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THE DEEP BODY TEMPERATURE OF AN UNRESTRAINED WELSH MOUNTAIN SHEEP RECORDED BY A RADIOTELEMETRIC TECHNIQUE DURING A 12-MONTH PERIOD

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Technical limitations have precluded the continuous measurement of the deep body temperature of animals when unrestrained in an environment in which they occur naturally, or are traditionally husbanded. Existing knowledge of the nychthemeral (24 hourly) and seasonal variations in body temperature derives from discontinuous measurements of rectal temperature under field or laboratory conditions which have required varying degrees of restraint and handling. In consequence, despite innumerable laboratory studies of the physiological processes upon which mammalian homoeothermy depends, there is little reliable information on the degrees of thermostability which different species of mammals actually achieve under natural conditions.

In the context of previous observations on the thermoregulatory physiology of sheep (Bligh, 1959, 1961, 1963) we wanted to know how well the sheep can thermoregulate under field conditions in all seasons of the year in Britain. Previous studies of the long-term pattern of body temperature of sheep in other climates (Minett & Sen, 1945; Symington, 1960; Eyal, 1963) have been subject to the experimental limitations mentioned above.

In principle, two techniques can be used to avoid the frequent attentions of the observer. An indwelling thermosensitive element can be coupled either to a miniature recorder attached to the animal, or to a portable radio transmitter. The miniature recorder has the advantage that it is not subject to the legal and technical difficulties which may limit the range of radio transmission. It has, however, the disadvantage that the record cannot be monitored. In fact, a satisfactory portable recorder of the required dimensions was not available when this study was planned.

A suitable radiotelemetric system for the transmission of thermal information with an accuracy of within 0·1° C continuously for more than 100 hr over a range of 110 m was devised for this purpose (Bligh & Robinson, 1963; Robinson, 1964). This has permitted the collection of a series of continuous 48 hr records of the deep body temperature of a Welsh Mountain sheep kept in a paddock during a 12-month period which included an exceptionally severe winter. A baled-straw shelter was provided so that the animal could voluntarily seek protection from wind, rain, snow and solar radiation. The purpose of the shelter was to permit the animal to exercise both physiological and behavioural processes of thermoregulation. The latter faculty would be denied the animal if it were restricted in a climatic chamber, or in an open field which offered no physical protection against the elements.

METHODS

The observations were made between 3 October 1962 and 16 October 1963 on a Welsh Mountain ewe which was born in spring, 1961. Its body weight remained between 37 and 40 kg during this period. Average fleece thickness was 7 cm at the beginning of the experiment and 10 cm before shearing in June 1963. After shearing it was reduced to 1 cm and had regrown to an average of 6 cm when the experiment ended.

A semi-flexible polyethylene probe 7 cm in length with a 100 KΩ glass-mounted thermistor head embedded in its tip was inserted, under local procaine anaesthesia, to its full depth in the lower dorsal neck region of the sheep: a fine pair of Mayo scissors was first inserted through a small skin incision to make a pathway between the muscle bundles to a depth of 7 cm. The scissors were then withdrawn and the probe introduced along this pathway. The Perspex hilt of the probe was secured to the skin by two sutures. The fleece was then closed over the probe hilt. The fine plastic-covered co-axial cable was led through the fleece to the transmitter held in a webbing harness on the back of the animal. The harness was held in position by two elastic straps which passed under the belly. The receiver measured $11 \times 6 \times 3$ cm and weighed approximately 450 g. A thin aerial extended 65 cm vertically upwards from the transmitter. The radiotelemetric system, which was specially developed for this work, has been described elsewhere (Robinson, 1964). It permits the continuous transmission and recording of thermal information with an accuracy of $\pm 0{\cdot}1^\circ$ C during more than 100 hr over a range of at least 100 m, and cannot readily transmit spurious information. Moderate frequency drift is tolerated, and a drift beyond this limit results in abrupt discontinuation of transmission.

Efforts were made to record deep body temperature continuously during a 48 hr period every week. Minor technical difficulties, mostly on the thermistor–transmitter side of the system, interfered with the programme several times and satisfactory records were obtained on only forty occasions during the 54-week duration of the experiment. For analysis and presentation of the results, data were extracted from the continuous record at intervals of 30 min.

