BODY HEAT CONTENT, HEAT PRODUCTION AND RESPIRATION IN SHEEP EXPOSED TO INTERMITTENT COLD[1]

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Summary

Five adult sheep were exposed to intermittent cold for 12 h (18:00-06:00) at an air temperature of 5 ± 1℃ followed by 12 h (06:00-18:00) at 25 ± 2℃ over a period of 8 days continuously. Carotid artery blood (Tc), mean skin (Ts) and mean body (Tb = 0.86 Tc + 0.14 Ts) temperatures, heat production rate (HP), respiratory evaporative heat loss, respiration rate (RR) and volume were measured before and after exposure. Tc during the 12 h cold period of intermittent cold exposure was similar to that during the corresponding period in the warm environment, while Tc in the 25℃ of intermittent cold was higher ($p < 0.05$) than that in the corresponding period in the warm environment. Ts during the cold period markedly decreased ($p < 0.001$) by about 9℃ when compared with that in the corresponding time period in the warm environment, while Ts during the 25℃ period of intermittent cold recovered to a similar level to that in the warm environment. Tb was lower ($p < 0.001$) during the cold period of intermittent cold, whereas a slight increase in Tb during the 25℃ period of intermittent cold was significant ($p < 0.05$) when compared with the value during the similar period in the warm environment. HP was greatly increased ($p < 0.001$) by cold exposure, followed by an immediate decrease during the first one hour of the 12 h warm period, reaching a similar level to that in the warm environment. A lower ($p < 0.05$) RR was observed during both the cold and 25℃ period of intermittent cold than during the corresponding periods in the warm environment. The results of the present investigation clearly show that the body temperature of sheep increased during a 12 h warm period following 12 h of exposure to cold. These results suggest that during a warm period of an intermittent cold exposure cycle, heat could be shored in the animal body.

(**Key Words**: Sheep, Intermittent Cold Exposure, Body Temperature, Body Heat Content, Heat Production, Respiration)

Introduction

Animals living in middle or high latitudes experience large day-night fluctuations in their thermal environment. In these regions, a relatively cold ambient temperature during the night time in the absence of solar radiation imposes a negative thermal load on the animal (Minlard, 1970).

Camels (Schmidt-Nielsen et al., 1957) and Australian Aborigines (Hicks et al., 1934) are known to allow body core temperature to fluctuate between day and night which helps them save metabolic losses and thereby reduce the needs for energy. Ruminant as large animals are usually kept outdoors and may also have this kind of thermoregulatory mechanisms to reduce energy needs to maintain internal homeothermy in the natural thermal environment.

McLean et al. (1983a,b, 1984) subjected cattle to changing thermal environment in a calorimeter or outdoors and it was observed that larger changes occur in body heat content possibly due to a buffer effect against thermal stress.

It is still unclear, however, how ruminants regulate their body heat in response to a fluctuating thermal environment.

The objective of this experiment was to examine the extent and pattern of change in body heat content and the heat production rate of sheep exposed to a intermittent cold. Change in heat content was estimated from thermometric measurements. Rates of metabolic heat production and respiration were also measured.

Materials and Methods

Animals

Five adult castrated crossbred male sheep (33-44 kg) were used. They were housed in metabolic

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cages having a head hood and kept in a controlled environment room at an air temperature of 25 ± 2℃. They were offered 20 g/kg body weight of alfalfa hay cube (approximately maintenance level) in a single meal daily at 10:00. 3 months before experiments began, animals had their left common carotid artery surgically placed in a loop of skin under general anesthesia with pentobarbitone sodium (25 mg/kg). During the postoperative recovery period, the sheep were shorn once weekly to keep a fleece depth of about 6 mm and trained to become accustomed to the experimental procedure and surroundings.

Measurement procedure

Three days before the measurements began, thermocouples for skin temperature measurement were attached on the skin of sheep.

After the two day's measurements in the warm environment, the animals were exposed to intermittent cold for 12 h (18:00-06:00) at an air temperature of 5±1℃ followed by 12 h (06:00-18:00) at 25±2℃ over a period of 8 successive days.

Twenty four hour measurements were made on days −1 and 7 of intermittent cold exposure. Respiratory volume was measured at 2, 2, 4 and 6 hours after feeding on days −2 and 8 of experimental period.

