ORIGINAL

Electrolyte-carbohydrate beverage prevents water loss in the early stage of high altitude training

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Abstract : To prevent water loss in the early stage of high altitude training, we focused on the effect of electrolyte-carbohydrate beverage (EC). Subjects were 16 male university students who belonged to a ski club. They had ski training at an altitude of 1,800 m. The water (WT) group drank only water, and the EC group drank only an electrolyte-carbohydrate beverage. They arrived at the training site in the late afternoon. The study started at 7 pm on the day of arrival and continued until noon of the 4th day. In the first 12 hours, 1 L of beverages were given. On the second and third days, 2.5 L of beverages were given. All subjects ate the same meals. Each morning while in fasting condition, subjects were weighed and blood was withdrawn for various parameters (hemoglobin, hematocrit, sodium, potassium and aldosterone). Urine was collected at 12 hour intervals for a total 60 hours (5 times). The urine volume, gravity, sodium and potassium concentrations were measured. Peripheral oxygen saturation and heart rate were measured during sleep with a pulse oximeter. Liquid intakes in both groups were similar, hence the electrolytes intake was higher in the EC group than in the WT group. The total urine volume was lower in the EC group than in the WT group, respectively ($p < 0.05$). Plasma volume decreased in the WT group and increased in the EC group but a significant difference was not observed in the final value. Aldosterone concentration tended to be less in the EC group than in the WT group. Electrolyte-carbohydrate beverage in the early stage of high altitude training may be effective in decreasing urinary output and preventing loss of blood plasma volume. J. Med. Invest. 59 : 102-110, February, 2012

Keywords **:** *rehydration, urine, plasma volume, sodium, aldosterone*

INTRODUCTION

The purpose of high altitude training is to improve physical ability and many favorable results have been reported (1). High altitude locations are characterized by low atmospheric pressure. Low atmospheric pressure stimulates the transient secretion of erythropoietin by the kidneys and the numbers of red blood cells and hemoglobin concentration both increase (2-4), enhancing oxygen transport to the muscles and improving aerobic performance (5, 6). High altitude training is also often required for the health of athletes. For example, ski competitions are often held at high altitude (7).

In early stages at high altitude, there is a tendency toward dehydration due to increased respiratory

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water loss secondary to enhanced pulmonary ventilation (8-11) and increased urinary water loss secondary to down-regulation of the renin-angiotensin hormonal mechanism (12, 13). Urinary water loss may average approximately 500 ml per day (14). A decrease in blood volume through dehydration increases the heart rate and decreases cardiac output, both of which reduce the physical performance level (15). A decrease in physical performance through dehydration is due not only to the cardiovascular system but also to various changes in the nervous system and/or metabolism (16). Cheuvront *et al.* (17) reviewed the effects of dehydration on physical performance and reported a 2-7% loss of body water in a hot environment, which decreased physical performance. All of this evidence indicates the importance of maintaining body water for normal physical performance. For high altitude training, 4-5 L of water a day is recommended (18).

The favorable effect of electrolyte carbohydrate has been reported in an environment of low moisture. The administration of an electrolyte-carbohydrate beverage (6 ml/day/kg body weight) to subjects sitting in low moisture conditions for 4 hours prevented a decrease in plasma volume and an increase in blood viscosity (19). Hamada *et al.* studied the favorable effect of an electrolyte-carbohydrate beverage on body fluid during a long flight under conditions of normal air pressure and low humidity (20).

In spite of this evidence, the effect of electrolyte-carbohydrate beverage on water-loss prevention at high altitudes has been little studied. If such beverages are in fact useful for athletes in high altitude training and competition, this would be a meaningful finding. In this study we tried to determine the effects of an electrolyte drink on body fluid in high altitude ski training.

METHODS

Subjects

Subjects were 16 male university students (21.3 ± 1.8 yr, 170.6 ± 7.4 cm height, 60.4 ± 8.4 kg weight, 20.6 ± 1.6 m^2 surface area) who belonged to a ski club. They received full information about the purpose and methods of the experiment and agreed to participate. To study the effect of two different drinks, we formed two groups, 8 subjects for the WT group (drinking only water) and 8 subjects for the EC group (drinking only an electrolyte carbohydrate beverage). The study was approved by the ethical committee on human study at Seitoku University.

