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ENERGY BALANCE AT HIGH ALTITUDE: 6542 m.[1]

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SUMMARY. Weight loss, due to malnutrition and possibly intestinal malabsortion, is a well known phenomenon in high altitude climbers. Up to ~5000 m energy balance may be attained and intestinal energy digestibility remains normal. In order to see whether 1) energy digestibility would play a significant role in the energy deficit, energy intake, energy expenditure, body composition and energy digestibility of 10 subjects (four women and six men, 27-44 yr) were assessed during a 21 day sojourn on the summit of Mt. Sajama, Bolivia (6542 m). Energy intake was measured during two 3 day intervals: 7-9 (EI_1) and 17-19 (EI_2). Total fecal energy loss during EI_1 was calculated from fecal energy measured by bomb calorimetry. Average daily metabolic rate (ADMR) at altitude was measured in six subjects, two women and four men, with doubly labeled water over a 10-day interval: 9-19. Basal metabolic rate (BMR) was measured before and after the expedition by respiratory gas analysis. Body composition was estimated from skinfolds and body mass before and during the altitude sojourn. Subjects were in negative energy balance throughout the observation period (EI_1 - ADMR = -2.9 ± 1.8 MJ/d and EI_2 - ADMR = -2.3 ± 1.8 MJ/d, based on a gross energy digestibility of 95%). The loss of fat mass (3.7 ± 1.5 Kg) represented 74 ± 15% of the loss of body mass. Energy content of the feces was 21 kJ/d dry weight and gross energy digestibility amounted to 85%. The energy deficit increased to 3.5 MJ/d after correction for the decreased energy digestibility. In conclusion, energy balance was not attained at 6542 m. The resulting energy deficit appeared to result mostly from malnutrition and only a limited part could be attributed to malabsorption.

Key words: Energy intake, Digestibility, Malabsorption, Energy expenditure, Body Composition, Doubly labeled water.

RESUMEN. La pérdida de peso debido a malnutrición y posiblemente a malabsorción intestinal es un fenómeno conocido en escaladores de montaña. Hasta 5000 metros el balance de energía es mantenido debido a que la energía por la digestión intestinal permanece normal. Se han estudiado 10 sujetos (cuatro mujeres y seis varones, 27-44 años) durante una permanencia de 21 días en el pico del Monte Sajama, Bolivia (6542 m), para observar si la energía de la digestión juega un rol importante en el déficit de energía, ingesta de energía, gasto de energía, composición corporal, y energía de la digestión. La ingesta de energía se midió durante dos intervalos de 3 días: 7-9 (EI_1) y 17-19 (EI_2). La pérdida de energía fecal total durante EI_1 fue calculada de la energía fecal medida por un calorímetro de bomba. La tasa metabólica diaria promedio (ADMR) en la altura fue medida en seis sujetos, dos mujeres y cuatro varones, con agua marcada con deuterio sobre un intervalo de 10 días: 9-19. La tasa metabólica basal (BMR) fue medida antes y después de la expedición por análisis de gas respirado. La composición corporal fue estimada de los panículos adiposos y de la masa corporal antes y durante la estadía en la altura. Los sujetos estuvieron en balance energético negativo durante todo el período de observación (EI_1 - ADMR= -2.9 ± 1.8 MJ/d y EI_2 - ADMR=-2.3 ± 1.8 MJ/d, basado en una gruesa energía de digestión de 95%). La pérdida de masa grasa (3.7 ± 1.5 Kg) representó 74 ± 15% de la pérdida de la masa corporal. El contenido de energía de las heces fue de 21 kJ/d de peso seco y la energía gruesa de la digestión llegó a 85%. El déficit de energía aumentó a 3.5 MJ/d después de corregir la disminuída energía de la digestión. En conclusión el balance energético no fue alcanzado a 6542 m. El deficit energético resultante parece ser el resultado de malnutrición y tan sólo una limitada parte puede ser atribuído a malabsorción.

Palabras Claves: Ingesta de energía, Digestibilidad, Malabsorción, Gasto de Energía, Composición Corporal, Agua con doble marca.

