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Regression of Body Density on Skinfold Thicknesses in High Altitude Natives: Decline in the Predictive Efficiency on De-Acclimatisation to Low Altitude

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ABSTRACT

Body density, stature, body weight and skinfold thicknesses at 11 sites were experimentally measured on two groups of high altitude natives (HAN) of Ladakh. Group 1, consisting of 31 young volunteers was studied at an altitude of 3658 m and Group 2, consisting of 38 similar volunteers was studied after 4-week stay at Delhi(altitude, 200 m). Although, there was a strong relationship between skinfolds, other anthropometric measurements and body density (R=0.898) at high altitude (HA), this relationship was significantly reduced at Delhi (R=0.642). Appropriate regression equations predicting body density from skinfold thicknesses, stature and body weight are given for HAN at both the locations. It is concluded that hyperhydration of the lean body and the adipose tissue may be responsible for the weakening of the multiple Rs on de-acclimatisation to low altitude.

NOMENCLATURE

D_b	body density
BTPS	body temperature pressure saturated
Rtt	reliability index
σ_e^2	error variance
σ_t^2	total variance
R	regression co-efficient
HA	high altitude
HAN	high altitude natives

1. INTRODUCTION

The hydrostatic procedure usually adopted for body density determination is cumbersome and often unsuitable in many field conditions. Since large proportion of body fat stored in the adipose tissue is located subcutaneously, thicknesses of skinfolds under a constant pressure have been utilised for its indirect estimation. The thicknesses of skinfolds at selected sites which depend upon age, sex, ethnicity and occupational background, have been correlated with body density, and multiple regression equations have been constructed[1-7].

At high altitude (HA) the hypoxic environment in association with cold imposes additional physiologic stress on sojourners and induces changes in the composition of the lean body, thus affecting the basic assumption of the constancy of the density of the lean body, a crucial factor in the correct evaluation of total body fat. Gross body composition changes have been reported on acute exposure to HA among the sojourners from the plains[8-11]. At the same time, it is believed that the high altitude natives (HAN) maintain the normal composition of the lean body at their own habitats[12,13].

Bharadwaj, *et al.*[14] have reported that the estimate of body fat content using Sloane's equation[2] differed significantly from that determined from body density after a 4-week de-acclimatisation at low altitude. Due

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to altered acclimatisation status in the plains, shifts in the regressive properties of the skinfolds among the HAN could be observed. Studies involving the regression of skinfolds and other anthropometric measurements on body density among the HAN are practically lacking. The present investigation attempts to highlight these aspects.

2. MATERIALS AND METHODS

Healthy native soldiers from Ladakh region of Jammu and Kashmir had volunteered themselves for the study. The age of the soldiers varied from 18 to 25 years. They were born and brought up in Ladakh, residing at altitudes between 3658 m and 3962 m and had never visited the plains earlier. These volunteers were divided into two groups.

Group 1 consisted of 31 soldiers. Experiments to determine body density and anthropometry in this group were conducted at a station which was located at an altitude of 3658 m.

Group 2 consisted of 38 soldiers, who were leter brought to Delhi. The anthropometry and other experiments in connection with the measurement of body density in this group were conducted after the expiry of a four-week stay at Delhi at an altitude of 200 m.

The soldiers in Group 1 were physically active and were on a ration scale which provided 144 g protein, 747 g carbohydrate and 138 g fat per soldier per day. This had a calorie content of 24.21 MJ. The Group 2 soldiers were provided 119 g protein, 598 g carbohydrate and 98 g fat per soldier per day. The energy content of such ration was 15.69 MJ per day. The soldiers in this group did not perform routine infantry duties as they were under observation.

The above-mentioned ration scales had been evolved earlier keeping in view the energy expenditure at HA as well as at low altitudes.

2.1 Anthropometry

Stature was measured with a Martin anthropometer, and nude body weight was measured on a sensitive Avery beam balance to the nearest 0.05 kg. Skinfold thicknesses at eleven sites were measured by Lange skinfold calipers, exerting a constant pressure of 10 g/mm between the jaws.

Subscapular and thigh skinfolds were measured according to the procedure of Sloane[2]. The procedure of Wilmore and Behnke[3] was followed for measuring mid-axillary, juxta-nipple, biceps and triceps skinfold thicknesses. Suprailiac skinfold thickness was measured according to the procedure of Tanner, *et al.*[15] The abdomen I refers to the skinfold pinched in a horizontal plane approximately 3 cm away from umbilicus, while abdomen II skinfold denotes a similar fold pinched perpendiculary below the right nipple and at the level of the umbilicus. The skinfold at the forearm was pinched at the maximum bulge in the medial aspect while at the maximum bulge of the calf, it was pinched in the lateral aspect.

2.2 Body Volume, Density and Total Body Fat

Experiments to measure body volume were conducted in the morning after voiding of bowels and bladder after an over-night fast. Total body volume was measured for each subject in full inspiration by using the water displacement technique of Jones[16], while the subject was submerged chin deep in water, the vital capacity was measured on a Godart 8-l spirometer, and the residual lung volume was measured by a modified three-breath nitrogen dilution method of Rahn, *et al.*[17] Both residual lung volume and vital capacity at body temperature pressure saturated (BTPS) were subtracted from the original volume to obtain actual body volume. The small amount of gas trapped in the abdomen was ignored.

