

EVIDENCE THAT BLACK BEARS REDUCE PERIPHERAL BLOOD FLOW DURING HIBERNATION

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Compartmentalization of the circulatory system and shunting of blood so that some parts of the body receive little blood flow are common adaptations for conserving energy in small hibernating mammals and diving marine mammals (Folk, 1966). Folk et al. (1972, 1976) suggested that similar changes in blood flow may occur in hibernating black bears and that this could partly explain the reduced oxygen consumption and heart rates of hibernating bears and the occasional inability of hibernating black bears in northern regions to run after being disturbed. Oxygen consumption by black bears during hibernation is approximately 50% the estimated nonhibernating basal metabolic rate, and heart rate periodically drops to between 8 and 21 beats/min (Folk et al., 1972, 1976; Hock, 1957, 1960; Watts et al., 1981). However, no data on blood circulation or cardiac output have been reported for bears in any season. To explore possibilities of shunting and Compartmentalization in black bears during hibernation, we used cardiac catheterization techniques to determine changes in cardiac output, blood pressure, and peripheral vascular resistance between summer and winter in a wild bear in northeastern Minnesota (Lat 47°45'N, Long 91°30'W).

The study bear, a wild, 10-year-old, radio-collared female, was selected for study because her weights and movements during previous study appeared normal, she was without cubs, and she was fully grown and therefore not likely to grow between hemodynamic measurements. Measurement dates were selected in mid-summer and mid-winter to maximize differences in metabolism and to minimize differences in body weights; mid-summer and mid-winter weights commonly are similar for adults in northeastern Minnesota (Rogers, unpublished data) and were 62.7 kg and 60.5 kg, respectively, in this case.

On 17 July 1982, the bear was live-trapped. For at least a half hour before being tranquilized, she rested alert in the barrel-trap. After being tranquilized with 70 mg of phencyclidine and 40 mg of promazine hydrochloride (Seal and Erickson, 1969), she was weighed and measured, and hemodynamic values were obtained using standard Swan-Ganz catheterization procedures (Jobin, 1981; Swan and Ganz, 1975). Catheterization procedures involved laying the bear on its back and inserting an arterial catheter into the heart through the right femoral artery and inserting a triple lumen thermistor Swan-Ganz catheter into the heart and pulmonary artery through the left femoral vein. Each catheter was connected to a transducer and pressure-monitoring system which in turn were connected to a Tektronics dual channel pressure monitor (Model 414 FA) to enable constant visualization of EKG and central arterial, central venous, and pulmonary artery pressures. All blood pressure waveforms were simultaneously recorded with a multi-channel strip chart recorder. Cardiac output values were determined by the thermodilution method (Ganz et al., 1971; Pugh, 1979; Riedinger and Shellock, 1984). After all data were collected, the catheters were removed. The bear was released in her territory after she recovered from the drugs, and she was radio-tracked to a den in fall.

On 22 January, the bear was observed in her den and a heated tent was erected 100 m away. The next day the bear was aroused in her den, allowed to rest alert in the den for 40 min, and then tranquilized with the previously used drugs. After the drugs took effect, she was carried to the tent, her hemodynamic profile was obtained, and she was returned to the den.

Body surface area (m^2) was calculated using the equation $m^2 = 0.1(kg)^{2/3}$ (Dukes, 1947; Kleiber, 1961). Body surface areas calculated for summer ($1.58 m^2$) and winter ($1.54 m^2$) using this equation were each within 3% of estimates using the DuBois human nomogram for body weights (DuBois, 1936).

Comparisons between summer and winter hemodynamic values were facilitated because the bear did not grow between measurements and because her weight change (-3.6%, 2.2 kg) was too small to substantially affect hemodynamic profiles. Any effect of the winter weight loss would be to underestimate seasonal differences. Those differences were probably further underestimated due to the bear's arousal in winter prior to the hemodynamic measurements. The bear rested alert prior to being tranquilized and measured in both summer and winter, and heart rates were similar (85 vs. 82 beats/min). Nevertheless, hemodynamic profiles

differed markedly between the seasons. Cardiac output decreased 45% in winter (5.83 to 3.23 l/min), while peripheral vascular resistance increased 45% (2,196 to 3,864 dynes/sec/cm⁵). Arterial blood pressures remained essentially unchanged (170/139 mm Hg in summer and 165/138 mm Hg in winter). This pattern indicates that blood flow was restricted to certain parts of the bear's body during hibernation. The inability of some bears to run or to move vigorously upon sudden arousal in winter is evidence that flow to skeletal muscle was reduced, as has been found in smaller hibernators (Folk, 1966, Folk et al., 1972).

To normalize for differences in body size, cardiac output is divided by body surface area (m²) to obtain cardiac index. Cardiac index for the study bear in summer was 3.69 l/min/m², which would be a normal resting value for a human (Daily and Schroeder, 1981:186; Forrester et al., 1976). However, cardiac index in winter was only 2.1 l/min/m², and presumably was even lower prior to arousal (see below). This value in a human would indicate insufficient perfusion of peripheral tissues to support aerobic metabolism (Forrester et al., 1976; Guyton, 1981:315), which suggests that hibernating bears tolerate lower perfusion rates than those tolerated by humans.

The heart rate after arousal in winter, 82 beats/min, was more than twice that reported for nonaroused hibernating bears, which typically have heart rates between 8 and 40 beats/min (Folk et al., 1972, 1976; Watts et al., 1981). The slower heart rates of nonaroused bears and reported difficulties in detecting heart beats of those bears (Rogers, 1981) is evidence that cardiac output and stroke volume are less in nonaroused bears than were measured in the aroused bear in this study (cardiac output = heart rate x stroke volume). As the bear roused, its heart beat became audible from the den entrance. The fact that substantial reduction in cardiac output persisted after arousal suggests that cardiovascular changes associated with hibernation are difficult for bears to abandon quickly. The process of entering or leaving hibernation is a gradual one involving complex physiological changes (Folk et al., 1976; Johnson and Pelton, 1980; Nelson, 1980; Nelson et al., 1973, 1975, 1983, 1984).

Shunting of blood away from the skeletal muscle of wintering black bears may differ between northern and southern populations. Unlike bears in northern Minnesota, bears in mild regions such as coastal Washington and coastal North Carolina readily flee from their dens or beds when approached in winter (Poelker and Hartwell, 1973; Hamilton and Marchinton, 1980). Denning periods in these mild regions are typically less than half as long as the 5-7 months in Minnesota. Bears in Minnesota may undergo more profound changes in physiology in order to ration body stores over the longer denning periods.

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