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Nutritional Requirements for Human Adaptation in Extreme Environments

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Humans are able to live and work in almost all the environmental extremes of planet Earth and also in space due to their remarkable physiological adaptability and/or by modification of environment itself. Adequate nutrition plays a key role in adaptation and accordingly nutritional needs vary to a great extent. Indian troops have to operate in diversified field conditions like, hot and dry deserts of Rajasthan where temperature goes above 50°C, humid forests of North East, hot humid coastal regions and high altitude (HA), snow bound areas of Himalayas with subzero temperatures. Proper nutrition is often overlooked but is a critical component of effective work under these conditions. HA presents an extreme environment with hypoxia, cold, high solar radiation as physical stresses beside the psychological stress. Many studies have shown that there is a significant decrease in body weight on ascent and/or a stay at HA. This weight loss is mainly caused by malnutrition due to hypoxia related anorexia, independent of acute mountain sickness. Intake of calories and nutrients is reduced by about 40% at HA without alterations in gastrointestinal functions up to a height of 5000m. Various causes for anorexia at HA like change in taste sensitivity and hormonal alterations have been studied. The vitamin requirements at HA are not different from sea levels. However supplementation of antioxidants i.e. vitamin C, Vitamin E and zinc have been found to be beneficial during initial stages of acclimatization. Health food supplements and "adaptogens" such as Composite Indian Herbal Preparation (CIHP) have been found to enhance the acclimatization of soldiers at HA. There is a common belief that cold climatic conditions lead to an increased appetite. However the reported increase in appetite is also associated with changes in other factors i.e. increased activity levels, energy expenditure due to thermogenesis, social isolation and modification in the diet. Increase in body weight is a common observation of various Indian Antarctic expeditions, which is mainly due to increased calorie intake.

Adequate fluid replacement is a primary requirement and overshadows all other nutrient requirements for work in hot environments. Heat acclimatization relatively has no effect on water requirements. The requirement of salt intake increases due to loss in sweat, 15 to 16g of salt normally taken in diet is quite adequate for acclimatized people. Potassium loss in perspiration however does not decrease with acclimatization, but on the other hand increases in wake of the accentuated sodium-potassium exchange system and there may be potassium deficiency if adequate intakes are not maintained.

Space explorations with increased duration have opened a challenging area of research in the field of nutrition. Major stress in space is micro-gravity. The body composition changes and body weight loss do not follow classical pattern. Most important is muscle loss and limited resistive exercise by crewmembers. The role of nutrition in musculoskeletal losses during space flight has not been clearly defined. Space food system have made significant advances and progressed from tubes and cubes to open containers in which food is consumed with regular utensils. Food variety has increased by use of innovative preservation technologies. Nutritional requirements for long flights have been refined, placing more demands on food technology.

Key Words: Adaptation, Extreme Environments, Heat, High Altitude, Hypoxia, Micro gravity, Nutritional needs, Space exploration

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Introduction

Humans have been able to survive and function in many extreme environments of almost all regions of the earth from poles to equator and also in space. Some places are visited for very brief periods due to inhospitable environmental extremes. An extreme environment can be defined as an environment where basic needs, like acquisition of food, shelter and protection, require extraordinary efforts.One important feature of these environments is that an error in judgment and behavior can have serious, even fatal consequences (Brubakk 2000). These environments both natural and man-made are presented in table 1.

When faced with hot, cold, high altitude (HA, terrestrial heights above 2700 meters) or space environments, human beings either try to modify the microenvironment accordingly or adapt their physiology to fit the environment or use a combination of these two strategies.Although human beings are remarkably adaptive but main limitation is homeothermy which means regardless of environ-mental temperature the normal body temperature must be maintained within a relatively narrow range.We have several physiological defense mechanisms to overcome this problem e.g. shivering, sweating, vasodilatation or vasoconstriction. When the capacity of these mechanisms is exceeded and body core temperature drops below 35^{0}C (95^{0}F) or rise above 41^{0}C (106^{0}F), the physical and mental performance deteriorates rapidly and both these conditions may be life threatening. Similarly hypoxia associated with cold at HA imposes severe restriction on adaptability. Metabolic adaptations to heat, cold and HA hypoxia may in some instance be accompanied by changes in nutrient requirements.Inadequate nutrition can impair metabolic response (figure1). Appetite and thirst perceptions are generally inappropriate in these environmental extremes, which lead to inadequate food and water intake. The availability of water and food is often limited due to logistic

Table 1 *Condition and Environmental Extremes*

Primary Natural	Primary man made	Condition	Environment
X		Low temperature	Arctic/Antarctic/ Altitude
X		High temperature	Tropics
X	X	Reduced pressure	Altitude/flight
X		Increased pressure	Diving
X		Reduced gravity	Space
	X	Increased gravity	Flight
X		Decreased oxygen Availability	Altitude
	X	Increased oxygen	Diving
	X	Change in inspired air Composition	Diving
X		Lack of water	Desert
X	X	Lack of food	anywhere
X		Increased radiation	Space/Altitude
X	X	Isolation	Arctic/Antarctic/ Space

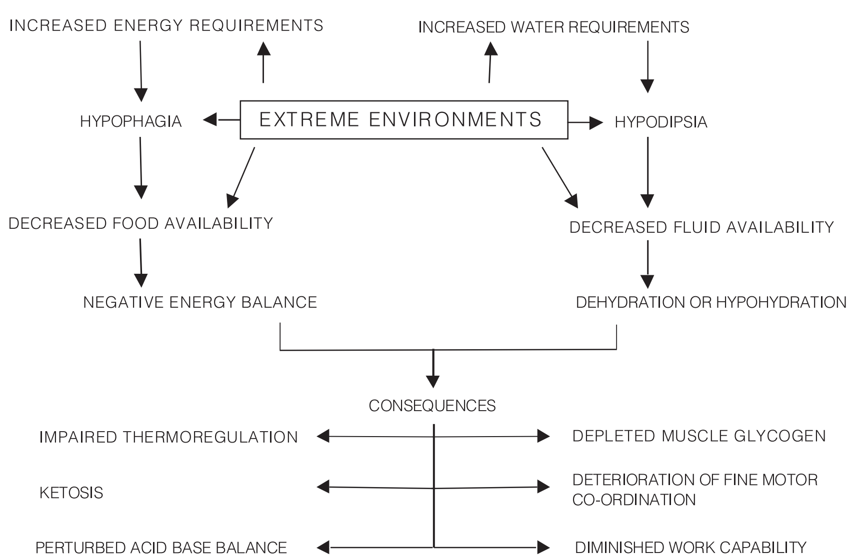

Figure 1 Cascade effect of environmental extremes on work performance

constraints or often get second priority for carrying of essential equipment, clothing and gear. Proper nutrition is often overlooked but is a critical component of effective work under these conditions. Energy requirement for work in temperate, hot, cold and HA environments are shown in table 2.

The diet of humans differs in quantity and composition in different climatic regions. Although much of this variation may be due to availability of food in that area, there is an intriguing possibility of selection of certain classes of foods or adaptation to some dietary habits, which help in acclimatization process in that environment. Most of the studies on 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 limejuice along with food items. Beriberi was the scourge of the Japanese Navy prior to 1882 when Admiral Takaki eliminated it by increasing allowances of vegetables, fish, meat and barley in addition to staple diet of polished rice.

