ANNALS OF HUMAN BIOLOGY, 1997, VOL. 24, NO. 6, 533–538

Body water distribution in highlanders versus lowlanders

G. BEDOGNI, N. BATTISTINI, S. SEVERI, F. FACCHINI†, D. PETTENER† and G. FIORI†

Modena University, Modena, Italy
† Bologna University, Bologna, Italy

Received 18 February 1997

Summary. Acute exposure to high altitude produces characteristic changes in body water distribution from which acclimatized individuals seem to be spared. However, it has been suggested that body water distribution may be different in highlanders (HL) as compared to lowlanders (LL). We studied the distribution of total body water (TBW) between extracellular water (ECW) and intracellular water (ICW) in a group of 20 HL (3200 m above sea level) versus one of 20 LL (900 m above sea level). Subjects were matched for ethnic group (Kirghiz), sex (male), weight (Wt), height and body mass index. TBW:Wt and ECW:TBW were not different in HL as compared to LL (mean ±SD, 58·5±5·0% versus 56·0±4·2% and 40·5±4·2% versus 40·7±2·2%; p=n.s. for both). This study does not support the hypothesis that body water distribution is different in HL as compared to LL.

1. Introduction

Acute exposure to high altitude produces a loss of water from the intracellular and extracellular spaces (Hannon, Chinn and Shields, 1971, Krzywicki, Consolazio, Johnson, Nielsen and Baenhart 1971, Frayser, Rennie, Gray and Houston 1975, Jain, Bardhan, Swamy, Krishna and Nayar 1980). The dehydration which ensues —especially the intracellular dehydration—may play a role in the pathogenesis of the so-called 'mountain sickness' which affects people ascending rapidly to high altitudes (Withey, Milledge, Williams, Minty, Bryson, Luff, Older and Beeley 1983). These events, which are probably triggered by cellular hypoxia, do not seem to occur in acclimatized subjects (Withey *et al.* 1983, Ward, Milledge and West 1989).

It would therefore be of interest to know whether individuals native and permanently living at high altitude (>2500 m) show modifications of body water distribution between intracellular and extracellular spaces compared to those living at low altitude. Unfortuately, the distribution of total body water (TBW) between extracellular water (ECW) and intracellular water (ICW) has not been studied thoroughly in high-altitude residents. In a classic study on Peruvians, Picón-Reátegui, Lozano and Valdivieso (1961) showed an increase in ECW per kg weight (Wt) in a group of highlanders (HL) versus one of lowlanders (LL). However, the groups were not strictly comparable, and differences in physical characteristics may have influenced the results of the study.

We studied body water distribution in HL and LL Kirghizs as a part of a larger research project on human adaptability to high altitudes (CAHAP, Central Asia High Altitude People), carried out in collaboration with the Academy of Sciences of Kazakhstan (Battistini, Facchini, Bedogni, Severi, Fiori and Pettener 1995a, Facchini, Pettener, Rimondi, Sichimbaeva, Riva, Salvi, Pretolani and Fiori 1997, Pettener, Facchini, Luiselli, Toselli, Rimondi, Ismagulova, Sichimbaeva, Ismagulov and Fiori 1997).

0301-4460/97 $12·00

2. Materials and methods

2.1. The Kirghiz population

Kirghizs are a Turkish-speaking population (Altaic linguistic family) that settled in the Pamir and Tien Shan mountains over the last four to five centuries. From an anthropological point of view they are a Turko-Mongolic population and are similar to Kazakhs, the other high-altitude population of Central Asia (Alekseev and Gochman 1983, Battistini *et al.* 1995a). The similarity between Kirghizs and Kazakhs is confirmed by recent genetic studies (Pettener *et al.* 1997).

