Defence Science Journal, Vol, 50, No 2, April 2000, pp. 167-176

Effect of Prolonged Exposure to High Altitude on Skeletal Muscles of Indian Soldiers

H. Bharadwaj, Jagdish Prasad, S.N. Pramanik, S. Kishnani, T. Zachariah, K.L. Chaudhary, K. Sridharan and K.K. Srivastava
Defence Institute of Physiology & Allied Sciences, Delhi - 110 054

ABSTRACT

The effects of 10-month stay at high altitude (HA) on body composition of Indian soldiers of mixed ethnic origins with special reference to body musculature were investigated. Body density was regressed from skinfold thicknesses and girth measurements. Bone mineral was estimated from body width and stature. Muscle X-ray shadow areas at upperarm and forearm and stature were correlated with body mass, and a regression equation was constructed. Analysis of data indicated that muscle mass degraded at HA. In soldiers of group 1 (height: 4100 m), 1.74 kg muscle mass degraded to generate 1.31 kg water. In soldiers of group 2 (height: 3750 m), 1.38 kg muscle mass was degraded to generate 1.04 kg water.

1. INTRODUCTION

Significant shifts in proteins from muscle-to-non-muscle fraction without any change in total body proteins were noted by Surks[1], *et al.* in subjects abruptly exposed to an altitude of 4300 m for two weeks. The observed body mass loss was attributed to the loss in body fat only. Consalazio[2], *et al.* observed negative nitrogen and water balance in their subjects after four week exposure to 4300 m. Krzywicki[3], *et al.* also reported losses in body fat, protein, water and minerals in the subjects exposed to the same altitude for two weeks. Rennie[4], *et al.* reported increased excretion of proteins in the urine of native high landers with normal creatinine clearance. Proteinuria was also found in climbers undergoing acclimatisation. Pines[5] reported proteinuria above 3000 m though this was not provoked in the strenuous and exhausting part of the trip below 3000 m.

Boyer and Blume[6] reported that 70.5 per cent decrease in body mass accounted for the loss in body fat during approach march at high altitude (HA), but during residence at 5400 m, fat accounted for only 27.2 per cent of the body mass loss. These authors concluded that muscle catabolism and malabsorption contributed significantly to body mass loss at HA. Rose[7], *et al.* subjected men to simulated hypoxia of Mt. Everest and observed significant reduction in the muscle X-ray shadow areas of thigh and upperarm and a significant loss in the mean body mass evaluated by the densitometric technique.

The above studies indicate that skeletal muscle may be subjected to degradation at HA, specially when individuals make strenuous physical effort and the loss in body mass may be partly due to the loss in muscle mass. But these studies were conducted on the sojourners and mountaineers whose stay at HA was short. Therefore, the present study

Revised 18 June 1999

was undertaken to find out the changes within the body composition in individuals of sea level residency staying for long durations at HA. Further, an attempt has also been made to assess the nature and extent of muscle degradation, if any, using radiographic technique and anthropometric measurements.

2 MATERIALS & METHODS

The study was carried out on 21 young and healthy male volunteers from the Indian Army. They were of mixed ethnic origins ranging between 18-30 years. In the control study carried out in plains (Delhi: height above sea level 220 m). Each soldier was given a diet which consisted of 15.7 MJ (3750 cal), 119 g protein, 598 g carbohydrate and 98 g fat per day. On completion of this study, the soldiers were divided into two groups. Group 1 proceeded to HA destination located at 4100 m and group 2 to a destination at 3700 m above the sea level. At these locations, they led a physically active life carrying out routine infantry duties, and each soldier was given a diet which consisted of 20.2 MJ (4830 cal), 144 g proteins, 747 g carbohydrates and 138 g fat per day. These ration scales had been evolved earlier after extensive nutritional studies for more than three months, after taking into consideration energy expenditure of the troops in the plains as well as at HA. The anthropometric and radiographic observations made on the soldiers in the control study were repeated at HA stations after a continuous tenure of 10 months.

2.1 Anthropometric Measurements

Stature was measured using Martin anthropometer and nude body mass (to the nearest 0.05 kg) was measured on a sensitive Avery beam balance. Width at elbow, wrist, knee and ankle was measured by sliding caliper, and bone mineral was estimated using the formula, of Allen[8], *et al*. Bone mineral (kg) = $3.9 \times T^2 \times H \times 10^{-4}$ where T is the transverse diameter equal to one quarter of the sum of four bony width and H is the stature. All measurements were in centimeter.

Skinfold (SF) thicknesses at biceps, subscapula, juxta nipple and anterior of the thigh were measured sing Lange SF caliper as per Sloane's[9] procedure. Body circumferences at forearm, thigh and ankle were measured as per Wilmore and Behnke's[10] procedure.

Body density (Y_{Db}) was computed from SF thicknesses and girths. For study on soldiers carried out in Delhi, the following equation of Jones[11], *et al*. was used.

