J. Hum. Ecol., 11(2): 83-99 (2000)
PRINT: ISSN 0970-9274 ONLINE: 2456-6608
DOI: 10.31901/24566608.2000/11.02.01

Human Adaptation to High Altitude: Body Proportion Analysis using Phantom Model

S.L. Malik

INTRODUCTION

Ladakh, the land of the Lamas, is inhabited by simple people. But life of these people is not so simple. It is under constant threat from the harsh environment of their habitat. Survival and continuance in the stressful environment has always been a daunting task. Population density as low as 2 persons/km^2 is an evidence to the problem of survival in the hazardous environment. Reproductive wastage, infant mortality and child mortality are high and are associated with the environmental stress. Thus, pre-natal and post-natal selections are operative in this zone. High fertility, as a consequence of the belief that children are economical assets and apprehension that not many of the offspring survive to childhood, reduces birth space and weakens mother's health culminating in high mortality (Prakash and Malik, 1990).

Physiological variations in human populations allow adaptation to a variety of ecosystems (Collins, 1999). Also, socio-cultural factors help in encountering or minimising the environmental stresses. Numerous stresses that include low atmospheric/ oxygen pressure, cold, difficult terrain, undernutrition, increased ultra-violet and solar radiation influence morpho-physiology of human populations, particularly when the socio-cultural concomitants are unable to counter these stresses. Genetical make-up and ecosensitivity of the populations also play vital roles in encountering the stresses. Survival and continuance in such an environment necessitates bio-cultural adaptation.

The most important stress at high altitude is low atmospheric/ oxygen pressure. To encounter this physiological functions, particularly cardio-respiratory functions, are improved to release the required energy by supplying adequate amount of oxygen to the tissues (Baker, 1969; Frisancho, 1969; Malik and Singh, 1979; de Meer, 1995; Beall et al., 1998). Natural selection, operative through generations, seems to have favoured genotypes having greater cardio-respiratory functions among natives living at high altitude. Mere survival and / or conducting routine work is not a true index of success of adaptation. During the phases of growth, such as infancy and adolescence, the demand of energy is increased. Similarly, supply of additional energy to pregnant women and lactating mothers is necessary to minimise reproductive wastage and limit infant mortality - which are important for normal population growth. Also the requirement of energy is increased during hard work. How the demands of additional energy during the aforementioned stages are met, is a major question in the rarefied high altitude environment. The degree to which these demands are met denotes the level of success in adaptation.

Keeping the above in mind, a study was conducted on Bods of Ladakh (high altitude) and Bods of Kullu (low altitude) in the age range of 12 to 18 years with an aim to study age group wise altitudinal variation in body proportions using phantom model. The present communication is an outcome of the ongoing research by our team among the Bods living at various altitudes.

MATERIALS AND METHODS

The Sample

A cross-sectional sample of three hundred forty-five male Bods in the age range of 12 to 18 years was collected from two localities. The high altitude sample was collected from the town of Leh (Ladakh) and villages in its vicinity, whereas the low altitude sample was collected from the migrant Bods now settled in the Kullu-Manali valley. Data were collected from schools as well as villages and covered over 75 per cent of the total population in that age range, without any bias. The distribution of sample by age and altitude is given in table 1.

Age has been calculated by converting date of birth and date of data collection in decimals using the decimal age calendar, as proposed by Tanner et al. (1966), and then subtracting the former from the latter. Age groups were formulated considering the decimal age in the following manner. The subjects between the age of 11.500 to 12.500 were classified as 12±, similarly those between the age of 12.500 to 13.500 were categorised in 13±, and so on.

Table 1: Age wise distribution of sample size in High Altitude (HA) and Low Altitude (LA) Bods in the age range 12-18 years

Age Group (Mean Age)	*High Altitude (Bods of Ladakh)*	*Low Altitude (Bods of Kullu)*
12 ±	24	06
13 ±	24	20
14 ±	33	20
15 ±	41	19
16 ±	59	21
17 ±	31	15
18 ±	21	11
Total	233	112

Area and the Population

Leh (Ladakh), from where the high altitude sample was drawn, is situated at 34°09' latitude and 77°34' longitude. Situated at an altitude ranging between 3500 and 3550 metres above mean sea level, the town of Leh and its surrounding villages have a cold dry climate that can best be categorised as cold Tundra. The atmospheric pressure is as low as 480 mm Hg. Lack of flora and fauna, except near the Indus river is the characteristic hallmark of the area. Dry brown barren mountains covered with snow make the environment monotonous. The chilly wind that shivers one and all in the winter nights becomes warm enough in summer noons to ripe the barley. The temperature ranges from -28°C in the winter nights to 32°C in summer noons, with an average annual temperature of 3.1°C. Also there is a wide variation in temperature in day and at night, as well as in sun and shade. The average annual rainfall (11.5 cm) is low. Snowfall on the other hand, is quite common and occurs for several months, specially in the higher ranges. The average annual relative humidity is also low (50 per cent).

Kullu-Manali valley is situated between 31°22' to 32°26' latitude and 76°57' to 77°54' longitude. The low altitude sample was collected from this area. The altitude in this valley ranges from 1200 m to 2000 m above mean sea level. The natural beauty and pleasant climate of the Kullu valley makes it a tourist's paradise. Its glamorous natural environment is adorned with charming hill slopes, fascinating coniferous forests, meandering rivers, dazzling falls and streams, gentle cool breeze, captivating snow-laden mountains, charming lust green pastures, beautiful flowered orchards, attractive terraced agricultural fields, enchanting birds and exciting fauna. It is, in the real sense, as the natives call, a Dev Bhumi (earth of Gods). There is plenty of rainfall (average annual rainfall: 92 cm) and the average annual relative humidity is high (64 per cent). The temperature is pleasant (average annual temperature: 15.8°C) and it ranges from -6°C in winter nights to 34°C in summer noons.

Bods are of Mongoloid stock who practise Budhism. Budhist monasteries, called Gompas, have influenced their religious life for centuries and are the hubs of their socio-cultural activities. Bods are endogamous who follow clan exogamy. Bods are extremely social and cheerful and even at the slightest pretext make it an occasion for feasting. Bods, at both low and high altitudes, are basically agriculturists, but are simultaneously involved in pastoralism.

Resource management by the local natives, particularly at high altitude, has been tough because of difficult terrain, primitive technology, poor irrigation, inadequate transport facilities and poor communication. Considering the above limitations, the eco-friendly activities pursued by them for living are worth appreciating. Construction of houses reflect their prudence in saving energy and using solar heat for warming. For example, the flat roofs that are useful in warming and drying of grains are maintained even at the cost of additional labour of removing ice in winter months. Similarly, the cattle quarter at the basement helps in keeping the floor of the house warm by utilising animal heat. In the winter months, when the outdoor activities are restricted, a couple of families get together and start living in a single house to save energy and costly fuel that is required for heating. Further, in the living room (a big hall) they have a hearth with a chimney that is used for releasing the smoke from the top of the roof. Such an arrangement helps in utilising heat energy simultaneously for cooking and warming. Protein and fat rich diet of the Bods, such as butter tea and Thupa, is a biological way of producing more body heat. The design of toilet is also well suited to the environment. The toilets are made at the back portion of the first floor with a hole in the floor. The soil is collected at the basement/ ground floor. Because of cold it does not stink. The soil collected over an year or so is used as manure. There are many other activities which show wisdom of the natives in eco-friendly development which have been presented in our earlier publications (Malik, 1976; Malik and Singh, 1984; Malik, 1987).

Bods of Kullu valley trace their origin from the high altitude areas of Lahaul and Ladakh and claim that they migrated to the lowlands several centuries ago. Even today they show their alliance with the highlander Bods. They even maintain that there is no restriction in the marriages between the highlander and lowlander Bods, but in practice such marriages are few due to practical difficulties and distance. Nonetheless these migrant Bods continue to follow the traditional customs, social institutions, myths, legends, folklores, totems, and so on.

The Phantom

Child is not a miniature form of man. It differs in size as well as in proportion. Different body parts grow at different rates at different time during the development period. They induce proportional differences with the advancement in age. The changes in size are easier to record through the measurements of various body parts using simple instruments such as anthropometer rod, callipers and weighing machine. It is far more difficult to have an agreement on the recording of the proportional difference.

The Phantom stratagem, proposed by Ross and Wilson (1974) and Ross and Ward (1982), for proportional growth assessment, is essentially based on the concept of a theoretical reference human. It is conceptually a unisex, bilaterally symmetrical model. Phantom model is a calculative device used for comparing individuals and groups. It is not a model meant for formulating norms. On the contrary, it encourages compilation of normative data through the routine studies. Using Phantom stratagem it is possible to analyse proportional differences (i) of the same subject in different measurements; (ii) of the same subject measured at different occasions; (iii) between subjects; (iv) between a subject and a sample mean; and (v) between sample means.

The proportionality values (or Z values), in the Phantom model, are obtained by using the following formula. This formula geometrically scales the measures to the Phantom's stature (170.18 cm) and observes the difference from the given phantom values (p) in terms of the standard deviation distances (s).

