WATER BALANCE AND ACUTE MOUNTAIN SICKNESS BEFORE AND AFTER ARRIVAL AT HIGH ALTITUDE:4,350 M

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RESUMEN: Balance Hídrico y Mal de Montaña Agudo Antes y Después de la Llegada a Alturas de 4.350 m

Este estudio es el primero que intenta medir el balance hídrico y sus componentes en altura, usando agua marcada y dilución de bromuro, y relacionando los resultados con mal de montaña agudo (AMS). Se midió ingesta de agua, excreción total de agua y excreción de agua en heces y orina en un intervalo de tiempo de 4 días, antes y luego de un período de de 4 días de permanencia a 4.350 m. Se midió el agua corporal total y el agua extracelular al inicio y al final de ambos intervalos. Hubo una relación estrecha entre la ingesta energética y la ingesta de agua y la relación no cambió con la permanencia en la altura. Los sujetos que desarrollaron AMS redujeron consecuentemente su ingesta energética y su ingesta de agua. El incremento en el agua corporal total (TBW) en sujetos afectados por AMS se acompañó de una reducción en la pérdida total de agua. Ellos no mostraron un débito urinario incrementado compensador de la pérdida evaporativa reducida de agua que se describe en altura. Los sujetos mostraron un incremento significativo de TBW luego de 4 días en altura. Los afectados con AMS mostraron las variaciones más grandes en agua extracelular (ECW) en relación al TBW. En conclusión la retención de líquido en relación al AMS es independiente de un cambio en los requerimientos hídricos debidos a la exposición a la altura. Los sujetos que desarrollaron AMS fueron los que mostraron un pasaje de líquido de por lo menos 1 l del compartimiento intracelular al extracelular o del extracelular al intracelular.

Palabras claves: Ingesta hídrica, Pérdida hídrica, Balance hídrico, Agua corporal total, Agua extracelular.

La présente étude est la première tentative de mesure du bilan hydrique et de ses composants en altitude au moyen d'eau marquée et d'une dilution de bromure, et d'une mise en relation des résultats avec le mal des montagnes aigu (AMS). L'ingestion d'eau, l'élimination totale d'eau et l'élimination d'eau par l'urine et les selles ont été mesurées dans un intervalle de temps de 4 jours, immédiatement avant et après une période de 4 jours de séjour à 4 350 m. L'eau corporelle totale et l'eau extracellulaire ont été mesurées au début et à la fin des deux périodes. Une étroite relation entre l'ingestion énergétique et l'ingestion d'eau a été observée, sans changement après passage en altitude. Les sujets affectés par l'AMS réduisirent en conséquence leur ingestion énergétique et hydrique. L'augmentation du poids corporel total (TBW) chez les sujets affectés s'est accompagnée d'une réduction de la perte totale d'eau. Une augmentation de l'excrétion urinaire compensant une perte par évaporation réduite du fait de l'altitude n'a pas été observée. Ce sont les sujets atteints d'AMS qui ont montré les plus grandes variations de l'eau extracellulaire (ECW) en rapport avec le TBW. En conclusion, la rétention de liquides liée à l'AMS est indépendante d'un changement des besoins hydriques dû à l'altitude. Chez les sujets affectés par l'AMS on a constaté le passage d'au moins 1 litre d'eau du compartiment intracellulaire à l'extracellulaire, ou de l'extracellulaire à l'intracellulaire.

Mots-clés : Ingestion hydrique, Perte hydrique, Bilan hydrique, Eau corporelle totale, Eau extracellulaire.

ABSTRACT

The present study is a first attempt to measure water balance and its components at altitude, using labeled water and bromide dilution, and relating the results with acute mountain sickness (AMS). Water intake, total water output and water output in urine and feces were measured over a 4-day interval before and a subsequent 4-day interval after transport to 4,350 m. Total body water and extracellular water were measured at the start and at the end of the two intervals. There was a close relationship between energy intake and water intake and the relation was unchanged by the altitude intervention. Subjects developing AMS reduced energy intake and water intake correspondingly. The increase in TBW in subjects developing AMS was accompanied by a reduction in total water loss. They did not show the increased urine output, compensating for the reduced evaporative water loss at altitude. Subjects showed a significant increase in TBW after 4 days at altitude. Subjects with AMS showed the biggest shifts in ECW relative to TBW. In conclusion, fluid retention in relation to AMS is independent of a change in water requirements due to altitude exposure. Subjects developing AMS were those showing a fluid shift of at least 1 l from the intracellular to the extracellular compartment or from the extracellular to the intracellular compartment.

