ANNALS OF HUMAN BIOLOGY, 1981, VOL. 8, NO. 2, 145–151

Variations in body dimensions in relation to altitude among the Sherpas of the eastern Himalayas

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Received 29 January 1980; revised 23 September 1980

Summary. A biomedical study was undertaken on the Sherpas of Upper Khumbu (3500–4500 m), Nepal, and their migrant counterparts in the lower altitudes (1000–1500 m) of Kalimpong subdivision, Darjeeling district, West Bengal, to study the impact of altitude on human biological characteristics in this Himalayan population, following the basic design of the IBP/Human Adaptability Panel. The results of the anthropometric survey of the adults (234 males and 169 females) are presented here. The high-altitude Sherpas of both sexes have significantly higher values than their low-altitude counterparts for most of the length, breadth and girth measurements, weight, cormic index, weight/stature ratio, weight/(stature)^2 ratio, chest/stature ratio, surface area and body fat.

1. Introduction

Between 20 and 30 million people reside permanently at high altitudes above 2500 metres (Baker 1978). This alone provides sufficient justification for studying the possible impact of physical environmental stresses associated with high altitude on these people. If all mountain dwellers including those inhabiting medium altitudes are considered, the number increases hugely and the study assumes still further importance (Clegg, Harrison and Baker 1970). A number of studies on the impacts of altitudinal stresses on human biological traits have been conducted in Latin America, East Africa and Tien Shan (Harrison *et al.* 1969, Baker and Dutt 1972, Hoff 1974, Mazess 1975, Frisancho 1976, Cruz-Coke 1977, Schull and Rothhammer 1977, Beall, Baker, Baker and Haas 1977, Mirrakhimov 1978, Mueller, Schull, Schull, Soto and Rothhammer 1978), but data on the Himalayan–Hindu Kush peoples in southern Asia have been scanty (Baker 1976). In view of this, a comprehensive, comparative biomedical survey of fertility, mortality, body dimensions, dietary intakes, intestinal parasitic load, haematological status, etc. was undertaken on the Sherpas of Upper Khumbu (3500–4500 m), Nepal, and Kalimpong subdivision (1000–1500 m), West Bengal, India. The present report studies the nature of altitudinal variations in adult body dimensions, if any, in this Himalayan population.

2. Materials and methods

The Sherpas (literally, 'people of the east') are indigenous high-altitude people who seem to have migrated from the eastern regions of Tibet to Upper Khumbu, north-eastern Nepal. They still speak a Tibetan dialect and belong to the Tibetan sect of Buddhism. In India, the Sherpas are mainly concentrated in the Sadar and Kalimpong subdivisions of Darjeeling district, northern West Bengal, and in Sikkim.

Our study areas in Nepal and India, as well as the distribution of the villages and hamlets surveyed within each, are shown in figure 1.

The basic design recommended by the International Biological Programme/Human Adaptability Panel, as modified by Baker and Dutt (1972), was followed. A comparison was made between two sub-units of a population native to high altitude of

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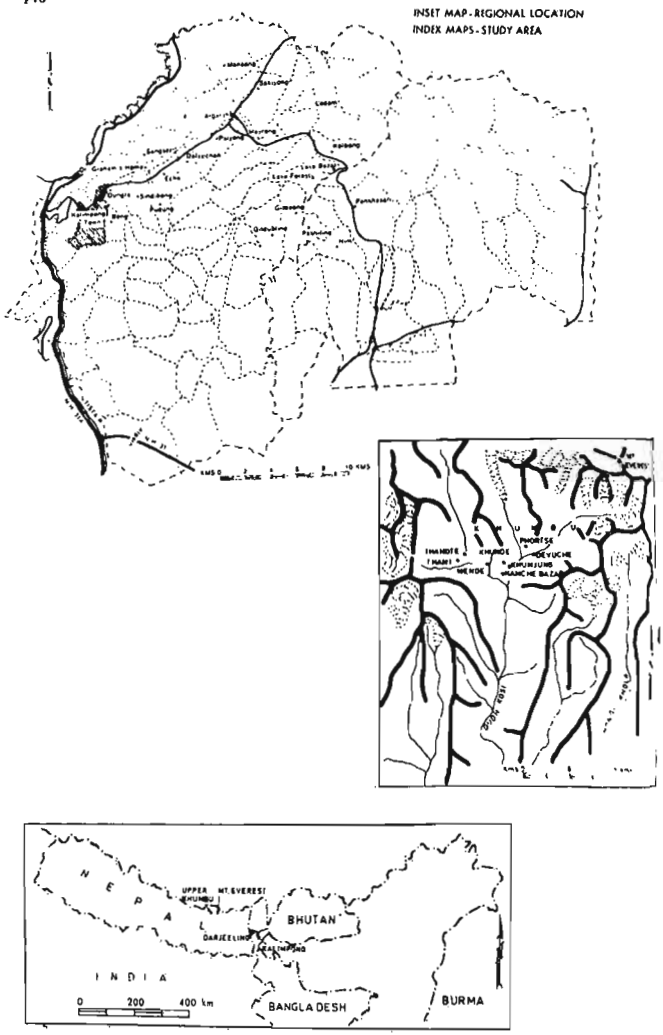

