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Physiological Research of Defence Interest in India: Part I—Studies in High Altitude Physiology

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ABSTRACT

Our troops have to operate under a variety of adverse environments including hypoxic, dry cold/wet cold conditions of high altitudes, hot dry/humid conditions in the plains, high noise levels from machinery, engines in ships and aircraft, gunfire, etc. Professor DS Kothari, the first Scientific Adviser, Ministry of Defence, could foresee as early as the late forties that it was only a scientific understanding of the basic physiological mechanisms that would lead to solutions which would ensure the optimal operational efficiency of men under such trying environments. He sowed the seeds of defence physiology as a major discipline in the then Defence Science Organisation, which developed into the Defence Research and Development Organisation. As a result, there have been outstanding contributions by the defence physiologists as well in the direct applications of their work in optimizing the operational efficiency of our defence personnel.

This paper reviews the wide spectrum of problems relevant to defence physiology studied over the last four decades, the significant findings; and their practical applications.

Part I reviews in detail work on the most pressing problem in our current geopolitical context, viz. high altitude physiology. Part II discusses studies on thermal stress, bioclimatology, noise exposure hazards, physical work capacity, effects of ageing on physical and mental capacities, and toxicology. In addition, the contributions of defence scientists towards the rationalisation of service ration scales, and resource development efforts are dealt with.

1. FOUNDATION FOR PHYSIOLOGICAL RESEARCH IN DEFENCE ESTABLISHMENTS

Health, physical fitness and capability of personnel handling sophisticated arms and equipment are no less important in the present-day defence operations than the maintenance of the equipment itself. A challenge to these elements in man is posed when our troops are to operate under the adverse hot dry and hot humid conditions in the plains, and under the dry cold and wet cold environments of high-altitude regions. Hypoxia at high altitudes is another daunting problem. Such problems could be studied and solved by the disciplines of applied physiology, biochemistry and psychology. Professor DS Kothari, the first Scientific Adviser to the Ministry of Defence, could foresee even in the late forties that such studies would have to be extensively and intensively undertaken in the near future. Consequently, a physiology group was included in the initial setup of the then Defence Science Organisation.

Professor Kothari was also aware that the physiologists to be drawn from the universities then were used to only academic research and had to be reoriented to the study of problems relevant to defence. With this background the first few physiologists who [illegible]

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Professor Kothari had the strong conviction that for quality research, the ingenuity and quality of the scientists were of greater importance than even the equipment they were handling. He took pains to inculcate the scientific spirit of inquisitiveness, thoroughness and open-mindedness in the young physiologists. This spirit was sustained in later years and went a long way in fostering of quality work when physiological research in defence expanded. After the Chinese invasion in 1962, the study of high altitude problems gained importance in the country and the defence physiologists made signal contributions in the areas of high altitude acclimatization, work physiology, and the like. The seed Professor Kothari had sown in the late forties has grown into a massive tree, as is borne out by the outstanding contributions by the scientists working in the various defence establishments where physiological research is conducted, as well as by the direct application of this work in optimizing the operational efficiency of our defence personnel.

2. HIGH-ALTITUDE EFFECTS: ACCLIMATIZATION STUDIES

The Chinese aggression in 1962 made us realize that troops may have to be stationed at very high altitudes on long-tenure basis. The physiological and biochemical changes in the human body on induction to high altitudes, the changes in the functional capacity and the process of acclimatization, had all to be studied in great detail. The Defence Institute of Physiology and Allied Sciences (DIPAS), the Directorate of Medical Research (DMR) in the office of the Director General Armed Forces Medical Services (DGAFMS) and the All India Institute of Medical Sciences conducted these studies.

2.1 Pulmonary Oedema-Acute Mountain Sickness (AMS)

In such studies the problem of acute mountain sickness (AMS) and high-altitude pulmonary oedema (HAPO) had to receive priority. Studies on soldiers who had earlier suffered from HAPO and recovered showed that failure to maintain normal adrenocortical response to altitude stress may be one of the precipitatory factors. For immediate treatment of HAPO cases, therefore, administration of cortisol with furesemide was recommended[5]. Work on the activity of the endocrine glands at HA revealed that a higher adrenal activity is the normal response on induction to high altitude. Failure to maintain this in some individuals may be another factor responsible for HAPO and AMS[6]. Increase in the alveolar capillary membrane permeability during hypoxic exposure is yet another factor identified[7]. More prone to HA sickness are soldiers who after high altitude exposure come down to sea level for 3-4 weeks and again return to high altitude. The cause was the enlarged pulmonary volume and retention of extracellular fluid in susceptible cases[8]. Another study established that the incidence of pulmonary oedema is not related to the higher levels of ozone prevailing at HA[9]. One of the preventive measures recommended against AMS was to administer acetazolamide and spironolactone in appropriate doses so as to reduce the pH of blood and improve the oxygen delivery to the tissues at the low oxygen tension at HA[10]. Phosphate supplementation was found to raise the plasma levels of 2-3 DPG, resulting in greater release of oxygen from oxyhaemoglobin. This would hasten the acclimatization process[11].