Indian troops have to operate in diversified field conditions like, hot and dry deserts of Rajasthan where temperature goes above 50°C, humid forests of North East, hot humid coastal regions and HA, snow bound areas of Himalayas with temperature much below zero degree Celsius. Under the field conditions, troops have to operate in difficult terrains and have to perform various strenuous duties like digging bunkers, maintaining vigil in the defensive positions, long distance route marches, loading and unloading of materials. Accordingly their energy and nutrient requirements in field areas are different and much above than 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 climatic conditions. Under these conditions high-energy expenditure not always compensated by adequate energy intakes have been recorded (Edwards & Roberts 1991, Shephard 1991). 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). Some of the salient findings of nutritional studies conducted in relation to acclimatization in environmental extremes are presented in this review article.

Table 2 *Energy Requirement for physical activity in temperate, cold and hot environment (kcal/kg body weight)*

	Environment		
Physical activity	Temperate	Cold	Hot
Light	32-44	35-46	40-54
Moderate	45-52	47-55	55-61
Heavy	53-63	56-68	62-75

Altitude energy requirements are similar to temperate, Hot > 30^0 C/86^0 F, Cold < 0^0 C/32^0 F, High altitude > 3050 m or 10,000 ft elevation (Askew 1994).

High Altitude Nutrition

High terrestrial altitudes and mountains have aroused great fascination and charm for mankind. Every year millions of people go to mountains for recreation and adventure sports. Besides these visitors, there are some 140 million permanent inhabitants of HA in the Himalayas, Central Asian, East African Andean and Rocky mountain regions (Moore 2001). Permanent residency is restricted to about 4300m, although some ethnic groups e.g. miners in the Peruvian Andes are reported to live at heights 5500m for a short period of time.

Himalayas constitute the northern frontiers of our country with human habitation upto an altitude of 4300m, while soldiers are deployed even upto 5800m for fixed tenure. HA presents an extreme environment with hypoxia, cold, high solar radiation as physical stresses beside the psychological stress. These areas are also arid in nature with sparse vegetation and shortage of potable water. These factors vary in magnitude depending upon the location and season, and set a formidable challenge to human adaptability.

Food Intake and Energy Requirements

Many studies have shown that subjects loose significant amounts of body mass, fat mass as well as fat free mass during a climb to and/or a stay at HA. HA induced weight loss is mainly caused by malnutrition probably due to hypoxia related anorexia, independent of acute mountain sickness (Bhardwaj et al. 1995, Westerterp 2001a). Hypophagia is more pronounced during the first

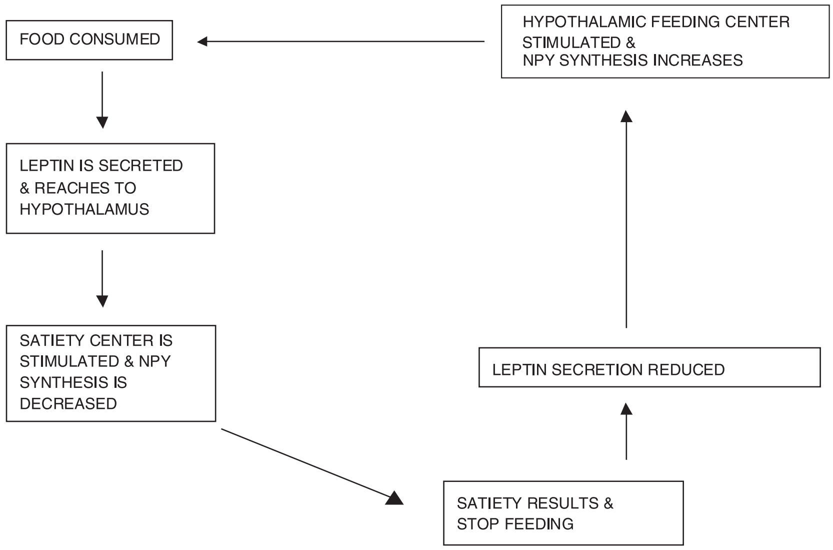

Figure 2 Negative feedback loop of leptin action

three days of exposure to HA even when best possible food is available. Calories consumption can get reduced by 40% at 4300m resulting in negative nitrogen balance (Hannon et al. 1976, Surks et al. 1966, Johnson et al. 1969, Whitten & Janoski 1969). This coupled with increased metabolic rate induced by HA exposure is considered as a major cause of weight loss (Butterfield et al. 1992). Various studies have been undertaken to explore physiological basis of anorexia of HA in humans as well as in experimental animals. One of the suggested mechanisms is alteration in hedonic matrix in terms of taste thresholds. The taste thresholds for sweet and salt modalities have been found to be elevated while for bitter and sour were reduced (Singh et al. 1997). The studies carried out on rats in simulated HA have shown mild suppression of electrical activity in the lateral hypothalamus (Singh et al. 1996). The feeding behavior is governed by several hormones, endocrine substances and can be modulated by environmental factors. The leptin, an appetite regulatory hormone secreted from adipocytes is involved in regulation of body weight in mammals (figure 2). The leptin levels have been found increased at HA and is being considered major cause of anorexia by providing false signal of plenty of body stores. Tschop et al. (1998) measured serum leptin levels in 20 male mountaineers at 120m and at altitude of 4559m after 22 hours of airlift of subject. The leptin concentrations at 0900hr were significantly higher at HA (1.22 $\pm$ 0.19 ng/ml at 120 m, 2.66 $\pm$ 0.34 at 4559m). In another group of 18 volunteers leptin levels were initially studied at 590 m at intervals of 1, 4, 12 and 20 hours thereafter at same intervals at altitude of 4559m. Twelve out of 18 volunteers reported loss of appetite and 10 developed symptoms of AMS. In the individuals with loss of appetite significant increase of leptin was seen (4.89 $\pm$ 1.18 ng/ml at 4559m, 3.19 $\pm$ 0.89 ng/ml at 590m at 0600h). The action of leptin is mediated through hypothalamic neuropeptide Y (NPY) (Friedman & Hallas 1998). The decrease in hypothalamic NPY and circulating levels of galanin have been observed in rats exposed to simulated HA with severe reduction of food intake by 40% (Singh et al. 2001a,b). The elevated levels of cholecystokinin, an appetite regulatory gut peptide have also been reported in human subjects at HA (Bailey et al. 2000).

Detailed studies are required to understand the basis of anorexia at extreme altitude above 5000m to develop effective therapeutic and preventive measures. The palatability of different tinned food items need to be increased using modern food processing techniques to restore fresh appearance, flavour etc., along with attractive packaging, so that they can be consumed in adequate amounts.

