

Research Report

Effect of a carbohydrate supplement on feeding behaviour and exercise in rats exposed to hypobaric hypoxia

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The effect of a carbohydrate supplement, offered as a diet option, on feeding behaviour, body weight gain, and endurance exercise was studied in rats exposed to hypobaric hypoxia. Male albino rats ($n=35$) were randomly divided into 5 groups; hypoxic supplemented and control groups; normoxic supplemented and control groups, and an untreated control group. After treadmill training for 5 days, the hypoxic groups were exposed to simulated high altitude equivalent to 6960 m for 18 days continuously. Food and water intakes, body weight and endurance exercise were recorded before and during the exposure period. Blood glucose, insulin, muscle and liver glycogen were assayed at the end of the exposure period. Hypobaric hypoxia resulted in a significant decrease in food and water intake, and body weight, and reduced endurance exercise capacity compared to the basal and normoxic group values. The carbohydrate supplement did not ameliorate the hypoxia-induced loss in body weight, but however, significantly delayed the onset of fatigue during exercise in the supplemented rats compared to the hypoxic control group.

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Introduction

Recent years have seen an exceedingly increasing number of people travel to mountains, for either sport or recreation. In the case of the armed forces personnel, high altitude (HA) postings are a professional necessity. With the durations of these sojourns varying from a few days to many months, the inherent problems of Acute Mountain Sickness (AMS) viz., reduced food intake, headache, nausea, dizziness, insomnia, etc., are also encountered. This altitude-induced hypophagia (Consolazio *et al.*, 1969; Hannon *et al.*, 1976; Rose *et al.*, 1988; Guillard & Klepping, 1985; Askew, 1989) and the resultant body weight loss (Consolazio *et al.*, 1968; Boyer & Blume, 1984; Butterfield *et al.*, 1992; Kayser, 1994) have been the

focus of many studies over the years. Food intakes are usually reduced by 10–50% during acute altitude exposure. Numerous attempts have been made to reverse this anorexia and hypophagia, but most have met with limited success. Rose *et al.* (1988) even allowed subjects in a hypobaric chamber study to have a “cafeteria choice”, where they could have desired foods, but still food intake decreased with time along with weight loss.

Carbohydrates are reportedly preferred over fats at HA since the days of Pugh (1954). Since the late 1960s, high-carbohydrate diets have been recommended as a “non-pharmacological” method to reduce the symptoms associated with AMS and improve performance (Askew *et al.*, 1989; Consolazio *et al.*, 1969). The Andean natives consume nearly 79–89% of their calories as CHO. High-CHO diets have been shown to increase lung pulmonary diffusion capacity (Dramise *et al.*, 1975), increase alveolar and arterial oxygen pressures (Hansen *et al.*, 1972) and improve endurance during HA acclimatization (Young *et al.*, 1982). Earlier studies at our laboratory have also reported a preference

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for sweet-tasting (carbohydrate) solutions over other taste stimuli in rats subjected to hypoxic stress (Singh *et al.*, 1996; 1997a). Similarly, preferences for sweet taste in human volunteers abruptly inducted to HA were also noted (Singh *et al.*, 1997b).

Besides being a palatable form of energy at altitude, carbohydrate solutions might help attenuate the reduction in body weight based on studies under normoxic conditions. The feeding of high sugar diets promotes overeating and obesity in laboratory animals (Kanarek & Hirsch, 1977; Sclafani, 1987). Furthermore, the form of CHO also influences the responses. When fed as a diet option, in the form of a solution, rats consume nearly 60% of their calories as sugar and increase their total calorie intake by 10–25% compared to control rats (Castonguay, 1981; Kanarek & Orthen-Gambill, 1982).

The goals of the present study were to ascertain whether a CHO supplement, offered as a diet option in addition to the normal diet would promote feeding and thus ameliorate HA-induced body weight loss, and second, to evaluate the ergogenic potential of the CHO supplement in endurance capacity at HA.