2.2. Subjects

We compared a group of Kirghizs living in Sary Tash village (3200 m above sea level) with a group living in Talas (900 m). Sary Tash is a village a few kilometres from the border with Tajikhstan, in the heart of the Pamir mountains. The local population numbers around 1500 and is largely concentrated in the village or scattered in outlying areas. Sary Tash is extremely isolated, especially during the winter months when it is cut off by snow. The local economy is based on grazing sheep and goats, or raising yaks and horses that are moved to the mountain pastures during the summer. The village of Talas is in the most northerly section of Kirghizstan, along the trade routes to Kazakhstan and Uzbekhstan, important since ancient times (the 'silk route'); the local economy is based on farming and cattle raising.

Twenty HL of Sary Tash were cross-matched for ethnic group (Kirghiz), sex (male), age, Wt, Ht, and body mass index (BMI) to 20 LL of Talas. All the subjects underwent a medical examination and blood analyses to exclude the presence of disease. The study protocol had been approved by the Ethical Committee at Modena University and all subjects gave informed consent.

2.3. Anthropometry

Wt, Ht, arm circumference (AC) and skinfolds [triceps (TSF), biceps (BSF), subscapular (SSF) and suprailiac (SISF)] were measured following the Anthropometric Standardization Reference Manual (Lohman, Roche and Martorell 1988). BMI was calculated as Wt (kg)/Ht^2 (m). Arm fat area (AFA) and arm muscle area (AMA) were calculated from AC and TSF as described by Frisancho (1990). The sum of TSF, BSF, SSF and SISF (4SF) was calculated according to Durnin and Womerseley (1974).

2.4. TBW and ECW assessment

TBW and ECW were measured by deuterium oxide (D_2O) and bromide (Br) dilution, respectively. A preliminary study aimed at establishing the equilibration time of D_2O and Br was performed on the plasma of three unselected subjects. In all cases D_2O and Br reached the equilibrium within 3·0 h after their administration, a time similar to that observed in healthy Caucasian and non-Caucasian (Kazakh) subjects (Battistini *et al.* 1995a). Subjects had fasted for at least 8 h before receiving orally a solution made up of 10 g of D_2O, 5 g of Br and 25 g of drinkable water. Based on the results of the preliminary study, plasma samples were collected before and 3·5 h after the administration of this solution, as described in detail elsewhere (Battistini, Severi, Brambilla, Virgili, Manzoni, Beccaria and Chiumello 1995b). D_2O concentration was measured by spectrophotometry according to the method of Lukaski and Johnson (1985). TBW was calculated as deuterium dilution space $\times 0{\cdot}95$, taking into account non-aqueous distribution of D_2O (Forbes 1987, Heymsfield and Waki 1991). Br concentration was measured by HPLC according to the method of Wong, Sheng, Morkebery, Kosanovich, Clarke and Klein (1989). ECW was calculated as Br dilution space $\times$ 0·90 $\times$ 0·95, taking into account non-extracellular distribution of Br and Donnan's effect, respectively (Forbes 1987). ICW was calculated as the difference between TBW and ECW. Body hydration (TBW%) was calculated as TBW per kg of Wt. ECW% was calculated as ECW per litre of TBW.

2.5. *Statistics*

Differences in body composition between HL and LL were evaluated by unpaired (two-tailed) *t*-tests. The significance level was set to a value of $p < 0.05$. Values are presented as mean $\pm$ SD.

3. Results

The characteristics of the subjects are given in table 1. As a result of the matching procedure, age, Wt, Ht and BMI were similar in HL and LL (p = n.s.). AMA was 10% lower in HL than LL (p = n.s.); AFA and 4SF were respectively 30% and 25% lower in HL than LL ($p < 0.005$ for both). These differences are similar to those observed between HL and LL in previous studies of populations from Central Asia (Facchini, Toselli, Fiori, Ismagulova and Pettener 1997). TBW, ECW and ICW were similar in HL and LL both as absolute and relative values (p = n.s.).

4. Discussion

Acute exposure to high altitude produces characteristic changes in body water distribution from which acclimatized individuals seem to be spared (Ward *et al.* 1989). However, Picón-Reátegui *et al.* (1961) detected an increase in ECW:Wt in gold-miners living at 4500 m (14 900 ft) versus medical students living at sea level [mean $\pm$ SEM, 17·9 $\pm$ 0·3% versus 16·4 $\pm$ 0·3%, $p < 0.01$]. To our knowledge this is the only study of body water distribution performed in HL. Although it shows that a relative expansion of ECW may occur in HL, the results may have been influenced

Table 1. Subject characteristics of highlanders (HL) and lowlanders (LL).