Basal Metabolism and Energy Expenditure

The energy and nutrient requirements depend upon total energy expenditure and metabolic rate of the individual. Total energy expenditure has three components i.e. basal metabolic rate (BMR), diet induced energy expenditure and expenditure related to activities. BMR is a major component and depends upon the body size, lean body mass, and physiological state of individual. The diet induced energy expenditure is 1/10th of energy intake for mixed diets. The activity induced energy expenditure is most variable part of total energy expenditure. Short-term measurements of gas exchange during field studies suggest that altitude hypoxia increases BMR. In a study by Surks et al. (1967) mean oxygen consumption in five young men increased significantly on first day at altitude, remained higher upto four days and then decreased progressively towards control value by day 8. In a study on Indian soldiers Nair et al. (1971) reported significant increase in BMR after seven days at 3353 m and sea level (SL) value was approached by day 14. Hoyt and Honing (1996) reported mean energy expenditure 3500 kcal/day in field maneuvers at altitude of 7000-11000 ft (2134-3353 m) for 3 to 34 days which is about 2.2 times of BMR. Some studies show these acute increases (20-30%) to be sustained for 1-2 weeks while others show elevation to be maintained throughout a three week stay (Butterfield et al. 1992). The decline in BMR with acclimatization seems to be the result of inadequate energy intake and decrease in metabolically active tissue that accompanies weight loss. The decrease in metabolic rate is expected to be approx. 20-25 kcal/d/kg lean tissue lost (Food and Nutrition Board 1989). Finally the stress of HA altitude decreases over a period of time as indicated by the decrease in epinephrine levels in both men and women (Mazzeo et al. 1991, 1998).

Increased energy expenditure ranging from 6.9 to 25% has been reported by Johnson et al. (1969) and Malhotra et al. (1967). As regards the energy cost of various activities under stationary conditions there is no variation as compared to SL (table 3). In a report by Burstein et al. (1996) energy expenditure in cold hilly terrain is reported to be 4281 kcal without change in energy cost of performing military maneuvers. Increased energy expenditure may be due to the heavier load carried by the troops as cold protective garments and efforts in walking in snow bound hilly terrain.

Table 3 *Comparison of energy cost at altitude and sea level.*

	Oxygen consumption (l/min)	
Activity	SL	4572 m
Sitting/resting	0.286	0.294
Standing (sentry duty)	0.480	0.500
Stepping up and down on stool at controlled rate	2.370	2.330
Working out on bicycle ergometer (600 kg · m · min^{-1})	1.460	1.400
Walking on level ground at 3.20 km. h^{-1} with appropriate clothing.	0.560	0.980
Walking on level ground at 5 km. h^{-1} with clothing	0.920	1.350
Trench digging	1.450	1.800

Values are average and of same subjects at SL and altitude (Sridharan et al. 1995)

Westerterp et al. (1992 and 1994) have reported energy expenditure of 3250 kcal/day in climbers to Mt. Everest using doubly labeled water technique out of this 1610 kcal/day was required just for climbing activities. The physical activity level (PAL) calculated using doubly labeled water and expressed as multiple of BMR in trained subjects during climbing reached 2.0- 2.7 which was lower than upper limit (4.0-5.0) at sea level (Westerterp 2001b). In a study by Reynolds et al. (1999) energy expenditures in 7 climbers to Mt. Everest were in range of 2675-7872-kcal/ day. On the basis of data obtained from climbers who are highly motivated people generalization of nutrient and energy requirements for general population is difficult.

Macronutrient Requirements

Carbohydrates

High carbohydrate diets are beneficial at HA (Kayser 1992). The advantage of high carbohydr-ate diet is that respiratory quotient (RQ) of carbohydrate diet is around 1.0; on the other hand if fat is exclusively taken then RQ is 0.7. In high terrestrial altitudes alveolar PO_2 falls with fall in barometric pressure and when there is shift of RQ from 0.7 to 1.0, there is an increase in PaO_2 and this gives rise to the increase in arterial oxygen saturation. Carbohydrates provide higher yield of energy per mole of oxygen. The energy equivalent of oxygen is 4.48 kcal/l for protein, 4.7 kcal/l for fat and 5.06 kcal/l for carbohydrate (Mc Clelland et al. 1998). Diets high in carbohydrates are shown to enhance the glucose metabolism at HA. Studies on Indian SL residents at HA and their dietary habits show that up to 60% energy is derived from carbohydrates (Sridharan et al. 1995). Proximate composition of ration of troops at 2700- 4000 m is given in table 4. Long term studies on carbohydrate metabolism by Srivastava et al. (1975) 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 to less than SL (table 5). Glucose tolerance remained normal throughout the stay at HA.

Table 4 *Proximate Composition and Nutrient Content of Diet for Active Individuals at Altitude 2700-4000 m.*

Nutrients	Quantity
Proteins	144 .0 g
(Animal Proteins)	(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	4894 kcal
Calories contributed by	
Carbohydrates	2987.2 kcal (61%)
Fat	1331.1 kcal (27.2%)
Proteins	576 kcal (11.7%)

Source: Sridharan et al. (1995)

Table 5 *Fasting blood sugar in man during acclimatization to HA and natives of HA*

Status	Period	Blood sugar (mg/100ml)
Sea level 200 m *	–	97.6 ± 2.29
Altitude (4000 m)*	2 Weeks	99.93 ± 3.83
	10 Months	136.0 ± 4.89
	15 Months	112.8 ± 3.03
	20 Months	82.0 ± 3.99
	24 Months	76.4 ± 3.87
Sea level (on return	1 Week	74.3 ± 3.75
from HA)*	1Month	84.0 ± 2.97
Native (4000m)	–	86.0 ± 7.28

Values are mean ± SEM (n=7) and. *from same subjects (Srivastava et al. 1975)

Protein

Negative nitrogen balance are reported at HA by Consolazio et al. (1963) and Surks et al. (1966), however caloric intake in these studies were less. Extensive studies on nitrogen metabolism at both acute and after long-term stay at HA have been carried out by DIPAS on Indian soldiers. In a well controlled study with 12 g/day dietary nitrogen intake Sridharan et al. (1982) have shown positive balance (table 6). On third day of stay at HA, Consolazio et al. (1972) have also repoted similar values. After prolonged stay at HA nitrogen utilization was not less than 85%. Variation in serum protein level in a longitudinal study during 24 months was within normal range (Grover et al. 1987). After acclimatization there is no alteration in protein metabolism at altitude when intake of food was adequate (4500 kcal) with protein at level of 2-g/kg body weight/day was ensured.

Fat

After acclimatization at altitude of 3500-4700 m for two years Rai et al. (1975) have studied utilization of fat by feeding up to 325g/day and found 95.5% fat digestibility with almost constant levels of fecal fat (table 7). In controlled study conducted by Sridharan et al. (1982) no adverse effect on digestion under HA was observed. Butterfield et al. (1992) and Kayser et al. (1992) have also concluded that there is no dysfunction of absorption, rather intake is low due to anorexia.

GI Functions

With regard to gastric functions no change in the volume of basal as well as maximal gastric juice was observed at altitude (Sridharan et al. 1982) (table 8). 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 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. (1977) in Indian troops. D-xylose excretion which is used as test of the absorptive activity of upper part of small intestine also remains normal indicating that absorption function of small intestine are not disturbed at HA (Sridharan et al. 1982).