Index terms: Water Intake, Water loss, Water balance, Total body water, Extracelular water

INTRODUCTION

One of the problems of high altitude is the maintenance of water balance. Water availability is low when the only water source is by melting snow. Theoretically water requirement is increased due to increased insensible water loss at low ambient water vapor pressure (Ferrus et al 1984). Consolazio et al (1968) measured consistently negative fluid balances during 28-day high-altitude exposure to 4,300 m. One of the speculative explanations was an increase in respiratory water loss due to the increased pulmonary ventilation and the decreased humidity at high altitude. However, there is insufficient data to support this statement.

The present study allowed the measurement of insensible water loss at high altitude by simultaneously measuring total water turnover and fluid loss in urine and feces. Water intake, total water output and water output in urine and feces were measured over a 4-day interval before and a subsequent 4-day interval after transport to 4,350 m. Total body water and extracellular water were measured at the start and at the end of the two intervals.

METHODS

Subjects were three women and seven men, aged 30±8 (SD) and with a body mass index of 21.1±2.0 kg/m^2 (Table 1). They gave their informed consent to participate in the study and the protocol was approved by the Ethical committee of Necker Hospital, Paris. The observation started with baseline measurements over 4 days at sea level (Paris, France). On the 5th day subjects were transported by car and helicopter to a field laboratory on Mont Blanc in the French Alps (observatoire Vallot, 4,350 m) to be observed for another 4 days (day 6-9, Fig. 1). The activity level of the subjects was low. They spent most of the time in reading and household activities and underwent two short exercise tests at sea level and at altitude. Mean ambient temperature, pressure and relative humidity in the laboratory in Paris and in observatoire Vallot on Mont Blanc were, respectively, 31±3 °C and 21±3 °C, 761±6 mm Hg and 452±1 mm Hg, and 58±4% and 48±2%. Measurements of water balance comprised food and water intake, water loss, and changes in body composition over the two obervation intervals.

Table 1. Subject characteristics

Subj No.	sex	age (y)	height (m)	body weight (kg)	body fat (%)
1	m	29	1.80	70.0	12
2	m	30	1.82	67.5	12
3	m	26	1.92	84.0	11
4	f	26	1.61	52.2	17
5	f	34	1.63	62.5	20
6	f	22	1.56	41.5	12
7	m	23	1.76	58.0	9
8	m	24	1.78	73.0	5
9	m	36	1.82	72.0	14
10	m	47	1.66	59.4	11
mean		30	1.74	64.0	12
SD		8	0.11	12.0	4

day	0	1	2	3	4	5	6	7	8	9	10

Paris (sea level) >< Vallot (4,350 m)

< water balance > < water balance >

BM	BM	BM
TBW	TBW	TBW
ECW	ECW	ECW

Fig. 1. The protocol. Body mass (BM), total body water (TBW), and extracellular water (ECW) were measured before and after two 4-day observation intervals of water balance, the first at sea level (day 1-4) and the second at 4,350 m (day 6-9). Vallot, Observatoire Vallot, French Alps.

Food and water intake was measured with a dietary record. Subjects recorded their food and fluid intake in a diary, including brand names and cooking recipes where appropriate. Food items were weighed with a table scale in most cases and volumes were measured with a graduated container. During the stay in the field laboratory the diaries were examined with the subject to clarify and eliminate inconsistencies. The energy and water content of the intake was then derived from food tables (Stichting Nederlands Voedingsstoffenbestand)

Total water loss was measured with labeled water (^2H_2O). The observation covered two times 4 days, day 1-4 at sea level and day 6-9 at altitude (Fig. 1). Subjects were given a weighed dose of 75 ml water with a measured enrichment of 4.36276 APE ^2H so that baseline levels were increased to ~100 ppm. Urine samples for isotope measurement were collected before dosing at night and from the second voiding every morning afterwards until the end of the observation interval. Isotope abundancies in the urine samples were measured with an isotope-ratio mass spectrometer (VG Isogas, Aqua Sira). Water loss was calculated from deuterium elimination as described before (Westerterp et al 1992). Subjects drank lowland water at altitude, allowing the assumption that background 2H levels do not change as has been observed before (Westerterp et al 1992).

