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CHANGES IN BODY MASS AND PLASMA METABOLITES DURING SHORT-TERM FASTING IN THE KING PENGUIN[1]

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Small birds can sustain only about 2 to 3 days of fasting (Ketterson and King 1977, Dawson et al. 1983). In contrast, various species of large birds spontaneously fast for several weeks (e.g., ducks and geese) or even months (e.g., penguins) in association with breeding and molt (Korschgen 1977, Cherel et al. 1987). The ability of penguins to tolerate such prolonged fasting is due to their ability to maintain an effective reduction in body protein utilization (phase II) for a long period. Most of the energy then derives from lipid oxidation. Afterwards protein utilization increases during a shorter phase III that is still reversible (Robin et al. 1988). Data on changes in body composition of fasting ducks and geese accord with these two distinct metabolic phases (Cherel et al. 1987). However, as penguins fast prior to their arrival in the colony, only a little information is available on the initial phase (I) of fasting. The present study, to our knowledge, provides the first data on changes in rate of loss in body mass and plasma metabolites in King Penguins, *Aptenodytes patagonica*, that were initially fed and then fasted.

This work was conducted from August to September 1982 in the sub-Antarctic area, at Possession Island (Crozet Archipelago; 46°25′S, 51°45′E). Five nonbreeding adult King Penguins were housed indoors near the station. Water was provided ad libitum. During 2 weeks, the birds were fed and they maintained constant body mass. Meals were given twice daily, in the morning and late afternoon; each meal weighed 500 g in the first week and 750 g thereafter. The diet consisted exclusively of filleted portions of fish (mainly *Notothenia coriiceps* and *N. squamifrons*) and of whole squids (*Illex* sp. and *Loligo* sp.). Each bird was weighed daily on a platform balance (accuracy ±20 g). Five ml of blood were collected every 2 days during the second week of feeding and during the fast. Blood treatment and metabolite assays for glucose, uric acid, free fatty acids, and β-hydroxybutyrate determinations were as previously described (Cherel and Le Maho 1985). The hematocrit did not change significantly during the experiment and remained between 41 and 44%. Values are means ± SE. Regression lines were calculated from the least square method.

The mean body mass of the five King Penguins was 13.22 ± 0.47 kg at capture, 13.49 ± 0.51 kg at the onset of fasting, and 14 days later it was 10.40 ± 0.60 kg, a 23% decrease. The plot of the daily loss in body mass as a function of time allows us to delimit clearly the phases of fasting (Le Maho et al. 1981). Phase I was marked by a sharp decrease ($r = 0.80$, $P < 0.001$) in the daily loss in body mass from 680 ± 48 g·24 hr^{-1} the first day of fasting to 150 ± 10 g·24 hr^{-1} on the seventh day. It was steady between days 7 and 14 (138 ± 5 g·24 hr^{-1}), i.e., at the beginning of phase II. Plasma glucose concentration (Table 1) was maintained at 12 to 14 mmol·L^{-1} in the fed state as well as during the fast. This level is about twice that for mammals but it accords with that for various avian species (Balasch et al. 1974, Gee et al. 1981, Le Maho et al. 1981). Uric acid level in the fed state (Table 1) was twice that in other birds including carnivorous species (Gee et al. 1981). This value, however, is identical to the plasma uric acid concentration of King Penguin chicks in the absorptive state (Cherel et al. 1987). Uric acid concentration decreased ($r = 0.87$; $P < 0.001$) by 70% in phase I and remained constant afterward (Table 1). Since decrease in both the rate of loss in body mass and plasma uric acid level reflects protein utilization during fasting in penguins (Robin et al. 1988), the present data indicate that low and steady level of protein utilization is reached within only 7 days in King Penguins.

In birds, as for mammals, the largest reservoir of body fuel is in the form of fat. The breakdown of stored triglyceride results in the liberation of free fatty acids, a portion of which are oxidized by the liver. In addition to using free fatty acids to form acetyl-CoA, the liver also converts some of this metabolite to ketone bodies, mainly β-hydroxybutyrate. In the King Penguins, fasting induced a nine-fold increase ($r = 0.80$; $P < 0.001$) in plasma free fatty acids and a three-fold increase ($r = 0.73$; $P < 0.001$) in plasma β-hydroxybutyrate (Table 1).

Previous data in man have demonstrated that fat is mobilized and proteins are spared efficiently during prolonged starvation (Felig 1979). This study supports the evidence that King Penguins respond to food deprivation with similar mechanisms. These birds, however, adapt more rapidly to fasting because the decrease in protein utilization is achieved in 1 week, whereas in man (Felig 1979) nitrogen excretion is still decreasing after 2 to 3 weeks of starvation.

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TABLE 1. Plasma metabolite concentrations vs. time of fasting in five King Penguins. Values in the table are means ± SE.

Metabolites	Time of fasting (days)					
	Phase I				Phase II	
	0	1	3	5	7–9	11–13
Glucose (mmol·L^{-1})	13.44 ± 0.28	14.07 ± 0.60	12.77 ± 0.20	12.34 ± 0.59	12.66 ± 0.41	12.36 ± 0.30
Uric acid (mmol·L^{-1})	1.06 ± 0.05	0.79 ± 0.06	0.40 ± 0.03	0.34 ± 0.03	0.30 ± 0.02	0.31 ± 0.03
β-hydroxybutyrate (mmol·L^{-1})	0.38 ± 0.02	0.54 ± 0.06	0.57 ± 0.09	0.64 ± 0.05	0.78 ± 0.11	0.97 ± 0.13
Free fatty acids (μmol·L^{-1})	44 ± 7	62 ± 15	110 ± 17	181 ± 23	254 ± 43	394 ± 65

TABLE 1. Extended.

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