NFI BULLETIN
Bulletin of the Nutrition Foundation of India
Volume 20 Number 3 July 1999

Nutrition In High Altitudes

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Man inhabits all regions of the earth, from the poles to the equator. Some places are visited for very brief periods due to inhospitable environmental extremes. When faced with hot, cold or high altitude environments, humans can either modify the micro-environment accordingly or adapt their physiology to fit the environment or use a combination of these two strategies. Metabolic adaptations to heat, cold and high altitude (HA) hypoxia may, in some instances, be accompanied by changes in nutrient requirements. The diet of humans differ in quantity and composition in different climatic regions.

Although much of this variation may be due to availability of food in the given area, there is the intriguing possibility of selection of certain classes of foods or adaptation to dietary habits which help in acclimatisation to a given environment. Most of the studies on the relationship of diet and extreme environment are the outcome of military research or expeditions to mountains and polar regions. Captain Cook kept his crew entirely free of scurvy during his second voyage to south seas (1772-75) by using germinating seeds and lime juice along with food items. Beriberi was the scourge of the Japanese Navy prior to 1882 when it was eliminated by Admiral Takaki by increasing allowances of vegetables, fish, meat and barley in addition to the staple diet of polished rice[1].

Indian troops have to operate in diversified field conditions like hot and dry deserts of Rajasthan where temperature exceeds 50°C, humid forests of the North East, hot humid coastal regions and HA snow- bound areas of the Himalayas with temperature much below 0°C. Under field conditions troops have to operate in difficult terrains and have various strenuous duties like digging bunkers, maintaining vigil in defensive positions, long distance route marches, loading and unloading. Accordingly, their energy and nutrient requirements in field areas are different and much above those of the general population. Military operations can often be a combination of intensive physical efforts alternating with long periods of minimal activities performed in hostile weather. Under these conditions, high energy expenditure, not always compensated by adequate energy intakes, has been recorded[2,3]. Studies on nutritional requirements of armed forces under different climatic conditions and formulation of different ration scales is a major area of research at the Defence Institute of Physiology and Allied Sciences (DIPAS). In this article, we are discussing our observations on high altitude nutrition.

HIGH ALTITUDE NUTRITION

The Himalayas constitute the northern frontiers of India with human habitation up to an altitude of 4,300 m, while soldiers are deployed even up to 5,800 m for fixed tenures. HA presents an extreme environment with hypoxia, cold, high solar radiation as physical and psychological stress. These areas are also arid in nature with sparse vegetation and scarce potable water. Reduced barometric pressure decreases boiling point of water making preparation of food difficult. All these factors give rise to nutritional problems.

Weight loss and anorexia: Weight loss, particularly at extreme HA, depending on the duration of stay is a major problem[4]. The basis for much of the initial loss of weight at HA is anorexia, hypophagia and nausea due to acute mountain sickness. Hypophagia is more pronounced during the first three days of exposure to HA even when best possible food is available. Calorie consumption can get reduced by 40 per cent at 4,300 m resulting in a negative nitrogen balance[5,6,7,8].

This, coupled with increased metabolic rate induced by HA exposure, is considered a major cause of weight loss[9]. Various factors affecting weight loss are indicated in Table 1.

Energy requirement and composition of diet: The energy cost of various activities performed determine the total energy expenditure and this in turn determines calorie and nutri-

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TABLE 1
Factors Affecting Weight Loss At High Altitude

- Disease
- Dysbarism
- Negative nitrogen balance
- Altered nutrient digestibility
- Increased insensible water loss
- Increased energy expenditure
- Appetite loss, hypophagia
- Diuresis, hypodypsia

tional requirements. Increase in energy expenditure ranging from 6.9 to 25 per cent have been seen by Johnson *et al*[7] and Malhotra *et al*[10]. As regards the energy cost of various activities under stationary conditions there is no variation as compared to the sea level. In a report by Burstein *et al*[11], energy expenditure in cold hilly terrain is reported to be 4,281 Kcal without change in energy cost of performing military manoeuvres. High energy expenditure may be due to heavier loads carried by troops as cold protection garments and effort in walking in snow-bound hilly terrain.

High carbohydrate diets are beneficial at HA[12]. The advantage of high carbohydrate diets is that respiratory coefficient (RQ) of carbohydrate diets is around 1.0; on the other hand, if fat is exclusively taken then RQ is 0.7. In high terrestrial altitudes alveolar partial pressure of oxygen (PO_2) falls with a fall in barometric pressure and when there is shift of RQ from 0.7 to 1.0, there is an increase in PO_2 and this gives rise to an increase in arterial oxygen saturation. Diets high in carbohydrates are shown to enhance the glucose metabolism at HA. Studies on Indian sea level residents at HA and their dietary habits show that up to 60 per cent energy is derived from carbohydrates[13]. A proximate composition of the ration of troops at 9,000-12,000 ft is given in Table 2.

Taste threshold for sweet and salt modalities were found elevated while for bitter and sour were reduced[14,15]. Long term studies on carbohydrate metabolism by Srivastava *et al*[16] have shown that fasting blood glucose level was raised initially and remained high up to 10 months of stay at HA and thereafter it fell even below the values observed at sea level. Glucose tolerance remained normal throughout the stay at HA.