Materials and methods

Animals

The experiments were carried out on male albino Sprague-Dawley rats. These animals ($n=35$), weight (150 ± 20 g), age (90 ± 5 days) were randomly divided into 5 groups viz., Normoxic Controls (NC, $n=7$); Normoxic Experimental (NE, $n=7$); Hypoxic Control (HC, $n=7$); Hypoxic Experimental (HE, $n=7$); and Untreated Control (UC, $n=7$). The rats were bred and maintained at the animal house facility of the Defence Institute of Physiology and Allied Sciences, (DIPAS), Delhi. The rats were housed in polypropylene cages ($30 \times 22 \times 14$ cm), with a stainless steel grill, and paddy husk as bedding material. The bedding was changed on alternate days. The colony was maintained in a well-aerated room with a 12:12 h light:dark cycle. The rats were housed singly. All the experimental procedures were carried out in accordance with the guidelines of the Ethical Committee of the institute. The rat diet consisted of food pellets (Amrut Laboratory Animal Feeds, Pranav Agro Industries, Ltd.). The caloric value of the feed was 3.41 cal/g. Food and water were provided *ad libitum* except when food and water intakes were being measured. The food pellets were provided in a metal cup of 120-g capacity fitted with an anti-scatter rim to prevent spillage. The water was provided in 50-ml graduated glass bottles. The diet

consisted of the following components by weight: Crude protein 21%, Fat 5%, Carbohydrate 53%, Crude fibre 4%, Ash 8%, Calcium 1%, Phosphorus 0.6% and a complete vitamin supplement.

Diet supplementation

Diet supplementation was done using a 32% glucose solution in drinking water. Dextrose anhydrous, AR grade, supplied by s.d. fine chemicals ltd. was used to prepare the supplement. The Hypoxic Experimental group (HE) and the Normoxic Experimental group (NE) received the supplement. The remaining control groups (NC, HC and UC) received the commercial chow only.

Animal environmental chamber

The environmental chamber provided a means of studying the effects of chronic hypobaric hypoxia under controlled conditions of temperature and humidity. This chamber consisted of an exposure chamber, barometric pressure, temperature and humidity control unit, vacuum pumps, and a video camera and monitor screen to monitor the behaviour of the experimental animals. The temperature in the chamber was maintained at 32 ± 0.5 °C. The relative humidity inside the chamber was maintained at 50% and fresh air was allowed to flow into the chamber at a rate of 5.5 L/m.

Training regimen for performance evaluation

All groups except the Untreated Control group were trained to run on a motorized rodent treadmill (Columbus Instruments, USA) for 5 days. Initially, all animals ran for 1–2 min up a 15% grade. Exercise time and treadmill speed was progressively increased each day until all the animals were running at 1.34 m/s. Rats were run at the same training intensity until they could no longer maintain the pace of the treadmill despite continued prodding of electrical shock. The failure to continue running despite prodding was defined as exhaustion, at which point the total duration of running time was recorded for the assessment of performance.

Experimental protocol

After one week of treadmill habituation, all the rats were run to exhaustion and their times to exhaustion were noted (Basal Endurance). All the rats were run at the same time of day in order to avoid any possible effects of diurnal variation in glucose or hormone concentrations. The hypoxic groups were gradually exposed to chronic simulated hypobaric hypoxia (349 mmHg) equivalent to 6960 m (20 000 ft) for 21 h

daily for 18 consecutive days from 1200 to 0900 h the next morning with a 3h break every day, during which maximum consumption took place. The rats were brought to sea-level conditions every morning and this 3-h period was used to replenish their food and water supplies and also to record the various parameters like food and water intakes, body weights, exercise endurance, and collect blood samples, as the protocol dictated. All the rats were given *ad libitum* food and water inside the chamber during the exposure period. At the end of the exposure session each day, the hypoxic experimental group was administered the CHO supplement in their respective cages in addition to water. These supplement bottles were withdrawn just before the animals were restored to the chamber at 1200 h every day. The normoxic and untreated control groups were maintained at ambient pressure and altitude (220 m) in individual cages.

