

FURTHER EVIDENCE FOR HIBERNATION OF BEARS

G. EDGAR FOLK, JR., Department of Physiology and Biophysics, The University of Iowa, Iowa City 52242

JILL M. HUNT, Department of Physiology and Biophysics, The University of Iowa, Iowa City 52242

MARY A. FOLK, Department of Physiology and Biophysics, The University of Iowa, Iowa City 52242

Abstract: Typical mammalian hibernators overwinter with low metabolism (0.01 normal), heart rate (7 bpm), and body temperature (5 C). There is some evidence that bears hibernate like typical small (50-500 g) mammalian hibernators. It is known that bears remain in winter dens for 4-7 months with very little movement and without food, water, urination, or defecation; they show a large reduction in heart rate and a small reduction in core temperature. To gain further evidence, we compared the unique EKG of typical hibernators with the EKG of bears with respect to season, activity, and dormancy. In this study, the EKG of 3 species of bears and of *Marmota* hibernators was recorded by implanted radio-capsule while they were in winter dens. The EKG of awake typical small hibernators is characterized by a reduced relaxation (QT) interval. It was determined that the 3 species of bears, when awake, also have a reduced relaxation interval (bears 0.14-0.23 second; marmota-species 0.07-0.14 second; man 0.39 second). This finding was interpreted as further evidence that bears are hibernators. Additional findings were that (1) the faster the heart rate of hibernators, the shorter is the relaxation interval; and (2) at a constant heart rate, the relaxation interval of both bears and typical hibernators when nondormant, changes from winter to summer.

In the previous symposia on the biology of bears, we presented evidence that 3 species of bears undergo a form of dormancy that in several respects is more profound than the dormancy of typical, classical hibernators such as woodchucks (*Marmota monax*) (Folk 1967, 1968; Folk et al. 1970, 1972, 1976). These 3 species of bears (black, *Ursus americanus*; grizzly, *U. arctos*; polar, *U. maritimus*) are independent of food and water and do not defecate or urinate for 3-5 months, and probably as long as 7 months in northern Alaska. These observations were confirmed by Nelson et al. (1973) and Craighead et al. (1976). The body temperature of bears does not drop in dormancy to the extent observed in small hibernators. Such a sharp decline would be biologically disadvantageous to bears because several days would be required for their body temperature to rise spontaneously at a time of emergency. However, Craighead et al. (1976) showed a drop from the usual core temperature of 37 C to 31.8 C, and Rausch (1961) found a drop to 33.0 C. Other physiological depression also occurs: the cardiovascular function of all 3 species of bears changes slowly over a period of approximately 1 month in the fall; their sleeping heart rate in summer ranges from 40 to 50 beats per minute (bpm); yet in dormancy during extreme weather, they frequently have a heart rate as low as 8-10 bpm. These findings have been detailed in the preceding 5 references from our laboratory.

During winter dormancy, some bears have been observed to assume the dormancy position of small hibernators. The body is rolled into a tight ball with nose near tail and forehead pressed against the ground. We frequently observed one black bear in this position when he was maintained at an air temperature of -1 C for an entire winter (Fig. 1). He sometimes raised his head but was not observed to leave his nest in the corner of the

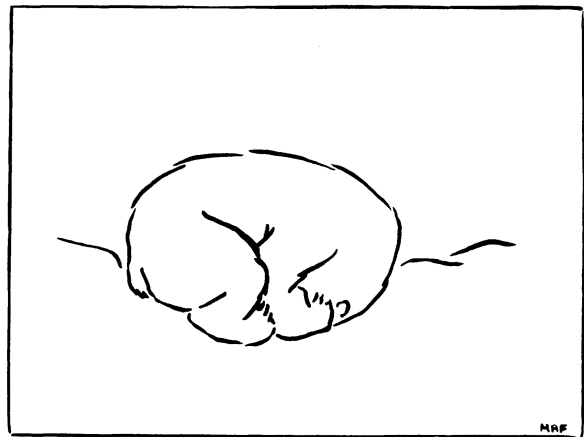


Fig. 1. Drawing of a hibernating black bear observed intermittently during its dormancy period of several months.

cage all winter. If this behavior is the rule, we must ask why muscles do not become cramped and bones do not show degenerative osteoporosis.