Protein requirement and nitrogen balance at high altitude: Negative nitrogen balance was reported at HA by Consolazio *et al*[17] and Surks *et al*[18]; however, caloric intake in these studies was less. Extensive studies on nitrogen metabolism at both acute and after long-term stay at HA have been carried out by DIPAS in subjects on adequate caloric intake. In a well VGL controlled study with 12 g/day of intake, Sridharan *et al*[19] had shown positive balance of about 5 g. On the third day of stay at HA, similar values were also reported by Consolazio *et al*[20]. Even after prolonged stay at HA nitrogen utilisation was satisfactory. Variation in serum protein level in a longitudinal study during 24 months was also within normal range[21]. After acclimatisation there is alteration in protein metabolism at altitude when intake of food was adequate (4,500 Kcal) with protein at level of 2 g/kg body weight/day ensured.

After acclimatisation to altitude of 3,800 m for two years, Rai *et al*[22] had studied utilisation of fat by feeding up to 325g/day and found 95.5 per cent fat digestibility with almost constant levels of faecal fat. In a controlled study conducted by Sridharan *et al*[19], no adverse effect on digestion under HA was observed. Butterfield *et al*[9] and Kayser *et al*[23] had also concluded that there was no dysfunction of absorption though intake was sometimes low due to anorexia. As regards gastric functions, change in the volume of basal as well as maximal gastric juice was observed at altitude[19]. The concentration of acid and total acid output in gastric juice under basal conditions was significantly reduced but there was no difference in maximum acid output or its concentration at altitude. This shows maximum reaction of acid normally occurs during digestion of food and is not affected by HA. The lower basal acid output at altitude does not affect the digestion of protein but could be a factor in the reduced incidence of peptic ulcer at HA which has been reported by Singh *et al*[24] in Indian troops. D-xylose excretion which is used as a test of the absorptive activity of the upper part of the small intestine also remains normal indicating that absorption functions of the small intestine are not disturbed at HA[19].

TABLE 2
Proximate Composition Nutrient Content of Diet for Active Individuals at Altitude 9,000 to 12,000 feet (Ref 13)

Nutrients	Quantity
Proteins	144.0 g
Animal protein	40.0 g
Fat	147.9 g
Carbohydrates	746.8 g
Vitamin A	6279 IU
Thiamine	4.5 mg
Riboflavin	3.8 mg
Nicotinic acid	37.5 mg
Ascorbic acid	247.6 mg
Iron	91.5 mg
Calcium	1.55 g
Calories	4,829 Kcal

(Carbohydrates: 61 per cent; fat: 27.3 per cent; Proteins; 11.7 per cent)

Fluid and electrolyte balance: The literature regarding fluid balance at HA is highly controversial. Negative water balance has been reported in troops at 4,300 m by Consolazio *et al*[20]. Besides cold-induced diuresis at HA, hyper ventilation along with the dry environment at altitude makes individuals prone to hypohydration. Investigations carried out for assessment of body fluid compartments by Jain *et al*[25] and Singh *et al*[26] had shown a decrease in plasma volume. These studies point out a fall in total water content. Bhardwaj and Malhotra[27] using the anthropometric technique and soft tissue X-ray of muscles had found a loss in body water and bone mineral content after a stay of four weeks at 4,300 m. Controlled studies on fluid intake and output by Sridharan *et al*[19] had shown that there was no change in the fluid balance, and similar findings had been reported by Rose *et al*[28]. Acute exposure to moderate altitude causes transient hypohydration which is due to increased diuresis and an acute reduction in fluid intake due to a decrease in thirst.

Prolonged stay at extreme altitudes may cause severe salt and water retention. The role of hormones in normal fluid metabolism at HA is not clear, but a number of hormones play a role in retention of salt and water in pathologic states like acute and subacute mountain sickness. Long-term effects of moderate and extreme altitude on body fluid compartments and its determinants need to be investigated[29]. Increased urinary excretion of Na^+ and K^+ on exposure to hypoxia have been reported while some workers have found only increase in Na^+ with decrease in K^+ excretion. Studies on Indian troops by Malhotra *et al*[30] as well as Chatterjee *et al*[31] had shown no significant change in serum Na^+ and K^+ levels. Chatterjee *et al*[31], however, found decreased levels of Mg^{2+} and Ca^{2+} excretion during acute exposure in humans at 3,770 m. At HA, though there is always a balance between blood formation and destruction, there is no evidence of increased dietary iron requirements. Urinary excretion of Zn^{2+} is increased during physical exertion as observed during an expedition to Mt Everest[28]. Further research is needed to identify dietary requirement of Zn^{2+} at altitude.

Requirement of vitamins: Studies were carried out on the nutritional status of troops with respect to vitamin requirement at altitude 3,660 m. A study was carried out with fresh as well as tinned food. It was observed that the requirement of vitamins was not different compared to sea level. Additional supply of multivitamin was not required at least for a period up to 30 days[32]. Antioxidant nutrients such as vitamin E, C and A (β-carotene) as well as selenium, copper, zinc and manganese may, however, be required in greater amounts in cold and HA environments to reduce lipid peroxidation. These antioxidants may act in a concerted manner to combat the oxidative stress arising from different sources. β-carotene protects against immuno-suppression caused by long-wave UV radiation encountered in the outdoor environment[33].

The oxidative stress from exercise that increases the rate of production of free radicals can be countered by enzymes like superoxide dismutase (copper, zinc and manganese) and glutathione peroxidase (selenium) reactions. Animal studies indicate increased levels of lipid peroxidation and decrease in levels of glutathione (GSH) in muscles and blood of rats during hypoxic exposure at altitude 7,620 m which may be due to limitation of ATP and inhibition of glutathione reductase activity (unpublished). In a human study at HA[34] the role of vitamin C and E in the initial stages of acclimatisation have pointed out positive effects of these antioxidant vitamins in warding off oxidative stress and concomitant effects on cell membrane integrity. During rough weather when supplies of fresh fruits and vegetables become limited at HA, vitamin C supplement is recommended due to its antioxidant role.

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