Figure 1. Maps showing the distribution of Sherpa villages/hamlets surveyed.

which one continues to live at high altitude, i.e. the Sherpas of Upper Khumbu, and another migrated to lower altitudes, i.e. the Sherpas of Kalimpong subdivision. The two study areas were selected so as to include highest and lowest altitude Sherpa settlements, to maximize altitudinal differences and their effects, if any, on the traits considered.

No statistical sampling of individuals within the villages could be made, because of the suspicion that any selection of subjects for examination and measurement usually generates in the populations studied. Any individual who could be persuaded to cooperate was measured. The sample sizes by location and sex are given in table 1.

Table 1. Sample sizes by location and sex.

High altitude (upper Khumbu)			Low altitude (Kalimpong)		
Male	Female	Total	Male	Female	Total
68	39	107	166	130	296

The sample size, particularly for Upper Khumbu, is admittedly small. This was due to, first, the very expensive nature of the area which has of late become an internationally known tourist resort and, second, the general resistance of the people concerned to anthropological investigations, because of some recent unpleasant experiences.

The usual difficulties involved in backward communities were encountered in the assessment of age. Ages were, therefore, estimated by reference to important local events or by comparison with other individuals of known ages or recorded from written records, where such records existed, but cross-checked from a number of sources in any case.

Anthropometric measurements listed in the IBP Basic List of recommended measurements were made, following standard techniques (Weiner and Lourie 1969), except that exhaled and inhaled chest circumferences were taken (with a metal tape at the level of the fourth rib) in place of anteroposterior and transverse chest diameters, and the wrist breadth as well as height of anteroposterior iliac spine were not taken. Specifically, the following measurements were taken on the adults ($\geqslant 20$ years of age) wearing light garments:

1. Stature
2. Sitting height
3. Bicondylar femur diameter
4. Calf girth
5. Biceps girth
6. Total arm length
7. Biacromial diameter
8. Chest girth
   (*a*) exhaled
   (*b*) inhaled
9. Biiliac diameter
10. Cephalic length
11. Cephalic breadth
12. Bizygomatic breadth
13. Morphological face height
14. Nose height
15. Nose breadth
16. Triceps skinfold: left and right
17. Subscapular skinfold: left and right
18. Body weight

From the skinfold measurements total body fat was estimated according to Sen's (1979) equation. Surface area was also estimated by Sen's (1979) equations.

From the above-mentioned measurements, the following indices were computed and estimates made:

1. Cephalic index
2. Nasal index
3. Cormic index
4. Ponderal index
5. Chest (exhaled)/stature ratio
6. Weight/stature ratio
7. Weight/(stature)^2 ratio
8. Surface area:
   (*a*) S.A. $= W^{0.425} \times H^{0.725} \times 74.66$ (for males)
   (*b*) S.A. $= W^{0.425} \times H^{0.725} \times 78.28$ (for females)
9. Surface area/weight ratio
10. Log of sum of skinfold thickness (triceps right + triceps left + subscapular right + subscapular left)
11. Body fat (kg) $= [F(\%) \times$ wt. (kg)]/100 where $F(\%) = (4.201/D - 3.813) \times 100$ and $D = 1.0890 - 0.0028 \times$ triceps skinfold thickness (mm)

3. Results

The means and standard deviations for the anthropometric measurements of the high- and low-altitude Sherpas, and the levels of significance of difference between the means for each measurement, are presented in table 2.

