

Physiology of Hibernating Bears

by G. EDGAR FOLK, JR.
*Department of Physiology and Biophysics
The University of Iowa, Iowa City, Iowa, USA*

ANNA LARSON
Arctic Medical Research Laboratory, Fairbanks, Alaska

MARY A. FOLK
Iowa City, Iowa

INTRODUCTION

This paper will consider the technique of physiological measurements in bears during their 'winter-sleep'; it will consider whether the term hibernation is justified in the case of bears; and it will review experiments showing the physiological changes in hibernating bears. We have also taken the opportunity to review all conspicuous papers on any aspect of physiology of bears; it is significant that these could be listed on about one page of this paper. Much more attention should be given to the unique physiological mechanisms of bears by experimental physiologists.

METHODS

In a previous report, the proof of a small reduction in body temperature and a large reduction in heart rate of bears during 'winter-sleep' has been presented (Folk *et al.* 1972). Eight bears were instrumented with the implanted Iowa radio-capsules originally designed by Professor Warren O. Essler; this equipment was described earlier (Folk & Copping 1973). The series consisted of two polar bears, three black bears and three grizzly bears. Several of these animals were instrumented three or four times during their lifetimes. The small reduction in body temperature during the many months of 'winter-sleep' of bears amounts to a decrease of no more than 5°C. Our attention has been devoted to the more interesting cardiovascular adjustment. Gradually, over a period of two to four weeks, the sleeping heart rate of the bear becomes lower and lower, changing from a summer heart rate of 54 bpm in young bears to a winter sleeping level of 24 bpm (a reduction to 43 per cent of summer rate), and in older bears from a summer sleeping heart rate of 40 bpm down to 10 or 8 bpm (a reduction to 25 per cent of summer rates). In our initial experiments, the long life, short-range transmitters usually had a life of only six months. This meant that transmitters placed in the summer would have a battery which would become depleted during the bear's dormancy period in the winter. Because of this condition in the implanted transmitter, some investigators have asked us whether the low heart rates attained were due to the change in the mercury battery of the transmitter during the last month of its activity. We have never carefully explained in the literature that this is by no means the case. For the following reasons, it can be categorically stated that low heart rates in bears in winter are always accurately recorded with the Iowa transmitter up to within one day of the cessation of the life of the transmitter. In the

first place, the circuit was carefully planned by Professor Warren Essler so that there was no diminution in signal from the transmitter near the end of the battery life; the battery was selected to represent an all-or-none situation. Secondly, an inherent characteristic of the circuit is a marked change in frequency in the last 24 hours of the life of the battery. In every instance, we have observed this change in frequency followed by cessation of signal from the animal within 24 hours. For example, the actual tuning on the classic ARC-5 receiver may be as follows: using the audio-speaker or a recorder, the heart rate is obtained by tuning to a frequency between 294 kHz and 298 kHz. In the middle of this range there is a null point that does not give a signal. Using the same receiver with all conditions being the same, we could listen to or record the heart rate of a bear for as long as two years at this same frequency. Furthermore, in other types of hibernators such as woodchucks, rates of 7 bpm changing within a few hours to 300 bpm, are always faithfully recorded. However, on a particular day, at the end of the lifetime of the circuit, we would find the transmitter functioning at a level 10 kHz lower. Always within 24 hours of such an event, the circuit would be dead due to depletion of the mercury battery. On several occasions, bears in winter sleep were aroused and normal heart beats were recorded. Usually this was not intentionally done, simply be-