Body density was obtained by dividing body weight in air by the actual body volume.

2.3 Statistical Techniques

Reliability index was calculated for all measurements according to the formula suggested by Guilford[18].

$$R_{tt} = 1 - \frac{\sigma_e^2}{\sigma_t^2} \text{ reliability index}$$

where

σ_e^2 error variance

σ_t^2 total variance, and

The calculated reliability index is greater than 0.91 for all anthropometric measurements and is 0.81 for body density.

A stepwise linear regression analysis was performed. Multiple linear equations of the form: $r = a + b_1x_1 + b_2x_2 + \cdots b_i x_i$ were fitted to the data in a stepwise manner (Draper and Smith[19]). In each step of computation, one independent variable was added to the regression equation. The variable added was the one which made the greatest reduction in the error sum of squares. This variable had the highest partial correlation with the dependent variable, given that the variables preceding it had already been included in the regression equation.

The correlations between body density (D_b) and skinfold thicknesses were tested by Z-transformation test, assuming that the correlation coefficients between D_b and other parameters at HA and at Delhi were the same (Rao[20]). In multiple *R*s it was ensured that the subsets of variables entering the regression equation for the two groups were identical.

3. RESULTS

The physical characteristics of the HAN at Ladakh for both the groups are given in Table 1. That the men in Group 2 were fatter is indicated by greater mean body weight, lower body density ($p < 0.01$) and thicker skinfolds ($p < 0.05$). Table 2 gives the correlations of different skinfolds with body density both at HA and at Delhi. The correlation coefficients for most of the skinfolds decline significantly at Delhi after a 4-week de-acclimatisation period. Out of 13 variables, 7 have shown a significant difference at 1 per cent level, 2 at 5 per cent level and 4 have not shown significant difference at all. All the correlation coefficients were stronger at HA than at Delhi ($p < 0.001$). The trend of stronger relationship between D_b and the skinfolds at HA is also seen in the case of multiple *R*s at all stages of stepwise regression (Table 3) The anthropometric variables entering the sixth step of the regression, multiple *R*s, regression coefficients, constants and the standard errors of estimates are given in Table 4 for both the groups of HAN. The strength of the multiple *R*s in the case of HAN at their own habitat (Group 1) is comparable to the values obtained in different population groups all over the world. Surprisingly, the choice of new variables in Group 2 does not significantly help in restoring the predictive accuracy to its original (Group 1) level. In the full model regression equations involving all the 13 variables, the multiple *R*s are 0.898 and 0.642 in Group 1 and Group 2, respectively (Table 5). Reliability index was calculated for all measurements so as to establish the reliability of data collected.

Table 1. Physical characteristics of high altitude natives of Ladakh

Physical characteristics	Units	Group 1 (n=31) (Mean + SD)	Group 2 (n=38) (Mean + SD)	Significance level
Body weight	kg	56.5 + 5.2	59.0 +5.6	NS*
Stature	cm	164.1 + 4.9	164.9 + 5.5	NS
Juxta nipple skinfold	mm	7.8 + 3.4	9.2 + 3.6	NS
Mid-axillary skinfold	mm	5.9 + 2.1	6.7 + 2.5	NS
Forearm skinfold	mm	4.8 + 0.9	4.7 + 1.7	NS
Abdomen I skinfold	mm	12.8 + 5.4	12.2+ 4.3	NS
Abdomen II skinfold	mm	6.2 + 2.1	11.2 + 5.3	p<0.001
Thigh anterior skinfold	mm	7.3 + 1.8	10.9 + 4.5	p<0.001
Calf lateral skinfold	mm	6.3 + 1.6	8.1 + 3.4	p<0.01
Biceps skinfold	mm	3.2 + 0.5	2.8 + 0.8	p<0.02
Triceps skinfold	mm	6.9 + 1.6	8.5 + 3.3	p<0.01
Subscapula skinfold	mm	8.6 + 2.5	9.3 + 2.5	NS
Suprailiac skinfold	mm	4.3 + 0.9	6.1 + 2.0	p<0.001
Body density	10^3 kg m	1.086 + 0.009	1.075 + 0.017	p<0.01

* : Not significant

Table 2. A comparison of the correlation coefficients (r_1, r_2 for body density, skinfold thicknesses, stature and body weight at high altitude and at Delhi