Y_{Db} = 1.1177-0.0008 (sub scapula, SF)-0.0007 (thigh anterior SF)-0.0006 (juxta nipple SF)-0.0003 (thigh circumference) 1(a)

R 0.82, and standard error of estimation (SEE) 0.0059 1(b)

(SF thickness is in millimeter and the other measurements are in centimeter)

At HA, similar equation of Bharadwaj[12], *et al*. was used.

Y_{Db} = 1.0741 – 0.0088 (thigh SF) – 0.0086 (juxta nipple SF) – 0.0392 (biceps SF) + 0.0033 (forearm circumference) – 0.0023 (ankle circumference). 2(a)

R 0.76, SEE 0.0078 2(b)

Body fat was estimated using the regressed density values and body mass by Siri's[13] formula. Body volume was obtained by dividing body mass by the regressed density.

2.2 Soft Tissue X-Ray Technique

The technique used in this investigation was similar to that used by Brozek and Mori[14].

2.2 *Upperarm*

A lateral view of the middle of the upperarm was selected. The distance from the tip of the acromion process to the tip of the elbow (olecranon) was measured. A point was marked at the back of arm which was located in the middle. A steel pin was then attached over the arm, with cellophane tape so that the tip of the pin was placed over the point already marked. An X-ray plate was then interposed between the rightarm and the rib cage and the subject was instructed not to press his arm over the X-ray plate, but only to maintain it in light contact with the plate. He was then told to stand in front of the X-ray machine, maintaining the plane of the plate perpendicular to the X-ray beam. The distance between the plate and the anode was then adjusted to 91.4 cm. The machine was so adjusted that the centre of the lateral aspect of the arm at the level of the pin was the target.

2.2.2 *Forearm*

An anterior view of the maximum bulge of the forearm was selected. The X-ray beam was directed from above so that the middle of the bulge was the target of the beam. The distance from the tabletop to the source of the beam was adjusted to 76.2 cm. The characteristics of the exposure were 45 KVP and 10 MAS. Such exposure gave good resolution of the three constituents, viz., skin, muscle and bone of differing density. The temperature of the developing bath was maintained between 70 °F and 75 °F. Screen films of two sizes (16.5 cm × 21.6 cm and 20.3 cm × 25.4 cm) were used. Selection of these sizes was directed by the anthropometric dimensions of the subjects. After processing, these films were studied using a viewing box.

For upperarm X-ray pictures, a line was drawn from the tip of the pin to the opposite edge of the shadow in such a way so as to intercept the bone shadow perpendicularly. In the forearm pictures, the line was drawn in the region of the maximum bulge. Two parallel lines were then drawn 2.5 cm above and below the central line, and the areas covered by the skin, muscle and the bone X-ray shadows, between the top and bottom lines were measured using a planimeter (Fig. 1).