The food intake was recorded daily to the second decimal place at the same time in the mornings. The water intake was recorded to the nearest 0.5 ml. The food and water intakes are expressed as g intake/100 g and ml/100 g body weight (BW), respectively. The food intakes were then subsequently expressed as kcal/100 g body weight of the animals. Body weight was recorded every day in a tared plastic 1000-ml beaker and their weights recorded to the second decimal place, and expressed in grams. The 32% CHO supplement intake was also measured daily. It was administered in graduated 25-ml glass bottles. It was prepared fresh every second day. The CHO supplement intake was expressed as ml ingested/100 g body weight and after determining the caloric value was added to the food intake to obtain the total energy intake expressed as kcal/100 g body weight.

Blood samples were collected at the end of the exposure period after the exercise session. Blood was withdrawn from the retro-orbital venous plexus under ether anesthesia for blood glucose and insulin estimations. Blood was collected in heparinized tubes and then subsequently centrifuged. Aliquots of the plasma were stored at -70°C till they were assayed for glucose and insulin. At the termination of exposure, i.e., 19th day, all the rats were sacrificed by decapitation and muscle and liver samples were taken for glycogen estimations.

Biochemical determinations

Blood glucose

Blood glucose estimations were done by an enzymatic colorimetric method using kits obtained from Boehringer Mannheim GmbH Diagnostica. The kit was based on the glucose oxidase–peroxidase method of Braham and Trinder (1972).

Blood insulin

Blood insulin estimation was done by the RIA method using a rat insulin kit obtained from INCSTAR Corporation, Stillwater, MN, USA

Glycogen content of muscle and liver

Immediately after decapitation, the muscles of the hind limb were skinned and rapidly exposed. A sample of muscle tissue was excised and immediately placed in pre-weighed tubes containing 30% KOH chilled on ice. Following this, a mid-sagittal incision was made in the abdomen of the animals and a portion of the lateral lobe of the liver was excised and immediately freeze-clamped in a similar fashion. The glycogen content of the muscle and liver was determined by the method of Montgomery (1957).

Statistical analysis

The hypoxic pre-exposure values were compared to their corresponding hypoxic exposure values using paired “*t*” test for body weight, food intake, water intake, and exercise endurance on various days separately. Similarly, the experimental groups were compared with their parallel age-matched control group using unpaired *t*-test.

One-way ANOVA was used to compare various groups using Newman–Keul’s Multiple Range test for blood glucose, muscle glycogen, liver glycogen and blood insulin values. Five percent level of probability was selected as the criterion of statistical significance.

Results

Food and water intakes

The food intake (FI) and water intakes (WI) of the hypoxic groups were significantly reduced ($p < 0.001$) in comparison with either their pre-exposure intakes or the intakes of the normoxic groups during the exposure period (Fig. 1). Compared with normoxic rats, the daily food intakes of the HA rats were lower by 47.6% and 43.53% for experimental and control groups, respectively. This fall in food consumption was noticeable right from day 1 of exposure, dipped to the lowest value by the end of the first week, and then picked up again by the end of the exposure protocol, i.e., the third week. There was no significant difference between the food intakes of the HE (CHO-supplemented) and HC (not supplemented) groups during the exposure period. The water intake of the HE group was significantly lower ($p < 0.001$) than that of the HC group and also

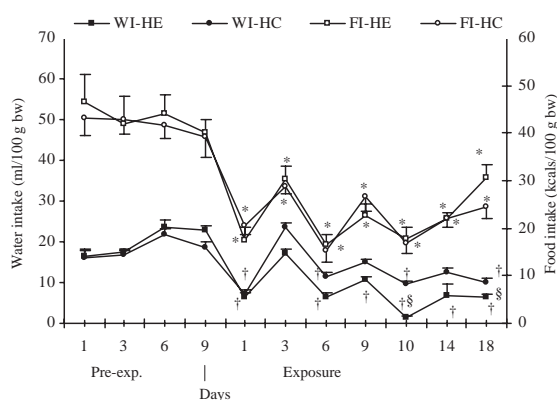


Figure 1. Effect of hypoxia on food and water intakes of control [FI-HC, WI-HC] and CHO-supplemented [FI-HE, WI-HE] rats. *Significantly different compared to corresponding PE 9 value ($p < 0.001$); †Significantly different compared to corresponding PE 9 value ($p < 0.001$); § Significantly different compared to corresponding control ($p < 0.05$).