The paddock measured $16{\cdot}5 \times 6{\cdot}5$ m. There were single-storey buildings on three sides, but it was open to the north-east. A straw-bale shelter was available to the animal. Hay was provided *ad libitum* and was supplemented by a daily ration of an oats and maize concentrate. Air temperature and relative humidity were recorded by a thermohygrograph in a standard Stevenson's screen adjacent to the paddock. Data were extracted from these records at hourly intervals. No local record was kept of sunshine or rainfall. No record was kept of the time spent by the animal in the shelter.

The rectum is the most commonly chosen site for measuring deep body temperature, but its continuous measurement over a 48 hr period under field conditions seemed impracticable. For previous studies of thermoregulation in cattle and sheep in climatic chambers the implantation of a thermosensitive element within the brachiocephalic trunk has permitted the continuous measurement of a definable deep body temperature (Bligh, 1957, 1959). Ingram & Whittow (1961) have shown that if the element is placed alongside the carotid artery an equally acceptable measurement of deep body temperature can be obtained. Such implanted elements cannot be readily replaced and usually remain serviceable for a few weeks only. For this experiment of a year's duration, it was necessary to adopt a technique which would permit the replacement of the implanted thermosensitive element from time to time.

It is well recognized that there are temperature gradients within the deeper body tissue (Bernard, 1876; Eichna, Berger, Rader & Becker, 1951) and that the temperature of the rectum is no more representative of deep body temperature than is any other single measurement except, perhaps, that of blood leaving the left side of the heart, which, it has been suggested, represents the mean temperature of the circulating blood (Bligh, 1957). It seemed, therefore, that a temperature-sensing element placed to a depth of about 7 cm in any part of the trunk might yield a record of deep body temperature no less acceptable than one obtained with the element inserted to a depth of 7 cm in the rectum. In practice, the penetration by a probe of either the thorax or the abdominal cavity was considered inadvisable. It was found that a probe could be quite easily inserted to the required depth in the muscular tissues surrounding the spinal column at the base of the neck. It was appreciated that the close proximity of the sensing element to muscular tissue which, when active, would be a local source of heat might result in the measurement of non-representative fluctuations in deep body temperature. Also there was the possibility that the probe might lie in close proximity to a vein carrying cooled blood from an area of heat loss. Preliminary experiments were made in which three probes containing thermocouples were inserted at different points in the lower neck region and the temperatures measured with these thermocouples were compared with those of the rectum and the blood in the brachiocephalic trunk. These comparisons were made both when body temperature was stable and when it was caused to vary as a result of changes in ambient temperature and humidity in a climatic chamber. The probe temperatures were found to lie between that of the brachiocephalic trunk and of the rectum, and showed no independent variations. There was no locomotive activity in the chamber, and the stability of the probe temperature in these experiments could be misleading. The field measurements do not yield the same smooth record of deep body temperature that is obtained in the climatic chamber, but one component of short-term fluctuations must be the variations in mean deep body temperature owing to locomotor and feeding activities. In fact, the remarkable feature of the records presented here is the smallness of the nychthemeral variation, and since any local thermal influence would exaggerate rather than diminish the extent of the variations in the recorded temperature, it is concluded that the use of the probe technique has not introduced any error of such magnitude as to invalidate its use in this study.

RESULTS

The record of deep body temperature together with those of air temperature and relative humidity during one 48 hr period is shown in Fig. 1. Each 24 hr period is divided into day and night by the vertical lines which denote sunrise and sunset. The shallow monophasic nychthemeral variation in deep body temperature, which fell by night and rose by day, is typical of the majority of the individual records. Occasionally no appreciable fluctuation in body temperature could be discerned, and sometimes the nychthemeral pattern appeared to be di- or triphasic.

The mean, maximum and minimum body temperatures, together with the mean, maximum and minimum air temperatures, the hours of day-

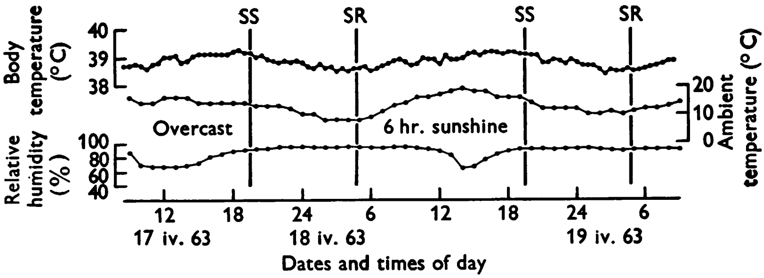

Fig. 1. Deep body temperature, ambient air temperature and relative humidity continuously measured during a period of 48 hr. Deep body temperature data were extracted from the recorder chart at intervals of 30 min. Air temperature and relative humidity data were extracted from the thermograph and hydrograph charts at intervals of 60 min. The vertical lines indicate sunrise (SR) and sunset (SS).