2.2 Biochemical Changes

Even in those who do not suffer from HAPO or AMS, there are many changes which are responses to hypoxic exposure. Hyperprolactenemia and impaired pituitary gonadal functions were noticed[12]. As for haematological and biochemical changes, packed cell volume of blood and RBC count rise progressively, but SGPT and SGOT levels, after an initial rise, come down subsequently. Initially, both albumin and globulin record a rise but albumin starts falling later. The fall could be due to a higher rate of its degradation and/or its slower rate of synthesis at HA. Thus protein metabolism seems to be altered at HA but it may not be due to liver damage[13]. After two years of acclimatization, some of the blood and urinary constituents tend to reach a new steady state comparable to that in the high altitude native (HAN). Similarities are noticed in the lowered fasting blood glucose level, lowered albumin/globulin ratio and lowered circulatory cholesterol level. Urinary creatine, creatinine, and creatinine coefficient increase progressively after an initial decline. But even after two years' stay at HA, all the values are in between those of lowlanders at sea level (SL) and HAN at high altitude, thereby suggesting that acclimatization may not be total even after two years' stay at HA[14]. Restriction in renal clearance is indicated by the depressed urea clearance[15]. The lowered circulating blood sugar level is attributed to the increased level of circulating insulin. Surprisingly, raised hyperglycemia was noticed after oral administration of glucose, which was explained as due to a disproportionate rise in the insulin-antagonistic hormones[16-18]. A decline in the production of thyroid hormone and its levels m the body was observed under hypoxic stress, which was attributed to a possible adaptive phenomenon under conditions of low oxygen availability[19].

2.3 Circulatory Adaptation

From the study of the pattern of ECG of soldiers who have spent over two years at 4267 m (14,000 ft), it has been postulated that adaptation takes place in two ways. There is one category with RVH, who have peripheral arterial unsaturation, tachycardia, and high cardiac output, stroke output and central blood volume. This category may represent some form of chronic mountain sickness. The other category is with normal ECG, and has a lesser degree of tachycardia and relatively lower cardiac output, stroke output and central blood volume. This category may be considered to be better adapted[20]. Subsequent work on maladaptation syndromes suggested that maladapted subjects exhibit lower sensitivity to both hypoxia and carbon dioxide. It was suggested that reduced chemoreceptor sensitivity might initiate the maladaptation syndrome[21]. Skin temperature and mean body temperature were found to record a steady and continuous fall throughout the stay at altitude. (This is rather surprising since there should have been some degree of acclimatization to hypoxia and cold after prolonged stay, and this should have arrested the fall in temperature.) Basal oxygen consumption increased initially but came back to normal by the third week of stay[22].

2.4 Work Capacity at High Altitude

Maximal oxygen uptake capacity (VO_2max) is considered to reflect work capacity. A 11 per cent fall in VO_2max was noticed at 3200 m (10,500 ft) and a 23 pre cent fall at 3500 m (11,500 ft). The speed of performance in a heavy task as well as work output was reduced[23]. In another study at 4100 m (13,530 ft), the HAN at that altitude had 12.3 per cent higher VO_2max as compared to acclimatized soldiers. This superiority was reflected in their better performance in running, hill climbing and endurance work[24,25]. Enhanced respiratory stress in the lowlanders as compared with HAN, while performing the same task, was stated to be the factor responsible for the difference in work capacity[26]. This finding was confirmed by the extensive data collected on troops directly inducted to altitudes of 2640 m (8712 ft), 3950 m (13,035 ft) and 4560 m (15,048 ft). Early attainment of the level of maximal breathing capacity, even at a lower level of oxygen uptake at increasing altitudes, seems to limit the maximal work rate at the altitudes[27].

2.5 Effect of Physical Training on Hypoxic Tolerance

DIPAS has studied the problem of combating the fall in functional capacity. Troops who were given extensive physical training at a moderate altitude of 1850 m (6105 ft) suffered less from AMS and retained higher work capacity than those who were given normal PT exercise at sea level or at moderate altitude or those who were given extensive training at sea level. It was hence recommended that endurance training at moderate altitude may be given to the troops prior to sojourn to HA, so that normal reduction in work capacity at the HA may be lowered[28]. The basis for the above improvement was stated to be the increased capillarisation of the muscles, increased storage of myoglobin and increased activity of the enzymes of the respiratory chain, all of which also take place during improvement due to acclimatization[29].