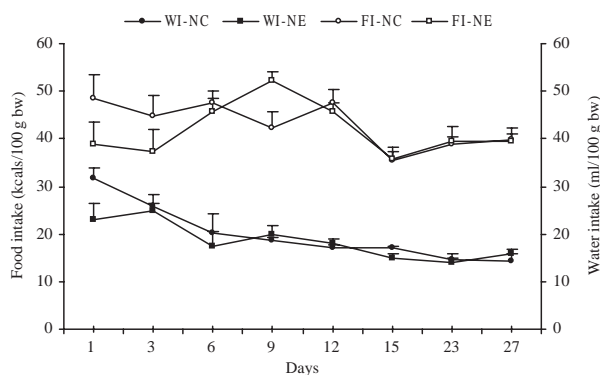


Figure 2. Food and water intakes of normoxic control [FI-NC, WI-NC] and CHO-supplemented [FI-NE, WI-NE] groups.

it's corresponding pre-exposure value during the exposure period (Fig. 1). There was no significant difference in the food and water intakes of NC and NE (CHO-supplemented) groups throughout the study period (Fig. 2).

The HE group consumed significantly more ($p < 0.01$) CHO supplement compared to the NE group (Table 1). The HE group thus managed to consume a similar amount of calories as the HC group even though the amount of chow consumed was reduced.

Body weight

The body weights of the hypoxic groups were significantly reduced ($p < 0.01$) in comparison with their pre-exposure weights (Fig. 3) and also the normoxic groups who continued to gain weight normally (Fig. 3).

Table 1. Supplement intake (ml/100 g BW) in CHO-supplemented hypoxic and normoxic rats

Days	NE	HE
1	3.07 ± 0.53	2.96 ± 0.33
3	3.73 ± 0.87	15.39 ± 1.58***
6	4.27 ± 0.88	10.41 ± 2.33*
9	5.31 ± 0.72	11.02 ± 0.99***
12	5.81 ± 0.66	12.77 ± 1.98**
15	6.09 ± 0.44	12.89 ± 0.99***

Values are: Mean ± SEM, $n = 7$.

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, significantly higher compared to NE.

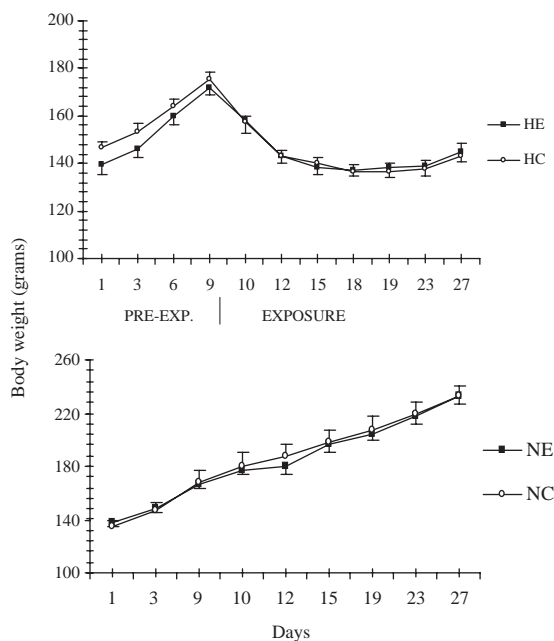


Figure 3. Growth rate of hypoxic [HC, HE] and normoxic [NC, NE] groups.

The CHO supplement however, did not have any protective effect on the body weight as the HE groups continued to lose weight in a similar fashion as the HC groups and there was no significant difference between the weights of both the hypoxic groups. This was borne out by the fact that the HE group consumed the same amount of calories as the HC group by voluntarily reducing the amount of chow.