Measurement

Air, carotid artery blood and skin temperatures were measured every 2 min. using Cu Ct thermocouple probes. The carotid artery blood temperature which represents the core temperature (Tc) was measured by a thermocouple probe with 1 mm diameter (accuracy ± 0.05℃). One week before the measurement began, the probe was inserted 15 cm into the carotid artery through an indwelling sterile needle (Venula V-1, TOP). Skin temperatures were taken from 2 sites of upper flank (T_1), lower flank (T_2), upper leg (T_3) and lower leg (T_4) and 1 site of dewlap (T_5) and ear (T_6) on the left side of the body surface with thermocouples (accuracy ± 0.1℃). Mean skin temperature (Ts) was then computed using the weighting factors described by McLean et al. (1983a).

$$Ts = 0.25\ T_1 + 0.25\ T_2 + 0.32\ T_3 + 0.12\ T_4 + 0.02\ T_5 + 0.04\ T_6$$

Mean body temperature (Tb) was also calculated using the equation of McLean et al. (1983a,b).

$$Tb = 0.86\ Tc + 0.14\ Ts$$

The rate of heat production and respiratory evaporative heat loss were calculated from measurements of exhausted air flow rate and the differences in O_2 and moisture concentrations between exhausted and inlet air of a head hood once an hour for 10 min. using an open circuit procedure. A para-magnetic analyzer (M755, Beckman) and two humidity sensors (PXK-67, TAKARA) were used for measuring O_2 and moisture concentration.

All variables were recorded with a data logging system constructed with A/D converter and personal computer (PC-9801, NEC) in our laboratory.

Respiration rate was measured hourly by palpating the movements of the abdomen.

To measure the respiration volume, a face-mask connected with 3 cm diameter vinyl hose to a Douglas bag was used. Total expired gas from a face-mask for 10 min. was collected in a Douglas bag and measured the volume with a dry gasometer, then respiration volume was calculated.

Electrocardiogram (ECG) was recorded continuously and heart rate was measured.

Statistical procedure

Results are shown as mean values for 1 or 12 h measurements for five animals. Student's paired t-test was employed for evaluating the significance of differences of 12 h mean values between days −1 and 7 for each corresponding 12 h period.

Results

The mean core temperature (Tc) during the period at 5℃ (18:00-06:00) of intermittent cold was similar to that during the corresponding period (18:00-06:00) in the warm environment, while Tc in the 25℃ period (06:00-18:00) of intermittent cold was significantly higher ($p < 0.05$) than that in the corresponding period (06:00-18:00) in the warm environment (table 1). Largely decreased Tc at the beginning of the cold period was recovered during the warm period (figure 1).

Mean skin temperature (Ts) during the cold period markedly decreased ($p < 0.001$) by about 9℃ when compared with that in the corresponding time period in the warm environment, while Ts during the 25℃ period recovered to a similar level to that in the warm environment (figure 2).

Mean body temperature (Tb) was significantly lower ($p < 0.001$) during the cold period of intermittent cold, whereas a slight increase in Tb during

TABLE 1. 12 h MEAN VALUES OF CORE (Tc), MEAN SKIN (Ts) AND MEAN BODY TEMPERATURES (Tb), HEAT PORDUCTION RATE (HP) AND RESPIRATION RATES (RR) OF SHEEP IN WARM AND INTERMITTENT COLD ENVIRONMENTS

Item	Warm		Intermittent	
	25℃ (18:00-06:00)	25℃ (06:00-18:00)	5℃ (18:00-06:00)	25℃ (06:00-18:00)
Tc (℃)	38.5 ± 0.02	38.81 ± 0.02	38.60 ± 0.04	39.12 ± 0.07*
Ts (℃)	36.0 ± 0.2	35.3 ± 0.2	27.2 ± 0.6***	35.4 ± 0.4
Tb (℃)	38.2 ± 0.0	38.3 ± 0.0	37.1 ± 0.1***	38.5 ± 0.1*
HP ($kJ/kg^{.75}$ BW · h)	16.69 + 0.58	18.62 ± 0.39	31.64 ± 0.18***	20.37 ± 0.84
RR (rate/min.)	16.5 ± 2.1	17.1 ± 2.1	12.2 ± 1.2*	14.3 ± 1.2*

Values represent Mean + SE. Significant differences between warm and intermittent cold for each corresponding 12 h period were determined using student's paired t-test. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

the 25℃ period of intermittent cold was statistically significant ($p < 0.05$) when compared with the value during the similar period in the warm environment.