INTRODUCTION

Weight loss at high altitude is a well known phenomenon. Several hypotheses have been forwarded to explain this phenomenon like e.g. simple malnutrition, loss of body water and intestinal malabsortion (for a review see Imray et al 1992). With regard to malnutrition there is evidence that subjects can maintain energy balance during exposure at altitudes up to ~5000 m. During a one month stay at 5050 m it was recently shown that, in the presence of

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sufficient comfort and palatable food, weight loss can be largely prevented (Kayser 1992). With regard to malabsortion it appears that up to 5000-5500 m intestinal absorptive function for macro nutrients remains normal (Butterfield et al 1992, Kayser et al 1992). It remains unclear whether malnutrition and malabsortion would play a significant role for energy balance at altitudes greater than 5500 m.

The present study was therefore designed to complement the foregoing studies on energy metabolism at very high altitude. The primary aim of the study was to test the hypothesis that energy balance can also be maintained at an altitude of 6542 m. The secondary aim of the study was to test the hypothesis that, in case energy balance could not be maintained, a decrease in energy digestibility would explain, at least in part, the energy deficit observed. To these aims energy intake, energy expenditure, body composition and energy digestibility of 10 subjects were assessed during a 21-day sojourn on the summit of Mt Sajama (6542 m).

METHODS

Subjects were four women and six men, age 35 ± 6 (SD) yr, body mass index 22.0 ± 1.5 kg/m^2. All residing at sea-level for at least 5 years before participating in the present study and all with previous high altitude experience (maximum altitude reached ranging from 4350-8760 m). The observations started with baseline measurements at sea level (Paris, France and Maastricht, The Netherlands). Subjects subsequently travelled to La Paz, Bolivia (3600 m) where they stayed for 5 days to acclimatize and to further organize the expedition. Subsequently, the remaining altitude change from 3600 to 6542 m was covered in 13 days. The stay in tents on the large flat summit of Mt. Sajama (6542 m) lasted 21 days. During the stay on the summit the subjects' activity level was low, mean ambient temperature was - 13° C. Finally, sea level observations were again performed upon return to Paris and Maastricht 10 days after leaving the summit. Energy balance was determined after the initial acclimatization, by measuring energy intake and energy expenditure.

Energy intake (EI) at altitude was measured with a dietary record over two 3-day intervals: day 7-9 (EI_1) and day 17-19 (EI_2). Food items were weighed with a table scale in most cases and volumes were measured with a graduated container. The energy content (metabolizable energy (ME) = gross energy (GE) - fecal energy - urinary energy) of the food intake was derived from food tables and the percentage for the intake of carbohydrate, fat and protein were calculated (Randoin 1982). From these data, the GE content of the diet (which includes undigestible material such as cellulose) was calculated using Atwater's factors for the heat of combustion (Widdowson 1955). In order to determine nutrient absorption and nitrogen balance, subjects collected 24 h urine for one day and total feces for all days of the first 3-day dietary record interval as described before (Kayser et al 1992). Energy content of the feces was measured with an adiabatic bomb calorimeter (Janke & Kunkel, IKA Kalometer C-400, Staufen). Nitrogen content of the feces and urine was measured with a Heraeus analyser (type CHN-O-rapid, Heraeus, Hanau).

Energy expenditure was measured under field conditions (average daily metabolic rate, ADMR) at altitude. Basal metabolic rate was measured with a ventilated hood system. At altitude, ADMR was measured in 2 women and 4 men randomly selected among the 10 subjects with doubly labeled water as described before (Westerterp et al 1994). The observation interval lasted 10 days from day 9-19 of the stay at the summit. Body fat and lean body mass were estimated according to Durnin and Womersley (1974).

Results are presented as mean$\pm$SD unless stated differently. Values obtained before, during, and after the stay on Mt. Sajama were compared with the Wilcoxon signed-rank test.