Exercise endurance

The animals of this batch were exercised to exhaustion on a rodent treadmill and the time taken till exhaustion was noted down. Hypobaric hypoxic exposure significantly reduced ($p < 0.001$) the endurance capacity of the hypoxic groups compared to either their pre-exposure values or the normoxic groups (Fig 4).

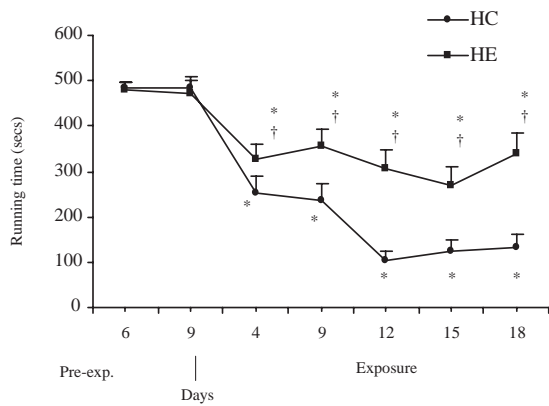


Figure 4. Effect of hypoxia on exercise endurance in control [HC] and CHO-supplemented [HE] groups. * Significantly different compared to corresponding PE 9 value ($p < 0.001$); † Significantly different compared to corresponding control ($p < 0.05$).

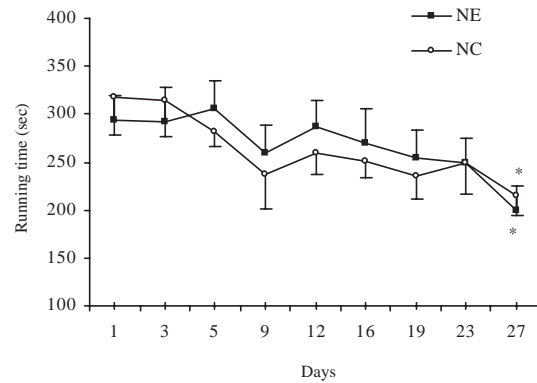


Figure 5. Exercise endurance in normoxic control [NC] and CHO-supplemented [NE] groups. * Significantly different compared to corresponding day 1 value ($p < 0.001$).

Table 2. Biochemical variables in groups

Variables	Groups					Error variance	Overall significance <i>p</i>			
	HC (1)	HE (2)	NC (3)	NE (4)	UC (5)					
*Plasma glucose (mg/dl) <i>n</i> = 7	62.7	77.00	114.96	106.85	103.86	159.25	< 0.001			
Muscle glycogen (mg/g tissue) <i>n</i> = 7	5.69	12.34	5.18	4.75	3.53	2.78	$p < 0.001$			
Liver glycogen (mg/g tissue) <i>n</i> = 7	25.22	21.28	28.49	23.1	16.64	24.35	< 0.05			
Plasma insulin (ng/ml) <i>n</i> = 6	2.36	2.66	9.15	7.38	6.08	6.36	< 0.001			
<i>Pair-wise statistical significance</i>										
	1 vs 2	1 vs 3	1 vs 4	1 vs 5	2 vs 3	2 vs 4	2 vs 5	3 vs 4	3 vs 5	4 vs 5
Plasma glucose	$p < 0.05$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	$p < 0.01$	NS	NS	NS
Muscle glycogen	$p < 0.01$	NS	NS	NS	$p < 0.01$	$p < 0.01$	$p < 0.01$	NS	NS	NS
Liver glycogen	NS	NS	NS	NS	NS	NS	NS	NS	$p < 0.01$	NS
Plasma insulin	NS	$p < 0.01$	$p < 0.01$	$p < 0.05$	$p < 0.01$	$p < 0.01$	$p < 0.05$	NS	$p < 0.05$	NS

Values are reported as mean.

*Blood samples were collected immediately after exercise.

However, the CHO-supplemented hypoxic (HE) group ran for a significantly longer duration ($p < 0.01$) than the HC group throughout the exposure period, the difference becoming apparent by the end of the first week of exposure. However, CHO supplementation in the NE group did not result in a significantly increased endurance over the NC group (Fig. 5).