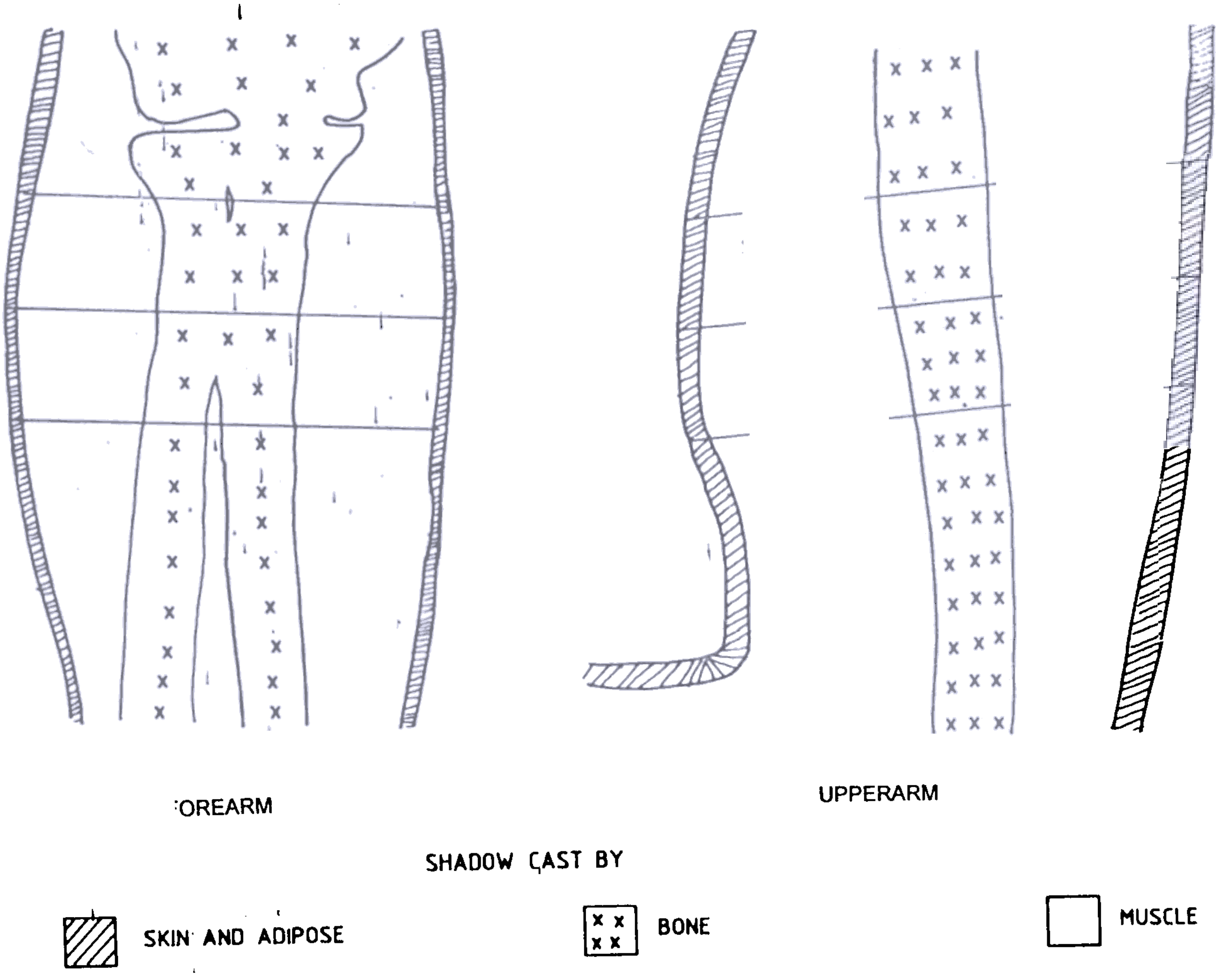

Figure 1. Soft tissue X-ray of the forearm and upperarm

Table 1. Effect of 10-month continuous exposure to high altitude on the physical characteristics of Indian soldiers

Physical characteristics	Group 1 (n=11) In plains (Delhi) (Mean + SD)	Group 1 (n=11) At 4100 m (Mean + SD)			Group 2 (n=10) In plains (Delhi) (Mean + SD)	Group 2 (n=10) At 3750 m (Mean + SD)		*p*
Stature (cm)	163.500 ± 5.400				169.700 ± 3.900			
Body mass (kg)	55.990 ± 4.690	54.960 ± 4.490	1.59	NS	60.620 ± 5.120	60.360 ± 5.490	0.47	NS
Elbow width (cm)	6.500 ± 0.300	6.500 ± 0.300	0.60	NS	6.900 ± 0.300	6.600 ± 0.400	2.50	< 0.05
Wrist width (cm)	5.400 ± 0.300	5.400 ± 0.300	0.82	NS	5.800 ± 0.300	5.700 ± 0.300	2.45	< 0.05
Knee width (cm)	8.900 ± 0.400	8.800 ± 0.400	2.61	< 0.05	9.400 ± 0.500	9.200 ± 0.400	1.96	NS
Ankle width (cm)	7.000 ± 0.400	6.900 ± 0.300	0.71	NS	7.200 ± 0.300	7.200 ± 0.400	0.00	NS
Thigh circumference (cm)	49.800 ± 2.900	48.900 ± 2.500	2.30	< 0.05	49.400 ± 2.400	49.700 ± 2.600	− 0.55	NS
Forearm circumference (cm)	25.100 ± 1.300	24.900 ± 1.300	0.97	NS	26.000 ± 1.300	26.000 ± 1.200	0.86	NS
Ankle circumference (cm)	20.400 ± 1.300	20.000 ± 1.000	1.85	NS	21.100 ± 1.400	21.000 ± 1.200	1.60	NS
Subscapula SF (mm)	10.300 ± 3.400	9.600 ± 2.400	0.79	NS	7.900 ± 1.300	9.100 ± 1.600	− 3.41	< 0.01
Biceps SF (mm)	3.000 ± 0.800	2.800 ± 0.800	1.33	NS	2.500 ± 0.500	3.100 ± 0.800	− 3.35	< 0.01
Juxta nipple SF (mm)	7.400 ± 1.800	7.900 ± 1.900	−0.69	NS	7.000 ± 2.500	8.700 ± 2.900	− 3.74	< 0.01
Thigh SF (mm)	10.300 ± 3.600	8.800 ± 2.400	1.73	NS	8.900 ± 3.300	9.100 ± 2.100	− 0.27	NS
Body Density (10^3 kg.m^{-3})	1.083 ± 0.005	1.085 ± 0.006	−0.86	NS	1.086 ± 0.004	1.084 ± 0.005	1.31	NS
Body fat* (kg)	4.020 ± 1.400	3.410 ± 1.400	1.01	NS	3.530 ± 1.200	4.110 ± 1.500	− 1.22	NS
Bone minerals** (kg)	3.080 ± 0.260	3.030 ± 0.250	1.98	NS	3.550 ± 0.370	3.450 ± 0.380	2.98	< 0.02

* Computed from Siri's formula

** Computed from bony width and stature

3. RELIABILITY OF MEASUREMENTS

For all the experimental parameters, the reliability index was calculated by the formula suggested by Guilford[15]:

$$Rtt = \frac{\sigma_e^2}{\sigma_t^2}$$

where *Rtt* is the coefficient of reliability, σ_e^2 is the error variance, and σ_t^2 is the total variance.