Absolute measurements

Adult males. In body measurements, the high-altitude group is significantly taller and heavier than the low-altitude counterpart; it also has significantly higher values of sitting height and surface area. In breadth measurements, while biacromial and biiliac breadths have significantly higher values in the high-altitude group, the low-altitude group has consistently higher values of bicondylar femur diameter. In all girth measurements except biceps, e.g. calf girth, and exhaled as well as inhaled chest girths, the high-altitude group has consistently higher values than the low-altitude counterpart. The high-altitude group has thicker skinfold thickness both at triceps and subscapular sites, as well as greater body fat, than the low-altitude counterpart, although the differences are statistically insignificant except in the case of triceps (right). The difference between the two altitude groups with regard to log of sum of skinfold thicknesses (triceps and subscapular, right and left sides) is also insignificant.

In cephalic and facial measurements, the high-altitude group has significantly higher values of cephalic length and breadth, morphological face height and nose height, and consistently lower values of nasal and bizygomatic breadths, than the low-altitude counterpart.

Adult females. In body measurements, in stature, sitting height, weight and surface area, the high-altitude group has higher values than the low-altitude counterpart, as in the case of the males, but the difference is not significant in the case of surface area. In the case of breadth measurements, biacromial and biiliac breadths are greater in the high-altitude group, while bicondylar femur diameter is smaller in them. In all the girth measurements, the high-altitude group has consistently higher values than the low-altitude counterpart, as in the males. The high-altitude group also has consistently higher values of skinfold thickness at triceps and subscapular sites and body fat, as in the males, and log of sum of skinfold thicknesses, than the low-altitude counterpart. This consistent pattern of difference between high- and low-altitude Sherpas in skinfold thicknesses must, however, be viewed with caution, for only one of the eight comparisons made shows a statistically significant difference.

Table 2. Anthropometric measurements and indices as well as body fat among the high- and low-altitude adult Sherpas.