In one biochemical characteristic — high serum magnesium during dormancy — the black bear, at least, is like typical hibernators. High serum magnesium is not found in non-hibernator mammals when they sleep nor under any circumstances when in health.

In this paper, we consider the relaxation interval of the EKG as a taxonomic clue to a common physiological characteristic, to determine whether the behavior of the hearts of bears (when not in winter dens) was more like that of man or like that of the classic hibernators. Each heartbeat is composed electrically of 3 spikes referred to as P, R, and T waves (Fig. 2). Hibernators are known to have a very short interval between the second spike (R wave) and the third spike (T wave) (Dawe and Morrison 1955). The T wave represents the relaxation of the heart and the preceding 2 waves (P and R) represent contrac-

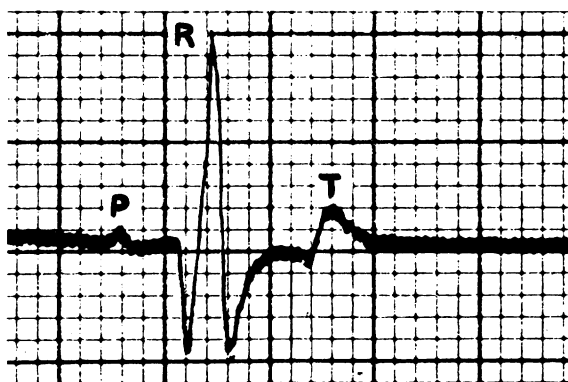


Fig. 2. A single heartbeat of a polar bear, recorded by radiotelemetry. Note the three spikes referred to as P, R, and T.

tion, and therefore we say that the relaxation interval of hibernators is relatively fast.

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METHODS

Three species of bears were given winter dens at the Naval Arctic Research Laboratory (Point Barrow, Alaska) or at the River Laboratory of the Arctic Aeromedical Laboratory (Fairbanks, Alaska). Small physiological radio-capsules were implanted in the abdominal cavities of these bears by methods described in earlier papers (Folk 1964, Shook and Folk 1965, Folk and Copping 1973). The method of recording was described in the same publications. Specifically, recording paper was turned on for 30 seconds every 30 minutes for periods sometimes lasting for 2 months. Signals from the radio-capsules were recorded by heat stylus. On occasion, the record was unsatisfactory because of electrical noise from the atmosphere or the ground, but on most occasions, heart rates at least could be easily read. On about 25 percent of the records, the complete EKG, or at least the R and T wave, could be read. The short interval between the R and the T waves, mentioned above, is referred to as the *QT interval*; the term *relaxation interval*, although used, is an oversimplification, because a small part of the contraction of the ventricle is actually included within this interval.

We used the same radio-capsules and the same technique to study 6 marmots (*Marmota caligata*) and 1 woodchuck. Because these species are in the same genus, we refer to them collectively as *marmota-species*. The woodchuck was in a natural burrow (Folk 1976). Comparisons between non-hibernators and

hibernators would best be made with human subjects since many thousands of measurements of QT intervals have been made on human subjects and the values are to be found in numerous citations concerned with the EKG.

A standardized procedure was used for measuring each interval: 10 QT intervals were always measured. If there were only 10 bpm, all QT intervals were measured. If there were 20 bpm, every other heartbeat was used. If the heartbeat was rapid, with a rate as high as 100 bpm, only the first half of the record was used (50 beats), the middle 20 beats were selected from these 50, and every other beat was measured. Breathing has an effect upon heart rate, but we believe that this effect was randomly distributed through our sample by the standardized procedure used.

Our comparisons among animals were made with absolute values of the QT interval usually at the same heart rate, or at the comparable sleeping heart rate, of the species. Use of a ratio of QT interval to the total interval between heartbeats proved unsatisfactory because the QT interval is relatively constant and only varies systematically and slightly with a change of heart rate, but the total interval between heartbeats is extremely variable, due partly to respiration.