The calculated reliability index is > 0.91 for all anthropometric measurements and varies from 0.88 to 0.96 for muscle X-ray shadow areas of the upperarm and the forearm.

4. RESULTS

Changes in the SF thicknesses and other anthropometric measurements on prolonged exposure at HA are shown in Table 1 for group 1 and group 2 soldiers. The table also shows the computed values of body density, total body fat and bone mineral content for the two groups before and after HA exposure.

On an average, group 1 soldiers lost 1.03 kg body mass after HA exposure. In group 2 soldiers, this loss was negligible (0.26 kg). The body mass change in both the groups was not statistically significant.

The subscapula, biceps and juxta nipple SF thicknesses were found to be significantly greater ($p < 0.01$) in group 2 soldiers at HA in comparison to the corresponding values in the plains (Delhi). After exposure, most of the SFs in group 1 were found to be reduced as compared to the corresponding values in the plains (Delhi). Such reductions were not statistically significant. Elbow width declined significantly in group 2 soldiers and knee width in group 1 soldiers. Thigh circumference was reduced in group 1 soldiers significantly ($p < 0.05$) but not in group 2 soldiers. Body fat content was found to be increased by 0.58 kg in group 2 soldiers, whereas it was reduced by 0.61 kg in group 1 soldiers. These changes were not statistically significant. The bone mineral content declined in both the groups, but such decline was statistically significant ($p < 0.02$) in group 2 soldiers only.

The total X-ray shadow areas of upper arm and forearm in the plains (Delhi) and at HA are given in Table 2 for groups 1 and 2 soldiers. Examination of the total X-ray shadow areas of the upperarm and forearm after prolonged exposure at HA revealed that bone areas were not reduced. Also, changes

Table 2. Reductions in the areas of upperarm and forearm X-ray shadows on prolonged exposure to high altitude

No. of soldiers	Muscle X-rayed	In plains (Delhi) Mean ± SD (cm²)	At high altitude* Mean ± SD (cm²)	Difference (cm²)	*t*	*p*
11	Upperarm (group 1)	57.50 ± 4.77	55.53 ± 4.57	1.97	3.70	< 0.002
10	Upperarm (group 2)	61.20 ± 4.53	60.58 ± 4.55	0.62	1.13	NS
21	Upperarm (pooled)	59.26 ± 4.92	57.94 ± 5.15	1.33	3.30	< 0.002
11	Forearm (group 1)	50.08 ± 2.68	49.26 ± 3.00	0.82	1.45	NS
10	Forearm (group 2)	51.65 ± 2.72	50.40 ± 2.62	1.25	3.84	< 0.002
21	Forearm (pooled)	50.83 ± 2.75	49.80 ± 2.82	1.93	3.11	< 0.003

* Group 1 exposed to 4100 m
* Group 2 exposed to 3750 m

Table 3. Regression of areas of X-ray shadows at upperarm and forearm and stature on body mass

Eqn No.	Parameter	Regression coefficient for upperarm X-ray area (*x*)	Regression coefficient for upperarm X-ray area (*y*)	Regression coefficient for stature (*z*)	Log constant	R	SEE
1(a)	Upperarm X-ray shadows and stature (Delhi data-based)	0.8939 0.1327 (SE)		0.5694 0.3166 (SE)	1.0850	0.8823	0.0199
1(b)	Upperarm X-ray shadows and stature (High altitude data-based)	0.8587 0.1490 (SE)		0.3688 0.3832 (SE)	− 0.5738	0.8563	0.0226
2(a)	Surface areas of the upperarm and forearm X-ray shadows and stature (Delhi data-based)	0.5655 0.1372 (SE)	0.7108 0.1967 (SE)	0.7010 0.2477 (SE)	2.0079	0.9353	0.0154
2(b)	Surface areas of the upperarm and forearm X-ray shadows and stature (High altitude data-based)	0.4542 0.1534 (SE)	0.8266 0.2142 (SE)	0.7533 0.3047 (SE	2.1178	0.9262	0.0170

Equation: Log body mass = x log (SA:UA) + y log (SA:FA) + z log (stature) + log (constant)

in the adipose tissue were hardly detectable. Only muscle shadow showed measurable changes. The upperarm muscle X-ray shadow areas in group 1 and forearm muscle X-ray shadow areas in group 2 were reduced significantly ($p < 0.002$)