A positive Z value indicates that the subject is proportionally greater than the Phantom. A negative Z value means that the subject is proportionally smaller than the Phantom and a Z value equal to 0.00 indicates that the subject is proportionally the same as the Phantom. The mean values (p), along with the standard deviation(s) for various body measurements of the Phantom are set out in table

$$Z = \frac{1}{s}\left[v\left(\frac{170.18}{h}\right)^{d} - p\right]$$

where, Z = proportionality value
v = size of any given measurement
h = subject's stature
p = Phantom value for the corresponding v
s = Phantom standard deviation value for the p
d = dimension exponent ; when scaled geometrically, d = 1 for all lengths, breadths, girths and skinfolds ; d = 2 for all areas ; and d = 3 for all volumes and weights.

2. Age group wise proportionality values were calculated separately for the high altitude and low altitude samples for studying altitudinal variation in proportionality.

It is noteworthy that the Phantom model does not require absolute adherence to the 'standard' techniques and landmarks if comparisons are made between the populations/ subjects measured using the same procedure and landmarks. Therefore, once the anthropometric technique is common for all the subjects, intra and inter population comparisons would not be influenced by the exactness of landmarks and techniques used in the development of Phantom model. This is a distinct advantage in examining group differences , conducting longitudinal growth studies and analysing secular trends.

Table 2: Mean values (p) and standard deviation (s) of various body measurements of the Phantom

Body Measurements	*p*	*s*
Stature, cm	170.18	6.29
Body weight, kg	64.58	8.60
Sitting height, cm	89.92	4.50
Height gnathion, cm	148.81	5.65
Height acromion, cm	139.37	5.45
Height radiale, cm	107.25	5.36
Height stylion radiale, cm	82.68	4.13
Height dactylion III, cm	63.83	3.38
Height iliospinale, cm	94.11	4.71
Height trochanterion, cm	86.40	4.32
Height tibiale, cm	44.82	2.56
Height spherion, cm	8.01	0.96
Total upper extremity length, cm	75.95	3.64
Upper arm length, cm	32.53	1.77
Forearm length, cm	24.57	1.37
Hand length, cm	18.85	0.85
Biacromial breadth, cm	38.04	1.92
Transverse diameter of chest, cm	27.92	1.74
Antero-posterior depth of chest, cm	17.50	1.38
Biiliocristal breadth, cm	28.84	1.75
Bitrochanteric breadth, cm	32.66	1.80
Bicondylar humerus, cm	6.48	0.35
Bicondylar femur, cm	9.52	0.48
Head circumference, cm	56.00	1.44
Chest circumference, cm	87.86	5.18
Mid upper arm circumference, cm	26.89	2.33
Forearm circumference, cm	25.13	1.41
Abdominal circumference, cm	79.06	6.95
Lower Leg circumference, cm	35.25	2.30
Head length, cm	19.15	0.68
Head breadth, cm	15.08	0.58
Byzygomatic breadth, cm	13.66	0.57
Bigonial breadth, cm	10.59	0.58
Morphological facial height, cm	11.94	0.69
Body fat, kg	12.13	3.25
Lean body mass, kg	52.45	6.14
Density, gm/cc	1.056	0.011
Skinfold at biceps, mm	8.0	2.00
Skinfold at triceps, mm	15.4	4.47
Skinfold at juxta nipple, mm	11.8	3.27
Skinfold at suprailiac, mm	15.4	4.47
Skinfold at subscapula, mm	17.2	5.07
Skinfold at calf, mm	16.0	4.67

Body Measurements

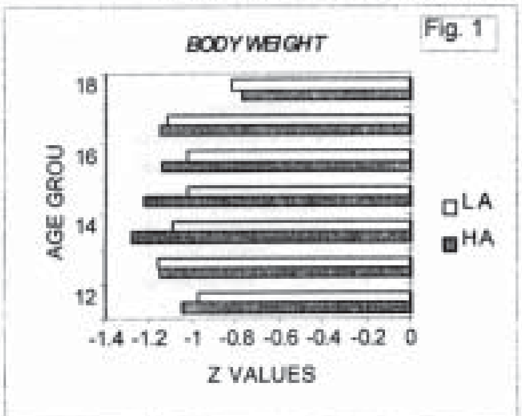
Thirty six anthropometric measurements, listed in table 2, were taken following the standard techniques (Martin and Saller, 1957, Tanner et al., 1969). Total upper extremity length was obtained by subtracting Height dactylion III from Height acromion; Upper arm length by subtracting Height radiale from Height acromion; Forearm length by subtracting Height stylion radiale from Height radiale, and Hand length by subtracting Height dactylion III from Height stylion radiale. Body density was calculated indirectly from a series of skinfolds using the equation forwarded by Durnin and Rahaman (1967). Body fat was calculated incorporating the formula given by Siri (1961). Lean body mass was determined by subtracting body fat from body weight. Descriptive statistics were calculated using SPSS program on a PC.

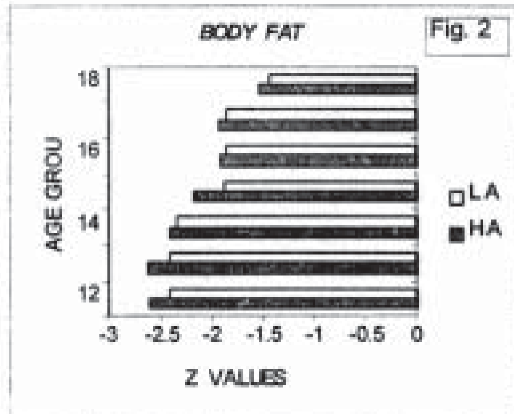
RESULTS AND DISCUSSION

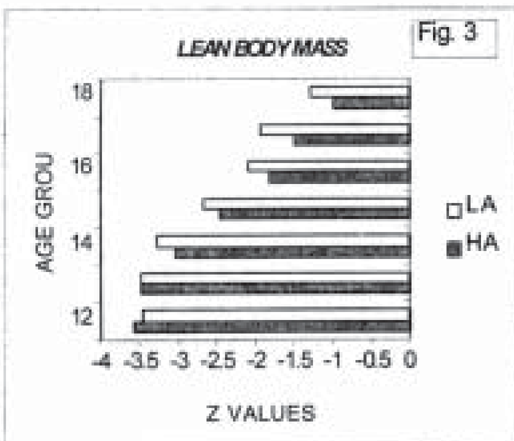
Age group wise body proportions, represented by Z values, of high altitude and low altitude Bods are presented in figures 1 to 42. The results have been analysed in this paper (i) for examining age group wise altitudinal differences in body proportions; and (ii) for studying age changes in body proportions in high and low altitude Bods in the age range of 12 to 18 years, by comparing them with the adult phantom values.

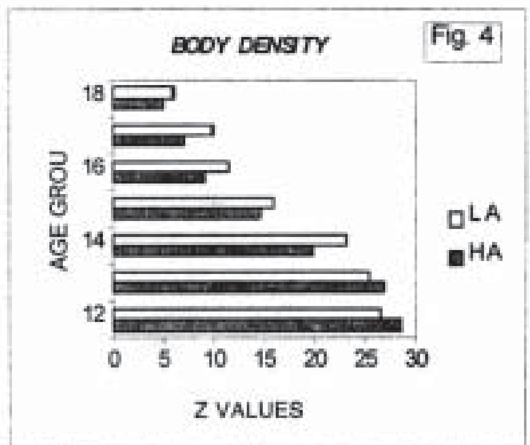
Proportionate body fat, body density, body weight, and skinfolds are generally lower in highland Bods than their coeval lowlanders wheras the highlanders have higher lean body mass (Figs. 1 to 10). Proportionate body

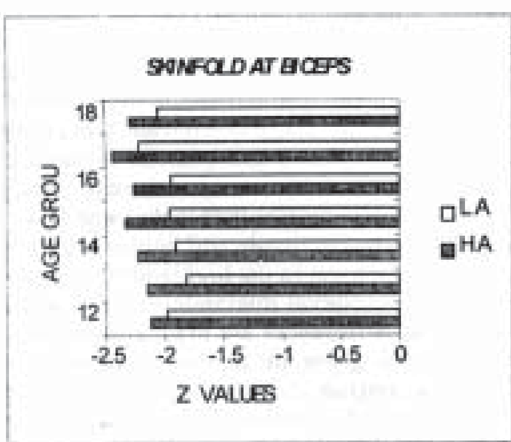
Figs. 1 to 6. Age group wise distribution of Z values in Body weight (Fig. 1), Body fat (Fig. 2), Lean body mass (Fig. 3), Body density (Fig. 4), Skinfold at biceps (Fig. 5) and Skinfold at triceps (Fig. 6) among High Altitude (HA) and Low Altitude (LA) Bods.

