Effect of High Carbohydrate, Protein, and Fat Diets and High Altitude on Growth and Caloric Intake of Rats[1] (34907)

DAVID D. SCHNAKENBERG AND ROY F. BURLINGTON[2]
(Introduced by J. P. Hannon)

Physiology Division, U. S. Army Medical Research and Nutrition Laboratory, Fitzsimons General Hospital, Denver, Colorado 80240

Depressed growth rates of rats exposed to hypoxic environents have been noted by several investigators (1–7); however, the possible effect of dietary modification upon growth at high altitude has received only limited attention. In a recent study, rats fed diets high in either carbohydrate, protein, or fat were found to consume fewer calories and grow at a slower rate when exposed to moderate altitude (3475 m), but neither altitude nor diet had any effect on the efficiency of food utilization for growth (1). Earlier animal studies indicated high carbohydrate diets may afford measurable protection against anoxia (8); whereas, diets high in protein (9) or fat (10) seem to have detrimental effects. Similar observations have been made during altitude tolerance studies with humans (11).

The present study was designed to study the effects of high carbohydrate, high protein, and high fat diets on growth and caloric intake of rats exposed to high altitude (4300 m).

Methods and Materials. Ninety-one male Holtzman rats (initial wt 140–178 g) were randomly assigned to three dietary and two environmental treatments. The compositions of the high carbohydrate, protein, and fat diets are shown in Table I. Following an initial 10-day dietary adjustment period, one-half of the animals were transported to the summit of Pikes Peak, Colorado (elevation 4300 m) and housed for 21 days in a 23 × 40-ft laboratory trailer. The control animals remained in Denver, Colorado (elevation 1620 m). An ambient temperature of 21 ± 1° was maintained at both locations. The animals were housed in individual wire cages and offered food and water *ad libitum*. Body weight and food consumption were measured over 2- or 3-day intervals.

TABLE I. Diet Composition.[a]

Ingredients	High carbo-hydrate	High protein	High fat
Casein	15	90	15
Dextrose	78	3	15
Corn oil	3	3	3
Crisco			63
USP salt mixture XIV[b]	4	4	4
Vitamin fortification mixture[bc]			

[a] Values are given in percentage by weight.
[b] Nutritional Biochemicals Corporation, Cleveland, Ohio.
[c] 2.2 g added/100 g of diet.

Atwater's physiological fuel values (12) were used to calculate the caloric equivalency of the diets. The calculated caloric equivalency for the high carbohydrate, protein, and fat diets were 4.0, 4.0, and 7.1 kcal/g, respectively. Average daily body weight gain, caloric intake, and food efficiency (wt gain/caloric intake) were individually calculated. Student's t test for significance of difference between means was used to compare different treatment groups.

[1] In conducting the research described in this report, the investigators adhered to the "Guide for Laboratory Animal Facilities and Care," as promulgated by the Committee on the Guide for Laboratory Animal Resources, National Academy of Sciences–National Research Council.

[2] Present address: Physiology-Medicine Laboratory, U. S. Army Medical Research Institute of Environmental Medicine, Natick, Massachusetts 01760.

TABLE II. Effects of Diet and Altitude on Growth, Caloric Intake, and Food Efficiency.[a]

Conditions	A Daily wt gain (g)	B Daily caloric intake (kcal/day)	C Food efficiency (A/B)
Carbohydrate, Denver	4.36 ± 0.17	57.8 ± 1.40	0.075 ± 0.002 (16)
Pikes Peak	2.89 ± 0.12[b]	49.1 ± 1.05[b]	0.059 ± 0.002[b] (16)
Protein, Denver	4.80 ± 0.28	55.0 ± 1.69	0.088 ± 0.006 (14)
Pikes Peak	1.99 ± 0.26[b]	42.2 ± 1.17[b]	0.046 ± 0.005[b] (13)
Fat, Denver	3.69 ± 0.14	61.1 ± 2.14	0.061 ± 0.003 (16)
Pikes Peak	2.88 ± 0.12[b]	56.7 ± 1.10	0.051 ± 0.002[b] (16)

[a] Mean ± SEM with number of observations in parentheses.
[b] Difference from Denver controls, $p < 0.001$.

Results. Body weight change. Growth rate was reduced at altitude ($p<0.001$) regardless of dietary treatment (Table II) and the depression appeared to be continuous throughout the 21-day period (Fig. 1). The greatest decrement (58%) was seen in protein-fed rats, with lesser decrements being observed in carbohydrate-fed (34%) and fat-fed (24%) animals. At Denver, both the carbohydrate and protein diets produced greater weight gains ($p<0.01$) than did the fat diet, but at altitude the protein diet was markedly inferior ($p<0.01$) to either the carbohydrate or fat diets.

Caloric intake. Caloric intake per day of the protein and carbohydrate diets but not the fat diet, was reduced at altitude (Table II). Caloric intake of the higher caloric density fat diet, however, was greater ($p<0.001$) than that of the other diets at altitude and greater ($p<0.05$) than the protein diet in Denver. The caloric intake of the carbohydrate diet was greater ($p<0.01$) than the protein diet at high altitude.

Food efficiency. The efficiency of caloric utilization for growth was reduced at altitude ($p<0.001$) regardless of diet (Table II). At altitude the carbohydrate diet was more efficiently utilized than either the fat ($p<0.01$) or protein ($p<0.05$) diet. In Denver, the food efficiency of the protein-fed rats was superior to that of the carbohydrate-fed ($p<0.05$) and fat-fed ($p<0.001$) rats. The carbohydrate diet was also more efficiently utilized in Denver ($p<0.001$) than was the fat diet.