DAILY MEAN HEART RATE OF ARCTIC GRIZZLY BEAR ('ONE EAR') IN WINTER DEN

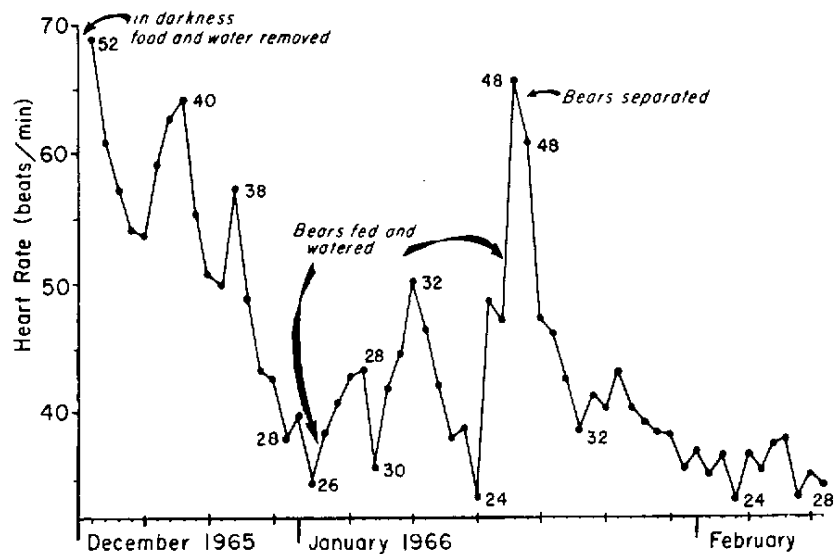


Fig. 1 Daily mean heart rate and lowest sleeping heart rate of arctic grizzly bear (One Ear) in winter den. The figures on graph are sleeping heart rates. In this experiment there was no attempt to keep the bear quiet and unfed until 17 December. Its sleeping heart rate had been about 52 bpm. When darkness, cold temperatures, quiet conditions were provided, its sleeping heart rate was reduced to 24 bpm. When disturbed, summer sleeping heart rates were again recorded during the night-time period.

cause it seemed valuable and even unusual to even get bears to go into deep winter sleep and we were reluctant to disturb them. One of several examples is here presented (Fig. 1). Recordings were made on a two-year-old grizzly during the summer and winter. The summer sleeping heart rate and the heart rate during 'winter-sleep' are relatively high in two-year-old animals; this could be predicted since in the natural state, two-year-old grizzlies usually are with the mother and will probably be nursing during 'winter-sleep'; at least Murie (1963, p. 38) observed sows nursing the same young in the fall and the following spring. In the particular case presented in this illustration, the heart rate during summer sleep was 56 bpm. Gradually over a period of five weeks, the heart rate of the animal (kept without food and water) reduced to 24 bpm. The animal was in the care of an Eskimo guide and naturalist, Pete Sovolic; because of lack of information about physiology of hibernation, he became alarmed that the two grizzly bears might starve to death (only one was instrumented). At this point he fed and watered the animals. Presumably they both ate and drank, and they resumed summer heart rates both during sleep and activity. However, no more food and water were given to them during the winter, and within a few weeks the instrumented animal again was showing a heart rate of 24 bpm. The above proof of a physiological reduction in heart rate followed by summer types of heart rates was also demonstrated with polar bears (Folk *et al.* 1972). In summary, we can say definitively that a heart rate during winter sleep of 10 bpm recorded again and again by our equipment over a month's time represents exactly and precisely the physiological condition of the heart of the bear.

DOES THE TERM 'HIBERNATION' APPLY TO BEARS?

There is some value in comparing in detail the winter dormancy of small, typical mammalian hibernators with the condition found in bears. The first comparison concerns the initial stages of going into dormancy. The small mammalian hibernator does this rapidly and does not even need to be cold-acclimated in order to accomplish this physiological change (Folk 1974, p. 302). Bears, on the other hand, take at least two weeks to change their physiological condition (Folk *et al.* 1972).

Next consider the condition of the small mammalian hibernator over a four-month period of cold exposure. Early naturalists observing this hibernator in a free environment or in the laboratory might have repeatedly observed 'complete dormancy in a tight rolled-up position' for many weeks at a time. Because of lack of electronic recordings, the impression at first was created that the animals remained dormant for several months. This is by no means the case. As far as we know, all small mammal hibernators repeatedly become normothermic and active every few days; 13-lined ground squirrels become active, on the average, every four days; a few will remain dormant with a body temperature of about 5°C for as long as 10 days. What do these small mammalian hibernators do when they become normothermic? Although there are hundreds of investigators of mammalian hibernation at this time in the history of biology, there is an incredible lack of information as to what physiological events take place in between the bouts of dormancy. Accordingly, an experiment is presented here to specifically answer this question in the case of two species of dormice. The procedure was quite simple: in a double-door refrigerator with complete air circulation, maintained at $5^{\circ} \pm 1^{\circ}\text{C}$, the animals were maintained all winter in large cages with open mesh bottoms. Each of three dormice hibernated in a small mass of cotton in one corner of its cage.