Body measurements/ indices	Adult male							Adult female						
	High altitude (Upper Khumbu) Mean age 47·21 ± 14·29			Low altitude (Kalimpong) Mean age 40·00 ± 13·48			Level of signi-ficance	High altitude (Upper Khumbu) Mean age 41·72 ± 12·65			Low altitude (Kalimpong) Mean age 38·13 ± 14·02			Level of signi-ficance
	n	x̄	s.d.	n	x̄	s.d.		n	x̄	s.d.	n	x̄	s.d.	
Weight (kg)	68	55·7	5·56	166	50·4	5·42	*	38	50·9	6·49	130	43·2	5·71	*
Stature (cm)	68	162·3	7·58	166	158·5	5·65	*	39	149·9	5·67	130	147·2	5·22	*
Sitting height (cm)	68	83·9	3·74	166	81·6	3·59	*	39	78·4	2·95	130	76·7	3·08	*
Biacromal bdth. (cm)	68	36·7	1·79	166	35·7	1·95	*	39	33·8	1·67	130	32·2	1·76	*
Biiliac diam. (cm)	68	30·2	2·01	166	27·7	1·60	*	39	31·6	2·50	130	26·7	1·76	*
Total arm length (cm)	68	69·4	3·97	166	69·8	3·13	Insig.	39	63·6	3·88	130	63·7	2·78	Insig.
Bicond. femur diam. (cm)	67	7·8	0·82	166	8·6	0·55	*	38	6·7	1·04	130	7·8	0·50	*
Biceps girth (cm)	67	22·4	1·77	166	23·1	1·86	*	38	22·0	2·10	130	21·3	2·05	Insig.
Calf girth (cm)	67	32·9	2·62	166	32·1	1·99	*	39	31·0	2·74	130	29·5	2·20	*
Chest (exhale) (cm)	67	88·1	4·06	166	83·4	4·76	*	39	87·6	5·35	130	80·8	4·71	*
Chest (inhale) (cm)	67	90·3	4·14	166	87·7	4·94	*	39	89·2	5·38	130	84·0	4·89	*
Skinfold thickness (mm)														
Triceps (lt.)	67	5·5	1·60	166	5·3	1·61	Insig.	38	9·8	3·44	130	8·7	3·00	Insig.
Triceps (rt.)	67	5·8	1·76	166	5·3	1·61	*	38	9·5	3·30	130	8·7	2·99	Insig.
Subscaps. (lt.)	67	8·8	2·03	166	8·9	2·15	Insig.	38	11·7	3·20	130	10·9	3·65	Insig.
Subscaps. (rt.)	67	8·5	2·04	166	9·0	2·16	Insig.	38	11·5	3·14	130	10·9	3·59	Insig.
Cephalic length (cm)	67	19·0	0·59	166	18·5	0·63	*	39	18·0	0·58	130	17·7	0·62	*
Cephalic bdth. (cm)	67	14·7	0·61	166	14·3	0·69	*	39	14·3	0·61	130	14·2	0·51	Insig.
Nose ht. (cm)	67	5·3	0·42	166	5·0	0·39	*	38	4·8	0·50	130	4·5	0·41	*
Nose bdth. (cm)	67	3·4	0·41	166	3·5	0·28	*	38	3·0	0·36	130	3·2	0·26	*
Bizygomatic bdth. (cm)	67	12·3	0·67	166	13·0	0·61	*	38	11·7	0·67	130	12·5	0·54	*
Morph. face ht. (cm)	67	12·0	0·58	166	11·4	0·59	*	38	11·3	0·67	130	10·7	0·65	*
Indices														
Weight/Stature	67	34·31	2·61	166	31·76	2·80	*	37	33·90	3·75	130	29·28	3·41	*
Weight/(Stature)^2	67	21·00	0·02	166	20·00	0·02	*	37	23·00	0·02	130	20·00	0·02	*
Ponderal index	67	42·56	1·48	166	42·98	1·27	*	37	40·48	1·39	130	42·11	1·61	*
Cormic index	67	51·80	1·64	166	51·53	1·80	Insig.	37	52·42	1·78	130	52·12	1·57	Insig.
Chest/Stature	67	54·31	2·77	166	52·64	2·74	*	37	58·61	3·53	130	54·87	3·03	*
Surface area	67	4·86	0·39	166	4·54	0·34	*	37	4·51	0·37	130	4·14	0·34	*
Surface area/Weight	67	8·72	0·39	166	9·03	0·42	*	37	8·91	0·51	130	9·65	0·62	*
Body fat (Triceps): % of body weight	67	5·70	1·21	166	4·96	1·15	*	37	7·41	2·66	130	5·85	1·81	*
Log of sum of skinfold thicknesses (tri.rt.+ tri.lt.+ subscap.rt.+ subscap.lt)	67	3·33	0·21	166	3·33	0·22	Insig.	37	3·71	0·26	130	3·63	0·30	Insig.
Cephalic index	67	77·54	3·52	166	77·27	4·41	Insig.	37	79·74	3·25	130	80·29	4·18	Insig.
Nasal index	67	64·61	9·32	166	70·02	7·46	*	37	64·84	10·45	130	71·76	8·62	*

*Significant at 5% level.

In cephalic and facial measurements, the high-altitude group has significantly higher values of cephalic length, nose height and morphological face height, and significantly lower values of nasal and bizygomatic breadths, than the low-altitude counterpart.

Indices and ratios

With regard to indices/ratios involving body measurements, in males, cormic index, weight/stature, weight/(stature)^2 and chest/stature have higher values in the high-altitude group, and ponderal index and surface area/weight have higher values in the low-altitude group. In females, cormic index, weight/stature, weight/(stature)^2 and chest/stature have higher values in the high-altitude group, and ponderal index and surface area/weight have higher values in the low-altitude group. In cephalic and facial indices, cephalic index has a higher value in the high-altitude males and nasal index has a higher value in the low-altitude males, but both have higher values in the low-altitude females.

4. Discussion

Both male and female high-altitude Sherpas have higher values for most length measurements (except total arm length in both), breadth and girth measurements (except biceps girth in males), weight, cormic index, weight/stature, weight/(stature)^2, chest/stature, surface area and body fat, and lower values for both bizygomatic breadth, nasal breadth and nasal index, than their low-altitude counterparts.