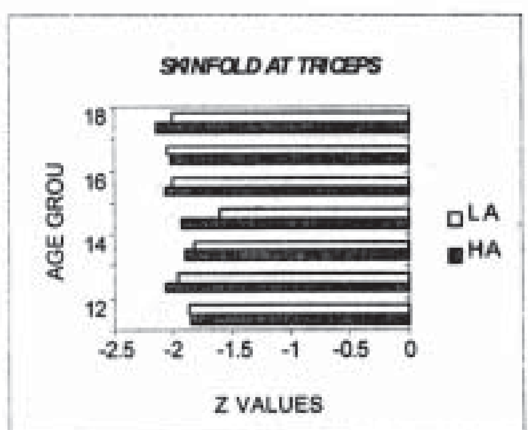




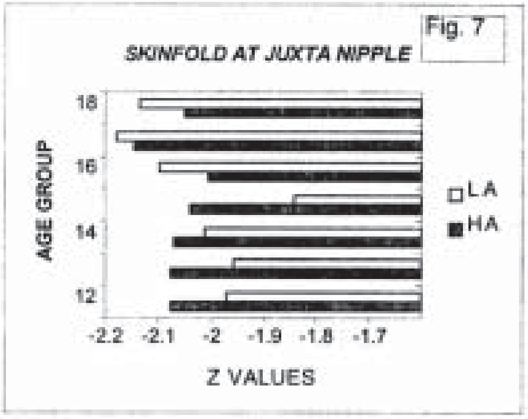


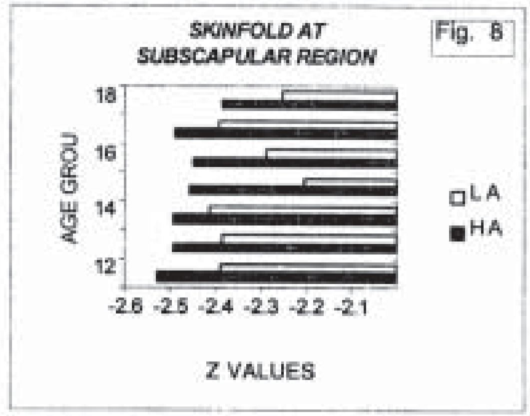


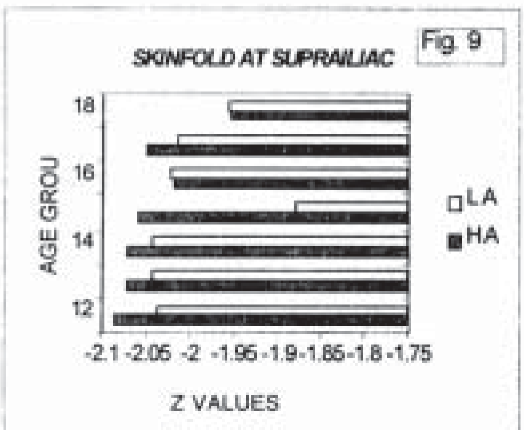


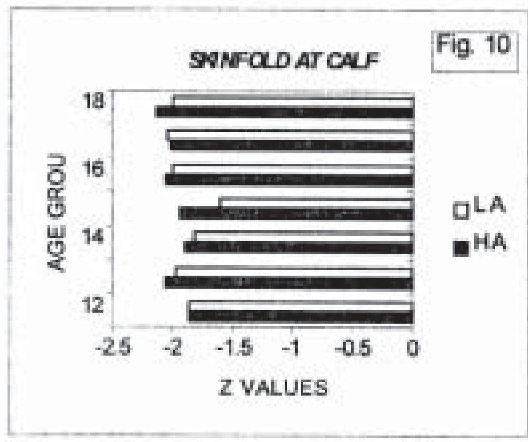


Figs. 7 to 10. Age group wise distribution of Z values in Skinfold at juxta nipple (Fig. 7), Skinfold at subscapular region (Fig. 8), Skinfold at suprailiac (Fig. 9), Skinfold at calf (Fig. 10), Sitting height vertex (Fig. 11) and Height gnathion (Fig. 12) among High Altitude (HA) and Low Altitude (LA) Bods.







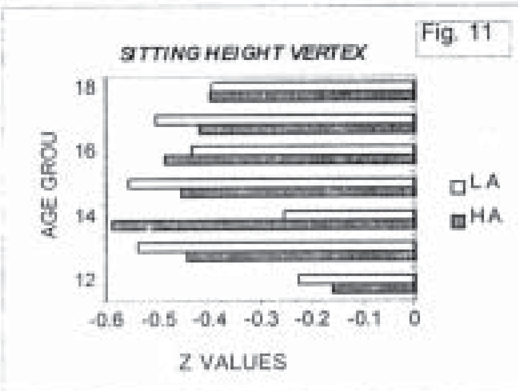


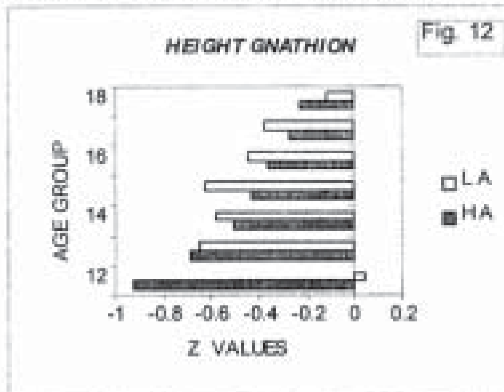
weight, body fat, lean body mass and all the skinfolds are lower in all the age groups in both high and low altitude populations as compared to the phantom values, but the body density is higher in all the age groups in both high and low altitude groups. Proportionate body fat and lean body mass increase marginally with age, whereas body density decreases with age.

The Z values of sitting height vertex, height gnathion, height acromion, height stylion, height dactylion III, height iliospinale, height trochanterion, and height spherion are lower in both high and low altitude Bod boys as compared to adult phantom values, whereas height radiale and height tibiale do not show any particular trend (Figs. 11 to 20). There is no specific altitudinal difference in these traits.

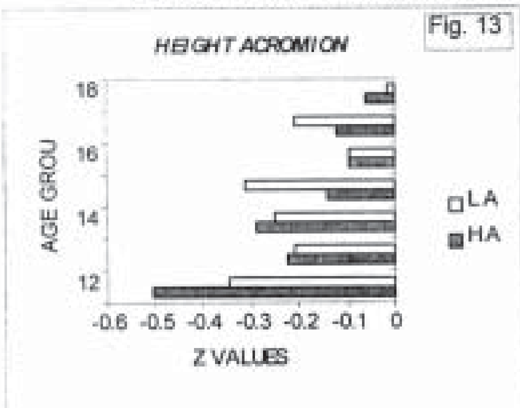
Proportionate height iliospinale and height trochanterion are lower in high altitude group than the low altitude group in the initial age groups from 12 to 15 years, but thereafter they are higher in the former than in the latter (Figs. 17 to 20). Height tibiale and height spherion is generally lower in the highlanders as compared to the coeval lowlanders. No marked altitudinal differences are evident in proportionate sitting height, height gnathion and height acromion. Z values of height radiale and height stylion radiale are generally high-

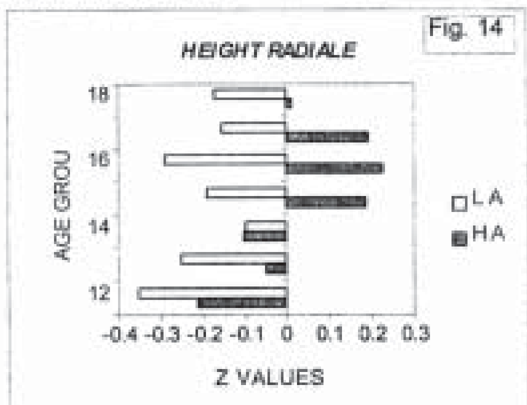
Figs. 11 to 12. Age group wise distribution of Z values in Skinfold at juxta nipple (Fig. 7), Skinfold at subscapular region (Fig. 8), Skinfold at suprailiac (Fig. 9), Skinfold at calf (Fig. 10), Sitting height vertex (Fig. 11) and Height gnathion (Fig. 12) among High Altitude (HA) and Low Altitude (LA) Bods.

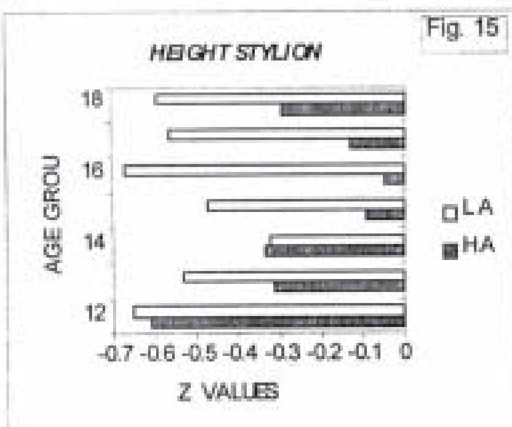


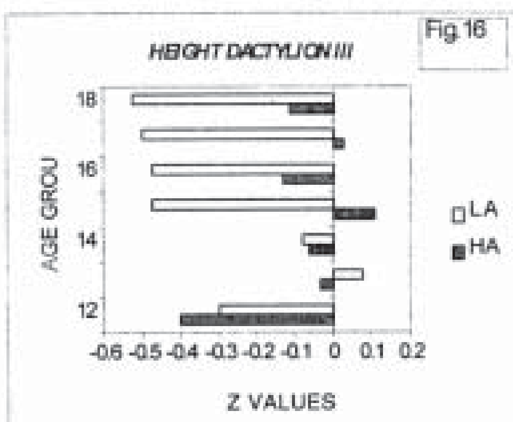


Figs. 13 to 16. Age group wise distribution of Z values in Height acromion (Fig. 13), Height radiale (Fig. 14), Height stylion (Fig. 15), Height dactylion III (Fig. 16), Height iliospinale (Fig. 17) and Height trochanterion (Fig. 18) among High Altitude (HA) and Low Altitude (LA) Bods.