Clearly readable records were obtained from 1 polar bear in summer and winter, 1 black bear in summer and winter, 1 additional black bear in winter, and 2 grizzly bears in summer and winter.

RESULTS

To compare relaxation intervals of non-hibernators with those of hibernators, one must determine whether there are differences in the relaxation interval (1) among man (A), bears (B), and marmota-species (C) during summer sleep; (2) among these species during summer activity (D, E, F); (3) between summer sleep and summer activity within each species; (4) between summer sleep and winter sleep (H, I) within each species; (5) between summer and winter activity (J, K) within each species; and (6) between winter sleep and hibernation (L, M) within each species.

These same questions are expressed in tabular form as:

	Summer sleep	Summer activity	Winter sleep	Winter activity	Hibernation
Man	A	D	--	--	--
Bears	B	E	H	J	L
Marmota-species	C	F	I	K	M

We compared: (1) A, B, and C (Table 1);
(2) D, E, and F (Table 2);

- (3) A with D, B-E, C-F (Table 2);
- (4) B with H, C-I (Table 3);
- (5) E with J, F-K (Table 4); and
- (6) H with L, I-M (Table 1).

In round figures, the relaxation interval in summer sleep of man is about 0.4 second, that of the grizzly bear about 0.2 second, and those of the polar bear, the woodchuck, and the marmot are about 0.1 second (Table 1).

Table 1. Mean QT intervals ± SE for summer sleeping and winter hibernation heart rates. Recorded by implanted radio-capsules.

Species	N	Summer sleep		Winter hibernation	
		QT interval (seconds)	Heart rate (bpm)	QT interval (seconds)	Heart rate (bpm)
Man	7	0.39±0.03	54	-	-
Grizzly bear	2	0.226±0.057	46±2	0.474±0.111	19±7
Black bear	2	-	-	0.448±0.033	22±4
Polar bear	1	0.141±0.003	48	-	-
Woodchuck	1	0.065±0.005	92	0.163±0.005	10
Mamot	6	0.144±0.031	90±8	0.170±0.015	12

Evidently the EKG patterns of bears and marmota-species are similar during summer sleep. This similarity holds during activity in summer (Table 2).

Table 2. Mean QT intervals ± SE for summer sleeping and summer active heart rates. Recorded by implanted radio-capsules.

Species	N	Summer sleep		Summer active	
		QT interval (seconds)	Heart rate (bpm)	QT interval (seconds)	Heart rate (bpm)
Man	7	0.39±0.03	54	0.33	90
Grizzly bear	2	0.226±0.057	46±2	0.204±0.036	90
Black bear	2	-	-	0.205±0.012	94
Polar bear	1	0.141±0.003	48	0.132±0.012	92
Woodchuck	1	0.065±0.005	92	0.057±0.005	150
Marmot	6	0.144±0.031	92±6	0.132±0.028	152±4

We next considered the question of winter activity; much of the time in winter, both bears and marmota-species are alert and normothermic, between bouts of hibernation. We found that when these animals were not dormant, the relaxation interval within species was longer in winter at the same sleeping (not hibernating) heart rate than in summer (Table 3). This finding prompted us to compare heart rates of bears and marmota-species during summer activity with rates during winter activity (Table 4). There was an increase of approximately 43 percent in the relaxation interval at a high heart rate of winter over summer. This increase is

Table 3. Mean QT intervals ± SE and low heart rates during sleep in two seasons at the same heart rates. Recorded by implanted radio-capsules.

Species	N	Summer sleep QT interval (seconds)	Low heart rates (bpm)	Winter QT intervals (seconds)
Grizzly bear	2	0.226±0.057	40±10	0.340±0.006
Black bear	2	-	39±5	0.329±0.015
Polar bear	1	0.141±0.003	48	0.351±0.024
Woodchuck	1	0.065±0.005	90	0.084±0.007
Marmot	6	0.144±0.031	90±10	0.174±0.058

Table 4. Mean QT intervals ± SE and high heart rates during activity in two seasons at the same heart rates. Recorded by implanted radio-capsules.