Table 6 *Nitrogen Intake and Excretion Pattern at High Altitude*

Parameters	Sea Level	3500 m	4572 m
Nitrogen Intake (g)	21.7 (18.0-23.0)	11.40 (8.4-14.6)	11.80 (9.6-10.3)
24h Total urinary nitrogen excretion (g)	13.5	9.1	7.38
Urea Nitrogen	11.5	5.56	5.78
Ammonia Nitrogen	0.57	0.58	0.46
Creatinine	1.27	1.27	1.23
Creatine	0.10	0.18	0.18

Source: Sridharan *et al.* (1995)

Table 7 *Intake, excretion and percentage digestibility of dietary fats at high altitude*

	At 3500 m			At 3800 m				At 4700 m		
Total fat intake (9)	128 (9)	168 (9)	198 (9)	124 (7)	224 (7)	324 (4)	364 (3)	142 (12)	189 (12)	232 (12)
Total fecal fat (9)	5.26 ± 0.49	6.45 ± 0.36	7.09 ± 0.79	8.17 ± 2.11	11.03 ± 3.71	8.92 ± 4.63	11.48 ± 2.66	6.44 ± 2.18	4.66 ± 1.89	5.24 ± 1.58
Percentage digestibility	95.9	96.2	96.6	93.4	95.0	97.2	96.9	95.4	97.5	97.5

Mean ± SD (Figures in parenthesis indicate numbers of subjects. Rai et al. 1975)

Table 8 *Comparison of mean (± SE) values of gastric juice basal and after pentagastrin stimulation, at sea level and altitude of 3,500 m in sojourners (S), acclimatized lowlanders (ALL) and high altitude natives (HAN)*

	Volume (ml)		HCl Conc (mEq/1)		Rate of acid production (m Eq/l)		Peptic activity unit/ total volume	
Subject	Basal	Maximum	Basal	Maximum	Basal	Maximum	Basal	Maximum
Sojourners Sea level	71.6 ± 6.3	136.7± 22.8	53.0 ± 8.6	89.8 ± 6.8	3.9 ± 0.7	12.8 ± 3.0	1102.0± 84.0	2354.0 ± 469
Day at HA2-3	70.0 ± 5.8	149.4± 12.2	31.9 ± 6.8^{+}	85.2 ± 6.3	2.1 ± 0.4^{++}	12.9 ±1.5	2546 ± 428^{+}	6310 ± 1062^{+}
11-12	58.3 ± 63	147.8± 15.0	33.6 ± 7.4	78.6 ± 9.2	2.1 ± 0.6^{++}	12.5 ± 2.1	1930 ± 386	5830 ±769^{+}
21-22	89.3 ± 9.3	144.7± 13.0	27.7± .5^{++}	70 ± 8.2	2.5 ± 0.5	11.1 ± 1.9	–	–
ALL	73.2± 15.7	170.0± 11.2	26.4± .3^{++}	70.6 ± 6.5	1.1 ± 0.4^{+}	12.0 ± 1.5	1557 ± 437	3756 ± 1100
H A N	61.5 ± 5.9	104.7± 12.2	21.1± 7.0^{++}	49.2 ± 7.6	1.2 ± 0.4^{++}	5.3 ±1.1^{+}	–	–

+ P< 0.05, ++ P< 0.01 as compared to sea level values. (Sridharan et al. 1982)

Fluid and Electrolyte Requirements

In addition to cold induced diuresis, hyperventilation together with a dry environment at HA makes individual prone to hypo-hydration. Investigations using isotope dilution techniques by Jain et al. (1980) and Singh et al (1990) to assess body fluid compartments revealed decrease in plasma volume and body water. These studies point out a fall in total water content. Bhardwaj and Malhotra (1974) using anthropometrical techniques and soft tissue X-ray of muscles have shown losses of body water and bone mineral content after 4 weeks at 4300 meters. Controlled studies on fluid intake and output have shown that there is no change in fluid balance (Sridharan et al. 1982, Rose et al. 1988). Acute exposure to moderate altitude causes transient hypohydration, which is due to increased diuresis and reduction in thirst perception. Prolonged stay at extreme altitude 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 sub acute mountain sickness. Studies on long term effects of moderate and extreme altitude on body fluid compartments and its determinants need to be investigated (Anand & Chandrashekhar 1996).

Increased urinary excretion of Na^+ and K^+ on exposure to hypoxia is reported while some workers have found only increase in Na^+ with decrease in K^+ excretion. Studies on Indian troops by Malhotra et al. (1975) as well as Chatterjee et al. (1982) have shown no significant change in serum Na^+ and K^+ levels. Chatterjee et al. (1982) at the same time have found decreased levels of Mg^{2+} and Ca^{2+} excretion during acute exposure in humans at 3770 m.

Micronutrient Requirements and Nutraceuticals

Iron and Zinc

At HA though there is always a balance between blood formation and destruction however there is no evidence for increased dietary iron requirements. The requirements of increased haemoglobin synthesis during early phase of stay at HA are fulfilled by redistributing body stores and from dietary iron. Urinary excretion of Zn^{2+} is more during physical exertion as observed during an expedition to Mt Everest (Rose et al. 1988). Reduced zinc levels are associated with anorexia. Zinc supplementation has been found to be beneficial in women mountaineers in controlling weight loss and their leptin levels also remain unchanged (Suri et al.2002). Zinc is an integral part of the enzyme carbonic anhydrase and is a co-factor for many antioxidant enzymes. Because of these important functions detailed studies on role of zinc under extreme environments are being investigated.

Vitamins and Antioxidants

Studies have been carried out on nutritional status of troops with regard to vitamin requirement at altitude of 3660 m while subjects were consuming either fresh or tinned foods. It was observed that requirement of vitamins is not different as compared to SL. Additional supply of multi-vitamin was not required at least for a period up to 30 days if soldiers are to be maintained on tinned food (Sridharan et al. 1996). Antioxidant nutrients such as vitamin E, C and A (β-carotene), as well as selenium, copper, zinc and manganese may 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 outdoors (Fuller et al. 1992). It is hypothesized that exposure to UV radiation along with malnutrition due to anorexia increases cis-urocanic acid accumulation in skin, which may cause increased risk of photo-immunosuppression (Hug et al. 2001).

In humans exposure to HA has been reported to cause marked increase in lipid peroxidation as indicated by increase in amounts of expired pentane (Simon-Schnass 1992, 1996). Increased oxidative stress as indicated by serum and urinary variables during extended work at a moderate altitude (2700m) have been reported, despite relatively high intake of dietary and supplemented antioxidants (Pfeiffer et al. 1999, Chao et al. 1999). Oral glutamate supplementation has shown amelioration of hypoxia induced oxidative stress in rats (Kumar et al. 1999). The oxidative stress increases the rate of production of free radicals, which is 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 reduced glutathione (GSH) with concomitant rise in oxidized glutathione in muscles and blood of rats during hypoxic exposure at an altitude of 7620m. This may be due to limitation of ATP and inhibition of glutathione reductase activity, the enzyme responsible for maintaining GSH levels (Singh et al. 2001). In a human study at HA (Ilavazhagan et al. 1996) the role of vitamin C and E in initial stages of acclimatization has brought out the beneficial effects of these antioxidant vitamins in warding off of the oxidative stress and concomitant effects on the cell membrane integrity. During rough weather when supply of fresh fruits and vegetables becomes limited at HA vitamin C supplement is recommended due to its antioxidant role.