Plasma glucose and insulin

The blood glucose of the hypoxic groups (HE, HC) was significantly reduced ($p < 0.01$) in comparison to the NE, NC and UC groups. There was no significant difference among the values of the NC, NE and UC groups. The blood glucose of the HE group was

significantly higher ($p < 0.05$) than the HC group (Table 2). HA exposure in either group also resulted in hypoinsulinaemia as the plasma insulin values of both the hypoxic groups were significantly reduced ($p < 0.01$ and $p < 0.05$, respectively) when compared to the Normoxic and UC groups, respectively. There was no significant difference between the plasma insulin values of the hypoxic groups (Table 2).

Muscle and liver glycogen

As shown in Table 2, the muscle glycogen content of the HE group was significantly higher ($p < 0.01$) compared to the HC, NE, NC and UC groups. There

was no significant difference in the liver glycogen levels among all the groups.

Discussion

When lowlanders ascend to HA, they are concurrently exposed to freezing temperatures, inadequate and unpalatable food and water supplies, and fatigue from exhausting work, in addition to the hypobaric hypoxia. All the above factors tend to confound the effects of hypoxia and thus it is difficult to isolate the effects of hypoxia alone. Adequate and desirable food and water supplies can be made available for a short duration. The workload can be voluntarily reduced. Sufficient and appropriate clothing can take care of the cold factor, but when freezing temperatures are combined with hypobaric hypoxia, their effects are accentuated. In view of this, the animal environmental chamber provides an ideal opportunity to create and study the effect of simulated hypoxic stress of HA by exposing rats to decreased ambient PO₂ while maintaining other factors like temperature in the thermo neutral range and humidity constant and providing them with a nourishing and palatable diet.

During the exposure period, the animals experienced significant anorexia as evidenced by their hypophagic response. The voluntary ingestion of diet was reduced which resulted in weight loss. It was observed that the animals did not consume much food and water during the exposure period, and the maximum consumption took place during the 3-h period when they were at sea-level. Many researchers have reported anorexia in animals (Tanaka *et al.*, 1997; Vats *et al.*, 1999; Singh *et al.*, 1996; 1997a) and in humans (Consolazio *et al.*, 1969; Hannon *et al.*, 1976; Young *et al.*, 1989), who attributed this decrease to loss of appetite. The anorexia observed in the present study was maximum during the first week and showed an improvement after two weeks of exposure. This was also observed by other scientists who reported that the anorexia in humans may last from 6 to 12 days at moderate altitude (Hannon *et al.*, 1976) and may continue indefinitely at an altitude where acclimatization is incomplete. In the present study, also, the animals did not resume normal level of food consumption during the 18-day exposure protocol and their food consumption was only about 55% compared to their pre-exposure intake.

The CHO-supplement intake of the hypoxic groups was significantly higher than the normoxic group. These findings are clearly in accordance with the reports of Jacobs and Sharma (1969), and Singh *et al.* (1996, 1997a) and clearly demonstrate the altered taste responsiveness

under the stress of hypoxia. The total intake of the supplemented group could have been higher but for the fact that they had access to the supplement for only the 3 h that they were outside the chamber. Thus, the supplement was consumed at the cost of the chow.