Table 3 shows the regression characteristics of upperarm of the X-ray shadow areas, forearm

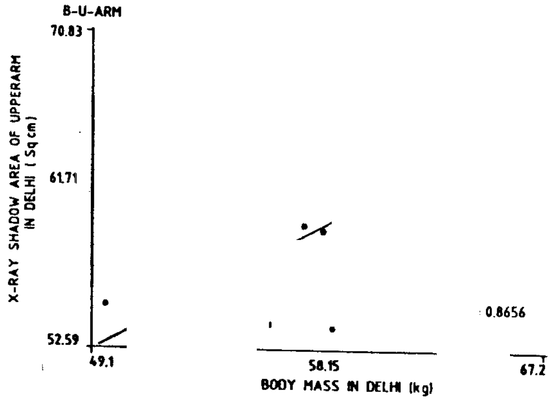

Figure 2. Relationship between body mass in Delhi with X-ray shadow area of the upperarm.

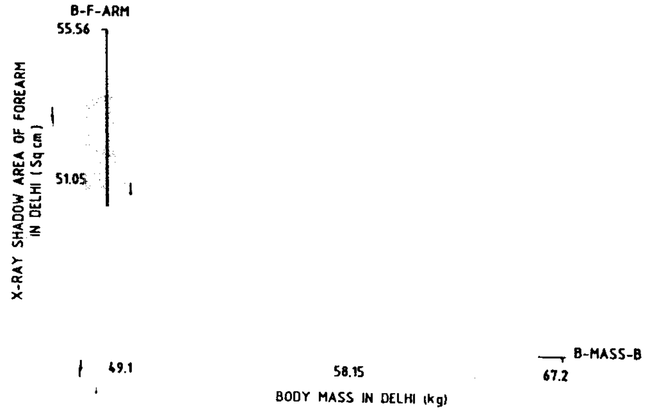

Figure 3. Relationship between body mass in Delhi with X-ray shadow area of the forearm.

X-ray shadow areas and stature on body mass, the equations are of the form:

Body mass (kg) = (X-ray surface area at upperarm, cm^2)^x × (X-ray surface area at forearm cm^2)^y × (stature, cm)^z × (constant)

On taking logarithms, this equation could be viewed in the linear form as

Log body mass = x log (surface area upperarm) + y log (surface area forearm) + z log (stature) + log (constant)

Table 3 also gives the regression coefficient, log value of the constant, multiple coefficient R and SEE for such type of equation constructed from plains (Delhi) as well as from HA data. The Eqn 1(a) is based on Delhi data and uses only upperarm X-ray shadow areas and stature for regressing body mass. The Eqn 1(b) is derived from the same independent variables, but utilises HA data. A comparison of these equations reveals that there is a shift in regression coefficient at HA with lowering of multipe R and increase in SEE, indicating compositional shifts in the body. By including forearm muscle X-ray shadows also in the regression on the body mass [Eqn 2 (a)], there is only a marginal increase in the multiple R. Its HA equivalent [Eqn 2(b)] also has equally highly significant multiple R and similar SEE. A comparison of Eqns 2(a) and 2(b) reveals a decline in the regression coefficient for upperarm X-ray shadows and a concurrent increase in the coefficients for forearm and stature.

Correlation of X-ray shadow areas of upperarm and forearm with body mass in plains (Delhi) (groups 1 and 2) is illustrated in scatter diagrams of Figs 2 and 3. A similar scatter at HA (pooled data) is illustrated in scatter diagrams of Figs 4 and 5. Figure 6 illustrates the scatter of predicted body mass by Eqn 2(a) wrt observed body mass. The predicted body mass at HA was obtained by feeding HA X-ray shadow areas in Eqn 2(a). As a result of this, the computed mass change or the amount of muscle degraded at HA in groups 1 and 2 amounts to 1.74 kg and 1.38 kg, respectively.

Table 4 collates the densitometric and X-ray computed parameters and shows the altered body composition picture after HA exposure.

Group 1 soldiers exposed to HA (4100 m) lost on an average 1.03 kg body mass. Based on computed body density in plains (Delhi) and at HA, there was a net shrinkage in body volume by 1.051 kg. Since total body volume is the sum of body fat, tissue solid, water, and minerals, change in body volume after prolonged exposure has been equated with observed changes in the body constituents. The muscle X-ray shadow data obtained for group 1 soldiers indicated a net muscle degradation amounting to 1.74 kg. This amount of muscle degraded to 0.43 kg tissue solids and 1.31 kg water[16]. As a result of balancing the volume equation (Table 4), loss of body fat to the tune of 0.65 kg was indicated. This estimate is in good agreement with that predicted from Siri's formula (0.61 kg). The losses in different constituents also added up close to total body mass loss (1.03 kg *vs* 1.12 kg). The difference in estimates is within the accuracy of the weighing instrument.