Adaptogens

Health food supplements and “adaptogens” such as Composite Indian Herbal Preparation (CIHP) and Panax ginseng, have been found to enhance the acclimatization of soldiers at HA (Srivastava et al. 1993, 1996, Kumar et al. 1996). Both of these products have been evaluated for their effect on physiological, biochemical variables and also on psychological well being of soldiers and for details original publications by Srivastava et al. (1993, 1996) can be consulted. CIHP reduced stress level, increased oxygen saturation (SaO_2) and facilitated utilization of fat for energy release, thereby helped in acclimatization at HA. Supplementation of branched chain amino acids (leucine, isoleucine and valine) have been reported to prevent muscle loss during trekking at HA (Schena et al. 1992).

Nutrition in Cold and Polar Environment

Energy requirements are the major consideration for providing nutritional support in a cold environment (Askew 1989). Energy expenditure is usually limited by rate of heat buildup and hypoxia respectively in hot and altitude environments whereas in cold no such type of restriction exists. Energy requirements in cold environment are influenced by the intensity of the cold, wind speed, physical factors (like melting snow, locomotion on icy or snow covered surfaces etc.) and altered solar periodicity in Arctic and Antarctic areas. Cold exposure increases energy requirements. Johnson and Kark (1947) have reported that people in cold climate normally eat more than those in warm climate. Gray et al. (1951) have suggested that increased energy requirements are due to 'hobbling' effect of the clothing weight (7-10 kg) and associated with efforts of locomotion. The weight of cold weather clothing has decreased as technology has improved, however clothing is still a considerable burden. Marriott and Carlson (1996) discussed nutritional needs in cold environments with respect to application for military personnel during field operation. It appears that heat loss in a cold environment is considerably reduced through thermoregulation, clothing and behavior i.e. seeking shelter whenever possible, creating or moving to warmer environments. Moreover, skeletal muscle contractions, either during voluntary exercise or involuntary shivering are the major source of metabolic heat produced to protect against cold stress.

Thermoregulation in Cold

Heat production parallels the increase in O_2 uptake the magnitude of which depends on the muscle mass engaged in shivering or work and the duration of activity. Shivering alone can produce only a four-fold increase above basal rates of heat production. The increase in O_2 uptake during shivering thermogenesis is also accompanied by an increase in cardiac output. This increase is due to increase in stroke volume, which is associated with cold-induced peripheral vasoconstriction. The effect of the mechanisms used to protect against heat loss depends on the body surface area in comparison with body mass (Young 1991). The problems may arise in malnourished subjects who have lost both fat mass as well as lean body mass. Cold acclimatization can occur in human subjects but it is minimal. An important modifying factor on the thermoregulatory response to cold is the individual's provision of subcutaneous fat, since fat reduces thermal conductance from the core to the body surfaces (Tonner & Mc Ardle 1988). Physical fitness has mixed effects; the fittest individuals show more heat production but at the same time being lean in structure they lose heat more quickly (Westerterp-Plantenga 1999). Severe losses of body weight in a cold environment complicate the normal physiological responses to cold. Thus maintaining adequate intake in cold environment especially under physically active conditions is important. There is a common belief that cold climate conditions lead to an increased appetite. The evidence for this conclusion is derived from changes in body weight; self reported intakes in cold environment at SL. However the reported increase in appetite is also associated with changes in other aspects of subject's environment such as increased activity levels, energy expenditure due to thermogenesis, social isolation and modification in the diet. In animals increased energy expenditure caused by increased thermogenesis due to cold environment is compensated by increased intakes (Louis-Sylvestre 1987).

Fat Metabolism

In human subjects increased energy intake requirements do not always trigger and increase intake and appetite immediately. Humans can adapt over a period of time to a high fat diet to make food energy dense. The question arises at this point that does consumption of high fat diet in the cold increase cardiovascular health risk? In this respect data of Ekstedt et al. (1991) show no such harmful effects of high fat diet. Despite consuming a diet containing twice fat and cholesterol as of low fat group, cross-country skiers fed high fat diet decreased their cholesterol, very low-density lipoproteins (VLDL) and triglycerides over a period of 8 days in cold environment (table 9).

Food intake in Polar Expeditions

Observation made by Easty (1967) at Halley Bay, the British Antarctic survey base during 1961-62 expeditions indicate mean calorie intake 3600 kcal/man per-day and 12.7% of those calories were supplied by protein, 39.8% by fat and 48.1% by carbohydrates. During winter months (polar night) when men were confined to the limits of base and activities showed a marked fall and there was gain of body weight ~ 2.5 kg. Similarly studies conducted by DIPAS during Antarctic expeditions have also indicated no change in cholesterol with low triglyceride levels though there was increased fat intake (Satija et al. 1998). Various Indian Antarctic expeditions have common observation of increase in body weight that is mainly due to increased intake. Several factors are responsible for an enhanced appetite in cold regions includes palatability of food, cold temperature, emotional factors (e.g. loneliness) and changes in physical activity habits. Recently during XX Indian Antarctic expedition attempt has been made to evaluate changes in leptin levels to find out

Table 9 *Effect of low-or high-fat diets on percentage change of serum lipids during 8 days cross country Ski exercise*

	Low Fat Diet*	High Fat Diet**
Total cholesterol	-26.4±4.3	-19.9±2.9
VLDL – LDL Cholesterol	-38.1±3.0	-41.1±5.7
HDL Cholesterol	+5.9±2.3	+19.0±3.8
Triglycerides	-30.6±6.8	-32.6±8.0
Body weight (kg)	-0.2±0.5	-0.9±0.4

*3800 kcal/d, 26% Fat/260 mg Cholesterol/day;**3800kcal/d, 52% Fat/480 mg Cholesterol/day

Values are mean ± SD of percent differences before and after 8 day Ski trip (Ekstedt et al. 1967).

hormonal basis of increased intake and it was observed that there is significant decrease in leptin levels despite of increase in body fat. The low leptin levels may be responsible for increased food intake. The average energy expenditure was found to be 3100 kcal/day indicating active life style of expedition members (Vats et al. 2003).

The dietary pattern of natives of arctic and sub arctic regions and their obvious success in coping with harsh environment have influenced arctic explorers to choose diets high in fat in general belief that this may be helpful. Such information is largely anecdotal and probably relates more to the availability of local foods (seal, fish, whale, caribou) and familiarity of Eskimos with these foods. However such diets are rich in n-3 fatty acids, which play important role in prevention of cardiovascular diseases (Ulbricht & Southgate 1991).

Despite the arguments that can be made for suitability of high fat diets in the cold, there is evidence suggesting that carbohydrates are more important than fat in fueling metabolic heat production during cold exposure (Mitchel et al. 1946). Vallerand and Jacobs (1989) studied the contribution of protein, carbohydrates and fat to energy expenditure during 2 hr exposure of semi-nude men to warm (29°C) or cold (2°C) environment. The cold exposure elevated the energy expenditure almost 2-5 times over that observed for subjects in the warm environment. This increase in energy expenditure resulted in an increase in carbohydrate oxidation by 5.9 folds and 63% in fat oxidation. Protein oxidation was unaffected.