To determine water loss in urine and feces, subjects collected total urine and total feces for all days. Urine was collected in a calibrated container to measure volume at each voiding and sampled for isotope analysis if appropriate. Feces were collected in preweighed bags, weighed, and a sample was collected in an airtight container for the measurement of moisture content by freeze drying in the laboratory.

Body mass, total body water, and extracellular water were measured at the start and end of the two 4-day intervals. Body mass (BM) was measured on rising, after emptying of the bladder, on a scale ±0.1 kg (Seca). Total body water (TBW) was calculated as the deuterium dilution space, from the deuterium enrichment of the second voiding minus the deuterium concentration of the sample before dose administration (Van Marken Lichtenbelt et al 1994a). The deuterium dilution space was divided by 1.04 to correct for isotope exchange with non-aqueous hydrogen of body solids

(Schoeller at al 1980). Extracellular water (ECW) was determined by bromide dilution. A known amount of sodium bromide (60 mg Br/L estimated TBW) was mixed with the ^2H_2O solution and thus administered simultaneously with the deuterium solution. Venous blood samples were obtained at 1030 PM, before bromide intake, and at 0800 AM the next morning, within one h before or after the second urine voiding for the measurement of TBW

Bromide concentration was determined in serum ultrafiltrate with HPLC, and ECW was calculated from corrected bromide space as described before (Van Marken Lichtenbelt et al 1994b).

Acclimatization to altitude was evaluated by a standardized scoring system of AMS of 4 symptoms: headache, digestive signs, fatigue, and insomnia (The Lake Louise consensus, 1992). The symptoms were scored on a 3-point scale each, 4 times a day with 4-hour intervals.

RESULTS

Four subjects, two women and two men, developed AMS after transport to 4,350 m. They had a mean AMS score of 17.0 (range, 16-18), 14.3 (8-19), 5.0 (3-7), and 4.5 (0- 11) on day 1 to 4 of the 4-day interval at altitude, respectively. The corresponding score for those who did not develop AMS was 2.5 (0-9), 2.0 (0-7), 0.5 (0-1), and 0.5 (0- 1). Results on food intake and the measured components of water balance will be presented for the group with AMS (n=4) and the group without AMS (n=6) separately (Fig. 2).

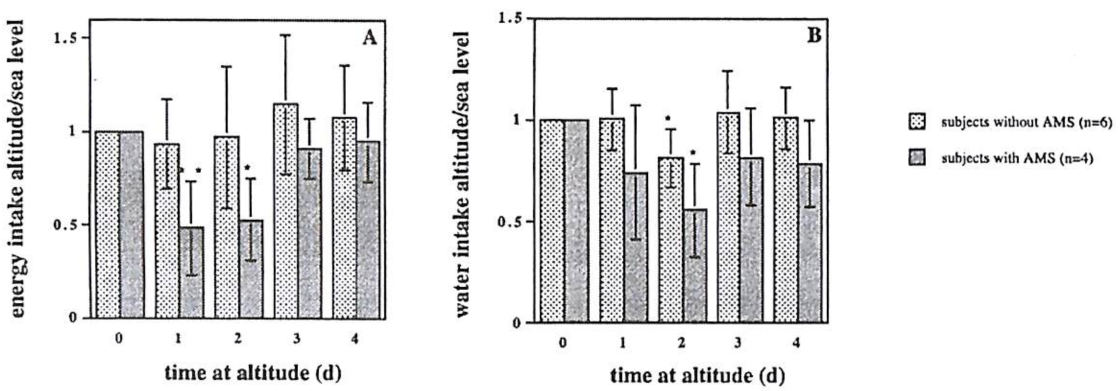

Fig 2. Energy intake (A) and water intake (B) on day 1 to 4 after arrival at 4,350 m, expressed as a multiple of the 4-day mean value over the preceding interval at sea level. Value was significantly different from value over preceding interval at sea level (*P<0.05, **P<0.01). AMS, acute mountain sickness.

