Blood glucose and body temperature in *Artibeus intermedius* (Chiroptera, phyllostomidae)

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ABSTRACT: Rectal temperature and blood glucose were measured in *ad libitum* fed or 36 hours fasted bats (*Artibeus intermedius*) at three different activity levels. Zero or low activity level was simulated by administration of a low dose of sodium pentobarbital. Medium and high activity levels marks were estimated according to the degree of animals' stress when taken out of the cage. Blood glucose was significantly correlated with the activity level showing a minimum in pentobarbital treated animals and a maximum in highly stressed bats. Only anesthetized bats presented significant decrease in body temperature. Fasting decreased blood glucose but had no significant effect on body temperature. However, using all the data, a significant ($r = 0.81$, $p < 0.001$) positive semi-logarithmic correlation between blood glucose and body temperature was obtained. These results show that, in this species of bats, availability of circulating fuel is related to the metabolic rate expressed by body temperature. This relationship may be important for the energy balance in animals such as bats, which have the metabolic capacities to present natural hibernation or, at least, daily torpor.

INDEX TERMS: anesthesia, bats, feeding state, hypothermia, relation glucose-temperature, stress.

INTRODUCTION

The relationship between body temperature and metabolism has been studied in hibernating (*Eptesicus fuscus*) and non hibernating (*Tadarida brasiliensis*) species of bats suggesting temperature and metabolic rate may decrease at low ambient temperature (Herreid and Schmidt-Nielsen, 1966). Bats have daily fluctuations in oxygen consumption (Riedesel and Williams, 1976). All this suggests bats slow their metabolic rate and lower their body temperature not only in experimentally but also under natural conditions, either during hibernation or periodic torpor; in fact, many authors consider these two processes to be physiologically similar (Schmidt-Nielsen, 1979).

Several studies have examined glucose metabolism in experimentally induced hypothermia; e.g. in rats (Deavers and Musacchia, 1979; Helman *et al.*, 1984; Hoo-Paris *et al.*, 1988), in hamsters (Prewitt *et al.*, 1972); Resch and Musacchia, 1976), and in rabbits (Bickord and Mottram, 1960). Some studies were also performed during natural hibernation in dormice (Castex *et al.*, 1987) in hedgehogs (Hoo-Paris *et al.*, 1978, 1984).

There are obviously few studies on blood glucose levels in bats. In *Myotis velifer*, normal values ranged from 45 to 110 mg/dl (Caire *et al.*, 1981). Normal values of 100 to 150 mg/dl were reported for *Myotis lucifugus* and *M. grisescens*, and the same bats during hibernation had values as low as 7 to 15 mg/dl. A significant positive correlation was found between blood glucose and body temperature (Dodgen and Blood, 1956).

Since glucose metabolism in bats and its relationship with body temperature is poorly known, this study examines the relationship between these two variables in a frugivorous bat, *Artibeus intermedius*.

Methods

Twenty-five adult bats were collected, using a mist net set between guava trees in November in Oaxtepec, Morelos (México). The bats were maintained in the laboratory of the Departamento de Fisiología, Escuela Nacional de Ciencias Biológicas, IPN. They were individually caged in metalic cages for 3 weeks prior to experimentation. Room temperature was 26 ± 2°C with light-on between 800 and 2,000. Bats were fed bananas and water was supplied *ad libitum*. Their body weight ranged between 45 and 55 grams.

Preliminary results showed a great variation in blood glucose levels between individual animals. Since the bats exhibited different degrees of stress when removed from the cage, we decided to compare blood glucose levels and body temperature at different levels of activity or stress.

Activity levels were estimated as follows:

- *High:* moving in the cage prior to manipulation; agitated (they struggled, bit and shrieked) when handled.
- *Medium*: awake but relatively quiet, did not struggle, bite or shriek when handled.

In order to have a group of completely immobile animals anesthesia was used resulting in a third level of activity:

- *Low:* anesthetized with a low dose of sodium pentobarbital (25 mg/kg of body weight in a dilution 1:3 with saline 0.9%) which represents half the dose given in another study (Basset, 1987). The animals were anesthetized for a period of 2 hours and all specimens survived anesthesia.

The three groups were subjected to two different feeding schedules: *ad libitum* fed or 36 hours-fasted.

Blood samples of 10 μl were taken from the uropatagial vein (Black and Wiederhielm, 1976), or by intracardiac puncture (when vasoconstriction in anesthetized animals was intense). When possible the analyses were performed in duplicate, or even triplicate for the same animal. Blood glucose levels were determined by the glucose-oxidase-peroxidase test (GOD-PERID, Boehringer-Manheim, Lakeside, CA). Rectal temperature was measured with a clinical digital thermometer with 0.1°C sensitivity.

Results of blood glucose levels and body temperatures were statistically analyzed by two-way ANOVA (feeding state X activity level) in each case. Newman-Keuls post-hoc tests were used to compare the means (Steel and Torrie, 1985). All data in figures and text are presented as mean ± standard error.