RESULTS

Mean EI showed a non significant increase from 7.8 ± 3.1 MJ/d in interval one to 8.2 ± 3.5 MJ/d in interval two, at the start and at the end of the observation interval of ADMR with doubly labeled water, respectively. The overall mean EI, calculated as the average of both values, was 8.0 ± 3.2 MJ/day based on standard figures for nutrient absorption. Mean fluid intake over the two 3-day observation intervals, including water in drinks as well as water in the food, was 1.9±0.5 l/d, respectively. The energy content of the feces was 20.6±1.7 kJ/g dry weight (range 18.0-23.0 kJ/g). The total energy loss in the feces from the food consumed in the 3 day observation period was 3.6±1.3 MJ. The GE content of the food consumed over the interval was 25.2±9.8 MJ. Combining these two figures, the average energy digestibility amounted to 85.2±4.7%. The combination of the dietary record with the nitrogen output in feces and urine allowed calculation of protein balance. Protein digestion was 88.6±3.8%. Protein balance was -28.6±24.2 g/d, based on the measured protein digestion. The figure for protein balance based on the dietary record and urine nitrogen output using the standard figure for protein digestion from the food tables was similar (-26.3±24.5 g/d).

Water loss and energy expenditure as calculated from isotope elimination are presented in Table 1. Comparing water loss with water input needs correction of water intake for metabolic water (see discussion). ADMR was higher than EI in all subjects; the mean difference was 24±14% of ADMR. Comparing BMR values before and after the expedition, differences were insignificant (mean difference -3±7%, n.s.).

Table 1. Body mass, body composition and basal metabolic rate before and after high altitude exposure, and fluid intake, fluid output, energy intake, and average daily metabolic rate during high altitude exposure.

	before			during				after		
Subj No.	BM kg	BF %	BMR MJ/day	$Fluid_{in}$ l/day	$Fluid_{out}$ l/day	EI MJ/d	ADMR MJ/d	BM* kg	BF* %	BMR** MJ/d
1	49.5	27.1	5.23	1.4	2.9	6.4	9.2	48.0	23.4	-
2	54.8	26.2	5.04	-	-	-	-	49.0	20.5	5.43
3	71.0	13.3	7.32	2.6	3.7	12.7	13.1	66.5	12.3	7.46
4	64.6	14.9	6.25	-	-	-	-	60.0	11.0	6.08
5	76.4	14.6	6.51	2.4	3.4	14.0	15.3	69.0	11.3	6.31
6	70.0	17.0	6.42	1.7	2.2	8.5	12.1	61.5	12.6	6.74
7	67.6	26.2	6.16	-	-	-	-	63.5	18.0	-
8	58.4	27.6	6.09	1.6	2.7	5.7	8.8	55.0	25.5	5.23
9	63.8	21.6	5.99	-	-	-	-	60.5	14.0	5.52
10	80.5	18.8	7.32	2.1	3.2	7.7	12.1	75.0	15.0	6.62
Mean	65.7	20.7	6.23	2.0	3.0	9.2	11.8	60.8	16.4	6.17
SD	9.6	5.7	0.74	0.5	0.5	3.4	2.4	5.5	5.2	0.76

*after 20 days at 6542 m; ** 10 days after descent from 6542 m (2 days after descent from 3600 m)
BM, body mass; BF, body fat as calculated from skinfold thickness; BMR, basal metabolic rate as measured in the early morning with a ventilated hood; $Fluid_{in}$, fluid intake; $Fluid_{out}$, Fluid output; ADMR, average daily metabolic rate.
The two missing values of BMR after the expedition were due to non availability of the subjects for practical reasons.

Body mass and body composition were different before and after 20 days at 6542 m (Table 1). Body mass decreased 4.9±2.0 kg ($P<0.01$) and fat mass (FM) decreased 3.5±1.5 kg ($P<0.01$). The decrease in fat-free mass (FFM) with 1.3±2.3 kg was not significant. However, changes in body composition as estimated during the stay at altitude with skinfold thickness measurements have to be interpreted with some care (Fulco et al 1992). One subject (N°8) showed indications of altitude edema. This fact probably influenced the accuracy of the skinfold thickness as a measure for body fat and this measurement for N°8 was therefore excluded from further analysis.