Discussion. Although growth retardation occurs at altitude regardless of diet, the present study shows this effect was markedly enhanced when a high protein diet was fed. Other detrimental effects of high protein diets have been shown previously by Langwill *et al.* (9) using hypoxic survival rate of rats as the criteria and by King *et al.* (11) who measured psychomotor performance in hypoxic humans. Chinn *et al.* (1) exposed rats to moderate altitude (3475 m) and fed diets similar to those used in our study. They also observed slightly reduced growth rates with high carbohydrate or fat diets but in contrast, no difference with a high protein diet. Rats fed normal diets have also been shown repeatedly to grow at a slower rate during exposure to hypoxic environments (2–7), but when food consumption has been reported, the effect of altitude on caloric intake has not been consistent.

The growth rate and food efficiency of the carbohydrate- and protein-fed rats in our study were reduced at altitude. Food intake was also reduced. Chinn *et al.* (1) and Weihe (7) reported the impaired growth rate of rats exposed to altidudes of 3475 m to be associated with reduced food intake. Sundstroem and Michaels (6) exposed rats to simulated altitudes of 4115 to 8845 m for extended periods and observed increased anorexia and weight loss as the degree of hypoxia became more severe. These studies indicate that the growth impairment may largely be attributed to an altitude-induced anorexia. However, reduced growth rates without a concomitant decrease in appetite have also been reported (3, 5). In the present

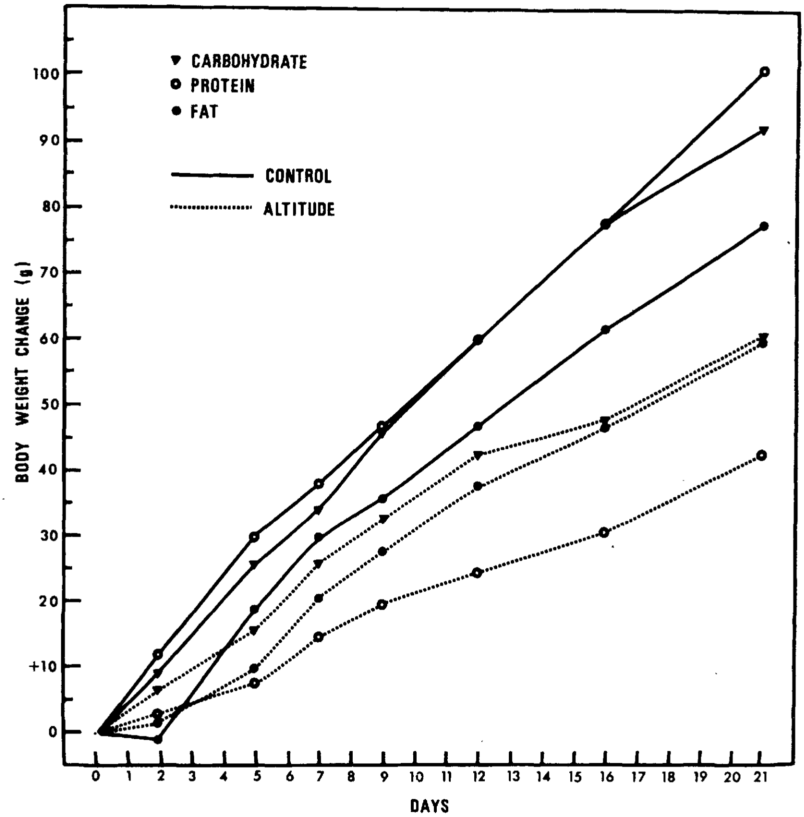

FIG. 1. Growth response curves of rats (initial wt 140–178 g) fed high carbohydrate, protein, or fat diets for 21 days at Denver, Colorado (elevation, 1620 m) or Pikes Peak, Colorado (elevation, 4300 m).

study caloric intake of fat-fed rats was only slightly reduced at altitude ($p<0.07$). However, growth rate and food efficiency were significantly ($p<0.001$) decreased suggesting that the decreased growth and food efficiency might also be attributable to high altitude exposure *per se*.

The impairment in food efficiency may reflect an increased maintenance requirement or possible alterations in nutrient digestion, absorption, and metabolism. There are indications that basal oxygen consumption is increased during altitude exposure (2). Hypoxia has been shown to delay gastric emptying time in dogs (13) and humans (14) and to depress the intestinal motility of the mouse (15) and rat (16). There is some evidence that hypoxia may inhibit gastrointestinal secretions (17, 18). A report by Panin (19) suggests a possible delay in protein absorption, this being reflected by a delay in the appearance of increased blood and urinary nitrogen levels after protein administration of dogs at 5000 m. Exposure of rats to a simulated altitude of 6100 m has been shown to depress intestinal absorption of glycine (6). Recently, Chinn and Hannon (2) exposed growing rats to an altitude of 4300 m for 26 days. The animals were fed a normal diet and complete urine and fecal collections were taken. Growth rate was retarded at altitude concomitant with a slight reduction in food consumption. Interestingly, fecal nitrogen excretion was increased at high altitude reflecting apparent decreased digestion of nitrogen.

Summary. Diminished growth rates were observed in rats exposed to an altitude of 4300 m and fed diets high in either carbohydrate, fat or protein. This effect was attributed to altitude-induced anorexia and to

alterations in nutrient utilization. A high protein diet is apparently the least desirable for the support of growth in rats at high altitude.

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