CAN EXTERNAL RADIOTRANSMITTERS BE USED TO ASSESS BODY TEMPERATURE AND TORPOR IN BATS?

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We tested externally applied, temperature-sensitive, radiotransmitters for determining the body temperature of big brown bats (*Eptesicus fuscus*) in various ambient temperatures (2–26°C). There was a slight, but significant, effect of ambient temperature on skin temperature (measured by the transmitters), but skin temperature accurately reflected rectal temperature in torpid and active bats, and it was never >3.3°C below rectal temperature. External radiotransmitters are, thus, useful in studies of torpor in bats, even when only small decreases in body temperature occur.

Key words: *Eptesicus fuscus,* bats, heterothermy, body temperature, radiotelemetry, torpor

Torpor, a controlled decrease in body temperature below normothermic levels, is used as an energy saving strategy by various mammals and birds (Wang and Wolowyk, 1988). Assessing the use of torpor by free-living animals in the field is a necessary component of studies of energy budgets and behavioral responses to various environmental conditions (Brigham, 1992; Lynch et al., 1978; Michener, 1992; Thomas et al., 1990). Temperature-sensitive radiotransmitters have been used in two different ways to asses the use of torpor. The first method involves surgically implanting transmitters (Barnes, 1989; Grigg et al., 1989; Reinertsen and Haftorn, 1983; Weatherhead and Anderka, 1984). Although an advantage of this method is that the transmitter relays information regarding core body temperature, there are several disadvantages. Surgical implantation may increase stress and the risk of infection, animals must be recaptured if transmitters are to be removed, and implanted transmitters tend to have a lower range of signal transmission than external transmitters.

The second method used to obtain field measurements of body temperature involves attaching external radiotransmitters with a collar, harness, or adhesive. The temperature sensor is placed next to the skin, and thus, measures skin temperature rather than core temperature. This technique has been used extensively with small animals, including several species of bats (Audet and Fenton, 1988; Fenton and Rautenbach, 1986; Grinevitch et al., 1995; Hamilton and Barclay, 1994), and birds (Brigham, 1992; Csada and Brigham, 1994; Firman et al., 1993; Hickey, 1993; Kissner and Brigham, 1993). The advantages of this method are that surgery is not required and the transmitter can either be easily removed or designed to fall off. The main disadvantage is that skin temperature may be a poor indicator of core body temperature. Ambient temperature may also influence the temperature registered by the transmitter. Thus, this technique may be a poor method of assessing the use of torpor. Small decreases in body temperature may be critical components of the thermoregulatory behavior of animals (Hamilton and Barclay, 1994) and can result in significant savings of energy (Studier, 1981; Webb et al., 1993). Small changes in core temperature may be particularly difficult to measure using external radiotransmitters. A recent study (Audet and Thomas, in press) found that temperature-sensitive radiotransmitters accurately reflected rectal temperature, although ambient temperature had a significant influence on the relationship. However, that study used a tropical species of bat that did not enter torpor, and bats were exposed to ambient temperatures only as low as 17°C. The effect of lower ambient temperatures on our ability to measure body temperature using external transmitters remains to be determined.

The purpose of our study was to assess the accuracy of external, temperature-sensitive radiotransmitters in determining the body temperature of active and torpid bats over a wide range of ambient temperatures. In particular, we wanted to determine what influence low ambient temperatures have on the relationship between skin temperature, as measured by external transmitters, and body temperature. We conducted experiments using big brown bats (*Eptesicus fuscus*), a small (15–20 g) insectivorous species that uses both daily torpor and hibernation as part of its thermoregulatory strategy. *E. fuscus* has been the subject of several studies on thermoregulation and energy budgets (Audet and Fenton, 1988; Grinevitch et al., 1995; Hamilton and Barclay, 1994; Kurta et al., 1990).

Materials and Methods

Experiments were conducted at the University of Calgary and at the University of Regina during January and February 1994. Four adult female big brown bats were used, two at each site. The bats had been found roosting in buildings in Calgary and Regina in December 1993. Big brown bats were housed in wire-mesh cages and fed a diet of mealworm larvae and adults (*Tenebrio molitor*) and mashed banana, ad lib. They were exercised regularly by allowing them to fly freely in a large room.