Results

Blood glucose levels (Fig. 1) were significantly affected by activity level (F= 56.6, d.f.= 2.44, p<0.001) and the food disposition (F= 20.2, d.f. = 1.44, p<0.001); the interaction was not significant (F= 0.13, d.f. = 2.44, p= 0.9). *A posteriori* comparisons of means revealed significant differences (p<0.01) between high *versus* medium and low activity levels, and also (p<0.05) between medium and low activity levels in both *ad libitum* and fasted animals. Significant differences (p<0.05 and p<0.01) existed between glycemias of fasted and *ad libitum* animals only for medium and high, but not for low activity levels.

Concerning body temperature (Fig.2), significant effects were also obtained both for activity level (F= 79.9, d.f. = 2.47, p<0.001) and for food disposition (F= 4.6, d.f. = 1.47, p<0.05); the interaction was not significant (F= 0.56, d.f. = 2.47, p= 0.6).

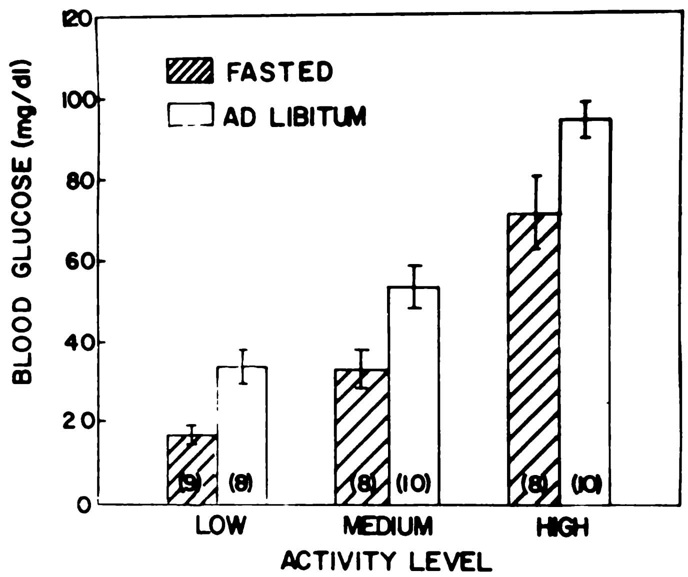

Fig. 1. Effect of activity level and feeding state on blood glucose. Data are presented as mean ± S.E. with sample size in parentheses. See text for statistical analysis.

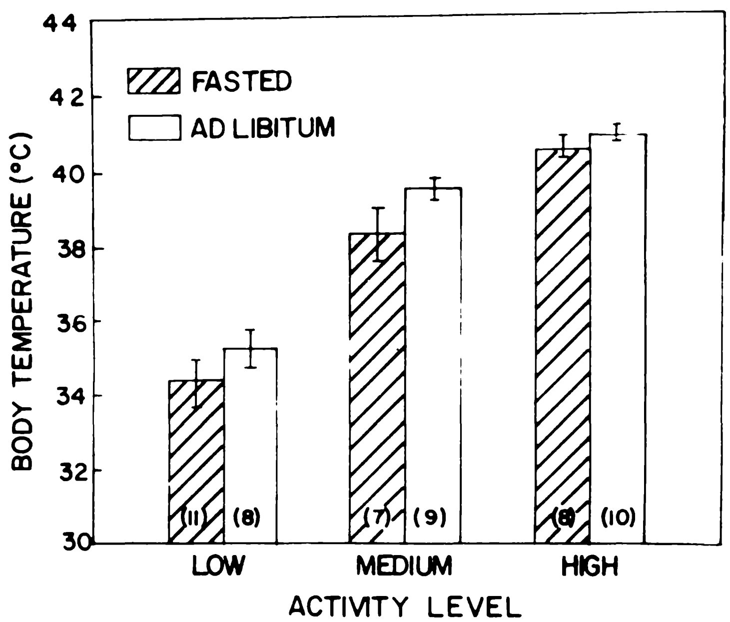

FIG. 2. Effect of activity level and feeding state on body temperature. Data are presented as mean ± S.E. with sample size in parentheses. See text for statistical analysis.

A posteriori analysis of means revealed significant differences ($p < 0.01$) among the three activity levels in fasted animals. In *ad libitum* animals, there were also significant differences ($p < 0.01$) between low *versus* medium and high activity levels, but not between the latter two groups. No significant differences were found between fasted and *ad libitum* animals for any activity level.

A significant positive semi-logarithmic correlation (Fig. 3) was obtained between blood glucose level and body temperature: log blood glucose = 0.22 × temperature — 4.6 ($r = 0.81$, $p < 0.001$). We used a semi-logarithmic correlation since blood glucose levels have a much greater range of variation than body temperatures.

Discussion

In awake animals, blood glucose levels varied from 33.1 ± 5.4 mg/dl (fasted animals at medium activity level) to 93.7 ± 4.5 mg/dl (*ad libitum* animals at high activity level). Such values are in agreement with previous results reported for normal bats (Caire *et al.*, 1981). In anesthetized bats, the range was from 16.8 ± 2.9 mg/dl (fasted animals) to 33.8 ± 4.4 mg/dl (*ad libitum* animals), i.e. twice the values obtained for another species of bats (*Myotis*) under natural hibernation (Dodgen and Blood, 1956).