	HL ($n = 20$)	LL ($n = 20$)
Age (years)	27·6 ± 7·7	29·1 ± 4·1
Wt (kg)	60·4 ± 6·4	62·9 ± 7·0
Ht (cm)	167·0 ± 5·7	169·6 ± 5·2
BMI (kg/m^2)	21·8 ± 2·9	21·6 ± 2·4
AMA (cm^2)	43·5 ± 5·1	48·3 ± 9·6
AFA (cm^2)	6·5 ± 2·2	9·0 ± 2·8*
4SF (mm)	22·2 ± 6·6	29·1 ± 7·5*
TBW (l)	35·2 ± 3·4	35·2 ± 4·4
ECW (l)	14·3 ± 2·0	14·4 ± 2·2
TBW% (%)	58·5 ± 5·0	56·0 ± 4·2
ECW% (%)	40·5 ± 4·2	40·7 ± 2·2
ECW:ICW	0·69 ± 0·12	0·69 ± 0·06

*$p < 0.005$ versus HL.
Abbreviations: Wt = weight; Ht = height; BMI = body mass index; AMA = arm muscle area; AFA = arm fat area; 4SF = Durnin and Womerseley (1974) sum of four skinfolds; TBW = total body water; ECW = extracellular water; TBW% = TBW:Wt; ECW% = ECW:TBW, ECW:ICW = extracellular to intracellular water ratio.

by the different physical characteristics of the enrolled subjects. For example, Wt was 14% lower in gold-miners as compared to medical students (mean ± SEM, 54·3 ± 1·1 kg versus 62·5 ± 1·4 kg, $p < 0{\cdot}001$).

Therefore, in our study, we tried to match HL and LL for ethnic group, sex, age, Wt, Ht and BMI. Although we controlled for the effects of race by selecting subjects with the same ethnic background, it was not possible to match HL and LL for socio-economic status and dietary habits because these are heavily influenced by the environmental conditions associated with low and high altitudes (Facchini *et al.* 1997). However, the occupational activity of our HL and LL was similar (shepherds versus cattle breeders or farmers). Moreover, Wt, Ht and BMI reflect long-term changes in nutritional status so that matching for these variables was expected at least to reduce the influence of nutritional status on body water distribution between ECW and ICW (Shetty 1995).

Contrary to the results of Picón-Reátegui and colleagues, we were not able to detect significant differences in body water distribution in HL versus LL (Table 1). This discrepancy may be due in part to the fact that we evaluated TBW and ECW by D_2O and Br dilution, as compared to the measurement of antipyrine and sucrose clearances employed by these authors. Interestingly, while the mean values of ECW and ECW:ICW were remarkably similar in our HL and LL, the CV were twice as high in the former, indicating a larger inter-individual variability in body water distribution for HL.

It should be noted that AFA and 4SF were significantly lower in HL than LL. However, the similarity in TBW% and ECW% between HL and LL argues against the possibility of physiologically important differences in fat mass between these subjects.

The results of the present study are in agreement with those of a previous one in which Kazakhs living at 2100 m on the Tien Shan mountains were shown to have values of TBW% (60%) and ECW% (39%) similar to Caucasian reference subjects (Battistini *et al.* 1995a).

In conclusion, our study suggests that TBW% and ECW% are similar in native HL and LL. This is in aggreement with the suggestion that acclimatization may reduce or eliminate the changes in body water distribution that occur in people ascending to high altitude (Withey *et al.* 1983, Ward *et al.* 1989). More detailed body composition studies are needed to ascertain whether the higher variability in ECW and ECW:ICW shown by HL as compared to LL can be considered an effect of the high-altitude environment.

