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ORIGINAL RESEARCH

Acute Mountain Sickness: Influence of Fluid Intake

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Objective.—High altitude and exposure to cold are associated with significant levels of dehydration because of cold-altitude urine output, high energy expenditures, and poor access to water. The aims of the present study were to measure the fluid intake and urine output among military mountaineers during their stay at high altitude and to study the level of fluid intake and decrease in urine output in relation with acute mountain sickness (AMS).

Methods.—This study used an analytic prospective follow-up design of hydration-dehydration conditions of a group of mountaineers with similar characteristics (military group). Data collected each day included quantity and type of fluid intake, urine output in 24 hours, other fluid output (as diarrhea or vomiting), and symptoms or signs of AMS according to the Lake Louise consensus score. Values are given as mean ± SE. A 1-factor analysis of variance procedure and *t* test were used to compare variables.

Results.—The mountaineers consumed a variety of fluids, including water, tea, coffee, soup, Isostar, and milk. Daily fluid intake was 2800 ± 979 mL, with a maximum intake of 4700 mL. Daily urine output was 1557 ± 758 mL. When we stratify our sample at the median by fluid intake, a significant correlation is detected with mean balance and mean urine output. Mountaineers developing AMS demonstrated reduced urine output (mean 1336 mL) when compared with those without AMS (mean 1655 mL).

Conclusions.—We found that fluid intake was associated but insignificantly correlated with incidence and degree of AMS. Past research suggests that vigorous hydration decreases incidence and severity of AMS and other altitude illnesses. Our results also imply that aggressive fluid intake is protective, but our limited sample size yielded insufficient power to demonstrate a statistically significant difference.

Key words: altitude sickness, dehydration, prevention

Introduction

Atmospheric pressure decreases as we ascend in altitude; therefore, the partial pressure of oxygen (PaO_2) also decreases. Hypobaria and hypoxia, which affect the organism above 3000 m, activate physiological mechanisms to allow acclimatization to altitude. Unacclimatized people develop a syndrome called acute mountain sickness (AMS). The cardinal symptoms are headache, nausea, dizziness, anorexia, lassitude, weakness, and sleeplessness. Acute mountain sickness may progress to high-altitude cerebral edema or high-altitude pulmonary edema.[1]

The prevalence of AMS correlated with altitude in the Swiss Alps[2] is 9% at 2850 m, 13% at 3050 m, 34% at 3650 m, and 53% at 4559 m. The AMS prevalence reported[3] is between 12% and 42% for altitudes below 4000 m and between 43% and 63% for altitudes above 4000 m.

Many studies have evaluated risk factors for AMS at moderate[4,5] and high altitudes.[6,7] The triad of chronic dehydration, hypoxia, and hemoconcentration is an important pathophysiological mechanism underlying many

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forms of altitude sickness. Exposure to high altitude and cold is associated with significant levels of dehydration caused by cold-altitude diuresis, high energy expenditures, and poor access to water.[8] Ironically, mountaineers are often surrounded by water in the form of snow, yet they face unique hydration challenges. Because of the time and energy needed to melt snow, potable water is not easily accessed. Unlike with other sportspersons, even carried water must often be thawed—a time-consuming inconvenience contributing to suboptimal oral hydration. Basnyat et al[4] concluded in a cross-sectional prospective study that increased reported fluid intake decreased the risk of AMS.

The aims of the present study were to determine the fluid intake and urine output among military mountaineers during their stay at high altitude and to study the level of fluid intake and decrease in urine output in relation with AMS.

Methods

RESEARCH DESIGN AND METHODS

This study used an analytic and prospective follow-up design of hydration-dehydration conditions of a group of mountaineers with similar characteristics (military group). Informed consent was obtained from each mountaineer, and the procedures followed were in accordance with the Helsinki Declaration.[9]

Nine healthy, male Caucasian mountaineers, ranging from 28 to 44 years of age, were studied on a 7-day mountaineering expedition in the Pamir during which they climbed to altitudes above 7000 m. Daily activity consisted of 8 to 10 hours of hiking, climbing, and performing mountaineering tasks with heavy loads (about 20 kg).