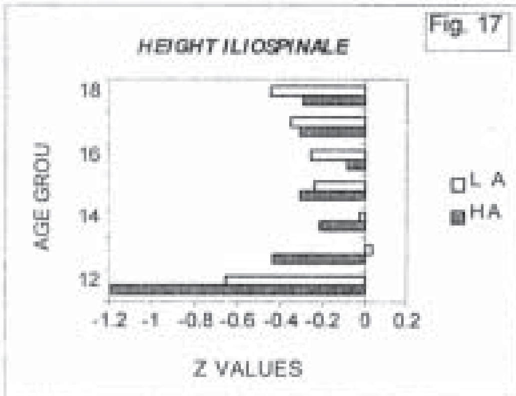


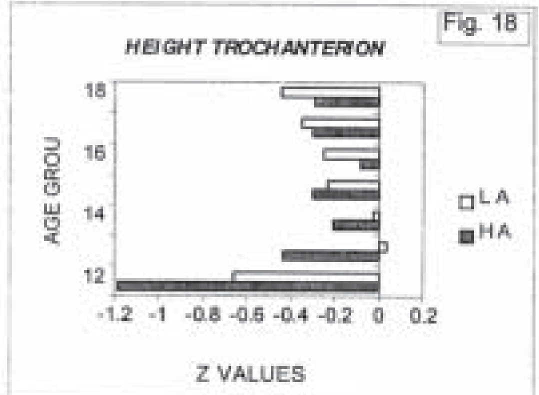




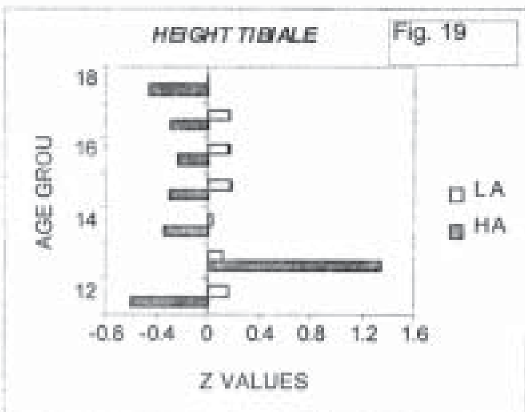


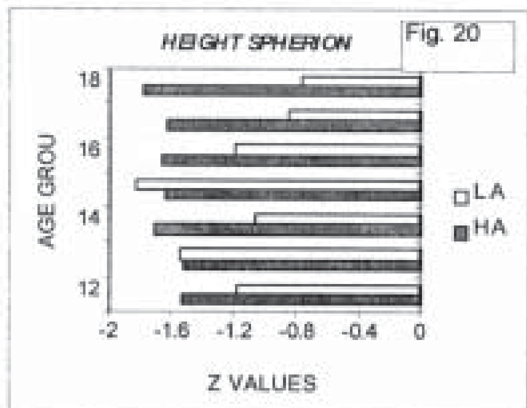
Figs. 17 to 18. Age group wise distribution of Z values in Height acromion (Fig. 13), Height radiale (Fig. 14), Height stylion (Fig. 15), Height dactylion III (Fig. 16), Height iliospinale (Fig. 17) and Height trochanterion (Fig. 18) among High Altitude (HA) and Low Altitude (LA) Bods.





Figs. 19 to 20. Age group wise distribution of Z values in Height tibiale (Fig. 19), Height spherion (Fig. 20), Total upper extremity length (Fig. 21), Upper arm length (Fig. 22), Forearm length (Fig. 23) and Hand length (Fig. 24) among High Altitude (HA) and Low Altitude (LA) Bods.



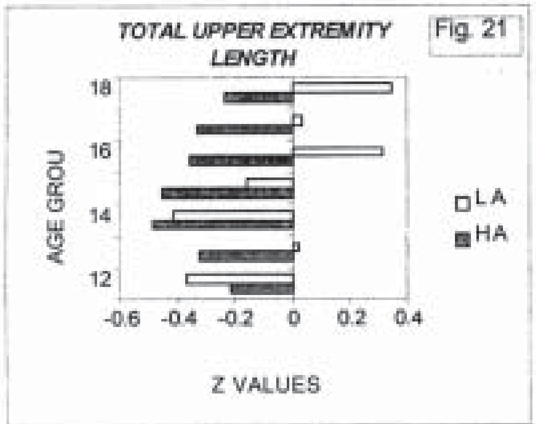


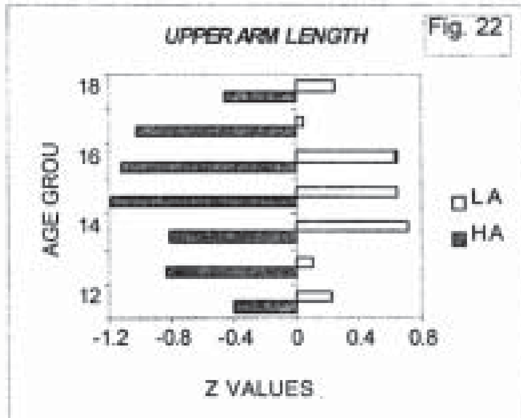
er in the highlanders than their coeval lowlanders. In height dactylion III, except in the initial age group of 12 and 13 years, the same trend as that of height radiale and height stylion is evident.

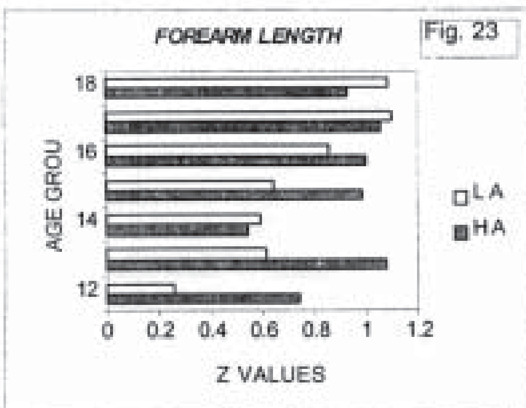
Total upper extremity length (with the exception at 12 years) and upper arm length have lower Z values in highlander Bods than in the lowlander Bods (Figs. 21 and 22). The trend is a mixed one in forearm length and hand length (Figs. 23 and 24). No particular age trend, either in highlanders or lowlanders is visible in these traits, but proportionately these measurements are lower in both the groups as compared to adult phantom values.

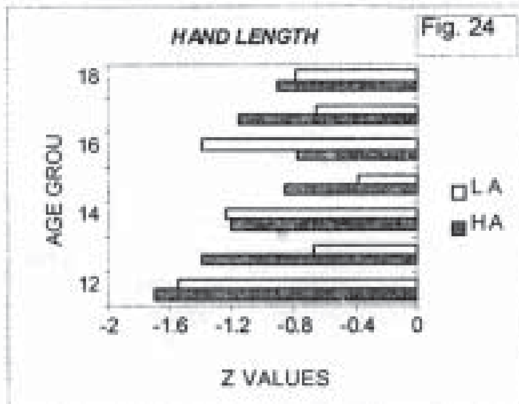
Proportionate antero-posterior depth of chest is higher in both the groups in all the age groups than the adult phantom value (Fig. 27). This is a remarkable finding in view of the hypothesis that chest expansion, specially in the sagittal direction has been associated with bigger size of lungs and perhaps with higher lung functions. Important enough is that these genetic adaptation even continues in the mi-

Figs. 21 to 24. Age group wise distribution of Z values in Height tibiale (Fig. 19), Height spherion (Fig. 20), Total upper extremity length (Fig. 21), Upper arm length (Fig. 22), Forearm length (Fig. 23) and Hand length (Fig. 24) among High Altitude (HA) and Low Altitude (LA) Bods.