Such variation, i.e. bigger dimensions at higher altitudes, is in conformity with Bergmann's and Allen's rules, which state that in warm-blooded animals body size, and consequently surface area/weight, as also length of the extremities, are smaller in colder than in warmer climates to minimize heat loss (Young 1971). This has also been observed in the case of humans by Harrison *et al.* (1969) in their Ethiopian study. The possibility of such differences being at least partially attributable to nutritional factors, as suggested by Harrison *et al.* (1969) may be ruled out in the case of the Sherpas, for the high-altitude Sherpas probably have a lower nutritional status than their low-altitude counterparts. Differential prevalence of debilitating diseases, e.g. possibly higher prevalence of malaria, hookworm, etc. at lower altitude, might be relevant in this context. Surveys on intestinal parasitic infestations in the low-altitude Sherpas have already been conducted and hookworm prevalence is found to be heavy in this group (Bhattacharya 1980, Bhattacharya *et al.* 1980). No definitive explanation in terms of the causations of altitudinal variations in body dimensions between the Sherpas of Upper Khumbu and Kalimpong subdivision can be offered. But it appears that these variations are not attributable to hypoxia alone; they may be caused by complex interactions of physical environmental factors with others, e.g. biological (diseases—degenerative and contagious), nutritional, economic and cultural (behavioural norms and practices relating to habitation, food, diseases, etc.). Much further study is necessary to understand fully the mechanisms and processes of adaptation of human populations to the stresses associated with high altitude.

Acknowledgements

The authors are indebted to the Sherpas of the study areas for their unhesitating help and cooperation; to Professor E. J. Clegg for his comments on the first draft of this paper; to His Majesty's Government of Nepal, for allowing us to undertake this research in Upper Khumbu; to the Indian Embassy at Kathmandu for organizational

help; to the subdivisional authorities, Kalimpong subdivision, Government of West Bengal, and the authorities of Government Cinchona Plantation, Munsong, for administrative assistance; to Mr Partha P. Majumder for statistical help; to Mr Prabhas C. Kumar for preparing the diagram; and to Mr Asish K. Basu and Mr Paritosh Adhikary for typing the manuscript.

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Zusammenfassung. Die Sherpas von Ober-Khumbu (3500–4500 m) in Nepal und ihre gewanderten Verwandten in niedrigerer Nöhe (1000–1500 m) im Kreis Kalimpong des Distrikts Darjeeling in Westbengal wurden biomedizinisch untersucht, um den Einfluß der Höhe ü.d.M. auf die biologischen Merkmale des Menschen dieser Himalaya-Bevölkerung abzuschätzen, wobei in der Grundanlage dem Untersuchungsschema des IBP/Human Adaptability gefolgt wurde. Die Ergebnisse der anthropometrischen Untersuchung der Erwachsenen (296 Männer und 107 Frauen) werden hier vorgestellt. Die Sherpas von großer Höhe haben in beiden Geschlechtern signifikant höhere Werte als die von niedriger Höhe bei den meisten der Längen-, Breiten- und Umfangsmaße, dem Gewicht, dem cormischen Index, dem relativen Gewicht, dem Verhältnis Gewicht/(Körperhöhe)^2, dem relativen Brustumfang, der Oberfläche und dem Körperfett.

Résumé. Une étude biomédicale a été entreprise chez les Sherpas du Khumbu supérieur, au Népal, à une altitude de 3500 à 4500 m, et chez leurs pendants émigrés à plus basse altitude (1000–1500 m) dans la subdivision de Kalimpong, district de Darjeeling, au Bengale occidental, afin d'étudier l'impact de l'altitude sur les caractéristiques biologiques humaines dans cette population himalayenne en suivant le plan de base du comité PBI/Adaptabilité Humaine. Les résultats de l'enquête anthropométrique sur les adultes (296 hommes et 107 femmes) sont présentés ici. Les Sherpas de haute altitude des deux sexes ont des valeurs significativement plus élèves que leurs pendants de basse altitude pour la plupart des mensurations de longueur, de largeur et de périmètre, le poids, l'indice cormique, le quotient poids/stature, le quotient poids/stature^2, le quotient thorax/stature, la surface corporelle et la graisse corporelle.