DISCUSSION

Water balance over the observation interval can be calculated from fluid input and fluid output correcting the former for metabolic water production. Metabolic water production was calculated from dietary intake and catabolism of body stores according to Consolazio et al (1972). Thus, there was no significant difference between water input and water output, i.e. subjects were in water balance. However, water balance was reached at a low level of water turnover. Water turnover was probably limited by a reduced water availability and comparable to the value of 3.3 ± 0.6 l/day measured during climbing between 5000 and 8872 m on Mt. Everest (Westerterp et al 1992).

Energy balance can be calculated from energy intakes as measured with the dietary record and energy expenditure as measured with doubly labeled water. Mean energy intake, the average over three days at the start and at the end of the ten-day observation period with doubly labeled water, was 2.6 ± 1.5 MJ/d lower than energy expenditure. There was a tendency for an increase in energy intake, probably as a result of a reduction in symptoms of acute mountain sikness (AMS). Thus, there was only a trend to a balance between energy intake and energy expenditure over the three week stay at 6542 m, leaving on average a gap of at least 2.3 MJ/day or 20% of ADMR.

The observed digestibility of 85% was lower than that usually measured at sea level (94%) (Widdowson 1955, Consolazio et al 1992), at 4300 m (95%) (Consolazio et al 1992) or at 5050 m (96%) (Kayser et al 1992). At first glance it therefore appears that the present subjects indeed experienced a certain degree of intestinal malabsortion. However, the energy content of the feces of the subjects (21 kJ/g dry weight) was actually lower than that reported for a mixed diet at sea level (22 kJ/g dry weight (Diem et al 1971)) and the same as that measured at 5050 m (Kayser et al 1992) for a diet of similar macronutrient and fiber composition, suggesting on the contrary a normal intestinal absorptive capacity. Thus, the present energy content of the feces seems to exclude significant malabsortion of fat or other macronutrients. The above evidence of malabsorption should therefore be interpreted with care and additional experiments seem necessary before the hypothesis of malabsortion at high altitude can be accepted. If one accepts the observed figure for digestibility it can be calculated that the mean difference between intake and expenditure increased from -2.6 ± 1.5 MJ/d to -3.5 ± 2.4 MJ/d. It thus appears that even if some degree of malabsortion would indeed develop at high altitude it would be relatively small when compared to the energy deficit resulting from simple malnutrition.

Body weight decreased 4.9 ± 2.1 kg from before until after 20 days at 6542 m, representing on average 74% body fat. Fulco et al (1992) recently stated that the skinfold method was not acceptable for the measurement of body water measurement, one of the subjects in the present study showed peripheral subcutaneous edema and had to be excluded from the analysis.

The activity level of the subjects can be calculated by expresing ADMR as a multiple of BMR, the physical activity index (PAI). Assuming BMR over day 9-19 at 6542 m was the same as at sea level and averaging BMR values before and after the expeditions, the mean PAI was 1.84 ± 0.28 (range 1.56-2.39). This value falls just outside the range of 1.5-1.8 for light to moderately active subjects (WHO 1985), but is lower than the mean PAI of 2.2 measured during climbing at high altitude (Westerterp et al 1992). Of course the PAI value has to be interpreted with some care as at high altitude BMR has been shown to be increased. Butterfield et al (1992) measured an increase of BMR during a 21-days stay at 4300 m of 0-15% compared to sea-level values. Whatever happened with BMR at 6542 m, ADMR was relatively high for subjects with a sedentary life style, living in tents and occasionally getting out in the close surroundings.

In conclusion the result from this study indicates that subjects with ad libitum access to food do not attain energy balance during a 3-

week sojourn at 6542 m. Energy intake is low while energy expenditure reaches values comparable to those for moderate activity at sea-level. The resulting energy deficit appears to be due mostly to malnutrition and only a limited part can be attributed to malabsorption.

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