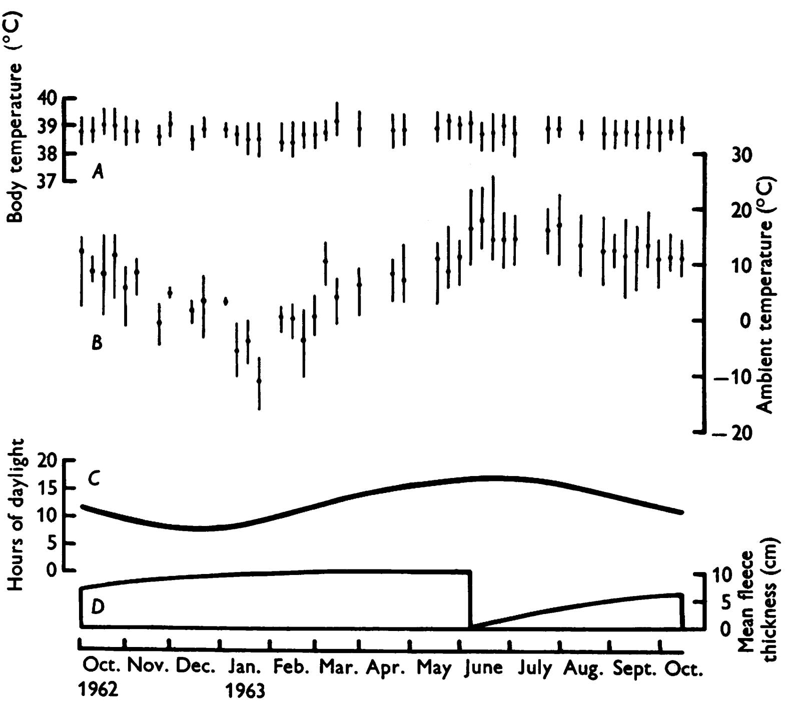

Fig. 2. Summarized data for deep body (*A*) and ambient temperature (*B*) during each period of continuous measurement during the year. The solid circles represent the mean temperatures during each 48 hr period of measurement. The vertical lines passing through the circles join the maximum and minimum temperatures recorded during these same periods. *C*. Annual variation in the length of the day. *D*. Length of fleece. The animal was shorn in early June.

light and the fleece length during every period of measurement are given in Fig. 2. The highest body temperature recorded during the year was 39·8° C and the lowest was 37·9° C. Thus the extent of the variation in body temperature over the year was 1·9° C. The mean nychthemeral variation in body temperature was 0·95° C (S.D. ± 0·25° C) with no discernible seasonal trend in the extent of this variation. However, the mean body temperature for each 48 hr period was 0·6–0·8° C lower during January

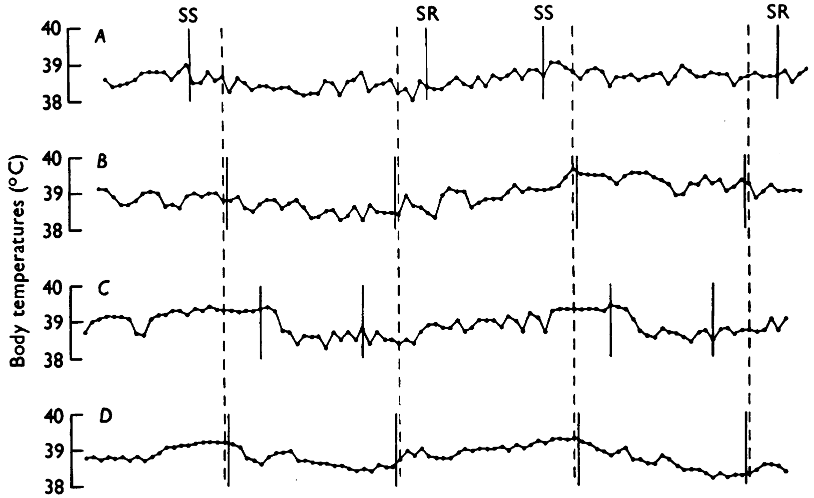

Fig. 3. Deep body temperature data extracted at intervals of 30 min from the recorder charts for the periods of continuous measurement nearest to the longest (*A*) and the shortest (*C*) days of the year, and to the vernal (*B*) and autumnal (*D*) equinoxes. The continuous vertical lines indicate sunrise (SR) and sunset (SS). The interrupted lines at 06.00 hr and 18.00 hr give arbitrary divisions of time at 12 hr intervals.