Species	N	Summer active QT interval (seconds)	High heart rates (bpm)	Winter active QT interval (seconds)
Grizzly bear	2	0.204±0.036	80±4	0.304±0.031
Black bear	2	0.205±0.012	72	0.278±0.013
Polar bear	1	0.132±0.012	92	0.153±0.013
Woodchuck	1	0.057±0.005	150	0.078±0.006
Marmot	6	0.132±0.028	150±10	0.136±0.029

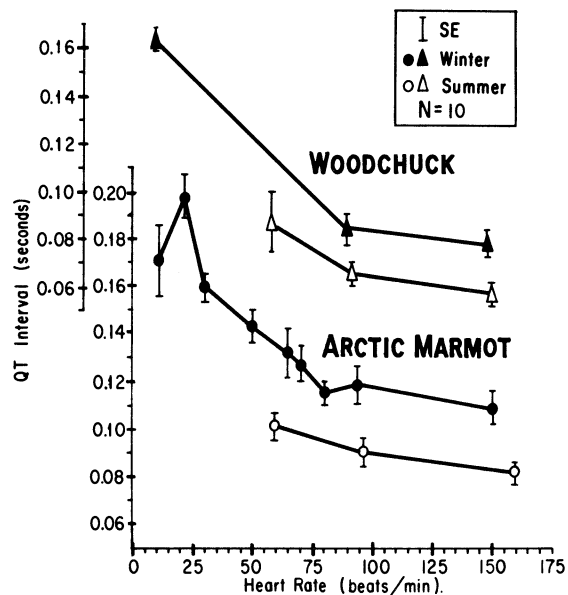


Fig. 3. QT intervals at different heart rates of 2 marmota-species (2 woodchuck, 1 marmot) in winter and summer. Heart rates lower than 30 bpm represent hibernation. Each point represents a mean of 10 heartbeats.

especially evident in a graphic analysis (Fig. 3); the graph of summer heart rates is significantly different for both woodchuck and arctic marmot. The results for bears are not quite as striking (Fig. 4); for grizzly bear no. I, the relaxation intervals were very different at low and high heart rates. For grizzly bear no. II, in one of the

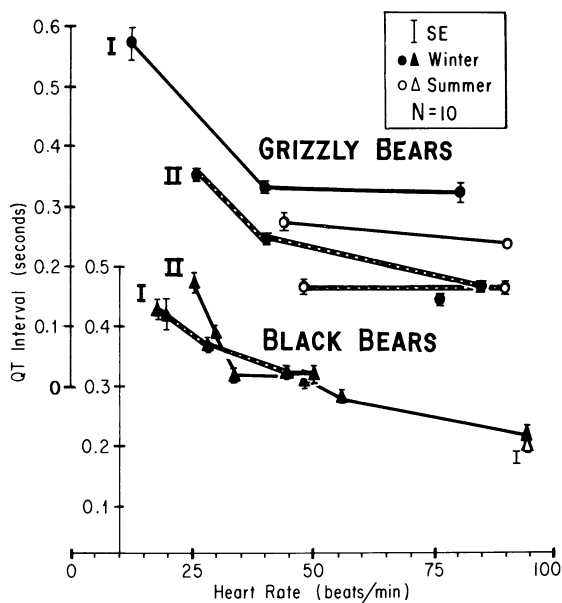


Fig. 4. QT intervals at different heart rates of 2 species of bears (2 grizzly, 2 black) in winter and summer. Heart rates lower than 40 bpm represent hibernation. Each point represents a mean of 10 heartbeats.

two cases the relaxation interval was different. Information for the black bears was inadequate to determine this point.

Disregarding the effect of summer and winter, the slope in Figs. 3 and 4 also demonstrates that the relaxation interval shortens with higher heart rates, as shown in Table 2. The graphs are best interpreted for marmota-species by considering only the heartbeats higher than 25 bpm (non-hibernating), and for bears, heartbeats above 40 bpm. For example, there was a 9 percent drop in the relaxation interval for the marmot when, in summer, its heart rate increased from 92 bpm to 152 bpm (Table 3). The heart is very cold during hibernation and so the

relaxation interval is lengthened during that period (Table 1).