Similar analysis of group 2 soldiers indicated

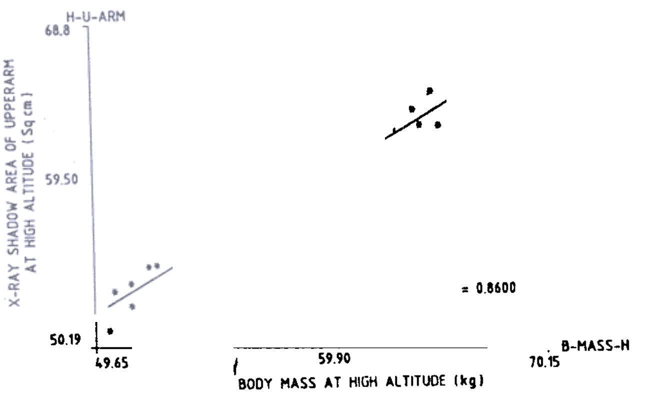

Figure 4. Relationship between body mass at high altitude with X-ray shadow area of the upperarm.

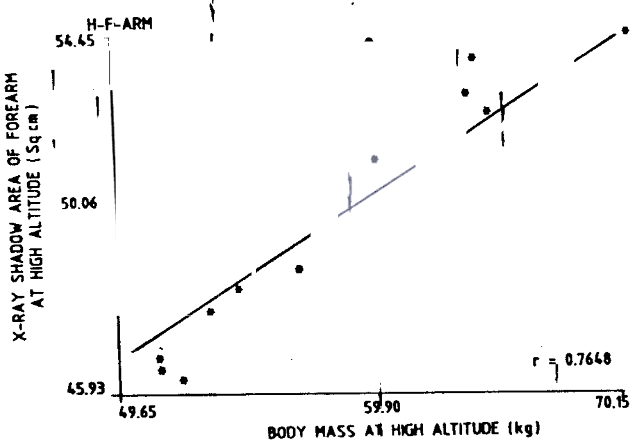

Figure 5. Relationship between body mass at high altitude with X-ray shadow area of the forearm.

Table 4. Analysis of body composition changes on prolonged exposure to high altitudes

Exposed group	No. of soldier	Mean change in* body mass (kg)	Mean change in body volume (l)	Amount of muscle degraded (kg)	Bone mineral* losts (kg)	Fat change indicated by Siri's formula* (kg)
ıup 1	(1	.03	$\frac{55.990}{1.083} - \frac{54.960}{1.085} = -1.05$	Total muscle = 1.74 Tissue solids lost = 0.43 Water liberated = 1.31		0.61
iroup 2	(10)	-0.26	$\frac{60.620}{1.086} - \frac{60.360}{1.084} = -0.14$	Total muscle = 1.38 Tissue solids lost = 0.34 Water liberated = 1.04	0.10	+ 0.5

Densitometric analysis

Group — Volume of tissue — Volume of fat + volume of tissue solid + volumen of bone mineral + volume of water

.05 — $\frac{x}{0.90}$ — $\frac{0.43}{1.40}$ — $\frac{0.05}{2.80}$

$x = -0.65$

Computed mass changes

Fat = − 0.65

Tissue solids = − 0.42

Bone mineral = − 0.05

Total** = − 1.12

Group 2. Volume of tissue — Volume of fat + volume of tissue solid + volume of bone mineral + volume of water

-0.14 — $\frac{x}{0.90}$ — $\frac{0.34}{1.40}$ — $\frac{0.10}{2.88}$

$x = 0.12$

Computed mass change:

Fat = + 0.12

Tissue solids = − 0.34

Bone mineral = − 0.10

Total** = − 0.32

* of Table I.

** Error in computed body mass change within the least count of the instrument.

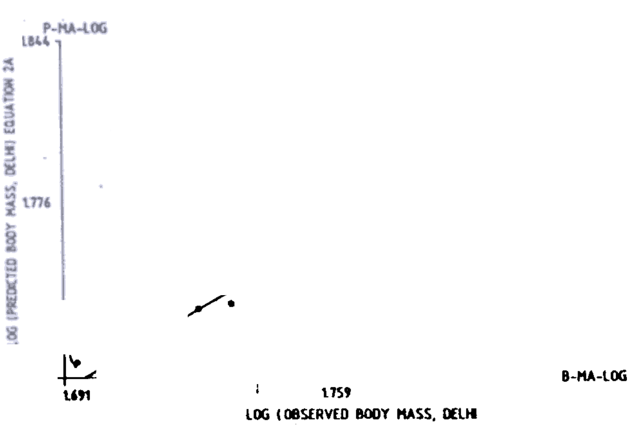

Figure 6. Relationship between body mass at high altitude with X-ray shadow area of the forearm.

a muscle degradation to the tune of 1.38 kg leading to the liberation of 0.34 kg tissue solids and 1.04 kg water. In case all the liberated water was retained and 0.34 kg tissue solids and 0.10 kg mineral was lost, a net gain of 0.10 kg fat would be indicated. There was apparent disagreement between fat gain indicated by Siri's formula (Table 1, 0.58 kg) and the densitometric analysis (Table 4, 0.10 kg).