These results demonstrate that cold exposure causes a much greater increase in oxidation of carbohydrates than lipids. There is evidence to suggest that stimulation of carbohydrates oxidation by ingestion of an ephedrine- caffeine mixture and it can improve cold tolerance in humans (Vallerand et al. 1989).

Nutrition in Hot Environments

Adequate fluid replacement overshadows all other considerations of nutrient requirements for work in a hot environment. Drinking adequate water for work in heat prevents dehydration, heat illness and reduced performance. Heat acclimatization

Table 10 *Water requirements (l/h) for rest and work in the heat as influenced by solar load and temperature*

	Indoor				Outdoor			
Temp °C and relative humidity %	Rest	Light	Medium	Heavy	Rest	Light	Medium	Heavy
30 @ 50	0.2	0.5	1.0	1.5	0.5	0.9	1.3	1.8
36@ 50	0.3	0.9	1.3	1.9	0.8	1.2	1.7	2.0
41 @ 30	0.6	1.0	1.5	2.0	0.9	1.3	1.9	2.0
46 @ 20	0.8	1.2	1.7	2.0	1.1	1.5	2.0	2.0
49 @ 20	0.9	1.3	1.9	2.0	1.3	1.7	2.0	2.0

The values for water requirement in 1/hr are calculated according to prediction model of Shapiro et al. (1982) Conditions assumed are clothing, tropical fatigues, heat acclimatized subjects, wind speed 2m/s.

relatively has no effect on water requirements (Sawka et al. 1984). Thirst is a poor indicator of hydration status (Sawka & Neuter 1989). Intense thirst is usually noticed at 5 to 6% body weight loss due to hypohydration. By this time physical performance is compromised. Severe hypohydration can lead to decreased blood volume and increase in plasma osmolality, which can result in decreased sweating and heat dissipation (Sawka et al. 1985). Eighty percent of the energy metabolized during exercise in hot environment is liberated as heat (only 20% is utilized as mechanical work) and 80-90% of heat dissipation during work in a hot-dry environment is accomplished by the evaporation of sweat (Brouns 1991). Each milliliter of sweat evaporated from the skin leads to heat loss of approximately 0.6 kcal. Sweat rates vary to a great extent from individual to individual, but can reach 2 l/hr for prolonged time periods. Hypohydration depends in large part upon sweat rate, which is in turn determined by workload and duration. Other environmental factors are solar load, wind speed, relative humidity and clothing (Shapiro et al. 1982). The influence of these factors on water requirement is given in table 10. To prevent hypohydration fluid should be taken periodically whether one is thirsty or not.

Energy Expenditure

Energy expenditure in hot environments is increased by a small but significant amount because of additional work of ventilation and increased sweat gland activity. Consolazio et al. (1963) estimated that there is rise of ~ 10% in energy requirement at 38°C. Very few studies exist for energy determinations using doubly labeled water technique during heat exposure; Forbes-Ewan et al. (1989) reported 4750 kcal/day for work in hot humid jungle environment and Moore et al. (1993) reported 4000 kcal/day for hot wet (Swamp) vs. 4200 kcal/day for hot dry desert conditions. Studies carried out at DIPAS indicate there is no difference in metabolic cost of different activities performed in hot or cold environment (Malhotra et al. 1960). Total energy cost of a fixed work 600 kg. m. min^{-1} remains the same as at different environmental temperature varying from comfortable to extremely hot, the aerobic function drops continuously with rise in environmental temperature and anaerobic function rises (Malhotra et al. 1962). The greater anaerobic function results in higher accumulation of lactic acid and causes reduction in endurance time. Excessive nitrogen losses are reported in perspiration of unacclimatized people but not in acclimatized persons (Shworth & Harrower 1967). The nitrogen concentration in perspiration is small and decreases with increase in perspiration rate; as 90% of the excretion of nitrogen is in faeces and urine and it is not significant enough to warrant extra protein in diet in tropics (Weiner et al. 1972).

Table 11 *Concentration of vitamins lost in sweat*

Vitamin	Concentration (mg/100ml)
Thiamin	0-15
Riboflavin	0.5-12
Nicotinic acid (total)	8-14
Pantothenic acid	4-30
Ascorbic acid	0-50
Pyridoxine	7
Folic acid	0.26

Clarkson (1993)

Vitamin and Mineral Requirements

There is no extra need of iron and vitamins (Micksen & Keys 1943). Although loss of water-soluble B-vitamins is minimal a deficiency could occur over time from profuse sweating coupled with an insufficient dietary intake (table 11). Because thiamine, riboflavin, niacin and Vitamin B_6 are important to energy metabolism, the level of these vitamin intakes should be related to amount of food consumed. Role of vitamin B_6 in carbohydrate metabolism was established in 1990. As much as 80% of the body's vitamin B_6 is present in muscle, as coenzyme of glycogen phosphorylase that is first enzyme in glycogenolysis (Bender 2000, Murray et al. 1993). If calorie intake is not sufficient to meet the demands of work in heat, then vitamin intake will be compromised as well and supplementation is required. Ascorbic acid may have some unexplained benefits when consumed above the usual dietary requirements during work in heat (Clarkson 1993). Hanschel et al. (1944) could find no significant beneficial effect of vitamin C supplementation (500 mg/day) in heat acclimatization where as Strydam et al. (1976) found that either 250 or 500 mg ascorbic acid supplementation/day benefited in a 10 day heat acclimatization process.

Electrolyte Requirements

It was found that NaCl requirement increases due to loss in sweat; 15 to 16 gm of salt normally taken in diet is quite adequate for acclimatized people (Malhotra 1960). The plasma concentration of electrolytes and losses in urine and sweat were evaluated during work in hot environments by Malhotra et al. (1976), while subjects were consuming 97.18 mEq of potassium and 274 mEq of sodium through Diet (3770 kcal). Potassium loss in perspiration however does not decrease with acclimatization, but on the other hand increases in wake of the accentuated sodium-potassium exchange system (Malhotra et al. 1981, Pichan et al. 1988) (table 12 & 13). Supplementation of potassium in drinking water may enhance the process of acclimatization. In a classical experimental study Malhotra et al. (1981) evaluated effect of low potassium (K+) intake on its excretion, concentration in sweat and

Table 12 *Electrolyte concentration (Mean ± SE) in Arm sweat and plasma of Indians exposed to Heat (40°C)*

Parameter	Plasma concentration	Day of experiments			
		D–1	D–2	D–3	D–4
Sweat loss [g/h]	–	210.0 ± 20.72	300.0 ± 5.38	505.5 ± 15.41	740.0 ± 79.65
K^+ Concentration [mEq/l]	3.73 ± 0.08	5.59 ± 0.69	7.59 ± 0.02	5.24 ± 0.02	5.38 ± 0.02
Na^+ Concentration [mEq/l]	138.90 ± 1.47	38.75 ± 7.96	39.11 ± 7.71	37.05 ± 9.05	40.43 ± 6.91
Cl^- Concentration [mEq/l]	125.00 ± 1.15	35.20 ± 7.41	44.40 ± 9.63	34.05 ± 10.97	55.60 ± 6.15