Assuming that the metabolic rate is reflected, in part, by body temperature, the correlation between blood glucose and body temperature, obtained here and also by Dodgen and Blood (1956), suggests a relationship between metabolism and the availability of circula-

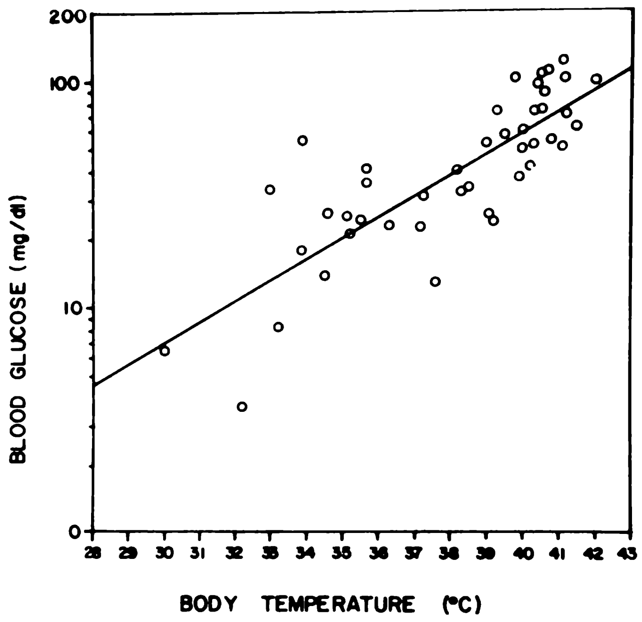

FIG. 3. Correlation between blood glucose and body temperature obtained with all data from the experiment; $r = 0.81$, $p < 0.001$.

ting fuel. Even in non-hibernating bats, oxygen consumption and body temperature can be substantially decreased by exposition to low ambient temperature (Herreid and Schmidt-Nielsen, 1966). Daily falls and bursts were observed in oxygen consumption (Riedesel and Williams, 1976) and the authors suggest that such oscillations may also occur during the natural changes of torpor and activity. Several studies showed a declive of blood glucose under natural hibernation in some species: Dodgen and Blood (1956) in *Myotis;* Hoo-Paris *et al.*, (1978) in *Erinacaeus.* During experimental hypothermia, decreased glycemias were reported by Resch and Musacchia (1976) in hamsters. In rats, which did not present either hibernation or daily torpor, Deavers and Musacchia (1979) found decreased but Helman *et al.*, (1984) and Hoo-Paris *et al.*, (1988) found increased blood glucose in the same condition.

Considering these previous findings and our results, we propose the following hypothesis: blood glucose levels in bats could be regulated according to the energetic demands of the organism. It is maintained at low levels if the requirements are minimal (induced hypothermia, daily torpor, or seasonal hibernation) sparing in this way the energetic storages and avoiding the high energetic cost of gluconeogenesis. When activity increases, there is a mobilization of glucose production pathways and high levels of blood glucose occur to meet the higher energetic requirements. The effect of anesthesia on body temperature and glucose levels is probably not due to a decline in activity alone. Even considering this possibility, it is interesting that these variables are correlated independently of the motor activity of the animal.

In conclusion, this study shows that a short period of hypothermia can be induced in bats with a relatively low dose of sodium pentobarbital and that this hypothermia is associated with a pronunced hypoglycemia which is in accord to some previous works. The relation between the two variables is possibly of physiological importance in terms of energetic balance. More studies are needed in order to elucidate the endocrine and autonomic nervous system participation in the metabolic adjustments to such experimentally imposed and, better, under natural conditions.

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Resumen

En el presente trabajo se midieron la tempertura rectal y la concentración de glucosa circulante en murciélagos (*Artibeus intermedius*), alimentados *ad libitum* o en ayuno de 36 horas, en tres diferentes grados de actividad. La menor actividad fue simulada mediante la administración de una dosis baja de pentobarbital sódico. La intermedia y la alta se asignaron dependiendo del grado de estrés que presentaban los animales en el momento de ser sacados de la jaula. Se obtuvo una relación entre el grado de actividad y los niveles de glucosa: el valor mínimo lo presentaron los animales anestesiados, mientras que el máximo se observó en los murciélagos con actividad alta. Por otro lado, la anestesia disminuyó significativamente la temperatura corporal. Finalmente, el ayuno total, durante 36 horas, produjo un decremento significativo de la glucemia, sin ningún cambio en la temperatura corporal. Sin embargo, al usar todos los datos del presente trabajo, se obtuvo una correlación semilogarítmica positiva ($r= 0.81$, $p<0.001$) entre la concentración de glucosa sanguínea y la temperatura corporal. Los resultados muestran que en esta especie de murciélagos la disponibilidad de combustible circulante está relacionada con la tasa metabólica expresada por la temperatura corporal. Esta relación puede ser importante en el balance energético de animales como los murciélagos que poseen las capacidades metabólicas que les permite hibernar o, al menos, entrar en sopor circádico.

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