In the present study, the HE and HC groups had a BW loss of 16% and 18%, respectively. There is now ample evidence that both long-term and short-term exposure to HA induces weight loss in humans (Boyer & Blume, 1984; Guillard & Klepping, 1985; Consolazio *et al.*, 1968; Rose *et al.*, 1988). The weight loss in humans recorded at extreme altitudes is due, at least partly, to drastic reduction of lean body weight and muscle wasting (Kayser, 1994). The exact causes for this weight loss, whether discomfort, decreased availability of palatable food, or changes in nutrient preferences and eating habits, are difficult to explain. Several investigators have used an animal model to study the direct effects of hypoxia on body and muscle growth. Many studies have reported a decrease in the growth rate of rats at least during the first days of exposure to HA (Bigard *et al.*, 1996; Schnakenberg *et al.*, 1971; Singh *et al.*, 1996; 1997a). The depression of growth rate has been attributed to anorexia, loss of body water, a direct effect of hypoxia on protein metabolism, or impaired absorption of nutrients (Schnakenberg *et al.*, 1971). However, other researchers have reported no adverse effects on digestibility of macronutrients at HA (Guillard & Klepping, 1985; Kayser *et al.*, 1992; Rai *et al.*, 1975). In the present study, the absorption of nutrients and faecal losses were not determined. As protein levels in the diet were maintained constant throughout the study, the gain in body weight was used as an indirect indicator of the severe effect of hypoxia on depression in food intake.

Schnakenberg and Burlington (1970) studied the effects of high CHO, protein and fat diets and HA on growth and caloric intake of rats. The growth rate of all the diet groups was reduced at altitude. The caloric intake was reduced and the high protein diet had a further anorectic effect. They found only a slight decrease in fat-diet consumption. Bigard *et al.* (1996) studied the effect of different dietary protein levels on growth rate and body composition during long-term (26 days) exposure to severe hypoxia (6000 m) in rats. They observed marked anorexia in response to HA exposure for all high protein diets. They concluded that hypobaric hypoxia *per se* (i.e. independently of anorexia) decreased the growth rate and that increased protein intake had no beneficial effect on the preservation of lean body weight.

The effect of CHO-supplementation in the solid form, i.e., in the diet pellets itself in order to compare its influence on food intake and weight gain with the liquid CHO was not done in this study. However, Edwards *et al.* (1994) studied nutritional intakes and the

effects of carbohydrate supplementation of soldiers performing moderate amounts of physical work at altitudes of 3200–3500 m for 13 days. They concluded that despite the availability of ample, well-cooked food soldiers with high rates of energy expenditure failed to maintain body weight and lost approximately 1.7 Kg. The effect of solid CHO supplementation was not significant.

The blood glucose levels of all the hypoxic groups were significantly decreased during the hypoxic exposure and the hypoxic groups were significantly hypoglycemic when compared to the normoxic and UC groups. Many investigators have reported changes in blood glucose levels at high altitude. A depressed utilization of glucose at high altitude has been reported (Picon-Reategui, 1966; Blume & Pace, 1967). A depressed oxidation of glucose and its conversion to fatty acids were also observed in high altitude-exposed rats (Picon-Reategui, 1966). Our earlier studies showed a decrease in blood glucose levels in rats subjected to continuous simulated hypobaric hypoxia (6960 m) for 21 days (Singh *et al.*, 1996). Tanaka *et al.*, 1997, reported similar findings. Fasting blood glucose has repeatedly been reported to be lower in rats exposed for various periods of time to simulated altitude (Davidson & Aoki, 1970; Ou, 1974). During acute exposure to altitude, the increase in haematocrit and semi-starvation imposed by hypoxia-induced anorexia may serve to lower the whole blood glucose concentration. Studies in experimental animals have shown a reduction in blood glucose during acclimatization to high altitude (Blume & Pace, 1967).

The hypoxic groups were significantly hypoinsulinaemic ($p < 0.05$) when compared to either the normoxic or the untreated groups. The NC group had significantly higher ($p < 0.05$) plasma insulin values compared to the UC group, though it did not differ from the NE group. Decreases in serum insulin have been reported in hypoxic dogs at rest by Baum and Porte (1969). Sutton (1977) also reported similar findings in men exercising under hypoxia concomitant with hyperglycemia. The decrease in insulin levels may be either due to reduction in synthesis or increase in turnover.