Subjects (n=6) were on diet containing 3730 Kcal, 97.18 mEq of potassium and 274 mEq of Sodium (Malhotra et al. 1976 a,b)

Table 13 *Electrolyte concentration in urine of Indians exposed to heat*

Parameter	DAY			
	D–1	D–2	D–3	D–4
K^+ Concentration [mEq/l]	42.66 ± 9.41	31.00 ± 8.23	39.62 ± 5.82	42.26 ± 12.92
Na^+ Concentration [mEq/l]	204.02 ± 5.18	178.8. ± 23.96	190.92 ± 22.34	192.84 ± 31.52
Cl^- Concentration [mEq/l]	214.04 ± 41.47	194.22 ± 22.12	234.25 ± 19.77	216.12 ± 30.64

Subjects (n=6) were on diet containing 3730 Kcal, 97.18 mEq of potassium and 274 mEq of Sodium (Malhotra et al. 1976 a,b).

physiological responses during heat stress on Indian soldiers. After stabilization period of three days on each diet i.e 85 mEq of potassium per day (diet I, normal), 55 mEq of potassium per day (diet II) and 45 mEq of potassium per day (diet III), the physiological responses and potassium, sodium concentrations in sweat, plasma, RBC and urine were measured when subjects were exposed to heat for three hours daily at 40^{0}C db and 32^{0}C wb. Subjects worked in chamber by stepping at 0.38m stool (15 times a minute) for 20 minutes period with 40 minutes rest between each period of exercise involving a mean energy expenditure of about 465 W/hr. The whole body sweat was collected after the first spell of work and was analyzed for sodium and potassium levels. Throughout the study the subjects remained on positive sodium balance except on day 4 on diet III. Fluid balance was also positive while potassium balance was negative in subjects on diet II and III. There was no significant change in heart rate, sweat volume, oral temperature, sodium and potassium concentration in sweat during exercise and heat. The only evidence of potassium conservation was reduced excretion in urine (table 14-16). Effect on ECG (flattening of T wave) was noted. By this study it is clear that there is likelihood of potassium deficiency if a liberal intake is not ensured.

Detailed studies on effect of consumption of brackish water of Rajasthan containing high levels of fluoride (1.47-2.67 ppm) and nitrate (35-64 ppm) have also been carried out. No adverse effect and symptoms of fluorosis upto two years of intake were noted in adequately nourished subjects although the excretion of fluoride was found high (Sridharan et al.1991,1999).

Nutrition in Space

Space exploration represents a new frontier in the nutritional sciences and humans are eating in space since Cosmonaut Yuri Gagarin's 108 min flight in 1961. Human presence in space has been almost continuous since these early flights. Missions have ranged from about 15 minutes to 14 months. Until the beginning of the International Space Station, all human habitable spacecrafts were built by Soviet Union or the United States, and both countries have made enormous contributions to human space flight capabilities, sciences and technology. Throughout the history of human space flight, life sciences research has been an integral part of the missions. As the mission duration increased, the framework of nutrition /research has expanded dramatically. Defence Food Research Laboratory (DFRL) Mysore developed foods for Sqdn. Ldr. Rakesh Sharma for his 7-day space voyage in joint Indo-Soviet manned space mission in April 1984 under programme named 'Pavan'.

Changes in Body Composition

Major stress in space is microgravity (Lane & Schulz 1992). Effects of microgravity are listed in table 17. Several of the pathophysiological changes associated with space flight manifest themselves as changes in body composition. Space flight presents a unique challenge for quantifying body composition changes since fluid, bone, muscle and adipose tissue levels all vary independently of one another in space, and body weight loss does not follow classical pattern. The body mass measurements were taken for the first time during 28 to 84 day Skylab mission and revealed 0.91 to 3.64 kg losses of preflight body weight. Analysis of component of the weight loss was based on both direct whole body measurements and on indirect metabolic balance data. A conclusion from the analysis was that more than half of the weight loss was from fat free mass and remaining from the fat stores. About half of the total weight loss that occurred within the first two days of flight was due to water loss (Leach et al. 1982, Leonand et al. 1983). All studies of fluid balance during micro gravity have indicated a decrease in total body fluids of approximately 500-900 ml (Leach et al. 1978).

Nutrition and Musculo-skeletal System

Most important is muscle loss and limited resistive exercise by crewmembers have been helpful in prevention upto some extent. Skeletal losses unlike muscle losses do appear to be related to the length of flight (Hollick 1992). About 0.4% to 1.0% of bone minerals is lost per month during space- flight (Leonard et al. 1983). The role of nutrition in musculoskeletal losses during space flight has not been clearly defined, but data from Skylab missions demonstrate negative nitrogen and potassium balance despite

Table 14 *Sodium balance on three different levels of dietary potassium intakes*

K^+ content of	Day	Na^+ Intake	Na^+ output (mEq/d)				
			Urine	Sweat	Faeces	Total	Balance
85	4	180.15±0.30	69.72±3.11	99.50±9.68	5.66±0.87	174.88±11.76	+5.27±11.64
	5	183.18±0.33	54.85±9.53	96.01±7.41	17.22±2.92	168.08±10.96	+15.10±10.67
55	4	217.19±0.32[a]	79.49±8.80	113.00±8.22	6.66±1.70	199.15±12.53	+18.04±12.41
	5	218.74±0.47[a]	68.82±14.72	117.14±10.95	5.65±1.08	191.61±10.31	+27.13±10.28
	6	218.86±0.44[a]	79.16±6.85	131.89±11.68	5.47±0.96	216.52±14.93	+2.34±14.80
45	4	217.11±0.50[a]	97.36±13.55	132.64±11.21	7.09±2.10	237.09±18.11	-19.98±18.27
	5	217.49±0.38[a]	49.12±5.68	119.00±11.82	5.59±0.96	171.07±15.95	+43.42±15.90
	6	216.98±0.67[a]	34.86±5.68	128.01±6.51	4.18±1.40	161.05±8.40	+49.93±8.42
	8	217.05±0.29[a]	58.23±11.02	135.30±11.02	5.61±1.10	191.14±17.85	+17.91±17.93

Values are mean ± SEM (n=8). Exposure to heat stress in climatic chamber at 40 C DB and 32 C WB for 3hr/day. [a] $p<0.05$ (Malhotra et al. 1981)

Table 15 *Potassium balance on three different levels of dietary potassium intakes*