References

Alekseev, V. P., and Gochman, I. I., 1983, Physical anthropology of Soviet Asia. In *Rassengeschichte der menschheit*, edited by R. Oldenbourg (Munchen: Verlag), pp. 123–138.

Battistini, N., Facchini, F., Bedogni, G., Severi, S., Fiori, G., and Pettener, D., 1995a, The prediction of total body water and extracellular water from bioelectric impedance in a non-caucasian population from Central Asia. *Annals of Human Biology*, **22,** 315–320.

Battistini, N., Severi, S., Brambilla, P., Virgili, F., Manzoni, P., Beccaria, L., and Chiumello, G., 1995b, Relative expansion of extracellular water in obese vs non obese children. *Journal of Applied Physiology*, **79,** 94–96.

Durnin, J., and Womerseley, J., 1974, Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *British Journal of Nutrition*, **32,** 77–97.

FACCHINI, F., PETTENER, D., RIMONDI, A., SICHIMBAEVA, K., RIVA, P., SALVI, P., PRETOLANI, E., and FIORI, G., 1997, Taste sensitivity to PTC and thyroid function (FT4 and TSH) in high and low altitude Kirghiz populations from Pamir. *Human Biology*, **69,** 97–106.

FACCHINI, F., TOSELLI, S., FIORI, G., ISMAGULOVA, A., and PETTENER, D., 1997, Body composition in Central Asia populations: the Kazhaks of the Tien Shan mountains (2.100) m and the Uigurs of Semericia. *American Journal of Human Biology*. (In press).

FORBES, G. B., 1987, *Human Body Composition. Growth, Aging, Nutrition and Activity* (New York: Springer-Verlag).

FRAYSER, R., RENNIE, I. D., GRAY, G W., and HOUSTON, C. S., 1975, Hormonal and electrolyte response to exposure to 17.500 ft. *Journal of Applied Physiology*, **38,** 636–642.

FRISANCHO, A., 1990, *Anthropometric Standards for the Assessment of Growth and Nutritional Status* (Ann Arbor: University of Michigan Press).

HANNON, J. P., CHINN, K. S. K., and SHIELDS, J. L., 1971, Alterations in serum and extracellular electrolytes during high-altitude exposure. *Journal of Applied Physiology*, **31,** 266–273.

HEYMSFIELD, S. B., and WAKI, M., 1991, Body composition in humans: advances in the development of multicompartment chemical models. *Nutrition Rewiews*, **49,** 97–108.

JAIN, S. C., BARDHAN, J., SWAMY, Y. V., KRISHNA, B., and NAYAR, H. S., 1980, Body fluid compartments in humans during acute high-altitude exposure. *Aviation Space Environmental Medicine*, **51,** 234–236.

KRZYWICKI, H., CONSOLAZIO, J. F., JOHNSON, H. L., NEILSON, W. C., and BARNHART, R. A., 1971, Water metabolism in humans during high-altitude exposure to 4.300 m. *Journal of Applied Physiology*, **30,** 806–809.

LOHMAN, T. G., ROCHE, A. F., and MARTORELL, R., (eds), 1988, *Anthropometric Standardization Reference Manual* (Champaign, IL: Human Kinetics Books).

LUKASKI, H. C., and JOHNSON, P. E., 1985, A simple inexpensive method of determining total body water using a tracer dose of deuterium oxide and infrared absorbtion of biological fluids. *American Journal of Clinical Nutrition*, **41,** 363–370.

PETTENER, D., FACCHINI, F., LUISELLI, D., TOSELLI, S., RIMONDI, A., ISMAGULOVA, A., SICHIMBAEVA, K., ISMAGULOV, O., and FIORI, G., 1997, Physiological adaptability, thyroid function, body composition and genetic variability in Central Asia high altitude populations. *Acta Andina* (In press).

PICÓN-REÁTEGUI, E., LOZANO, R., and VALDIVIESO, J., 1961, Body composition at sea level and high altitude. *Journal of Applied Physiology*, **16,** 589–592.