and February when air temperatures were lowest, than it was in May–June when air temperatures were highest. The total variation in body temperature over the year of 1·9° C thus consisted of two principal components: a nychthemeral variation of about 1° C and a seasonal variation of about 0·8° C.

The mean air temperature during each 48 hr period of measurement varied between −11 and +18° C (29° C) and the total recorded variation in air temperature extended from −16 to +26° C (42° C).

In Fig. 3 are shown the four recordings of body temperature made nearest to the shortest and longest days of the year and to the vernal and autumnal equinoxes. Sunrise and sunset are indicated by the solid vertical lines. An arbitrary division of the record at 06.00 hr and 18.00 hr is indicated by the interrupted vertical lines. At the equinoxes, when there were almost exactly 12 hr of daylight, the rising (diurnal) and falling (nocturnal) phases of the nychthemeral variation in body temperature appear to be of equal slope and duration. During the shortest and longest days, the duration of the rising and falling phases of body temperature appear to be proportional to the hours of daylight and darkness respectively. This suggests that the temporal pattern, though not the extent, of

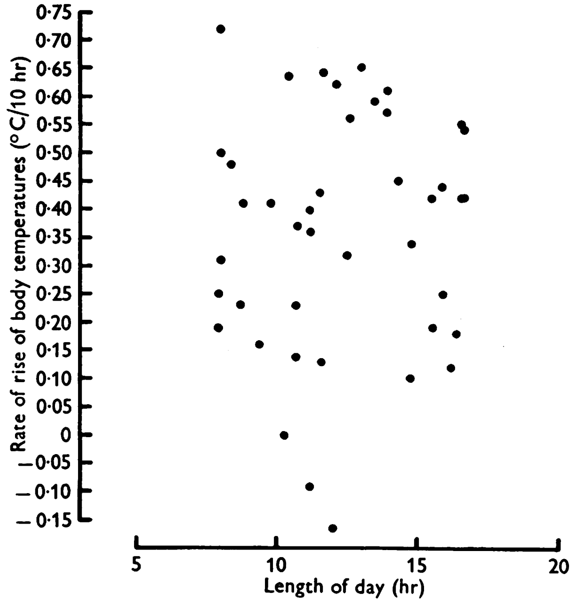

Fig. 4. The rate of rise of deep body temperature during the hours of daylight for each period of measurement plotted against the length of the day.

the nychthemeral variation in body temperature may be related directly or indirectly to the length of the day, but when all the records are examined the relation is less apparent. For such a relation to exist, the slope of the diurnal rise in body temperature would have to vary inversely with the length of the day, since there is no seasonal trend in the extent of the nychthemeral variation in body temperature. The slope of the diurnal rise in body temperature is shown in Fig. 4. There is no evidence here to substantiate the suggested relation between the variation in body temperature and the length of the day.

The sheep was shorn in the summer in accordance with husbandry practice and when the effect on thermal balance might be expected to be least. There was a depression in the mean body temperature during the two experimental periods immediately after shearing (Fig. 2), which could be due to the change in thermal insulation.

DISCUSSION

Previous long-term studies of the deep body temperature patterns of sheep have varied widely in technique, experimental régime and location, and the breed studied, but the results agree well with the essential points reported here. Eyal (1963), in his studies of the nychthemeral variations in rectal temperature of shorn and unshorn Awassi sheep during summer and winter, and in sunshine and shade, in Israel, found a monophasic nychthemeral variation of less than 1° C in all these circumstances, with the lowest temperature in the early morning and the highest in the evening. Minett & Sen (1945), Miller & Monge (1946) and Veeraraghavan & Mendel (1963) have also reported similar monophasic nychthemeral variations in the rectal temperature of different breeds of sheep. Symington (1960) made twice-daily measurements of rectal temperature of Merino, Persian and native sheep at two locations in the Rhodesias and has reported an annual cycle in rectal temperature of 0·5–1·5° C synchronously with the variations in ambient temperature. Kijatkin & Tapiljskit (1959) found a seasonal variation of 0·6° C in the rectal temperature of Merino sheep in Russia.