K^+ content of diet (mEq/d)	Day	K^+ Intake (mEq/d)	K^+ output (mEq/d)				
			Urine	Sweat	Faeces	Total	Balance
85	5	79.98 ± 3.50	36.39 ± 7.09	12.56 ± 0.83	27.03 ± 1.87	75.98 ± 7.25	+ 4.00 ± 6.47
	6	83.39 ± 3.73	32.91 ± 4.68	12.96 ± 0.89	35.47 ± 5.63	81.34 ± 6.36	+ 2.05 ± 4.88
55	4	43.20 ± 2.34	30.41 ± 2.18	13.48 ± 0.85	7.53 ± 2.89	51.42 ± 2.48	- 8.22 ± 3.46
	5	52.10 ± 2.32	31.04 ± 3.94	14.12 ± 1.09	16.57 ± 3.36	61.73 ± 2.62	-9.63 ± 3.89
	6	56.17 ± 1.92	32.36 ± 2.56	16.43 ± 1.22	14.79 ± 1.51	63.58 ± 3.66	-7.41 ± 3.82
45	4	45.55 ± 2.28	29.40 ± 3.96	12.49 ± 0.96	16.84 ± 5.58	58.73 ± 6.46	-13.18 ± 7.14
	5	43.88 ± 3.37	26.37 ± 2.60	13.38 ± 0.53	12.02 ± 1.57	51.77 ± 4.10	-7.89 ± 2.41
	6	44.52 ± 1.95	21.68 ± 2.59**	15.90 ± 0.99*	12.55 ± 2.04	50.13 ± 3.32	-5.61 ± 2.21
	8	42.74 ± 2.84	18.29 ± 2.06**	15.30 ± 0.97*	11.18 ± 1.69	44.77 ± 3.03	-2.03 ± 2.19

Values are mean ± SEM (n=8) *$P< 0.05$, ** $P< 0.015$. Exposure to heat stress in climatic chamber at 40 C DB and 32 C WB for 3 hr/day. (Malhotra et al. 1981)

Table 16 *Concentration of Na^+ and K^+(mEq) in urine and Sweat on three different level of dietary potassium intakes*

K^+ content of diet (mEq/d)	Day	Na^+Urine	Na^+Sweat	K^+Urine	K^+Sweat
85	4	48.83±5.26	50.09±5.04	25.04±3.36	5.72±0.41
	5	50.00±6.40	52.88±2.85	30.97±4.07	7.14±0.34
55	4	59.24±7.07	55.36±2.67	23.72±2.86	6.66±0.37
	5	65.02±8.42	58.88±3.04	29.85±2.38	6.93±0.22
	6	78.51±12.43	54.79±3.31	30.50±4.11	6.84±0.26
45	4	93.24±28.15	65.75±4.04	24.78±3.40	6.33±0.50
	5	61.43±11.61	54.47±5.50	32.56±5.65	6.11±0.21
	6	49.50±9.24	56.88±1.97	31.71±6.02	7.05±0.33
	8	56.63±8.25	61.70±4.86	18.79±2.29[a]	6.47±0.58

Values are mean + SEM (n=8) [a] $p <0.05$. Exposure to heat stress in climatic chamber at 40 C DB and 32 C WB for 3 hr/day (Malhotra et al. 1981)

Table 17 *Effects of Microgravity on humans*

Space motion sickness	Experienced by 60-70% of Astronauts and Cosmonauts; produces malaise, headache, anorexia, nausea and vomiting. Symptoms appear early in flight and last about 2-7 days.
Cardiovascular	Cephald shift of fluid estimated at 1.5 to 2.0 liters
deconditioning	lower extremities, decreased orthostalic tolerance,
increased heart rate,	decrease in pulse pressure, tendencytowards spontaneous syncope.
Haematological changes	Reduction in plasma volume and Red blood cell mass.
Bone mineral loss	Loss of total body calcium in both humans as well as animals flown to space from 1 week to more than 237 days.
Muscle deconditioning	Loss of lean tissue and decreased muscle strength

supposedly adequate ingestion of energy and protein. Return to earth poses a major concern. Stress fractures, muscle pulls, ligament stress and inability to ambulate occur and may take 2-8 weeks to resolve. Although experience with long-term space flight has provided considerable confidence in the ability of human body to recover from space flight and readapt to the earth environment, effects observed on the long Sky lab, Mir, and Shuttle-Mir missions have convinced the researchers that counter measures and monitoring are essential to success of space flight. Dietary intakes monitored during Apollo, Skylab and Shuttle flight (Bourland et al. 2000) are presented in table 18.

Space Food

Space food system has made significant advances in the past four decades. Food packaging has progressed from tube and cubes to open containers in which food is consumed with regular utensils. Food variety has increased through the use of innovative preservation technologies such as thermostablized retort

Table 18 Dietary intakes of Apollo, Skylab and Shuttle astronauts

	Apollo (n=33)	Skylab (n=9)	Shuttle (n=26)
Energy Intakes (kcal/d)	1880±404	2832±309	2118±476
% of WHO predicted energy requirement	64.2±13.6	99.1±8.2	74.0±16.2
Protein intake (g/d)	76.1±18.7	111.0±18.4	79.0±19
Carbohydrate intake (g/d)	268.8±49.1	413.3±59.3	309.0±73
Fat intake (g/d)	61.4±21.4	83.2±13.8	63.0±18
Energy % provided by			
protein	16.3±2.1	15.5±1.2	15±3.0
C H O	58.1 ±7.1	58.1±4.4	59±5
Fat	28.8±5.4	26.4±3.8	27±4
Water ml/d)	1647±188	2829±529	2285±715
Sodium(mg/d)	3665.9±889.6	5185.4±947.9	4048.2±871.9
Potassium (mg/d)	2039.2±762.1	853.8±566.9	2436.9±564.0
Calcium(mg/d)	773.6±212.3	894.2±141.5	847.4±206.9
Phosphorus (mg/d)	1121.6±324.6	759.9±266.5	1242.2±294.9
Magnesium (mg/d)	–	310.4±54.8	297.1±72.3
Iron (mg/d)	–	–	15.6±3.8
Zinc (mg/d)	–	–	11.9±3.0

Source: Bourland et al. (2000)

pouch, intermediate – moisture foods and irradiation. Nutritional requirements for long flights have been refined, placing more demands on food development. Despite the technological advances and increased variety most space crews, with the exception of Sky labs Astronauts have not met the nutritional requirements. This problem must be solved. An integrated approach for various studies has been proposed during the meeting at Bad Honnef, Germany in Sept 1998 (Gerzer & Ruyteers 2000). Biotechnology holds great promise for devising specific foods that would meet many of the stringent mission requirements. The use of plants in combination of physicochemical technologies for supply of fresh food, water, and oxygen has shown to be promising for human life support during planetary exploration (Gitelson et al. 1989). The bioregenerative system for growing food in hydroponic plant growth chambers may be advantageous. However this will require additional training of growing and harvesting of crops and selection of various plant species and even use of genetically modified ones for high yields. A primary concern in use of plants is requirement of high light intensity for better yield. Various studies on plants growth under controlled environments have been carried out and some of the plants selected are wheat, lettuce, soybean, potato, sweet potato, tomato, radish, spinach and strawberry (Wheeler 2000). Significant research and development is still required using ground based models and real flight before a bioregenerative food system can be chosen for the sojourn on the Moon or Mars.

Conclusion

Nutrition is thus a challenge for human acclimatization in extreme environments such as high altitude, cold, desert, polar environments, under water and aerospace environments. Innovative approaches are required to design foods for such special environments considering the nutritional requirements, hedonicity and acceptability employing modern food technologies.

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