Comparing energy intake of the subsequent days at altitude with the 4-day mean energy intake at sea level, all subjects with AMS showed a reduction of intake at altitude. Energy intake was 48±25%, 53±22, 91±16, and 95±21 % of the mean sea level value on the subsequent days at altitude. Corresponding values in the other six subjects were 93±24%, 97±38%, 115±37%, and 108±28%. Water intake was more variable but showed the same trend. Water intake in subjects with AMS was 75±33%, 56±23%, 82±24%, and 79±21% of the mean sea level value on the subsequent days at altitude. Corresponding values in the other six subjects were 100±15%, 81±14%, 104±20%, and 101±15%. Comparing mean energy intake and mean water intake over the two 4-day intervals there was a significant relation at sea level ($r = 0.83$, $p < 0.01$) and at altitude ($r = 0.84$, $p < 0.01$), with no difference between slope and intercept of the two regression lines (Fig. 3, co-variance analysis).

Mean total water loss at altitude in subjects with AMS (nrs 3,4,5,10) was significantly reduced to 74±21 % of the sea level value ($p = 0.05$), while the change in subjects without AMS to 92±15% was not significant.

Urine production, as a component of water loss, in subjects with AMS was 83±27%, 97±36%, 99±34%, and 68±22% of the mean sea level value on the subsequent days at altitude. Corresponding values in the other six subjects were 200±58%, 165±52%, 179±34%, and 142±50%, i.e. significantly increased on the first day ($p < 0.01$), second day ($p < 0.01$), and

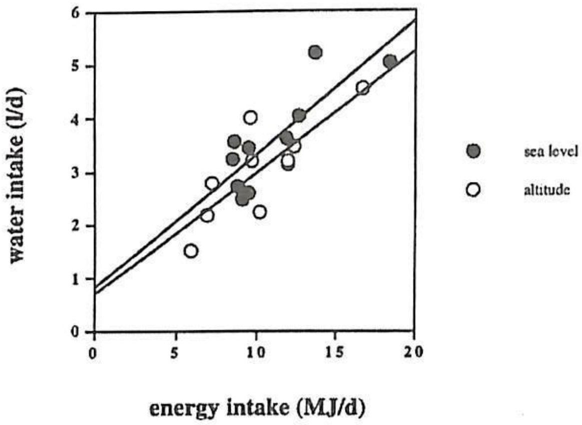

Fig. 3. Mean water intake as a function of mean energy intake in ten subjects over 4-day intervals at sea level and at altitude with the calculated linear regression line.

third day (p <0.001) at altitude. Water loss in feces was at altitude decreased in all subjects with AMS. The decrease was due do a decrease of mean fecal mass from 0.25±0.14 kg/d at sea level to 0.13±0.08 kg/d at altitude and a decrease in mean fecal hydration from 79±5% to 68±11%. Water loss in feces at altitude was unchanged in subjects without AMS.

The mean fecal mass was 0.19±0.06 kg/d at sea level and 0.19±0.10 kg/d at altitude, and the corresponding values for mean fecal hydration were 62±17% and 67±18%. Evaporative water loss, calculated as total water loss minus urine water and fecal water, was decreased at altitude. In absolute figures it went down from 2.5±0.8 l/d to 1.3±0.5 l/d (p < 0.001). Expressed as a proportion of total water loss it went down from 57±14% to 38±11% (p < 0.01). Changes in evaporative water loss were not different for subjects with AMS and subjects without AMS.

Mean changes in TBW and ECW were not different for subjects without and with AMS. There was a significant increase in TBW of 1.2±1.0 l between the mean of the two observations at sea level and after 4 days at altitude (p<0.01). The increase in ECW of 0.5±1.2 l was not significant. However, subjects with AMS showed the biggest shifts in ECW (Fig. 4). Three subjects gained more than 1.5 l ECW (nrs: 3, 4, 10) and one subject lost 1.0 l ECW (nr 5), while the mean change in ECW in the subjects without AMS was -0.1±0.5 l (range +0.5 to -0.8 l).