5 DISCUSSION

A significant reduction seen in muscle X-ray shadow areas with elevated levels of creatine phosphokinase in the serum (Table 5) suggests

Table 5. Some biochemical observations on Indian soldiers continuously exposed to high altitudes for six and ten months

Biochemical parameter	Plains (Delhi) Mean ± SD/SE	High altitude Mean ± SD/SE	Courtesy of
Creatine phosphokinase (Milli International Unit)	!0.080 250 (SE	84.46 ± 4.71 (SE)* (10 months)	Srivastava et al.
l serum proteins (g %)	7.103 ± 0.712 (SD)	!83 ± 0.660 (SD)* (10 months)	Grover[23], et al.
xtracellular space (ml/k	50.70 ± 4.000 (SE)**	157.400 ± 5.400 (SE (6 months)	Singh[19],
Intracellular space (ml/kg)	525.000 3.100 (SE)**	534.000 ± 6.500 (SE) (6 months)	Singh[19], et al.

Mean difference significant $P < 0.05$
For a man weighing 57.53 kg, total increase in water content would amount to 0.90 kg

muscle degradation at HA. It appears that muscle solids leak out into the extracellular space due to alteration in membrane permeability. During exposure to 4300 m, protein shift from muscle to non-muscle fraction has been reported by Surks[1], *et al.* also. A significant portion of these solids is probably lost through urine, as suggested by Rennie and Joseph[4] and Pines[5]. Since the subjects in both the groups have similar and adequate dietary intakes and were fully protected from cold, the HA hypoxia could be singled out for such muscular degradation. Sridharan[17], *et al.* found no disturbance in gastrointestinal function at 3500 m, while Rai[18], *et al.* showed no disturbance in digestibility and utilisation of dietary fat up to 4700 m. Thus, it is unlikely that protein and fat malabsorption at moderate altitudes could be an important factor contributing to the muscle loss observed in the radiographs.

Table 5 also gives the data of Singh[19], *et al.* which indicates expansion of intracellular and extracellular compartments of the body in troops, who had been continuously exposed to similar altitudes for six months. The decrease in the plasma proteins after 10-month continuous exposure to HA indicates that the muscle loss might be associated with significant hyper-hydration.

In group 1 soldiers, the degraded muscle (1.74 kg) would generate 1.31 kg water. This could be redistributed between intracellular and extracellular spaces of the lean body. In group 2 soldiers, only 1.04 kg water would be available for such redistribution as a result of degradation of 1.38 kg muscle. As the densitometric approach indicated a loss of 0.65 kg in body fat in group 1 soldiers (Table 4), a portion of the water liberated from the degraded skeletal muscle could have moved into fat tissue. Volumewise, the fat cells could accommodate 0.721 kg of water only in place of lost fat. The remaining 0.591 kg could be redistributed between interstitial and plasma volumes constituting the extracellular space. The portion of water thus retained by the fat cells would amount to 45 per cent of the water liberated from the degraded muscles. There is evidence to suggest that adipose tissue may increase its water content in the event of fat loss[20].

There was a discrepancy in the estimates of fat gained by group 2 soldiers by Siri's formula and radiographic approach. Use of Siri's formula indicated 0.58 kg of body fat gain, whereas body fat gain estimated in the present study was only 0.12 kg. Siri's formula does not take into account the changes in water gain or loss from the body. Thus, it is likely that this group excreted 45 per cent of 1.04 kg, i.e., 0.471 water (Table 4). Balancing the volume equation again, fat gain to the tune of 0.55 kg would indicate that the two approaches would lead to the same results. Thus, the SF measurements may not be true indicators of fat loss possibly due to concommitant hyper-hydration of adipose tissue. At the same time, the gross composition of the skeletal muscle could be changing which could result in a change in the density of the lean body. Use of Siri's formula for estimating body fat in such circumstances could be misleading[21]. From the experimental data and the findings of other workers in similar situations, it may be concluded that HA hypoxia may be an important factor in skeletal muscle degradation at moderate altitudes (3700 m to 4100 m).

ACKNOWLEDGEMENTS

The authors are grateful to Mr T.L. Rao of Scientific Analysis Group, (SAG), Delhi, for valuable discussions regarding various statistical procedures. Thanks are also due to Dr W. Selvamurthy, Director, DIPAS, Delhi, for critical appraisal and permission to publish the work.

