3 cm from the edge of each disk. The CSP was 0.3 cm from the CMTP. The distance of the CMTP and CSP from the edge of each disk was a compromise between two factors: (1) it was selected to be far enough from disks 1 and 2 to avoid the effect of the disks on the CSP temperature, yet (2) close enough to have a similar temperature to the uncovered SP1 and SP2 skin sensors (which occurred during time 0–60 min). The CSP and CMTP were left uncovered for the entire 180 min exposure. Disks 1 and 2 covered SP1 and SP2, respectively, from time 60 to 180 min.

A t-shirt, shorts, socks, and running shoes were worn during the entire exposure. Subjects were asked to sit still during their session in the climatic chamber in order to prevent movement artifacts and any possible changes in local blood flow and muscle metabolism.

The data from CMTP, SP1, SP2, and CSP were scanned five times per minute using a 75000 Hewlett Packard data acquisition system and an average value was stored every minute. The data were analyzed using a repeated measures two-way ANOVA with "insulation disk thickness" and "time" as the independent variables which were used to compare SP1, SP2, and CSP from time 0 to 180 min. A *P* value (using a Greenhouse Geiser correction) of < 0.05 was considered significant. A Newman–Keuls post hoc test was used to determine the time at which there was a significant difference between SP1, SP2, and CSP.

Fig. 1 Position of the three skin temperature probes [SP1, SP2, and the control skin probe (CSP)] and the control multicouple muscle temperature probe (CMTP) on the lateral thigh. CMTP was inserted on average 2.8 ± 0.2°C cm below the skin surface into the vastus lateralis muscle. Each CMTP contained a thermocouple junction at the tip (2.8 ± 0.2°C cm below the skin) and four other junctions located 0.5, 1, 1.5, and 2 cm from the tip



Results

The lateral thigh skin temperatures SP1, SP2, and CSP and the vastus lateralis muscle temperatures (CMTP) at various depths are presented for time 0–120 min based on a mean of eight subjects (Fig. 2). The SP1 and SP2 temperatures were normalized to CSP, so that the temperature was the same for all three probes at time 0 min. The last hour of data (time 120–180 min) was not presented for two reasons: (1) the ΔT in SP1 and SP2 after time 120 min was very small (only a 0.1 and 0.2°C increase, respectively, by time 180 min). The SP1 and SP2 values at time 120 min were 88 and 87%, respectively, of the final skin temperatures observed at time 180 min; (2) for the sake of clarity (because two subjects did not complete the full 3-h session. This caused significant step changes in the SP1 and SP2 data at time 120 min). Originally the protocol was only 2 h. However, after the first two subjects had completed the experiment, the protocol was modified so that the exposure was 3 h in order to ensure that there was not a significant change in skin temperature under each insulation disk if subject were exposed for an additional hour.

Lateral thigh skin temperatures

On average, SP1, SP2, and CSP remained stable at 32.8 ± 0.3, 32.6 ± 0.3, and 32.7 ± 0.3°C for the first hour when all three probes were left uncovered (see Fig. 2).