Data collected each day included quantity (with measured cup) and type of fluid intake, urine output in 24 hours (with measured container), other quantifiable fluid output (as diarrhea or vomiting), and symptoms or signs of AMS according to the Lake Louise consensus score (LLS).[2] The LLS is effective for the assessment of acute altitude illness. On the Lake Louise self-report questionnaire, which was completed daily, AMS was defined as moderate if the score was 4 to 6 and severe if the score was ≥7.[7] Each day of each mountaineer was included in the study as a "case" but only those for whom data were available for all the variables in the model. If one of the subjects presented with AMS, successive days were not considered as a new case until the subject had recovered. The medical doctor of the expedition supervised the study.

STATISTICAL ANALYSIS

Statistical analysis was performed with the SPSS software package (version 12.0). Values are given as mean ± SE. A 1-factor analysis of variance procedure was used to compare variables[10] after having verified the conditions of application (normality of the variables and homogeneity of variances). Differences were considered statistically significant at $P < .05$. In addition, we considered stratifying our data in a more meaningful way for a *t* test, such as calculating submeans for strata for LLS scores of 0 to 2 and 3 to 9 and by AMS symptoms.

Results

The average maximum and minimum temperatures during the stay at altitude were 22°C and −6°C, with weak winds. None of the mountaineers presented with a body temperature above 37°C, and all were Europeans who lived at altitudes below 1000 m.

Data were available for all the variables in the model (fluid intake, urine output, and LLS) in 36 cases, a mean of approximately 5 days for each mountaineer (Table 1).

The maximum altitude reached was 7134 m (mean 5720 ± 652 m).

The mountaineers consumed a variety of fluids, including water, tea, coffee, soup, Isostar, and milk. Daily fluid intake was 2800 ± 979 mL, with a maximum intake of 4700 mL. Daily urine output was 1557 ± 758 mL. The variable of balance (fluid intake minus urine output, excluding the cases with diarrhea or vomiting) was 1248 ± 880 mL. Higher fluid intake did not result in greater urine output in all cases.

The retention fluid percentage was 41% in subjects who presented with AMS and 43% in those who did not present AMS.

A subset of subjects was affected by moderate (n = 9) or severe (n = 2) AMS. The 2 cases of severe AMS (LLS = 9) were the 2 mountaineers who reached the Lenin summit at 7134 m and had a fluid intake of 1100 mL and 1200 mL. None of the subjects developed high-altitude cerebral edema or high-altitude pulmonary edema.

All 1-factor analysis of variance procedures that were used gave P values above .05. Although underpowered, our study suggests that increasing fluid intake was protective against AMS. Because of the small sample size, our analysis did not reach statistical significance, but the trend was obvious.

Subjects with LLS < 2 had an average intake of 2937 mL, and those with scores of 2 or 3 had less average fluid intake of only 2491 mL. Even though the important *t* test results did not reach statistical significance, one

Table 1. Daily quantity of fluid intake, urine output, Lake Louise score (LLS), and acute mountain sickness (AMS) symptoms for each case included in the study

Case	*Maximum altitude, m*	*Night altitude, m*	*Fluid intake, mL*	*Urine output, mL*	*LLS*	*AMS symptoms**
1	5300	4300	2850	1200	5	2
2	5100	5100	2600	2200	2	1
3	5800	5800	1900	1450	6	2
4	5800	5800	2600	1400	1	1
5	5400	5400	2950	2100	2	1
6	6100	6100	3000	1300	4	2
7	5300	4300	2900	1850	6	2
8	7134	6100	1100	850	9	3
9	5300	4300	4400	3375	3	1
10	5800	5800	3300	2400	2	1
11	5400	5400	3775	2925	0	0
12	5100	5100	2000	2000	1	1
13	5300	5300	2800	3050	3	1
14	5400	5400	3675	2300	0	0
15	7134	6100	2000	700	3	1
16	5100	5100	4700	2200	1	1
17	5800	5300	3500	1700	6	2
18	5400	5400	4075	3000	2	1
19	7134	6100	1200	1200	9	3
20	5300	4300	4350	1325	3	1
21	5100	5100	2450	1925	3	1
22	5300	4300	2350	1500	1	1
23	5400	5400	2650	1850	4	2
24	5300	4300	3700	1000	6	2
25	5100	5100	3200	1400	0	0
26	5800	5800	2550	1350	2	1
27	6800	4300	2600	1250	6	2
28	5300	4300	3500	1170	1	1
29	5800	5300	2450	900	1	1
30	5400	5400	1825	700	0	0
31	6100	6100	1825	550	0	0
32	7134	6100	700	300	2	1
33	5300	4300	4700	900	3	1
34	5800	5300	2050	875	3	1
35	5400	5400	2000	1050	5	2
36	6800	4300	2600	825	2	1

*AMS symptoms: mild (LLS 1–3), 1; moderate (LLS 4–6), 2; severe (LLS ≥ 7), 3.

can see that, independent of fluid intake, mountaineers developing AMS demonstrated reduced urine output (mean 1336 mL) when compared with those without AMS (mean 1655 mL).