REFERENCES

1. Surks, M.I.; Chinn, K.S.K. & Matoush, L.O. Alterations in body composition in man after acute exposure to high altitude. *J.Appl. Physiol.*, 1996, **21**, 1741-746.
2. Consolazio, C.F.; Matoush, L.O.; Johnson, H.L. & Daws, I.A. Protein and water balances of young adults during prolonged exposure to high altitude (4300 m). *Am. J. Clin. Nutr.*, 1968, **21**, 154-61.
3. Krzywicki, H.J.; Consolazio, C.F.; Matoush, L.O.; Johnson, H.L. & Barnhart, R.A. Body compostion changes during exposure to altitude. *Fed. Proc. Am. Soc. Exp. Biol.*, 1969, **28**, 1190-194.
4. Rennie, I.D.B. & Joseph, B.J. Urinary protein excretion in climbers at high altitude. *Lancet*, 1970, **1**, 1247.
5. Pines, A. High altitude acclimatisation and proteinuria in East Africa. *Br. J. Dis. Chest.*, 1978, **72**, 196.
6. Boyer, S.J. & Blume, F.D. Weight loss and changes in body composition at high altitude. *J. Appl. Physiol.*, 1984, **57**, 1580-585.
7. Rose, M.S.; Houston, C.S.; Fulco, C.S.; Coates, G.; Sutton, J.R. & Cymerman, A. Operation Everest II. Nutrition and body composition. *J. Appl. Physiol.*, 1988, **65**(6), 2545-551.
8. Allen, T.H.; Welch, B.E.; Trujillo, T.T. & Roberts, J.E. Fat, water and tissue solids of the whole body less its bone mineral. *J. Appl. Physiol.*, 1959, **14**, 1009-12.
9. Sloane, A.W. Estimation of body fat in young men. *J. Appl. Physiol.*, 1967, **23**, 311-15.
10. Wilmore. J.H. & Behnke, A.R. An anthropometric estimation of body density and lean body weight in young men. *J. Appl. Physiol.*, 1969, **27**, 25-31.
11. Jones, P.R.M.; Satwanti; Bharadwaj, H.; Bhatia, M.R.; Zachariah, T. & Kishnani, S. Relationship of body density and lean body mass to body measurements; application to Indian soldiers of relationships developed for people of European descent. *Ann. Hum. Biol.*, 1982, **9**, 355-62.
12. Bharadwaj, H.; Verma, S.S.; Zachariah, T.;Bhatia, M.R.; Kishnani, S. & Malhotra, M.S. Estimation of density and lean body weight from body measurements at high altitude. *Eur. J. Appl. Physiol.*, 1977, **36**, 141-50.
13. Siri, W.E. The gross composition of the body. *Adv. Biol. M. Phs.*, 1956, **4**, 239-80.
14. Brozek, J. & Mori, H. Some interrelations between somatic, roentgenographic and densitometric criteria of fatness. *Human Biology*, 1958, **30**, 322-36.
15. Guilford, J.P. Fundamental statistics in psychology and education. Ed. 3, McGraw-Hill Book Company Inc., New York, 1956. pp. 435-60.
16. Martin, D.W.; Mayes, P.A. & Rodwell, V.W. (Editors). Harper review of biochemistry, Ed. 18, 1981. 446-47.
17. Sridharan, K.; Malhotra, M.S.; Upadhyay, T.N.; Grover, S.K. & Dua, G.L. Changes in gastrointestinal function in humans at an altitude of 3500 m. *Eur. J. Appl. Physiol.*, 1982, **50**, 145-54.
18. Rai, R.M.; Malhotra, M.S.; Dimri, G.P. & Sampat Kumar, T. Utilisation of different quantities of fat at high altitude. *Am. J. Clin. Nutr.*, 1975, **28**, 242-45.
19. Singh, M.V.; Rawal, S.B. & Tyagi, A.K. Body fluid status on induction, re-induction and prolonged stay at high altitude of human volunteers. *Int. J. Biometeorol.*, 1990, **34**, 93-97.

20. Bernard, J.R. Lipid components of adipose tissue. *In* Handbook of physiology, Section V, edited by A.E. Ronald and G.F. Cahill (Jr). American Physiological Society, Washington, D.C., 1965. pp. 170.

21. Bharadwaj, H.; Singh, M.V.; Rawal, S.B.; Zachariah, T.; Kishnani, S.; Pramanik, S.N.; Gupta, A. & Rai, R.M. Hydration and tissue solid content of the lean body on prolonged exposure to altitude. *Int. J. Biometerol.*, 1989, **33**, 27-31.

22. Srivastava, K.K.; Rao Y.B.M.; Bharadwaj S.K.; Chander, A. & Malhotra, M.S. Serum creatine phosphokinase activity and urinary excretion of creatine and creatinine in man during acclimatisation to high altitude and in high altitude natives. *Aerospace Medicine*, 1973, **44**(3), 272-75.

23. Grover, S.K.; Sridharan, K. & Srivastava, K.K. Longitudinal studies on serum protein in man during two years of stay at an altitude of 4000 m. *Int.J. Biometeorol.*, 1987, **31**, 163-68.