2.6 Effect of Drugs on Hypoxic Tolerance

Oral intake of 40 mg propanol hydrochloride, thrice a day for 5 days, did not have any effect on the capacity for prolonged work at high altitude[30]. However, in animal experiments, administration of a single dose of 10,000 IU of vitamin A 12 hr before hypoxic exposure 7600 m (25,000 ft) reversed the hypoxic effects on certain oxidative enzymes[31]. Feeding of animals with 100 mg of ascorbic acid daily for 5 days before exposure to simulated altitudes of 6060 m and 7576 m was found to protect the male reproductive system from the adverse effects of hypoxia[32]. These studies strengthen the case for liberal intake of vitamin A and Vitamin C at high altitudes.

2.7 Simple Indices to Evaluate the Acclimatization Status

Some work has been done to identify simple parameters or indices to evaluate the HA acclimatization status of individuals. It was noticed that the time of useful consciousness (TUC), when actually exposed to a simulated altitude of around 7600 m (25,000 ft) in a decompression chamber, as well as the Critical Flicker Frequency (CFF) could be used as indices. On induction to HA, TUC was strikingly reduced and CFF was also lowered. On acclimatization both the indices recovered[33].

2.8 Neurological Changes at High Altitude

On induction to HA, orthostatic tolerance decreased during the first week, mainly due to hypocapnia which caused frequent fainting during prolonged standing. Later, tolerance improved due to relative sympathetic hyperactivity and adaptation of the vasomotor centre to the reduced P_aCO_2 level[34]. This sympathetic hyperactivity was accompanied by a slight increase in anxiety level. In these individuals, slow wave sleep was curtailed and there were frequent short arousals during sleep. Acclimatized lowlanders and HAN had less of sympathetic hyperactivity and fewer arousals but suffered curtailment of slow wave sleep (SWS). Curtailment of SWS and frequent arousals were considered to be adaptive features to prevent the accentuation of arterial hypoxemia due to sleep hypoventilation[35].

As adaptation takes place, there is a selective hypertonus of the autonomic nervous system, some parts favouring the sympathetic activity and others showing predominance of parasympathetic activity[36]. That this gradual switchover to the parasympathetic system is an indicator of adaptation is borne out by the observation that in the HAN there is parasympathetic predominance at HA, but within two months of stay at SL declines, probably due to the elevation in sympathetic activity, and tends to reach the autonomic equilibrium of lowlanders. On return to HA there is a further increase in sympathetic excitation, as seen in lowlanders on acute induction, but to a lesser level. There is a trend in their case to return faster to their old response[37-39]. It has been stated that the onset of pulmonary oedema on induction to altitude can be attributed to the pulmonary effects brought about by the activation of the sympathetic system by the oedemogenic area in the posterior part and the anti-oedemogenic area in the preoptic region of the hypothalamus. This is confirmed by the finding that in albino rats and rhesus monkeys bilateral electrolytic lesions in the preoptic region resulted in 80 per cent of the animals suffering from pulmonary oedema[40].

2.9 Cold Stress at High Altitude

An indication of acclimatization to cold is that, during an experimental exposure to low ambient temperature (2-3 °C) for 1 hr, cold-induced heat output as well as shivering is much less in the cold-acclimatized individuals than in the non-acclimatized[41].

The responses of HAN (of 3352 m; 11,000 ft) were exactly similar to those of lowlanders at SL. Lowlanders who had been acclimatized to HA for one year showed responses in between those of newcomers and HAN[42]. Physiological stress during cold exposure was the same both in humid cold and in dry cold. But when cold stress was compounded with hypoxia the stress was definitely higher[43].

On induction to HA, the cryoglobulin levels in the body increase but become normal on deinduction to SL. Cryoglobulin, however, does not seem to have any relation to cold injury since there is no correlation between the two, and the levels of cryoglobulin in cold injury cases are the same as in normal individuals[44]. Making use of cold pressor responses and BMR responses, it has been established that simultaneous acclimatization to hypoxia and cold is more effective than stresswise acclimatization[45,46]. As early as 1963, it was observed that 3 weeks' deliberate exposure to cold was sufficient to result in adequate cold acclimatization[47]. A recommendation to this effect was accepted by the Army Headquarters. This observation was subsequently confirmed by an independent study[48].

2.10 Psychological Effects—Mental Functions

Studies have shown that at high altitudes adverse psychological reactions of feeling of loneliness, social isolation, homesickness, dejection/depression, apathy and dullness, and worries about the family are prevalent. Still group acceptance and social adjustment of an individual are fairly stable[49].

As for mental functions, psychomotor efficiency and its accuracy and speed declined during the early stages of altitude exposure. After 13 months' stay, there was an improvement in accuracy, but not in the speed of performance[50].