SHETTY, P. S., 1995, Body composition in malnutrition. In *Body Composition Techniques in Health and Disease*, edited by P. S. W. Davies and T. J. Cole (Cambridge: Cambridge University Press), pp. 71–84.

WARD, M. P., MILLEDGE, J. S., and WEST, J. B., 1989, Acute mountain sickness (AMS). In *High Altitude Medicine and Physiology*, edited by M. P. Ward, J. S. Milledge and J. B. West (Philadelphia PA: University of Pennsylvania Press), pp. 373–374.

WITHEY, W. R., MILLEDGE, J. S., WILLIAMS, E. S., MINTY, B. D., BRYSON, E. I., LUFF, N. P., OLDER, M. W. J., and BEELEY, J. M., 1983, Fluid and electrolyte homeostasis during prolonged exercise at high altitude. *Journal of Applied Physiology*, **55,** 409–412.

WONG, W. W., SHENG, H. P., MORKEBERG, J. C., KOSANOVICH, J. L., CLARKE, L L., and KLEIN, P. D., 1989, Measurement of extracellular water volume by bromide ion chromatography. *American Journal of Clinical Nutrition*, **50,** 1290–1295.

Address for correspondence: N. Battistini, Human Nutrition Chair, Department of Biomedical Sciences, Faculty of Medicine & Surgery, Modena University, Via Campi 287, 41100 Modena, Italy.

Zusammenfassung. Eine plötzliche Exposition gegenüber grossen Höhen erzeugt charakteristische Veränderungen in der Verteilung des Körperwassers, von denen akklimatisierte Individuen ausgenommen zu sein scheinen. Es wurde jedoch angenommen, dass die Verteilung des Körperwassers bei Bewohnern des Flachlandes (LL) und bei Bewohnern des Hochlandes (HL) unterschiedlich sein könnte. Die Verteilung des Gesamtkörperwassers (TBW) hinsichtlich des extrazellulären (EWC) und des intrazellulären (ICW) Anteils wurde an einer Gruppe von 20 HL (3200 m über dem Meeresspiegel) im Vergleich zu 20 LL (900 m über dem Meeresspiegel) untersucht. Die Probanden wurden hinsichtlich der ethnischen Zugehörigkeit (Kirghiz), des Geschlects (männlich), des Gewichts (Wt), der Körperhöhe und des Body Mass Index gemacht. Die Verhältnisse TBW:Wt und ECW:TBW unterschieden sich nicht zwischen HL und LL (arithmetisches Mittel $\pm$ SA, $58{\cdot}5 \pm 5{\cdot}0\%$ versus $56{\cdot}0 \pm 4{\cdot}2\%$ und $40{\cdot}5 \pm 4{\cdot}2\%$ versus $40{\cdot}7 \pm 2{\cdot}2\%$; $p =$ ns für beide Vergleiche). Die Hypothese, dass die Verteilungen des Körperwassers bei HL und LL verschieden sind, wird durch diese Studie nicht unterstützt.

Résumé. L'exposition intense à la haute altitude produit des changements caractéristiques dans la distribution de l'eau corporelle, qui ne semblent pas affecter les individus adaptés. Cependant, il a été suggéré que la distribution de l'eau corporelle peut être différente chez les montagnards comparés aux habitants des basses terres. On a étudié la distribution de l'eau corporelle totale (ECT) entre eau extra-cellulaire (eec) et eau intra-cellulaire (eic) dans un groupe de 20 montagnards (à l'altitude de 3200 m) par rapport à un groupe de 20 personnes de basse altitude (900 m). Les sujets étaient appariés en fonction du groupe ethnique (Kirghiz), du sexe (masculin), du poids, de la stature et de l'indice de masse corporelle. ECT/poids et EEC/ECT n'étaient pas différentes dans les deux groupes (moy. ± e.t., 58·5 ± 5·0% contre 56·0 ± 4·2%; p = ns et 40·5 ± 4·2% contre 40·7 ± 2·2%; p = ns). Cette étude n'est pas favorable à l'hypothèse d'une différence de la distribution d'eau corporelle totale entre les montagnards et les habitants des plaines.