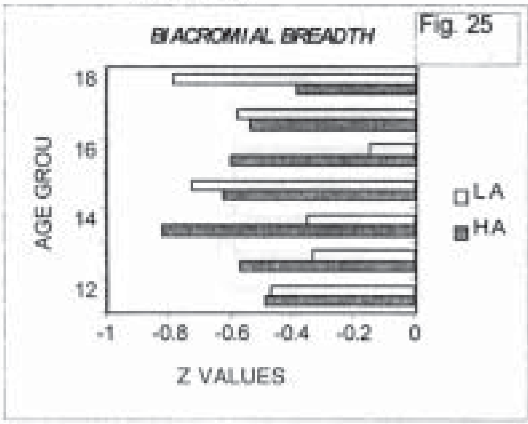


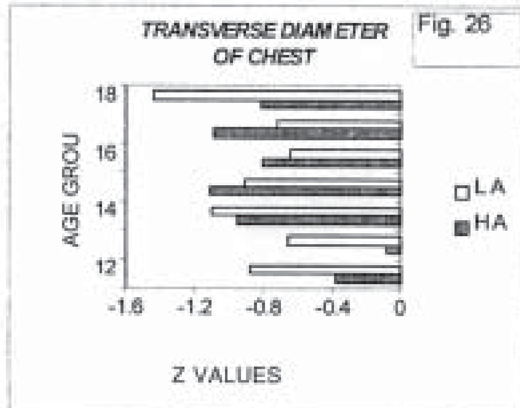


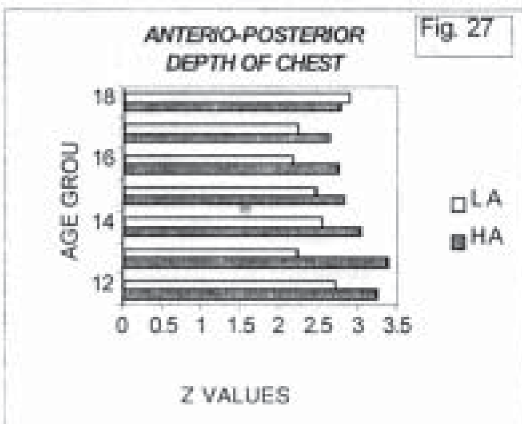
grant Bods (low altitude) despite their migration several centuries ago. Also, it is noteworthy that the highlanders have higher proportionate antero-posterior depth of chest than the lowlanders, except at 18 years. Like most of the measurements, biacromial breadth, transverse diameter of chest, bicristale breadth, bitrochanteric breadth (Figs. 25,26,28,29) have values lower than that of the Phantom. These measurements also do not show much marked altitudinal difference or age trend. Bicondylar humerus and bicondylar femur have higher Z values in both highlander and lowlander Bods in all the age groups than the phantom values (Fig. 30 and 31). Also, bicondylar humerus is higher in all age groups in highlander Bods than in the lowlander Bods, but a reverse trend is noticeable in bicondylar femur. There is no specific age trend in bicondylar humerus in both high and low altitude groups, but there is a general decline in proportionate bicondylar femur with age in both the groups.

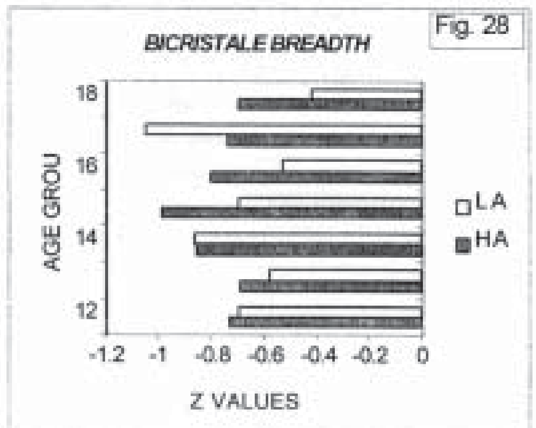
Except head circumference, all the circumferences have negative Z values indicating that both highlander and lowlander Bods have lower proportionate values in all the age groups than the adult phantom values (Figs. 32 to 37). Proportionate chest circumference and abdominal circumference are higher in

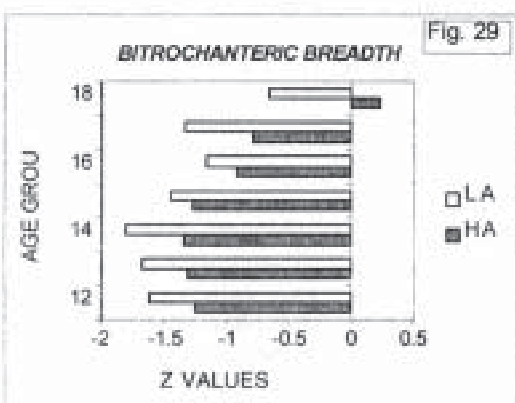
Figs. 25 to 30. Age group wise distribution of Z values in Biacromial breadth (Fig. 25), Transverse diameter of chest (Fig. 26), Antero-posterior depth of chest (Fig. 27), Bicristale breadth (Fig. 28), Bitrochanteric breadth (Fig. 29) and Bicondylar humerus (Fig. 30) among High Altitude (HA) and Low Altitude (LA) Bods.

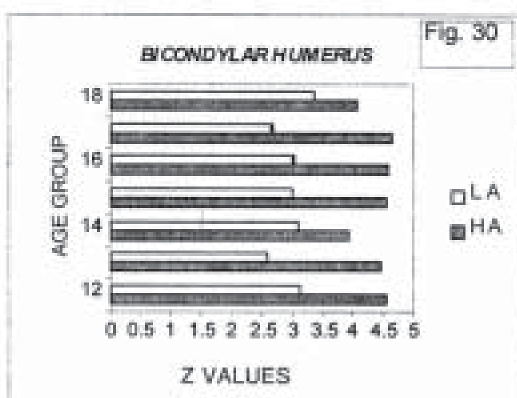




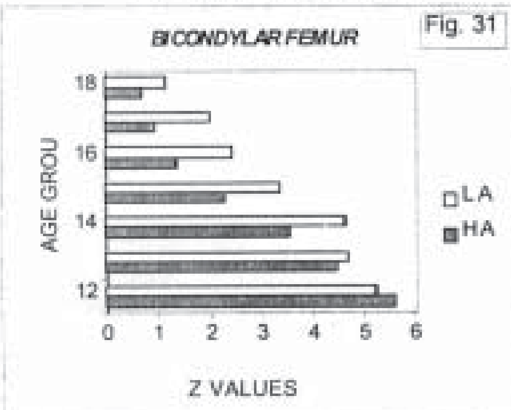


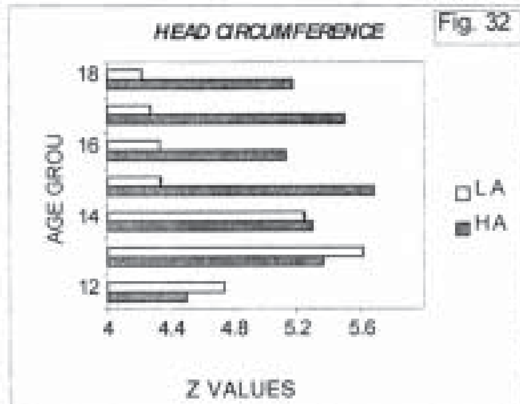


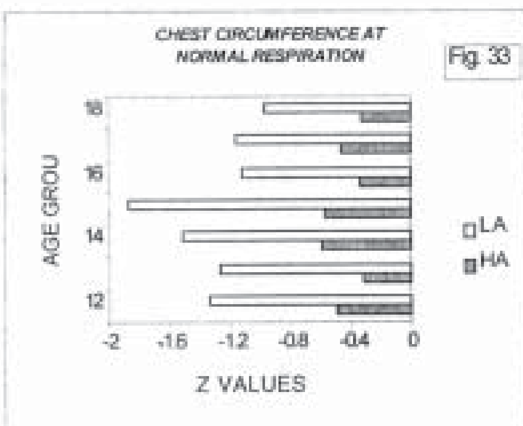


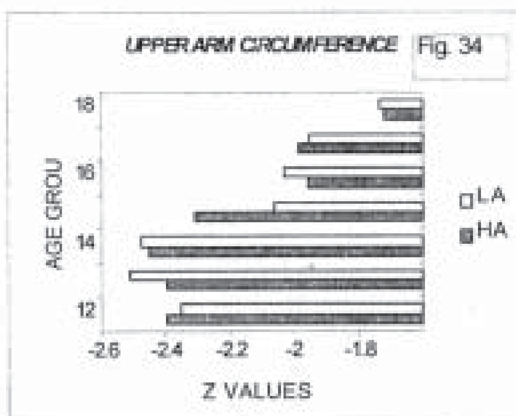


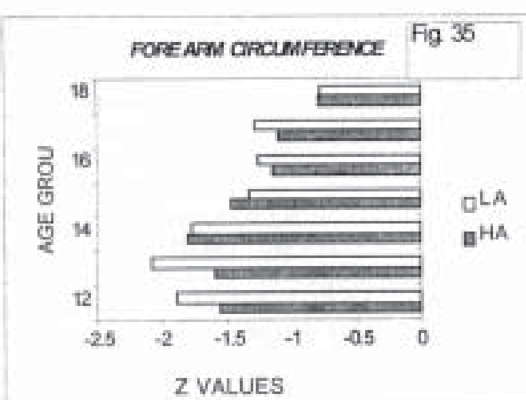
Figs. 31 to 36. Age group wise distribution of Z values in Bicondylar femur (Fig. 31), Head circumference (Fig. 32), Chest circumference at normal respiration (Fig. 33), Upper arm circumference (Fig. 34), Forearm circumference (Fig. 35) and Abdominal circumference (Fig. 36) among High Altitude (HA) and Low Altitude (LA) Bods.