The CHO supplemented group had significantly higher muscle glycogen contents compared to the HC group and the Normoxic and Untreated Groups. The liver glycogen levels of all the groups did not differ much. Reduced liver glycogen levels have been found in adult rats exposed to simulated altitude of 4000 m for 6 weeks (Davidson & Aoki, 1970) and 5400 m for 3 months. This has been attributed to a reduction in the activities of the rate limiting gluconeogenic enzymes (Ou, 1974) and in gluconeogenesis by the liver (Freminet, 1976). Vats *et al.*, 1999, found increased liver glycogen by day 1 of exposure and subsequently, decreased liver

glycogen towards the end of a 21-day exposure period along with decreased glycogen synthetase activity. The altitude-induced decrease in muscle glycogen is consistent with results of previous studies (Blume & Pace, 1967; Taguchi *et al.*, 1985; Bigard *et al.*, 1996). Bigard *et al.* (1996) demonstrated that glycogen stores in the muscle, particularly soleus, were altered by both decreased energy intake and hypoxia *per se*. Enhancement of protein in the diet had further deleterious effects on glycogen stores (Bigard *et al.*, 1996). In the present study, except for the HE group, all the other groups had comparable muscle glycogen levels. It is difficult to explain the decreased muscle glycogen levels in the NE group.

Hypobaric hypoxia resulted in deterioration in exercise capacity compared to the basal values. Supplementation with CHO however ameliorated this deterioration and the HE group performed better compared to the HC groups and ran significantly longer than the HC group throughout the exposure period, the difference becoming apparent as early as the first week of exposure. There was no significant difference in the exercise capacity of the NE group when compared to the NC. This surprising result becomes clear in the light of the actual CHO consumption that was very low and total energy intake, which was not significantly different from that of the control group.

The reduction in work capacity and physical performance under hypoxia has been studied by many workers who have reported decreased work capacity in men at HA (Cymerman *et al.*, 1989; Sutton *et al.*, 1988). After acclimatization at moderate altitudes (3000 m), the deterioration in exercise performance is regained to a large extent; but at higher altitudes (3000–8000 m) no amount of acclimatization helps in full recovery of aerobic function (Cymerman *et al.*, 1989). A reduction in treadmill exercise performance in rats was reported by Altland *et al.*, (1969) at sea level after acclimatization to a simulated altitude of 7600 m, 5 h daily for 6 weeks. However, Abdelmalki *et al.* (1996) reported greater VO_{2max} and endurance times to exhaustion in trained rats exposed to normobaric hypoxia for 9 weeks compared to normoxic rats fed *ad libitum* and normoxic pair-weight rats. The rigorous and prolonged training schedule (90 min running/day, 5 days/week, for 9 weeks) used in the study resulted in this improved performance. In addition, the altitude simulated was moderate (3700 m).

Previous findings of a decreased rate of muscle glycogen degradation (Young *et al.*, 1982) and increased muscle free fatty acid levels (Young *et al.*, 1982; 1992) during exercise after acclimatization to HA have been interpreted to mean that HA acclimatization causes an enhanced ability to utilize lipid energy sources (Young

et al., 1982; 1992) and a glycogen-sparing effect. However, Young et al. (1982) did not control energy intake in this study and no direct evidence has been observed for utilization of muscle triglycerides or plasma FFA in support of this theory. Butterfield (1996) and Brooks et al. (1991) suggest that these interpretations have been influenced by the cachexia and energy imbalance occurring at HA and which is similar to the dependency on fat utilization seen in starvation. The increase in BMR at HA would further exacerbate these findings. In fact, recent evidence by Brooks et al. (1991), Roberts et al. (1996a,b) have shown increased glucose dependency in well-nourished men. The picture however, is different in women exercising at HA, in whom no such shift toward greater utilization of CHO is found (Braun et al., 2000).

In conclusion, chronic 21 h/day hypobaric hypoxia equivalent to 6960 m for 18 days in rats resulted in decreased food intake resulting in loss of body weight, decreased exercise endurance capacity, lower blood glucose, insulin and muscle glycogen levels, compared to normoxic controls. Supplementation with a 32% CHO solution did not ameliorate the hypoxia-induced hypophagia and body weight loss. However, the 32% CHO supplement did significantly delay the onset of fatigue during exercise. This delay in fatigue onset may be due to the maintenance of CHO oxidation and/or reduction in rate of muscle glycogen utilization.

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