DISCUSSION

During summer sleep, the relaxation interval of bears (0.18 second) was about one-half that of man (0.39 second) and was approximately the same as that of marmota-species (0.11 second). Thus, this aspect of the physiology of bears is in accord with the more common types of hibernators.

An unexpected finding was that in both bears and marmota-species, the heart behaves very differently in winter even when the animal is not in hibernation. There is a conspicuous shortening of the relaxation interval in summer or a lengthening in winter. Another phenomenon is that in both bears and marmota-species, there is approximately a 45 percent change in the relaxation interval as these animals become more active and have an increased heart rate. Finally, it should be pointed out that the relaxation interval is prolonged in the cold heart during hibernation.

To summarize, Folk et al. (1976) suggested that bears could be considered better hibernators than the classic, small hibernators because only the bears are independent of food, water, defecation, and urination for many months. Comparisons of cardiac function, presented here, also place bears with hibernators. We conclude that we need no longer hesitate over such terms as "winter denning," "winter dormancy," "winter sleep," or "winter lethargy." After 10 years of experience with bears in winter dens, two groups of investigators (not only in our laboratory but also in that of R. Nelson at the Mayo Clinic) have agreed that bears assume a physiological state in winter that is best designated as "hibernation."

LITERATURE CITED

- CRAIGHEAD, J. J., J. R. VARNEY, F. C. CRAIGHEAD, JR., AND J. S. SUMNER. 1976. Telemetry experiments with a hibernating black bear. Pages 357-371 in M. R. Pelton, J. W. Lentfer, and G. E. Folk, Jr., eds. Bears — their biology and management. IUCN Publ. New Ser. 40.
- DAWE, A. R., AND P. R. MORRISON. 1955. Characteristics of the hibernating heart. *Am. Heart J.* 49:367-384.
- FOLK, G. E., JR. 1964. The problem of electrodes for use with electrocardiogram radio capsules. Pages 235-265 in W. E. Murry and P. F. Salisbury, eds. Biomedical sciences instrumentation No. 2. Plenum Press, New York.
- . 1967. Physiological observations on subarctic bears under winter den conditions. Pages 78-85 in K. Fisher and F. South, eds. Mammalian hibernation. American Elsevier Publishing Co., Inc., New York.
- . 1968. Telemetry of physiological function of large carnivores. *Proc. Alaskan Sci. Conf.* 19:52-63.
- . 1976. Effects of cold stress on cardiovascular responses in mammals. Pages 305-309 in S. W. Tromp, ed. *Progress in biometeorology: effect of temperature on animals*. Vol. 1, Part 1, Period 1963-1973. Swetz and Zeitlinger, Amsterdam.
- , M. C. BREWER, AND D. SANDERS. 1970. Cardiac physiology of polar bears in winter dens. *Arctic* 23:130-131.
- , M. A. FOLK, AND J. J. MINOR. 1972. Physiological condition of three species of bears in winter dens. Pages 107-124 in S. Herrero, ed. *Bears — their biology and management*. IUCN Publ. New Ser. 23.
- , AND J. R. COPPING. 1973. Telemetry in animal biometeorology. *Int. J. Biometeorol.* 16 (Suppl. 5, Part II):153-170.

- _____, A. LARSON, AND M. A. FOLK. 1976. Physiology of hibernating bears. Pages 373-380 in M. R. Pelton, J. W. Lentfer and G. E. Folk, Jr., eds. Bears — their biology and management. IUCN Publ. New Ser. 40.
- NELSON, R. A., H. W. WAHNER, J. D. JONES, R. D. ELLEFSON, AND P. E. ZOLLMAN. 1973. Metabolism of bears before, during, and after winter sleep. Am. J. Physiol. 224(2):491-496.
- RAUSCH, R. L. 1961. Notes on the black bear, *Ursus americanus* Pallas, in Alaska, with particular reference to dentition and growth. Z. Säugetierk. 26(2):65-128.
- SHOOK, G. L., AND G. E. FOLK, JR. 1965. Body moisture and the operating life of implantable heart rate transmitters. Trans. Biomed. Engineering 12:44-46.