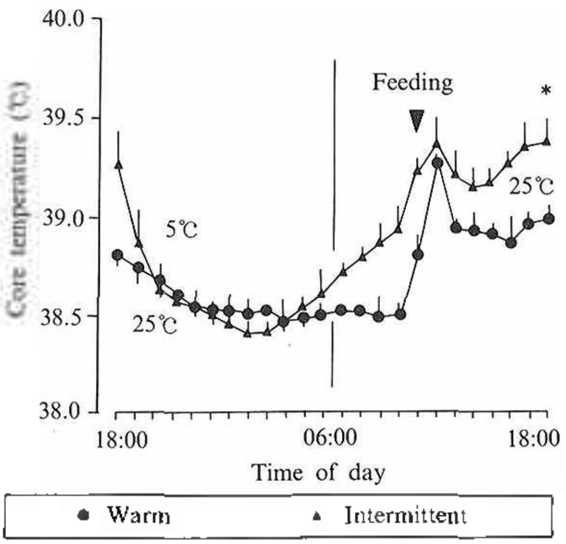

Figure 1. Changes in mean core temperature in sheep in constant warm (18:00 - 18:00 : 25℃) and intermittent cold environment (18:00-06:00 : 5℃, 06:00-18:00 : 25℃). * $p < 0.05$.

Cyclic pattern of Tb were observed (figure 3). The amplitude of this cycle tended to be greater in sheep exposed to intermittent cold than constant 25℃.

Heat production rate was greatly increased ($p < 0.001$) by cold exposure, followed by an immediate decrease during the first one hour of the 12 h warm period, reaching a similar level to that in the warm environment (figure 4).

The respiratory evaporative heat loss (figure 5), which is a part of the heat loss, was significantly lowered ($p < 0.05$) during the first 3 hours of warm period (figure 4). However the mean respiratory evaporative heat loss during the warm period of intermittent cold was not significantly lower than that of control warm period.

A significantly lower ($p < 0.05$) respiration rate was observed during both the cold and 25℃ period of intermittent cold than during the corresponding periods in the warm environment. But there were no differences in respiration volume between the warm period of intermittent cold and control warm (figure 7).

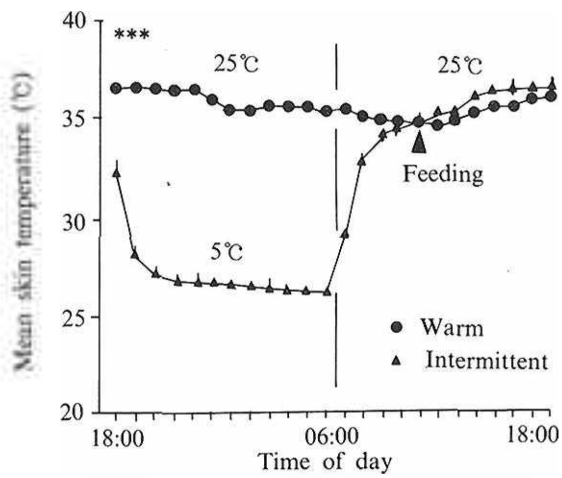

Figure 2. Changes in mean skin temperature in sheep in constant warm (18:00 - 18:00 : 25℃) and intermittent cold environment (18:00-06:00 : 5℃, 06:00-18:00 : 25℃). *** $p < 0.001$.

Discussion

The ambient temperature of 5℃ employed as a cold environment in the present study can be located under the lower critical temperature for shorn sheep (Blaxter, 1967). However, shivering in sheep was not observed during the 8 days of 12 h experimental intermittent cold exposure except the first day. This may indicates that sheep were acclimated to the cold (Slee, 1964).

Both body temperature (figure 1, 2) and its calculated body heat content (figure 3) in sheep under the intermittent cold exposure showed a dramatic decrease at the beginning of cold period and the mean body temperature and body heat production were lower ($p < 0.05$) than those in control period. It indicates that the body heat was dissipated at the beginning of the cold period and appeared to be a metabolic saving. This kind of hypothermic adaption which is characterized by a greater cooling with less metabolic compensation were also observed in nonruminants (Aschoff, 1981; Gwosdow, 1985) and even in mankind; Bushmen of the kalahari desert (Jacques, 1987), in Peruvian Indians living at an altitude of 4,500 m in the Andes (Elsner, 1953) and in cold-acclimated subjects under laboratory conditions (Bruch, 1976).