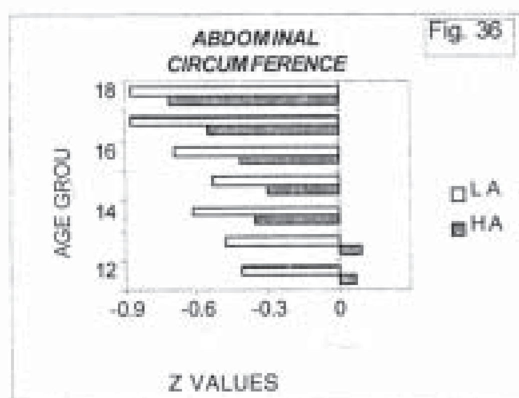












high altitude group than in the low altitude group in all age groups. Also head circumference shows a similar trend except in 12 and 13 years age group. Proportionate upper arm circumference and forearm circumference do not show any particular trend in altitudinal difference. Except at 13 year age group, the proportionate lower leg circumference is lower in highlander Bods than in the lowlander Bods. There is no specific age trend in these circumferential measurements, except that the proportional abdominal circumference decreases with age in both high and low altitude groups.

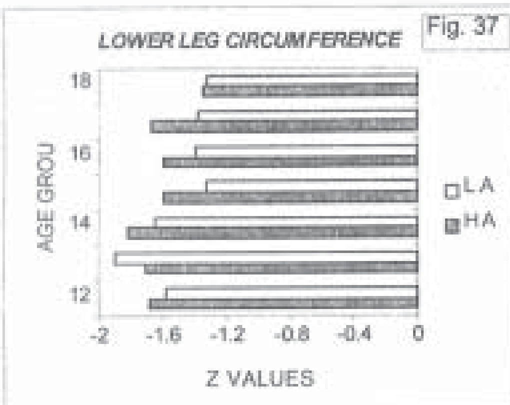
Head length, head breadth, bizygomatic breadth, bigonial breadth and morphological facial height show a decrease in Z values with age in both high and low altitude groups (Figs. 38 to 42). These measurements are generally higher in the high altitude group in the initial age groups, *i.e.*, 12 and 13 years, thereafter they are lower as compared to the low altitude groups.

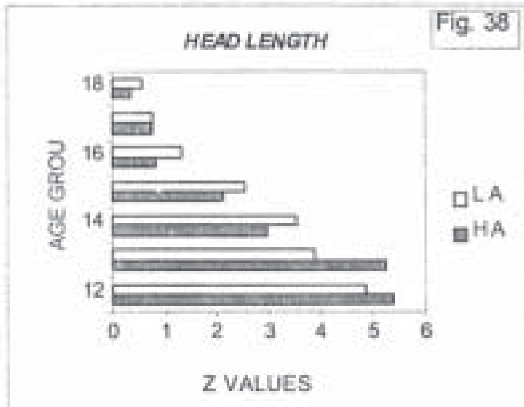
Altitudinal variations in body proportion can best be understood in a wider perspective of human adaptation to high altitude. Also the present communication is a part of an ongoing project at high altitude and discussing the finding of this study along with the results of our earlier communications is likely to provide better insight. How the human body encounters the stresses of the high altitude, particularly the one caused by the low oxygen/ atmospheric pressure? Are the changes in body function sufficient to meet the additional requirements during growth, pregnancy and hard work or are they only sufficient enough for a routine work and/ or survival? What are the problems, particularly in growth and development if sufficient energy is not available at the appropriate time? These are some of the important issues.

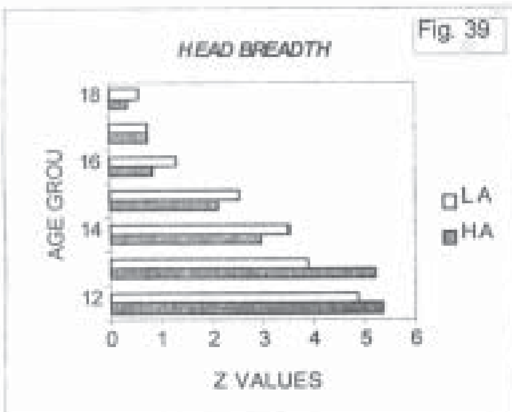
Higher forced vital capacity, forced expiratory volume 1st second, maximal voluntary ventilation are higher in highlander Bod boys as compared to ethically similar lowlander Bod boys (Malik and Singh, 1979 ; Malik, 1984). In conformity with the findings on the Bod boys, the highlander Bod girls also show higher lung functions (Malik and Pandey, 1993). Vital capacity is also higher in highlander from Andes (Hurtado, 1932; Choidi, 1963; Monge and Monge, 1966; Frisancho, 1969; Baker, 1971; Boyce et al., 1974; Greska et al., 1994), Nepal (Bangham and Veale, 1976), Bhutan (Cotes and Ward, 1966), Tibet (Droma et al., 1991), Poland (Pyzuk and Wolanski, 1972) and the USSR (Mikhlaschevskaya et al., 1976). Higher lung functions have been associated with the pivotal high altitude stress, *viz.*, low atmospheric/ oxygen pressure.

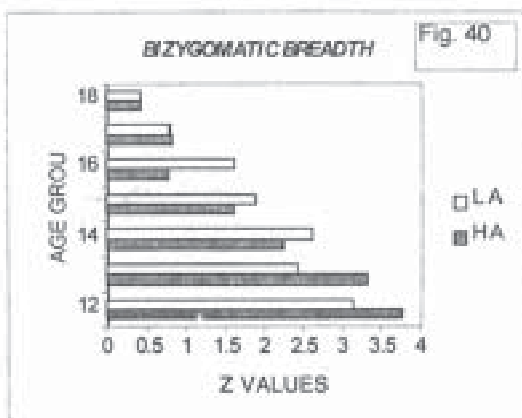
Some of the salient characteristics related to growth and development, associated with high altitude environment are slow and prolonged growth (Frisancho, 1968; Baker, 1969; Frisancho and Baker, 1970; Malik and Singh, 1978; Malik, 1979, Mikhlaschevskaya, 1979; Mikhlaschevskaya et al., 1979; Stinson, 1980; Leonard, 1995; Dittmar, 1997), a non-clear adolescent spurt in stature in male adolescents (Frisancho, 1968; Frisancho and Baker, 1970; Malik and Singh, 1978; Malik and Singh, 1984). This non-clear adolescent spurt when analysed critically, seems to be a part of the slow growth during this period. It is likely that though the enhanced physiological functions are able to encounter the stress of low oxygen pressure for conducting daily routine work, but are unable to meet the extra energy demand required for the achievement of adolescent spurt. Not many studies have been conducted on female highland adolescents. One of such studies conducted by us on female Bods of Ladakh delineates that females have clear adolescent spurt, unlike male Bods of Ladakh (Singh and Malik, 1977). Several arguments have been forwarded to explain this. Firstly, that females are superior than males because of XX chromosome and secondly that they are less ecosensitive than males. These hypotheses need further investigation. Interestingly, however, maturation, as assessed from age at menarche is delayed in the highlander populations (Malcolm, 1970; Mikhlaschevskaya et al., 1972; Pawson, 1976; Beall, 1983; Malik and Hauspie, 1984; Greska, 1990). Chest dimensions, *viz.*, chest circumference, antero-posterior depth of chest, transverse depth of chest, are higher in high-

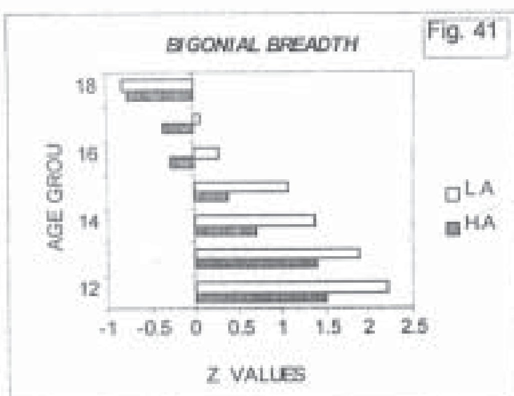
Figs. 37 to 42. Age group wise distribution of Z values in Lower leg circumference (Fig. 37), Head length (Fig. 38), Head breadth (Fig. 39), Bizygomatic breadth (Fig. 40), Bigonial breadth (Fig. 41) and Morphological facial height (Fig. 42) among High Altitude (HA) and Low Altitude (LA) Bods.