Although breed differences in both the nychthemeral and seasonal variations in body temperature are evident from the studies of Miller & Monge (1946) and Symington (1960), the similarity of the patterns is more impressive than the differences. The nychthemeral variation in the body temperature of the Welsh Mountain sheep is very similar to that found in a 'local' East African sheep when measured in Uganda by the same probe and radiotelemetric system (Bligh & Harthoorn, 1964). It would seem that the patterns of the deep body temperature variations of the one Welsh Mountain sheep revealed in this study under field conditions in Britain describe the general thermoregulatory behaviour of the species only marginally modified by the particular circumstances of the investigation.

It is generally accepted that most mammals are homoeothermic and can regulate body temperature within 1° C (Scholander, Hock, Walters, Johnson & Irving, 1950). If this generality is accepted, then the thermoregulatory performance of the sheep under field conditions is unexceptional. However, a recent comparative study of the nychthemeral variation of body temperature of some mammals in East Africa (Bligh & Harthoorn, 1964) has indicated that there are species-specific differences in the degree of thermostability of mammals. In that study, where nychthemeral variations of up to 3° C were recorded in some species, the sheep was found to be the most thermostable. It is known that the fleece protects the sheep under both conditions of extreme cold and intense solar radiation, and the thermostability of the sheep during subjection to the wide range of ambient conditions experienced during the year in Britain may depend upon the fleece. Eyal (1963), however, found remarkably little difference in the thermoregulatory behaviour of shorn and unshorn sheep. In the study reported here, the Welsh Mountain sheep did not always use the shelter when the weather was bad. It was noticed that the wind could divide the fleece right down to the skin, and that during snowy weather the fleece could be encrusted with snow and ice to a considerable depth.

The information reported here on the thermostability of the unrestrained sheep under field conditions may well be typical of the degree of homoeothermy which mammals, in general, can achieve. No strictly comparable data are available. But, whether it is exceptional or unexceptional, it remains impressive. The total variation in body temperature of 1·9° C over the year included all effects on body temperature of activity, feeding, intrinsic rhythmicity, shearing in early summer, the whole range of climatic variations and such errors as the novel method of measurement might introduce, and is composed essentially of two simple monophasic cycles, one nychthemeral and the other annual.

It cannot be said whether the nychthemeral variation in body temperature is essentially intrinsic or dependent upon extrinsic climatic factors. Ritzman & Benedict (1931) stated that the thermostability of the sheep is not influenced by the ambient temperature. Minett & Sen (1945) came to the converse conclusion. There is no obvious relation between the extent of the nychthemeral variation in body temperature and that of the ambient temperature or of the length of the day in this study. When a sheep was kept at constant temperature with constant light for 72 hr and its temperature recorded by radiotelemetry, the nychthemeral variation in body temperature was no less than that of the previous 3 days when the sheep was in paddock (Bligh, unpublished), but further studies will be necessary to resolve this problem.

SUMMARY

1. The deep body temperature of an unrestrained Welsh Mountain ewe has been recorded continuously under field conditions during 48 hr periods at frequent intervals throughout a year, by means of an implanted thermistor connected to a radiotelemetric system.

2. The highest and lowest temperatures recorded during the year, which included a severe winter, were 39·8 and 37·9° C respectively. The range of the deep body temperature was 1·9° C.

3. The mean nychthemeral variation in deep body temperature was 0·95° C (S.D. 0·25° C), with no discernible seasonal trends in its extent.

4. The mean deep body temperature during the 48 hr period of measurement was lowest during the coldest months of the year and highest during the hottest. The difference was 0·6–0·8° C.

5. The total variation in deep body temperature of 1·9° C during the year can be divided into two principal components: the nychthemeral variation of about 1° C and the seasonal variation of 0·6–0·8° C.

6. The validity of the method of measuring body temperatures continuously under field conditions is discussed.

We wish to record our appreciation of the diligence and skill with which Mr A. J. Barton carried out all the routine procedures in this study.

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