We attached temperature-sensitive radiotransmitters (model BD2T, Holohil Systems, Carp, Ontario), 0.9 g in weight, to the back of each bat in the same manner as in previous field studies (Audet and Fenton, 1988; Grinevitch et al., 1995, Hamilton and Barclay, 1994). The fur between the shoulder blades was clipped as close to the skin as possible, and the radiotransmitter, with the temperature sensor against the skin, was applied using Skinbond (Smith and Nephew United Ltd., Largo, FL) surgical adhesive. We determined skin temperatures (to the nearest 0.1°C) by measuring the interval required for 10 pulses from the transmitter using Merlin 12 receivers (Custom Electronics, Urbana, IL). We took three such measurements, averaged them and calculated skin temperature using conversion graphs supplied by the manufacturer for each transmitter. We confirmed the accuracy of the conversion graphs at the beginning of the study.

We conducted two sets of experiments with each bat, one in which they were kept active and the other in which they were allowed to enter torpor. In the experiments involving active bats, each individual was flown in a large room for 15–30 min prior to being placed in an environmental chamber set at a particular temperature. The trials conducted in Calgary used five ambient temperatures ranging from 3.0 to 25.7°C, and the trials in Regina used six ambient temperatures ranging from 2.0 to 25.0°C. Bats were allowed to move about their cage for ≥15 min to allow the transmitter to acclimate to the ambient temperature. The bats were kept as active as possible (to ensure a high body temperature) by hand-feeding them; although at low ambient temperatures this was sometimes difficult. After the acclimation period, we measured skin temperature (using the transmitters) and rectal temperature (to the nearest 0.1°C) within 5 min using a Fluke 52 digital thermometer (John Fluke Manufacturing Company, Everett, WA) with a 1-mm diameter probe. We used rectal temperature as a measure of body temperature. The probe was coated in Vaseline and inserted a standard distance (4 mm). At the same time, the ambient temperature in the chamber was taken (to the nearest 0.1°C) using a mercury-in-glass thermometer. We checked the consistency of the three measuring devices (transmitters, thermometer, and thermistor) at the beginning of the study. Readings were within 1°C of each other. Bats were always handled using gloves to minimize heat transfer to the bat or the transmitter.

The same basic protocol was used in the experiments with torpid bats. Individuals were left

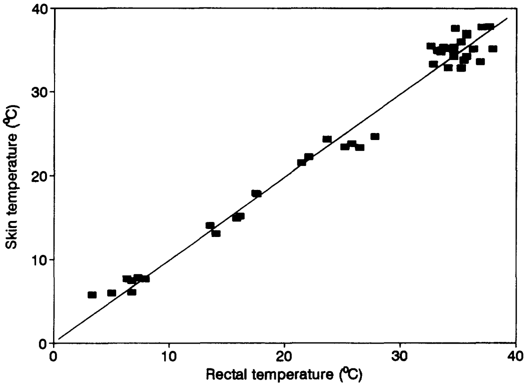

FIG. 1.—Relationship between skin temperature and rectal temperature for active and torpid *Eptesicus fuscus* as measured using external radiotransmitters and a thermistor, respectively. The solid line indicates a 1:1 relationship (i.e., skin temperature = rectal temperature).

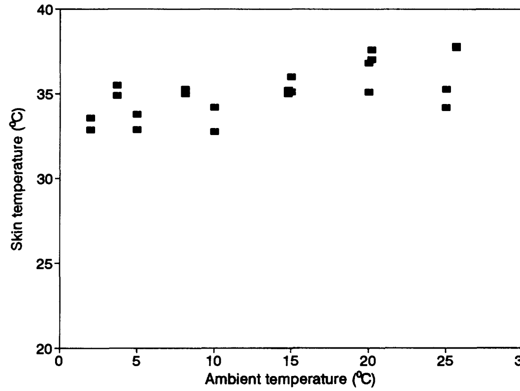

FIG. 2.—Relationship of skin temperature to ambient temperature of active *Eptesicus fuscus.*

undisturbed in the environmental chamber for 6–8 h to allow them to enter torpor. We determined skin temperature from outside the chamber and measured ambient and rectal temperatures within 5 min, as described above. Actual handling time for any individual bat was <2 min. Although this may have allowed a bat to begin to rewarm, this would have increased the difference between the measurements of skin and rectal temperature, and thus, our comparison was conservative.

RESULTS

Individual *E. fuscus* in torpor had rectal temperatures 1–2°C above the ambient temperature, except for one instance in which the bat maintained a rectal temperature of 27.8°C in an ambient temperature of 3.0°C. Active *E. fuscus,* conversely, maintained rectal temperatures ranging from 32.6 to 38.0°C.