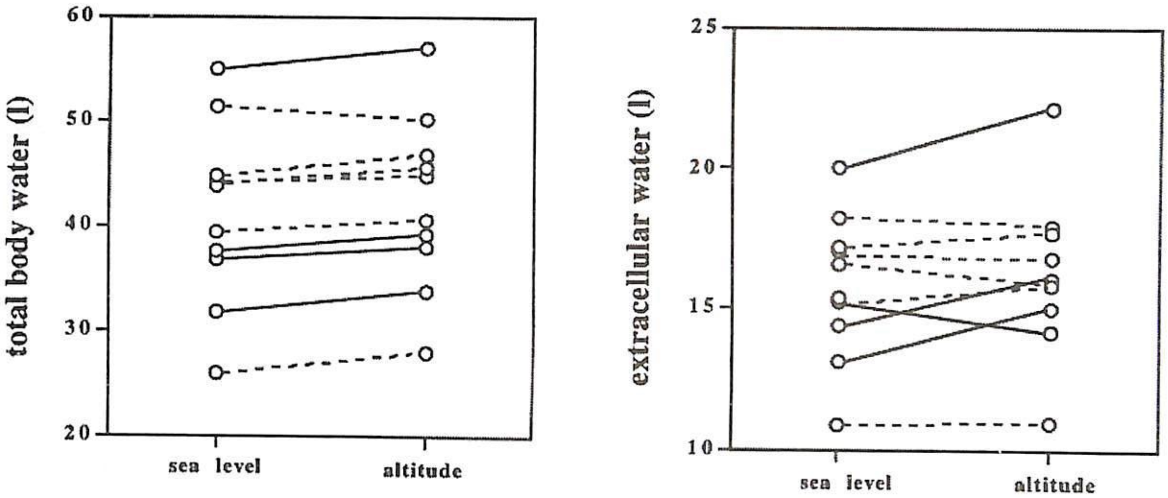

Fig. 4. Change in total body water and extracellular water from sea level to altitude for subjects without acute mountain sickness (data points connected with continuous lines) and subjects developing acute mountain sickness (data points connected with dotted lines).

DISCUSSION

The present study is a first attempt to measure water balance and its components at altitude, using labeled water and bromide dilution, and relating the results with AMS. There was a close relationship between energy intake and water intake and the relation was unchanged by the altitude intervention. Subjects developing AMS reduced energy intake and water intake correspondingly because nausea and loss of appetite are part of the clinical syndrome of AMS. The increase in TBW in subjects developing AMS was accompanied by a reduction in total water loss. They did not show the increased urine output, compensating for the reduced evaporative water loss at altitude.

AMS is associated with rapid ascent and with fluid retention (Bärtsch et al 1991).

Fluid retention seemed to be independent of a change in water requirements due to altitude exposure. The relation between energy intake and water intake was not affected by the ascent, not in subjects without AMS nor in subjects with AMS. Apparently altitude exposure does not affect fluid intake independent from energy (food) intake. Water requirement is not increased. The increase in evaporative water loss due to decreased barometric pressure is counterbalanced by additional clothing reducing cutaneous water efflux as suggested by Hoyt et al (1994). Evaporative water loss in the present study even went down from 2.5±0.8 l/d to 1.3±0.5 l/d ($p < 0.001$) or from 57±14% to 38_11% ($p < 0.01$) of total water loss. The decrease could be an effect of the high temperature during the interval at sea level (31±3 °C) though temperature at altitude also was relatively high. Subjects stayed nearly all the time in a comfortable hut at room temperatue (21±3 °C). The difference of 10 °C between sea level and altitude was probably even less than subjects normally experience in altitude studies. Thus, altitude exposure in the presence of sufficient food and water is a problem of how to increase water loss. This study shows for the first time that total water loss was reduced in subjects with AMS because they did not increase diuresis at the reduced evaporative water loss.

Subjects showed a significant increase in TBW after 4 days at altitude. Subjects with AMS showed the biggest shifts in ECW relative to TBW. Hannon et al. (1969) observed a shift from ECW to intracellular water (ICW = TBW - ECW) while TBW was unchanged in subjects exposed to 4,300 m, under sedentary conditions and no change in environmental temperature (25 °C), by transporting soldiers from sea level to a laboratory trailer at altitude. Krzywicki et al. (1971) observed a decrease in TBW and ICW after 6 days exposure to 4,300 m with 'normal' exercise, while ECW was increased. In both studies mentioned, subjects had minimal symptoms of AMS. Whatever happens with TBW at altitude exposure, hypohydration (Krzywicki et al 1971), euhydration (Hannon et al 1969), or hyperhydration (present study), the present study showed that subjects with AMS showed the biggest shifts in ECW relative to TBW. This is in accordance with a study of Carson et al. (1969) also showing that maximum severity of AMS went together with the greatest fluid shifts. This can be a relative gain (present study 3 subjects) or relative loss in ECW (present study 1 subject).

In conclusion, fluid retention in relation to AMS is independent of a change in water requirements due to altitude exposure. Subjects developing AMS were those showing a fluid shift of at least 1l from the intracellular to the extracellular compartment or from the extracellular to the intracellular compartment.

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