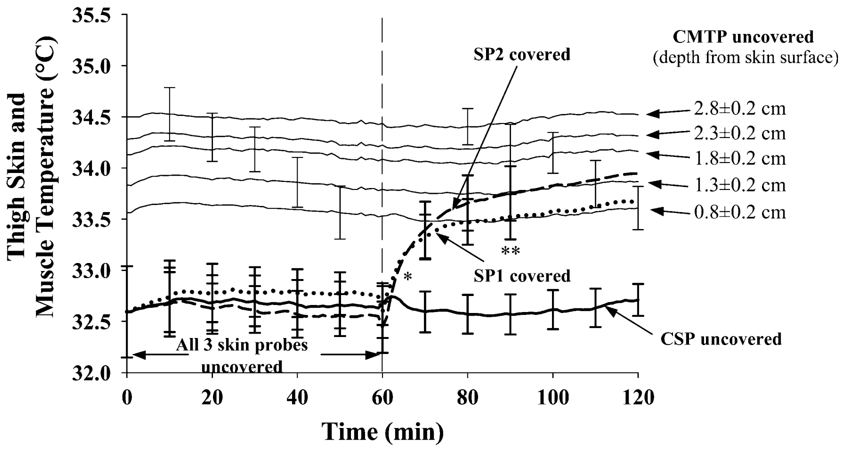


Fig. 2 A comparison of lateral thigh skin temperatures (*three bold lines*) (above the vastus lateralis muscle) measured 15.3 cm [Skin Probe 1 (SP1)], 20.8 cm [Control Skin Probe (CSP)], and 26.3 cm [Skin Probe 2 (SP2)] superior to the patella, along with the temperature of the vastus lateralis muscle (*five thin lines*) at 0.8 ± 0.2, 1.3 ± 0.2, 1.8 ± 0.2, 2.3 ± 0.2, and 2.8 ± 0.2 cm below the CSP while subjects were seated during exposure to 28°C air (30 ± 5% RH) for 120 min. The five vastus lateralis measurements were made using an uncovered control multicouple muscle temperature probe (CMTP). The *straight dashed line* bisecting the graph at time 60 min represents the time at which the 3.2- and 4.8-mm neoprene insulation disks were taped over top of SP1 and SP2, respectively. There was no significant ($P \geq 0.05$) change in CSP during the entire exposure. SP1 and SP2 were significantly ($P < 0.05$) greater than CSP after time 65 min (denoted by *). SP2 was significantly ($P < 0.05$) greater than SP1 after time 90 min (denoted by **). The data represent the mean ± SE for eight subjects

There was a small, but insignificant, increase in the thigh skin temperature during the first 10 min of exposure after the subjects moved from the cooler (22 ± 2°C) room outside the climatic chamber to the inside of the chamber (28 ± 1°C). There were no significant differences in skin temperature between the three probes during the first hour. At time 60 min, disks 1 and 2 were placed on top of SP1 and SP2, respectively. This resulted in a significant increase in SP1 from 32.6 ± 0.3 to 33.7 ± 0.2°C (increase of 1.1 ± 0.2°C) from time 60 to 120 min. In addition, there was a significant increase in SP2 from 32.4 ± 0.3 to 33.9 ± 0.2°C (increase of 1.5 ± 0.2°C) from time 60 to 120 min. The CSP continued to remain stable after time 60 min. The mean CSP temperature from time 0 to 120 min was 32.6 ± 0.2°C. Both SP1 and SP2 were significantly greater than CSP after 65 min (denoted by * in Fig. 2), and SP2 was significantly greater than SP1 after 90 min (denoted by ** in Fig. 2).

Lateral thigh muscle temperature

Overall, thigh muscle temperature remained stable at all depths from time 0 to 120 min, however, there was a small, but insignificant, increase in the thigh muscle temperature during the first 10 min after the subjects entered the climatic chamber. The muscle temperatures at depths of 0.8 ± 0.2, 1.3 ± 0.2, 1.8 ± 0.2, 2.3 ± 0.2, and 2.8 ± 0.2 cm were 33.6 ± 0.3, 33.8 ± 0.3, 34.1 ± 0.2, 34.3 ± 0.2, and 34.5 ± 0.2°C, respectively (see Fig. 2). It should be noted that, unlike the muscle temperature profile shown in Fig. 2 that was based on the mean data of eight subjects, in three subjects, there was a non-linear rise in muscle temperature with increasing depth, gradually attaining an asymptotic value.

Discussion

This study found that the skin temperature under a foam neoprene insulated disk can be used as an indicator of the muscle temperature at a certain depth during the ambient and steady-state resting conditions used in this experiment. From a practical standpoint, a good estimation of muscle temperature (difference of −0.3 to 0.1°C compared to actual muscle temperature measured) may be made after the 3.2- and 4.8-mm disks have been placed on the skin for a minimum of 15 and 20 min, respectively.

In the present study, the diameter of the disk was kept constant and the disk thickness was varied to alter the simulated depth of measurement. However, the steady-state skin temperature obtained is the result of a heat balance between local heat loss and local heat gain at the skin. In practice, several factors in addition to the thickness of the disk (e.g., disk insulating characteristics, disk diameter, ambient temperature, convective heat transfer from the disks, subcutaneous fat thickness, muscle metabolism, and local blood perfusion) can affect the balance. The present study, based on a very specific set of conditions, can be made more practical by modeling the effects of the factors mentioned above on local heat balance, and hence, steady-state skin temperature underneath the disk.

Conclusion

Foam neoprene insulation disks placed on the surface of the lateral thigh may be used to indirectly and non-invasively estimate the muscle temperature of the thigh within a few centimeters of the skin surface in resting subjects exposed to a thermoneutral ambient environment.

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