Physical characteristics	High altitude		Delhi		
			r_2	n_2	Significance of difference
Body weight	-0.457	31	-0.348	38	NS*
Stature	-0.253	31	-0.146	38	NS
Juxta nipple skinfold	-0.439	31	-0.434	38	NS
Mid axillary skinfold	-0.573	31	-0.383	38	$p<0.01$
Forearm skinfold	-0.525	31	-0.383	38	$p<0.01$
Abdomen I skinfold	-0.572	31	-0.241	38	$p<0.01$
Abdomen II skinfold	-0.530	31	-0.073	38	$p<0.01$
Thigh anterior skinfold	-0.578	31	-0.388	38	$p<0.01$
Calf lateral skinfold	0.331	31	-0.354	38	NS
Biceps skinfold	-0.448	31	-0.287	38	$p<0.05$
Triceps skinfold	-0.479	31	-0.264	38	$p<0.01$
Subscapular skinfold	-0.568	31	-0.432	38	$p<0.05$
Suprailiac skinfold	-0.551	31	-0.338	38	$p<0.01$

Not significant

3. Correlation of body density with skinfold thickness: a comparison of multiple correlation coefficients (R) obtained at high altitude and Delhi

Steps of regression analysis and skinfolds selected	High altitude natives	
	Group 1, $n=31$ R	Group 2, $n=38$ R
Thigh anterior skinfold	0.5776	0.3877
Above + abdomen II skinfold	0.7030	0.3885
Above + juxta nipple skinfold	0.7460	0.4747
Above + triceps skinfold	0.7999	0.4887
Above + stature	0.8300	0.5108
Above + mid-axillary skinfold	0.8515	0.5121
Above + abdomen II skinfold	0.8629	0.5613
Above + subscapular skinfold	0.8779	0.6005
Above + calf lateral skinfold	0.8852	0.6182
Above + forearm skinfold	0.8937	0.6191
Above + biceps skinfold	0.8970	0.6318
Above + weight	0.8977	0.6362
Above + suprailiac skinfold	0.8978	0.6424

4. DISCUSSION

The decline in the strength of the multiple Rs in the regression equations after a 4-week de-acclimatisation period is striking. Human biologists would like to ponder over this blurring of the sensitivity of the skinfolds as predictors of body density among healthy HAN. The authors feel that the ensuing hyperhydration on de-acclimatisation[14,21] could be responsible for this reduced sensitivity.

Some of the possibilities are :

(a) In Group 2 subjects, the increase or decrease in the thickness of skinfolds was not merely due to the entry or exit of triglycerides from the adipose tissue, but was complicated by different levels of hydration of the adipocytes. In such a situation the increase in skinfold thickness will not correspond to the expected decrease in body density, in spite of overall body weight gain. Reductions in blood flow to the skin on high altitude acclimatisation are known[22] and variations in the hydration level of the adipose sites in mouse have been reported[23]; but more experimental evidence is needed for humans to clarify this aspect.

(b) The hyperhydration of the lean tissue would tend to reduce the density of the lean body. This change would be aggravated if protein loss occurs from the lean tissue as well. The overall reduction in body density in these circumstances would falsely suggest fat gain.

There could be changes in the storage patterns of fat in the subcutaneous tissue *vis-a-vis* that stored internally. Though, Wilmore, *et al*[24] have questioned the validity of skinfold and girth assessment for predicting alterations in body composition, little is known about these aspects during de-acclimatisation to low altitude.

5. CONCLUSION

In conclusion, it may be stated that the use of the density- predicting equations on HAN is not desirable in the plains, if these were derived at HA for them. The underlying causes for such inapplicability could be the altered state of hydration of the skin and the adipose tissue as well as the altered density of the lean body itself.

Table 4. Body density from skinfold thickness among high altitude natives of Ladakh

	Group	*N*	Variables entering in the sixth step of regression	Regression coefficient	Constant	Multiple *R*	Standard Error of estimate
I.	High altitude natives of Ladakh studied at their own habitat (3658 m) (Engaged in routine infantry duties)	31	Stature,	-0.00038	1.1726	0.852	0.005
			Juxta nipple skinfold	+0.0024			
			Mid-axillary skinfold	-0.0019			
			Abdomen I skinfold	-0.0019			
			Thigh anterior skinfold	-0.0041			
			Triceps skinfold	+0.0031			
II	High altitude natives studied after four-week de-acclimatisation period in Delhi. (Not engaged in any strenuous physical activity)	38	Juxta nipple skinfold	-0.0023	.1262	0.601	0.015
			Abdomen II skinfold	+0.0011			
			Body weight	-0.000486			
			Calf lateral skinfold	-0.0012			
			Triceps skinfold	+0.0014			
			Subscapular skinfold	-0.0017			

Table 5 Biochemical observations on Indian soldiers exposed to high altitudes for six and ten months

Biochemical parameter	Delhi Mean + SD/SE	High altitude Mean + SD/SE
Creatine phosphokinase Milli International Unit	20.08 + 1.25 (SE)	184.46 + 4.71 (SE)* (10 month continuous stay
Total serum proteins gm %	7.103 + 0.712 (SD)	6.283 + 0.660 (SD)* (10 month continuous stay
Extra cellular space ml/kg	150.7 + 4.0 (SE	157.4 + 5.4 (SE) (6 month continuous stay)
Intra cellular space ml/kg	525.0 + 13.1 (SE)	534.0 + 6.5 (SE) (6 month continuous stay)

* Mean difference significant $P < 0.05$

** For a man weighing 57.53 kg, total increase in water content would amount to 0.90 kg

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