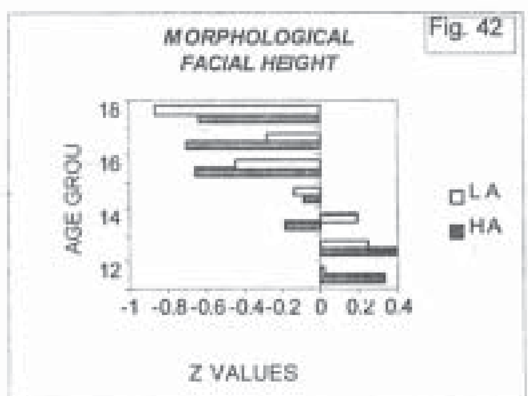












lander Bods as compared to lowlander Bods (Malik, 1984, 1987). Most of the other high altitude populations also show higher chest circumference, if not absolutely then relative to stature (Hurtado, 1932; Monge, 1948; Frisancho, 1969; Harrison et al., 1969; Frisancho and Baker, 1970; Hoff, 1972; Frisancho et al., 1975; Pawson, 1976; Malik and Singh, 1978; Mueller et al., 1978A; Malik, 1979, 1984, 1987; Mueller et al., 1980; Stinson, 1980, 1985; Droma et al., 1991). There are two distinct schools of thought as far as the impact of high altitude on body size is concerned. The first group observes that the highlanders are generally bigger in size during adolescence or as adults (Harrison et al, 1969, Clegg et al., 1972; Malik, 1976; Pawson, 1976; , Stinson and Frisancho, 1978; Gupta and Basu, 1981; Malik and Singh, 1984; Dastider and Gupta, 1988; Gupta et al., 1989). The other group finds that they are smaller in size (Frisancho, 1969; Frisancho et al., 1975; Beall et al., 1977; Mueller et al., 1978B; Mueller et al., 1980; de Meer et al., 1993).

Highlander Bods are more mesomorphic and ectomorphic than the coeval ethnically similar lowlanders (Malik et al., 1986). Similarly high altitude adolescent Bod girls also show higher mesomorphy than the lowlanders (Pandey and Malik, 1990). Such a physique is of high adaptive value for working in the difficult terrain in the rarefied atmosphere.

CONCLUSION

From the foregoing results and discussion it is evident that the highlander Bods have higher proportionate lean body mass. In view of the fact that the highlanders have higher mesomorphy and muscle area, it seems that the highlanders have strong musculature that allows them to work hard under the harsh conditions. The highlander Bods also have lower proportionate body fat, body weight and skinfolds. Also evident from our earlier studies is that they have lower sum of skinfolds and lower endomorphy. It seems that fat deposition is low despite fat rich diet and the advantage of fat layer in the cold climate. The reason may be that working hard in the difficult terrain does not allow fat deposition to that extent. Higher bicondylar humerus also points out that they have strong bony structure useful for doing hard work in the harsh environment. One of the most important features of the highlander Bods is that they have higher proportionate chest circumference and antero-posterior depth of chest. On the basis of the observation that the highlanders have greater lung functions and have strong relationship with the chest dimensions, it has been hypothesised that this is a structural modification related to the function. From the study it is evident that though there may be slow and prolonged growth in some variables like stature, but on the other hand, chest dimensions have greater values, if not absolutely, then in proportionality. It is important here to recall that the proportionate antero-posterior depth of chest is higher in Bods even as compared to the Phantom value. Thus, different body measurements respond differently to the stresses of high altitude. It may be concluded from our studies, including this one, on Bods that the native highlanders are well acclimatised to the high altitude stresses. They are able to survive and to do routine work, but these stresses continue to cause higher reproductive wastage, infant mortality, inhibit growth to some extent in some measurements like stature and weight, advance growth in some measurements, like chest circumference, antero-posterior diameter of chest and bicondylar humerus, and delay maturation. Most of the high altitude populations delineate a similar trend. The varying environmental impact on different high altitude populations may be because of differences in genetical make up, ecosensitivity, socio-cultural factors, and degree, kind and amount of stress.

ACKNOWLEDGEMENTS

I am thankful to all those who agreed to become the subjects of this study. Many thanks to Ms. Inuka Gakhar for her help in preparing the manuscript.

KEY WORDS High Altitude. Bods. Human Adaptation. Body Proportion. Physical Growth. Phantom.

ABSTRACT Altitude variation in body proportion was studied on the basis of data collected on 345 Bod boys ranging in age from 12 to 18 years. High altitude (3514 m) sample (n=233) was collected from the town of Leh (Ladakh, Jammu and Kashmir, India) and villages in its vicinity, whereas low altitude (1200m-2000m) sample (n=112) was collected from the Kullu valley (Himachal Pradesh, India). Higher proportionate lean body mass, bicondylar humerus, and lower proportionate fat and skinfolds indicate that the body proportion of the highlander Bods is suited to undertake hard work under the rarefied atmosphere and difficult terrain. Even the rich fat diet and the advantage of fatty layer in the cold climate has not allowed an increase in fat depositions. Highlander Bods have higher proportional chest dimensions than the lowlanders. In view of our earlier observation that highlander Bods have higher lung functions and they have strong relationship with the chest dimensions, it seems justified that the enlarged chest may be a structural modification to the function. It is also evident from the results that different body measurements respond differently to the stress of high altitude. Some measurements depict retardation, while others show advancement in growth. Also, the environmental response is not uniform in all high altitude populations. The differences accrue because of variation in genetical make-up, ecosensitivity, socio-cultural factors, and degree, kind and amount of stress.

REFERENCES

Baker, P.T. : Human adaptation to high altitude. *Science*, **163**: 1149-1156 (1969).

Baker, P.T. : Adaptation problems in Andean human populations. In: *Ongoing Evolution of Latin American Populations*. F. Salzano (Ed.). Charles C. Thomas Publishers, Springfield (1971).

Bangham, C.R.M. and Veale, K.E.A. : Ventilatory capacity in healthy Nepalese. *Journal of Physiology*, **265**: 31-32 (1976).

Beall, C.M : Age of menopause and menarche in a high altitude Himalayan Population. *Ann. Hum. Biol.*, **10**: 365-370 (1983).

Beall, C.M, Baker, P.T. and Haas, J.D. : The effects of high altitude on adolescent growth in Southern Peruvian Amerindians. *Hum. Biol.*, **49**:109-124 (1977).

Beall, C.M., Brittenham, G.M., Strohl, K.P., Blangero, J., Williams-Blangero, S., Goldstein, M.C., Decker, M.J., Vargas, E., Villena, M., Soria, R., Alarcon, A.M., Gonzales, C. : Haemoglobin concentration of high altitude Tibetans and Bolivian Aymara. *Am. J. Phys. Anth.*, **106**: 385-400 (1998).

Boyce, A.J., Haight, J.S.J., Rimmer, D.B. and Harrison, G.A. : Respiratory function in Peruvian Quechua Indians. *Ann. Hum. Biol.*, 1:137-148 (1974).

Choidi, H. : Respiratory adaptation to high altitude. In : *The Regulation of Human Respiration*. D.J.C. Cunningham and B.B. Lloyd (Eds.). Blackwell, Oxford (1963).

Clegg, E.J., Pawson, I.G., Ashton, E.S. and Flynn, R.M. : The growth of children at different altitudes in Ethiopia. *Phil. Trans. R. Soc. Lond. B*, **264**: 403-437 (1972).

Collins, K.J. : Physiological variation and adaptability in human populations. *Ann. Hum. Biol.*, **26**: 19-38 (1999).

Cotes, J.E. and Ward, M.P. : Ventilatory capacity in normal Bhutanese. *Journal of Physiology*, **186**: 88-89 (1966).

Dastider, M.G. and Gupta, R. : Age changes in anthropometric characters among the Sherpas of the eastern Himalaya : Altitude effect. *J. Indian Anthrop. Soc.*, **23**: 232-241 (1988).

de Meer, K., Bergman, R., Kusner, J.S. and Voorhoeve, H.W.A. : Differences in physical growth of Aymara and Quechua children living at high altitude in Peru. *Am. J. Phys. Anth.*, **90**: 59-75 (1993).

de Meer, K., Heymans, H.S.A. and Zijlstra, V.G. : Physical Adaptation of children to life at high altitude. *Eur. J. Pediatr.*, **154 (4)**:263-72 (1995).

Dittmar, M. : Linear growth in weight, stature, sitting height and leg length and body proportions of Aymara school children living in a hypoxic environment at high altitude in Chile. *Z. Morph. Anthrop.*, **81**: 333-344 (1997).

Droma, T., McCullough, R.G., McCullough, R.E., Zhuang, J., Cymerman, A., Sun, S., Sutton, J.R. and Moore, L.G. : Increased vital and total lung capacities in Tibetan compared to Han residents of Lhasa (3,685m). *Am. J. Phys. Anth.*, **86**: 341-351 (1991).

Durnin, J.V.A.G. and Rahaman, M.M. : The assessment of the amount of fat in the human body from measurement of skinfold thickness. *British Journal of Nutrition*, **21**: 681-689 (1967).

Frisancho, A.R. : *Growth, Physique and Pulmonary Functions of a High Altitude Peruvian Quechua Population*. Ph.D. Thesis, Pennsylvania State University, Pennsylvania (1968).

Frisancho, A.R. : Human growth and pulmonary function of a high altitude Peruvian Quechua population. *Hum. Biol.*, **41**: 365-379 (1969).

Frisancho, A.R. and Baker, P.T. : Altitude and growth : A study of the patterns of physical growth of a high altitude Peruvian Quechua population. *Am. J. Phys. Anth.*, **32**: 279-292 (1970).

Frisancho, A.R., Borkan, G.A. and Klayman, J.E. : Pattern of growth of lowland and highland Peruvian Quechua of similar genetic composition. *Hum Biol.*, **47**: 233-243 (1975).