Fresh carrots and rat chow were provided on the other side of the cage. Fresh white paper was changed daily under the cage. Over each animal in dormancy there was placed a few thin strips of tissue paper and flakes of sawdust. We have previously determined in our laboratory, and other investigators have shown, that when small mammalian hibernators awake from dormancy and become active, they always clean these indicators from their fur. The results were consistent: deposition of feces and urine and feeding took place regularly between bouts of hibernation (Table 1). For example, the specimen of *Glis glis* awoke approximately every three days (on one occasion after nine days). On every occasion except one, he deposited feces, urinated and ate. The only exception was that in one case he did not deposit urine.

TABLE 1. PHYSIOLOGICAL ACTIVITY BETWEEN BOUTS OF HIBERNATION IN DORMICE

	Length of Bout		No. of Bouts	Present Between Bouts:		
	Mean	(Range)		Feces	Urine	Feeding
Edible Dormouse <i>Glis glis</i>	3	(2-9) days	17	16	15	16
Garden Dormouse (1)	4	(2-10) days	15	13	14	14
<i>Eliomys quercinus</i> (2)	3	(2-6) days	4	3	3	3

Let us compare this situation with bears. We had a unique opportunity to do the same sort of experiment with two two-year-old polar bears, one adult black bear, and one four-year-old grizzly bear. In each case the animals were recorded in deep 'winter-sleep' for at least one month and in one case for 4.5 months; this means that they assumed the typical position of 'winter-sleep' in a curled-up position with the top of the skull pressed against the bedding and the nose near the tail. These observations were made by having an electric light bulb in each cage with rheostat outside. The black bear and the grizzly bear were observed with through-the-door lenses as used in some apartment houses. The polar bears were observed by closed circuit television. We do not have proof that the three species of bears remained in the curled-up position for one to four months, but on no occasion were they seen to be walking around the cages or away from their place of bedding down. During about 50 per cent of the observations, the bears would raise their heads when a dim light was turned up gradually. Much more attention should be paid to such experiments. We consider it possible that in similar experiments, it might be demonstrated that a bear in 'winter-sleep' does not change his position for several months; this introduces the question of how the animal avoids cramped muscles and continues circulation to tissues of the limbs.

The remarkable condition of these bears under these circumstances is not the long period of time they remain in the 'nest' but the fact that we obtained evidence of the lack of urination or defecation for at least a 4.5 month period. At the end of all experiments, which were begun with absolutely clean cages, we examined all surfaces, took apart all bedding and found that there was no urine or feces present. Because the temperature was well below freezing, the urine would have been preserved. When the grizzly bear was taken out of winter sleep which had lasted 4.5 months, he was placed in a cage with a heavy mesh bottom under which there was a plastic sheet to collect urine. The animal still did not urinate for two days (Table 2). Other investigators have demonstrated that for even longer periods than this 4.5 months, bears in winter sleep

do not defecate, urinate, drink or eat even when food and water is available. Thus we see the remarkable difference between small mammal hibernation and the hibernation of the bear.

TABLE 2. URINE VOLUMES OF BEAR AFTER HIBERNATION.

Dates	Time	Volumes	Type of Sample	Comment
Nov. 14- April 4	—	No urination	—	In hibernation
April 5	8:00 am	No urination	—	Moved from den
April 6	—	No urination	—	—
April 7	10:30 am	160 ml	—	1st urination, 4.5 mos.
April 7	4:00 pm	21 ml	24 hour (181 ml)	Moved to large enclosure
April 17	3:00 pm	116 ml	single emptying	Analyzed
April 27	2:00 pm	140 ml	single emptying	Analyzed
June 10	—	2010 ml	24-hour	Not analyzed
July 15	—	2080 ml	24-hour	Analyzed

We must also realize that in the case of the bear, there may be shunting of blood so that some compartments receive little blood flow. This is consistent with the observation by Hock (1966c) that the oxygen consumption of bears is reduced by 50 per cent during winter sleep. We suggest that a comparison can be made between the reduction of heart rate during the diving of marine mammals, and the winter sleep of bears. The same advantage which diving mammals find in a reduced heart rate may be applicable to the bear in winter sleep; we say it is possible that the bear may 'dive' into hibernation in the winter (Ansuetz 1971; Folk *et al.* 1973), making itself into a 'heart-lung-brain preparation'.