Combining the results from experiments on both the active and torpid bats, skin temperature, as measured by the transmitters, was a good indicator of rectal temperature (Fig. 1). The regression equation was Ts = 0.51 + 0.98Tr ($r^2 = 0.98$), where Ts is skin temperature and Tr is rectal temperature. The slope of the regression was not significantly different from a slope of 1.0 (t = 1.06, *d.f.* = 42, $P > 0.200$), nor was the intercept different from zero (t = 0.8, *d.f.* = 42, $P > 0.400$). Skin temperature was within 2.0°C of rectal temperature in 35 of 44 measurements (79.5%) and was always within 3.3°C.

In the experiments in which the bats remained active, skin temperature measured by the transmitters again was consistently close to rectal temperature, although there was a slight but significant effect of ambient temperature (Fig. 2). We used an analysis of covariance (ANCOVA) to test the influence of ambient temperature, rectal temperature, and different individuals (and their transmitters) on measured skin temperature. In the analysis, individual was the main effect, and ambient and rectal temperatures were covariates. We sequentially removed nonsignificant interactions, starting with third-order interactions. The final model involved only individual, ambient temperature, and rectal temperature, and was significant (F = 8.84, *d.f.* = 5,16, $P <$ 0.001). Ambient temperature significantly influenced skin temperature (F = 12.45, *d.f.* = 1,16, $P < 0.005$), and individual bats were different (F = 5.05, *d.f.* = 3,16, $P <$ 0.050). Rectal temperature had no effect on skin temperature (F = 0.49, *d.f.* = 1,16, P > 0.400). Even at ambient temperatures of 2–5°C, the transmitters recorded skin temperatures of 32.8°C and above. At these ambient temperatures, skin temperature averaged 0.67°C below rectal temperature (n = 6).

Discussion

Core body temperatures of small animals, including bats, commonly are measured via thermistors inserted in the rectum or cloaca. Although this works well for instantaneous readings on captive animals or those captured in the wild, continuous measurements from undisturbed free-living animals are required for studies of energetics or thermoregulation. Our results indicate that for small heterothermic bats, external, temperature-sensitive, radiotransmitters can provide reliable measurements of body temperature over a range of ambient temperatures.

In previous studies, it has been assumed that, because of the small size of bats and their high thermal conductance, skin temperature accurately reflects core body temperature (Audet and Fenton, 1988; Grinevitch et al., 1995). Subcutaneous temperature is a good measure of core body temperature in bats (Brown and Bernard, 1991), but dorsal temperature, with the fur intact, is a compromise between rectal and ambient temperature (Webb et al., 1993). In our study and previous field studies (Audet and Fenton, 1988; Fenton and Rautenbach, 1986; Grinevitch et al., 1995; Hamilton and Barclay, 1994), the fur was clipped so that the sensor of the transmitter lay as close as possible to the skin. This is likely important if measurements are to reflect core body temperature and to minimize the influence of ambient temperature; although variation in the amount of fur and adhesive may result in some variation in skin temperature as measured by transmitters. As the transmitters are placed over the location of deposits of brown fat, temperatures measured from actively rewarming bats may be somewhat higher than core temperatures. External transmitters accurately reflect the rectal temperature of some birds (common poorwills, *Phalaenoptilus nuttallii*) when the transmitter is placed under the dorsal feathers, next to the skin (Brigham, 1992).

Although external transmitters closely reflected core body temperature in both the active and torpid bats in our study, there was a small, but significant, influence of ambient temperature. At low ambient temperatures, the transmitter registered lower skin temperature than rectal temperature, on average. This could be due either to lower skin temperature (i.e., the transmitters accurately measured skin temperature), or to cooling of the transmitter by the outside air. In either instance, the fact that there was some variation in skin temperature relative to rectal temperature, points out that caution needs to be exercised when using external transmitters to infer small changes in core body temperature, especially during periods of low ambient temperatures. Previous studies (Grinevitch et al., 1995; Hamilton and Barclay, 1994) have used the skin temperature, measured by transmitters, of bats known to be active (i.e., just prior to or after flight) as a reference, and defined shallow or deep torpor relative to that reference value. This seems appropriate, not only because of the influence of ambient temperature on skin temperature, but also because each bat-transmitter combination measures skin temperature slightly differently. This latter result may have been due to differences in the amount of fur remaining between the skin and the transmitter or to the specific placement of the sensor. Taking into account the above caution, we believe that external, temperature-sensitive, radiotransmitters do provide reliable measures of body temperature for small bats, and can be used effectively in studies of torpor, even when only small declines in body temperature are involved.

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