Greska, L.P. : Age of menarche in Bolivian girls of European and Aymara ancestry. *Ann. Hum. Biol.*, **17**: 49-53 (1990).

Greska, L.P., Spielvogel, H. and Caceres, E. : Total lung capacity in young highlanders of Aymara ancestry. *Am. J. Phys. Anth.*, **94**: 477-486 (1994).

Gupta, R. and Basu, A. : Variations in body dimensions in relation to altitude among the Sherpas of the eastern Himalayas. *Ann. Hum. Biol.*, **8**: 145-151 (1981).

Gupta, R., Basu, A., Pawson, I.G., Bharati, P., Mukhopadhyay, B., Mukhopadhyay, S., Roy, S.K., Majumdar, P.P., Bhattacharya, S.K., Bhattacharya, K.K. and Das, S.K. : Altitude and human biology:A comparative study of Himalayan Andean and Ethiopian data. *J. Indian Anthrop. Soc.*, **24**: 1-80 (1989).

Harrison, G.A., Kuchermann, C.F., Moore, M.A.S., Boyce, A.J., Baju, T., Mourant, A.E., Godber, M.J., Glasgow, B.G., Kopec, A.C., Tills, D. and Clegg, E.J.: The effects of altitudinal variation in Ethiopian populations. *Phil. Trans. R. Soc. Lond. B.*, **256**: 147-182 (1969).

Hoff, C.J. : Altitudinal variation in the physical growth and development of Pervian Quechua. *Homo*, **24**: 87-99 (1972).

Hurtado, A. : Respiratory adaptation in the Indian natives of Peruvian Andes : Studies at high altitude. *Am. J. Phys. Anth.*, **17**: 137-165 (1932).

Leonard, W.R., Dewalt, K.M., Stansbury, J.P., McCaston, M.K. : Growth differences between children of highland and coastal Ecuador. *Am. J. Phys. Anth.*, **98**: 47-57 (1995).

Malcolm, L.A. : Growth and development of Bundi child of New Guinea highlands. *Hum Biol.*, **42**: 293-328 (1970).

Malik, S.L. : *Age Changes and Few Biological Responses at High Altitude : A Study Among Male Bods of Ladakh.* Ph.D. Thesis, University of Delhi, Delhi (1976).

Malik, S.L. : Effect of altitude on physical development comparison of highland and lowland Bods. *Spectra of Anthropological Progress*, **2**:45-50 (1979).

Malik, S.L. : Morpho-physiological adaptation to high altitude. In:*Genetic of Psychomotor Traits in Man*. N. Wolanski and A. Šinirska (Eds.). International Society of Sports Genetics and Somatology, Warsaw (1984).

Malik, S.L. : Physical growth and altitude : Comparison of High- and Low- land Bods of the Western Himalayas : *Indian Anthropologist*, **17(2)**: 9-48 (1987).

Malik, S.L. and Hauspie, R. : Age at menarche among high altitude Bods of Ladakh (India). *Hum. Biol.*, **58(4)**: 541-548 (1986).

Malik, S.L. and Pandey, A.K. : Respiratory adaptation to high altitude in adolescent Bod girls of the western Himalayas. *Ann. Hum. Biol.*, **20**: 575-581 (1993).

Malik, S.L. and Singh, I.P. : Growth trends among male Bods of Ladakh- A high altitude population. *Am J. Phys. Anth.*, **48**: 171-176 (1978).

Malik, S.L. and Singh, I.P. : Ventilatory capacity among highland Bods: A possible adaptive mechanism at high altitude. *Ann. Hum. Biol.*, **6**: 471-476 (1979).

Malik, S.L. and Singh, I.P. : Ecology and Human Physiology in Ladakh. pp. 421-439. In: *The People of South Asia*. J. Lukacs (Ed.). Plenum Publishers, U.S.A. (1984).

Malik, S.L., Eiben, O.G., Parkash, M. and Mittal, M. : Impact of High altitude on body shape. *Anthrop. Kozl.*, **30**: 203-208 (1986).

Martin, R. and Saller, K. : *Lehrbuch der Anthropologie in Systamischer Darstellung*. Fisher, Stuttgart (1957).

Mikhlashevskaya, N.N. : The effect of climatic factors on growth processes in Man. *Coll. Anthrop.*, **3**: 173-182 (1979).

Mikhlashevskaya, N.N., Solovyeka, V.S., Godina, E.Z. and Kondik, V.M. : Growth processes in man under conditions of high mountains. *Transactions of the Moscow Society of Naturalists*, **43**: 181-193 (1972). (In Russian with English Summary).

Mikhlashevskaya, N.N., Solovyeka, V.S. and Godina, E.Z. : The effect of climatic factors on growth processes in man. *Symposium on Human Biology (Growth and Development; Physique)*, Hungary, Abstract 17 (1976).

Mikhlashevskaya, N.N., Solovyeka, V.S. and Godina, E.Z. : Process of human growth in high altitudes, pp. 243-254. In:*Physiological and Morphological Adaptation and Evolution*. Mouton Publishers, The Hague (1979).

Monge, C. : *Acclimatization in the Andes. Historical Confirmation of 'Climatic Aggression' in the Development of Andes Man.* John Hopkins Press, Baltimore (1948).

Monge, C. and Monge, C. : *High Altitude Diseases : Mechanism and Management*. Charles C. Thomas Publishers, Springfield (1966).

Mueller, W.H., Schull, V.N., Schull, W.J., Soto, P. and Rothhammer, F. : A multinational Andean Genetic and Health Program : Growth and Development in an hypoxic environment. *Ann. Hum Biol.*, **5**:329-352 (1978A).

Mueller, W.H., Yen, F., Rothhammer, F. and Schull, W.J.: A multinational Andean Genetic and Health Program : VII Lung function and physical growth-Multivariate analysis in high- and low altitude populations. *Aviation, Space and Environmental Medicine*, Oct. issue:1189-1196 (1978B).

Mueller, W.H., Murillo, F., Palamino, H., Badzioch, M., Chakraborty, R., Fuerst, P. and Schull, W.J. : The Aymara of Western Bolivia : V : Growth and development in an hypoxic environment. *Hum. Biol.*, **52**: 529-546 (1980).

Pandey, A.K. and Malik, S.L. : Anthropometric somatotype of Bod girls: A comparison of high and low altitude populations. *Am. J. Hum Biol*, **2**: 467-473 (1990).

Pawson, I.G. : Growth and development of high altitude population : A review of Ethiopian Peruvian and Nepalese studies. *Proc. R. Soc. Lond. B.*, **194**: 83-94 (1976).

Prakash, M. and Malik, S.L. : Differences in fertility in highlander and lowlander Bods of Himachal Pradesh. *J. Hum. Ecol.*, **1**: 175-180 (1990).

Pyzuk, M.and Wolanski, N. : Uklad Oddychanla I Krazenia ulzieci u Roznorodnych Uarunkachi Srodowiskowvch. *Panstwowe Wydawnictwo Naukowe*, Warsaw (1972).

Ross, W.D. and Wilson, N.C. : Growth and development: a stratagem for proportional growth assessment. *Acta Paediat. Bel.*, **28**: 169-182 (1974).

Ross, W.D. and Ward, R. : Human proportionality and sexual dimorphism, pp. 317-361. In: *Sexual Dimorphism in Homo sapiens*. R. Hall (Ed.). Praeger, New York (1982).

Singh, I.P. and Malik, S.L. : A study of human growth among high altitude female Bods of Ladakh with remarks on morphological adaptation. *Anthrop. Kozl.*, **21**: 70 (1977).

Singh, S.P., Sidhu, L.S. and Malhotra, P. : Body morphology of high altitude Spitians of North West Himalayas. *Z. Morph. Anthrop.*, **76**: 91-94 (1986).

Siri, W.E. : Body composition from fluid spaces and density : analysis of methods, pp. 223-244. In : *Techniques for Measuring Body Composition*. J. Brozek and A. Henschel (Eds.). Nat. Acad. Sci., Nat. Res. Council, Washington (1961).

Stinson, S. : The physical growth of high altitude Bolivian Aymara children. *Am. J. Phys. Anth.*, **52**: 377-385 (1980).

Stinson, S. : Chest dimensions in European and Aymara children at high altitude. *Ann. Hum. Biol.*, **12**: 333-338 (1985).

Stinson, S. and Frisancho, A.R. : Body proportions of highland and lowland Peruvian Quechua children. *Hum Biol.*, **50**: 57-68 (1978).

Tanner, J.M., Whitehouse, J.R.H. and Takaishi : Standards from birth to maturity for height, weight, height velocity, weight velocity for British children. *Arch. Dis. Childhood*, **41**: 454-471 (1966).

Tanner, J.M., Hiernaux, J. and Jarman, S. : Growth and physique studies. In: *Human Biology: A Guide to Field Methods*. IBP Handbook No. 9, Blackwell, Oxford (1969).

Author's Address: **S.L. Malik**, *Professor*, Department of Anthropology, University of Delhi, Delhi 110 007, India