Although it is generally assumed that bears can quickly reach an active state when stimulated during 'winter-sleep', there is one known case observed by Wakefield (1974, pers. comm.) in Pennsylvania where a black bear was found in 'winter-sleep' above ground. Several men surrounded the bear and prodded it, and for 20 minutes it did not even raise its head. Eventually it did become active and ran away rapidly.

It should be pointed out that renal and digestive activity in denning bears is reduced greatly. We can say in humor, that at least these two organ systems are more 'in hibernation' than is the case with small mammalian hibernators. Assessing the entire picture of the condition of dormancy of the bear in mid-winter, we would like to propose that there is really no conspicuous reason not to apply the term 'hibernation' to bears as well as small mammalian hibernators. Bears are unusually well adapted as they *stay* dormant and do not consume or eliminate.

PHYSIOLOGICAL CHANGES IN HIBERNATING BEARS

Many blood samples have been taken by Nelson (1973) and his team from black

bears in hibernation, but under anesthesia. They demonstrated that because the bear does not urinate, metabolic water from fat is produced in sufficient quantities to satisfy water needs. Throughout the winter, the water content of plasma and of red blood cells remains constant. The bear does not produce those products of protein metabolism that require urinary excretion. The animal relies on body fat stores so that lean-body mass apparently remains constant. The blood concentration of total protein, urea and uric acid remains unchanged throughout the winter; as may be expected, however, creatinine concentration increases more than two-fold during hibernation. Nelson's team found no evidence of intestinal storage of nitrogen produced from protein catabolism. They also proved that urea is formed but the cycle of urea metabolism functions so as to recycle nitrogen back into the body pool (Nelson *et al.* 1975). The animal would not be able to tolerate the condition of a continuous net amount of urea produced each day.

In one experiment we were able to collect urine samples from the grizzly bear mentioned above after 4.5 months of deep hibernation. After removal from the den, the animal was maintained on a heavy grill over plastic sheeting. The animal and the plastic were hosed down and then drenched with large volumes of distilled water. An observer remained beside the cage at all times of the day and night. If the animal defecated, the hosing and distilled water treatment was repeated. When the animal urinated, the sample was collected from the plastic funnel and immediately frozen. By this means, all 'first' samples after hibernation were collected, and two control samples after the animal had been fed. The analyses of these urine samples confirm in the grizzly bear the observation made by analysis of blood by Nelson *et al.* (1973). The urea from a 4.5 month bladder filling during hibernation was only one gram, compared with 55 grams from a 24 hour control sample (Table 3). Our results also confirm those of D.C. Brown *et al.* (1971). However, the samples collected by both Nelson and by Brown were obtained from anaesthetized bears.

TABLE 3. ANALYSES OF HIBERNATING AND CONTROL URINE SAMPLES FROM FOUR-YEAR-OLD GRIZZLY BEAR.

	Hibernating	Control
Time of bladder filling	4.5 months	24 hours
Volume	181 ml	2080 ml
Total nitrogen	1.43 gm	34.00 gm
Urea	0.98 gm	55.05 gm
Ammonia	72.20 mg	1785.00 mg

What is the weight loss during hibernation? Some of our bears lost 27 per cent of their body weight during hibernation, whereas some other authors have indicated that their specimens lost only 15 per cent. Note that Nelson *et al.* (1973) stated that the loss of weight is merely from body fat stores and that there is no loss in lean-body mass. It should be recognized that the lactating bear in winter represents a special case; Nelson has explained some of the details of this physiological challenge (1971).

SUMMARY

It has been an accepted premise by some biologists that the three species of North American bears (polar, black and grizzly) do not experience mammalian hibernation. The conclusion of this paper, based upon an eight-year study of bears, is exactly the opposite. We believe that the hibernation observed in bears is an example which in the evolutionary sense is more perfected than that of small mammals; furthermore bears maintain their modified state for a much longer period than is the case with any other mammal.

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