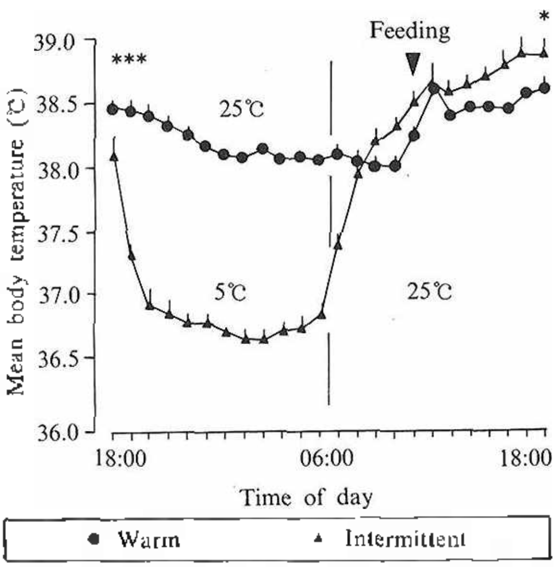

Figure 3. Changes in mean body temperature in sheep in constant warm (18:00 - 18:00 : 25℃) and intermittent cold environment (18:00-06:00 : 5℃, 06:00-18:00 : 25℃). *** $p < 0.001$, * $p < 0.05$.

The decreased body temperature and body heat content during the cold period of intermittent cold exposure increased when animals were returned to their warm environment and reached significantly higher values than the corresponding period of continuous warm environment. It was therefore clearly demonstrated that body heat was stored during the warm period of intermittent cold exposure. We have tried to calculate the amount of body heat storage during the 12 h warm period following a cold period, based on the difference in mean body temperature measured between just before the beginning of the warm period (or at the end of the cold period) and at the end of the 12 h warm period. Body heat storage of about 7 kJ/kg BW · 12 h was equivalent to 8% of heat production for the 12 h cold period. McLean et al. (1984) and Young et al. (1984) estimated the body heat stored was 3-7% of the daily heat production in the cattle exposed to the temperature of 18℃ for 2 days after being adapted to the temperature of −13.5℃. The body heat stored during the warm period is believed to be slowly released when animals are consecutively exposed to the cold and have a saving effect on heat production, at the same time it prevents the sudden drop in body temperature. Camels (Schmidt-Nielsen et al., 1957) allow body core temperature to rise by up to 6℃ during the heat of day and then lose body heat by radiation and convection during the cold desert night, thus economizing on the use of water for evaporative cooling.

Greater changes was occurred in the mean skin temperature shown in this experiment (figure 2) when compared to those in the core temperature (figure 1). However, a high proportion of body tissues lies close to the surface which undergoes extensive temperature change in response to alteration of environmental temperature. There is therefore considerable potential for heat storage in the body even if core temperature does not change (McLean et al., 1983a).

The body heat storage in the warm period in animals exposed to intermittent cold may mean that the balancing mechanism between heat production and heat loss was not maintained, and it can be caused either by too-much heat production or by too-lower heat loss (Ames, 1976). In the present study, however, it was believed to be caused by the latter since the heat production in the warm period of intermittent cold was not higher than that in the corresponding warm period (figure 4). Although the total heat loss was not measured in this experiment, the measured respiratory evaporative heat loss (figure 5), which is a part of the heat loss, was significantly lowered ($p < 0.05$) during the first 3 hours of warm period while the heat production was not increased at that time (figure 4). However the mean respiratory evaporative heat loss during the warm period of intermittent cold was not significantly lower than that of control warm period. The respiration rate which is relative to the respiratory heat loss also showed a decrease during the cold compared with those of control warm period (figure 6). On the other hand, the mean skin temperature at the beginning of the warm period was not recovered immediately to the level of control when animals were reheld to the warm temperature and it is believed to be due to the lowered heat loss from the skin by the small gap between the 25℃ of environmental temperature and the skin temperature. These may result in the increase of body heat content. Actually the increase in body heat storage was observed at the beginning of warm period in this study.