2.11 Yogic Exercises—Beneficial Effects at High Altitude

At high altitudes, it may not be always possible to carry out outdoor PT exercise. In such situations, recourse to yogic exercises may be an alternative. Comparative physiological studies on improvements due to physical training on the one hand, and yogic training on the other, have pointed to the superiority of the latter over the former. Studies by AFMC, Pune[51], revealed that inclusion of yoga exercises in normal NDA training results in greater improvement in pulmonary functions, and would be an advantage at high altitudes. Shoulder flexion extension and hip flexion extension improved as a result of *Hatha Yoga* performed for 1 hr daily for 6 months but not because of PT exercise[52]. Improvement in muscular endurance and delay in onset of fatigue due to *Hatha Yoga* exercises were also reported[53].

In another study, 3 months of yoga training (22 *asanas* administered for 1 hr daily) was found to result in decrease in heart rate, BP, blood glucose, and plasma cholesterol level, and increase in mean skin temperature and in alpha index of EEG. There were also changes in some enzyme activities. All these indicated a shift in the autonomic balance towards relative parasympathetic dominance[54]. Since such a shift is noticed also during HA acclimatization, it can be reasonably surmised that yoga exercises may accelerate the acclimatization process. Improvements in thermoregulatory efficiency and orthostatic tolerance, and economy in energy expenditure in sub-maximal activities, all due to 6 months of yoga exercises, were also reported[55,56]. Studies on the responses to experimental cold exposure (10 °C) indicated the improvements in cold tolerance achievable due to even six months of yogic exercises[57]. There were, thus, definite evidences for the beneficial effects of yogic exercises at high altitude.

2.12 Changes Body Composition at High Altitude

Anthropometric measurements can be used to determine the body composition changes. Studies carried out by DIPAS indicated that from the measurements of body weight, thigh anterior skinfold and juxta-nipple skinfold thicknesses, and forearm circumference, the lean body mass can be accurately predicted. Similarly, body density could be predicted from a set of 5 measurements[58]. Making use of such measurements on troops at HA, it was reported that on acute exposure, a progressive decrease in total body water, extracellular water, plasma volume and blood volume, and a slight increase in red cell mass occurred. These were indications of hypohydration on acute exposure[59]. Other anthropometric studies at HA pointed to a gain in mean body fat content and very little changes in cell solids after 4 weeks' stay at HA[60]. After 10 months' stay, the body fat content seemed to come down and lean body mass to go up[61]. The latter finding seems to be in accord with the observations on HAN. On descent from HA, there were significant increases in body fat content, cell solids and mineral content of the body. The density of the lean body was also found to have increased owing to increased protein synthesis and its retention in the intracellular space[62].

Ladakhi soldiers (HA natives), in spite of their higher calorie intake at HA as compared to the intake of soldiers (lowlanders) at SL, had smaller skinfold thickness and higher body density than soldiers in plains. When the same Ladakhi soldiers were brought down to SL and made to consume only three-fourths of the calories consumed at HA and to lead a sedentary life, their skinfold thickness increased and body density decreased[63,64]. It can therefore be inferred that the recorded changes in body fat at HA are more due to the changes in physical activity level which, immediately after induction to HA, has to be low, and with duration of stay has to become gradually more intensive.

2.13 Load Carriage by Infantry Soldier

The steepness of the terrains encountered at high altitudes was observed to raise the energy expenditure during load march to a greater extent than the loads themselves. Making use of the experimental data collected, a table of optimum speeds for march by a soldier weighing 60 kg (clothed), and carrying different loads on terrains of varying steepness was made available to the Army Headquarters[65,66]. While marching on loose-snow covered ground, the energy requirement was found to be a function of the depression of feet in snow, and was highly taxing. Walking at natural speed without any load on loose snow causing a foot depression of 30 cm was found to be as strenuous as marching with 31.8 kg load at a speed of 6 km/h on snow-free ground[67]. Recommendations were also made to distribute the load on the body and reduce the weight of the footwear.

2.14 Load Transporting Animals

Mules and horses are used at high altitudes to transport essential goods on narrow and difficult terrains. Their fitness is as important as that of men. Since such animals were reported to suffer from colic and lose their physical fitness at high altitudes, a physiological study was carried out which revealed that these animals had stabilized physiological responses on the sixth day after induction, and their water and feed intake had become normal. The high iron and silica content of water in some places at HA was considered to have caused gastrointestinal irritation[68]. Animals needed only a 2 week acclimatization at 3600 m[69]. A recommendation was also made that the load to be transported by the animals in the hilly and marshy terrains may be restricted to 40 per cent of the animal's body weight[70].

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