When we stratify our sample at the median by fluid intake into moderate drinkers (>2600 mL per day) and light drinkers (≤2600 mL per day), both of these subgroups have 18 cases (Table 2). From this we can perform *t* tests on the other observations and urine output correlates. Between the groups there was significant intake-output correlation: the mean urine output was 1168 mL for light drinkers and 1947 mL for moderate drinkers (P = .00112259). A significant correlation was also detected with mean balance of 1350 mL for light drinkers and 1610 mL for moderate drinkers (P = .005942).

Discussion

High-altitude mountaineering is a dangerous activity performed in a challenging environment. Human performance reduction can be life threatening in the isolated and hostile alpine environment. Previous studies have

Table 2. Sample stratified at the median by fluid intake into moderate drinkers (>2600 mL per day) and light drinkers (≤2600 mL per day), with *t*-test results comparing for strata urine output and balance

Mean intake, mL	*n*	*Mean urine output, mL*	*Mean balance, mL**
≤2600	18	1168	1350
>2600	18	1947	1610
P-value		.0011	.0059

*Mean balance equals fluid intake minus urine output.

suggested that dehydration reduces one's strength and endurance through excessive lactate accumulation and other mechanisms.[11] Kenefick et al[12] failed to show a correlation among hypohydration and heat production, skin temperature, or heat loss. Their study also found no significant relationship among hydration, thermoregulation, and cardiovascular stress during moderate physical exercise in cold environments.[12]

We observed high-altitude mountaineers operating in a hostile environment with multiple simultaneous stressors. In addition to frigid temperatures, our participants also functioned at a high intensity of physical work under the added stress of hypoxia and hypobarism. In many ways our scenario was more rigorous than that of Kenefick et al,[12] but we also failed to detect a significant correlation between measurable markers of hydration and performance. Although we postulate a correlation between hydration and protection against AMS, our study was underpowered to prove this. Given the austere and observational nature of our research, more sophisticated measurements of hydration were not practically available. Future research may include improved measures of dehydration, including urine-specific gravity, blood urea nitrogen, or body mass (weight).

Our observed incidence rates of AMS were lower than those reported by other studies. Various predictive and protective factors could explain this discrepancy. Acclimatization is inversely correlated with AMS.[7,13] Immediately before this study period, the mountaineers in our study spent more than 5 of 30 days between 2500 m and 3500 m elevation. Furthermore, this group had low risk for AMS because they were highly experienced mountaineers who had logged several stays at high altitude during the same year without serious cases of AMS.

Presumably, group members prone to AMS would have self-eliminated from this vocational field (military mountaineering) if they had experienced problems on past expeditions. Because history of AMS is a positive predictive risk factor for recurrent AMS,[1,8,14,15] our group was self-selected to have reduced a priori risk for AMS before the observation period, and this may represent a sampling bias. Finally, the participants in our study were experienced military mountaineers trained to tolerate and ignore mild AMS symptoms, and this may have introduced reporting bias.

None of the subjects in our study reached a fluid intake of 5000 mL per day (the maximum fluid intake was 4700 mL per 24 hours). Basnyat et al[4] demonstrated there was strong evidence for a decreasing risk of AMS when trekkers reported consuming more water, up to 5 L per day.

The average fluid intake in the mountaineers in our study is similar to that registered by Scott et al[11] in their study of the effect of drinking tea at high altitude on hydration status and mood at 5345 m on Mt Everest. There are no significant differences between the percentage of retained fluid in individuals with AMS and those who did not present with symptoms; the values of these percentages are considerably higher than those registered by Scott et al,[11] coded in little more than 15%.