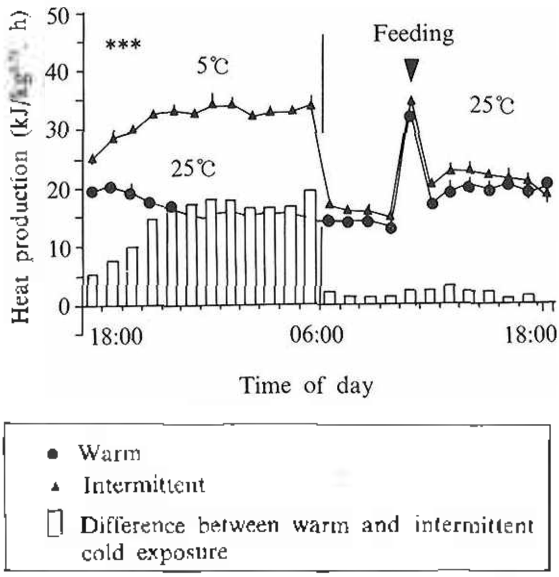

Figure 4. Changes in mean heat production rate in sheep in constant warm (18:00 - 18:00 : 25℃) and intermittent cold environment (18:00 06:00 : 5℃, 06:00-18:00 : 25℃). *** $p < 0.001$.

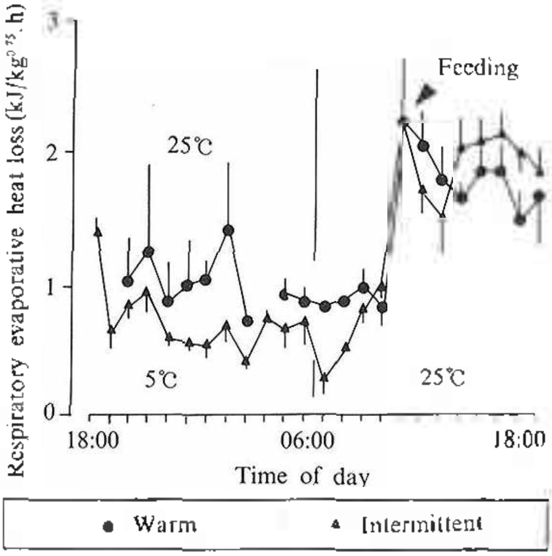

Figure 5. Changes in mean respiratory evaporative heat loss in sheep in constant warm (18:00-18:00 : 25℃) and intermittent cold environment (18 : 00-06 : 00 : 5℃, 06 : 00-18 : 00 : 25℃).

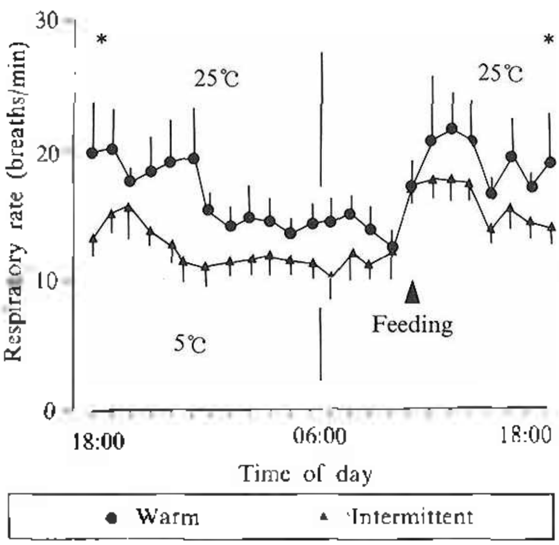

Figure 6. Changes in mean respiration rate in sheep in constant warm (18:00-18:00 : 25℃) and intermittent cold environment (18 : 00-06 : 00 : 5℃, 06 : 00-18 : 00 : 25℃). * $p < 0.05$.

In conclusion, it may be strongly suggested that the body heat storage during warm period was due to a restriction of heat loss, not by the increased heat production.

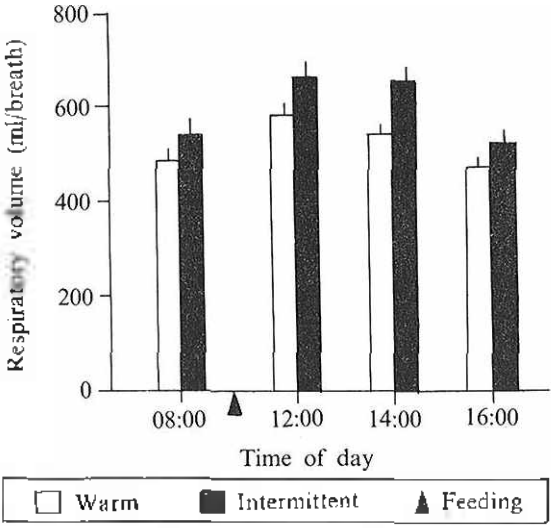

Figure 7. Respiration volume in sheep in constant warm (18:00-18:00 : 25℃) and intermittent cold environment (18:00-06:00 : 5℃, 06:00-18:00 : 25℃).

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