Of the mountaineers who drank less than 3000 mL per day, 90.9% developed AMS (20 of 22 cases), compared with 78.5% of those who drank more than 3000 mL per day (11 of 14 cases). Basnyat et al[4] concluded that drinking less than 3000 mL of water increased the risk of AMS by about 60%, even when other factors were controlled. Our data are not inconsistent with the conclusion by Basnyat et al,[4] as shown in Table 2. Independent of fluid intake, mountaineers developing AMS demonstrated reduced urine output (mean 1336 mL) when compared with asymptomatic climbers (mean 1655 mL). Although this observation did not reach statistical significance, it reflects the suspected physiological response to an internal homeostatic recognition of organ hypoperfusion. This is probably a subtle "pre-shock" adaptation mechanism.

There was significant intake-output correlation: mean urine output was 1168 mL for light drinkers and 1947 mL for moderate drinkers (P = .00112259). Although this statistically significant relationship is not surprising, it does help confirm that there were predictable and consistent undetectable fluid losses (evaporation, breath vapor, sweat, other secretions, edema) to account for the differential inputs. Insensible water loss at altitudes of 5000 m to 7000 m has been reported as roughly 1.7 L per day.[16,17] Specifically in our study, water losses in breath and sweat were not accounted. When reviewing the variable of balance, a significant correlation is also detected, with mean balance of 1350 mL for light drinkers and 1610 mL for moderate drinkers (P = .005942). Unfortunately, this did not correlate with LLS or AMS scores, but this helps strengthen and validate our methodology. The physiological correlation between intake and output provides important clinical context for a de facto conclusion that there was no detectable significant AMS protection from hyperhydration in our study. The significant output and balance endpoints support our findings because they corroborate and confirm that the subjects were actually drinking the fluid that they claimed to consume. This finding therefore strengthens the "negative" conclusions of this study and helps future researchers by letting them know that they will need a study designed with greater "power."

The fact that no statistically significant results were found lead us to think that symptoms of AMS are not attributed so much to a problem of dehydration but rather to the influence of other variables, such as individual susceptibility and previous AMS occurrences, because the speed of ascent and the preacclimatization was the same for all members of the expedition. In any case, this was not an experimental study in which the water intake was restricted; the subjects of our study consumed liquids on demand, and it is possible that this fact prevents a demonstration of a relation that seems to be evident.

Many different variables affect a person's likelihood of developing AMS. No one has yet developed a scientifically validated model to predict risk of AMS. As described by Cumbo et al,[18] risk factors for AMS include lack of prior acclimatization; prior incidence; hypothermia; fever; genetic predisposition; and environmental variables such as wind, temperature, and elevation. Additionally, it is difficult to maintain rigorous data control in the alpine environment; therefore, human measurement and reporting errors may have affected our data.

Potentially serious mountain pathologies include AMS, high-altitude pulmonary edema, high-altitude cerebral edema, ischemia, hypovolemic shock, hemorrhagic or thrombotic accidents, and predisposition to frostbite. Although our study was underpowered to prove a correlation, we did notice a statistically insignificant trend suggesting that hydration confers AMS protection. Our data and experience lead us to believe that aggressive hydration at altitude can prevent or mitigate AMS and other altitude-associated illnesses and injuries. When comparing subjects consuming more or less than 3000 mL per day (see Table 3), we observed a predictable and significant difference in urine output (P = .01725) and balance (P = .00025). We also observed a protective effect against AMS. Although our study suggests that hydration protects against AMS, this correlation did not reach clinical significance (P = .208 for LLS and .0882 for AMS correlation).

Table 3. Sample stratified at 3000 mL by fluid intake, with t-test results comparing for strata urine output and balance

Mean intake, mL	*n*	*Mean urine output, mL*	*Mean balance, mL**	*Mean acute moutain sickness symptoms*
≤3000 (average = 2248)	24	1349	899	1.375
>3000 (average = 3906)	12	1975	1932	0.91666
P-value		.01725	.00025	.0882

*Mean balance equals fluid intake minus urine output.

Conclusions

We tracked 36 man-days of fluid intake and output for a group of mountaineers and found intake and output varied among individuals. The mountaineers consumed a variety of fluids, including water, tea, coffee, soup, Isostar, and milk. Daily fluid intake was 2800 ± 979 mL, with a maximum intake of 4700 mL. Daily urine output was 1557 ± 758 mL. We found that fluid intake was significantly correlated with fluid balance and output.

We also found that fluid intake was associated but insignificantly correlated with incidence and degree of AMS. We believe that aggressive hydration at altitude is protective against several altitude-related illnesses.

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