Study design

The accommodation and the ski training course were located at an altitude of about 1,800 m. Subjects planned to have training on the second and third day. However, due to bad weather they were able to train only on the morning of the second day and the afternoon of the third day. Figure 1 shows the study design. The various factors were measured for 1-2 days before the participants moved to high altitude. They had a meal from 6-7 pm on the first day. At 7 pm they were asked to urinate and the urine was discarded ; regular collection started from this time. The same meals were given to all participants. Two experienced dietitians measured the food residues and calculated the energy and nutrient intakes. The electrolyte-carbohydrate beverage contained sodium 15 mEq/L, potassium 4 mEq/L and carbohydrates 4.7%. In the first 12 hours, 1 L of each beverage was given. On the second and third days, 2.5 L of beverage were given. Each morning while in fasting condition, subjects were weighed and blood was withdrawn for analysis of various parameters (hemoglobin, hematocrit, sodium, potassium and aldosterone). All urine was collected at 12 hour

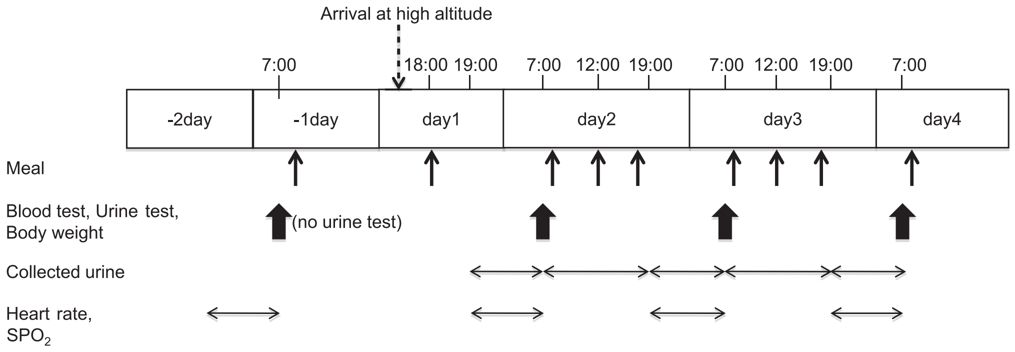

Figure 1 Experimental protocol

intervals for a total 60 hours (5 times). The urine volume, gravity, sodium and potassium concentrations were measured. Peripheral oxygen saturation and heart rate were measured during sleep with a pulse oximeter. Neither exercise other than skiing nor long baths were allowed.

Physical characteristics

Height and weight in fasting condition were taken on the morning of the previous day (sea level) and for the 3 days at the site of about 1,800 m. Peripheral oxygen saturation and heart rate were measured during sleep with a pulse oximeter (SpO_2, Pulsox-3i, Konica Minolta, Japan). This is a non-invasive method to monitor the oxygenation of hemoglobin by a sensor placed on a fingertip.

Blood test

Fasting blood was withdrawn 2 days before the study and every day during the study (Fig. 1). Blood samples were smoothly centrifuged and kept frozen until analysis (Mitsubishi Chemical Medience Corporation, Japan). Hemoglobin concentration was measured by sodium lauryl sulfate- hemoglobin method, hematocrit by RBC pulse height detection method, plasma sodium and potassium concentrations by ion selective electrode, plasma osmotic pressure by freezing point method, plasma aldosterone by radioimmunoassay method. Changes in plasma volume were calculated from the hematocrit and hemoglobin values (21).

Urine test

Collected urine was well mixed and the total volume was measured and then the urine sample was extracted. It was kept refrigerated until it presented to the analysis company along with the blood samples. The urine specific gravity was measured by refractometry, urinary osmolality by freezing point method, urine sodium and potassium concentrations by ion selective electrode.

Statistical analysis

All data were presented as mean ± SD. Comparisons between groups were performed with unpaired *t*-test. The differences between data at sea level and each time point for each trial were determined with Dunnet's post hoc test. The relationships among the variables were analyzed using simple correlation. Statistical analyses were performed using IBM SPSS Statistics 19 (IBM, Japan). Statistical differences were accepted when $p < 0.05$.

RESULTS

Intakes of food and beverages at the high altitude site are shown in Table 1. There was no significant difference between the two groups in total water intake ($p > 0.05$).

Sodium and potassium from food and beverages are shown in Table 1. There was no significant difference in sodium intake from meals, but total sodium intakes were significantly greater in the EC group than in the WT group ($p < 0.001$). Total potassium intakes were similar for the two groups ($p > 0.05$), in spite of the greater intake in the EC group than in the WT group ($p < 0.001$).

Table 1 Intake of water, sodium and potassium during stay at high altitude

	WT	EC
Intake of water, mL	10921 ± 149	10719 ± 504
Beverage, mL	6000 ± 0	6000 ± 0
Meal, mL	4921 ± 149	4719 ± 504
Intake of sodium, mg	12293 ± 354	14013 ± 731***
Beverage, mg	68 ± 0	2040 ± 0***
Meal, mg	12225 ± 354	11973 ± 731
Intake of potassium, mg	9248 ± 247	9290 ± 914
Beverage, mg	11 ± 0	480 ± 0***
Meal, mg	9238 ± 247	8810 ± 914

mean ± SD. ***$p < 0.001$ vs. WT.

Table 2 shows changes in subjects' body weight. In the EC group, body weight increased on day 2, but on day 3 and on day 4 it decreased ($p < 0.05$). In the WT group, body weight decreased on day 2, on day 3, and on day 4 ($p < 0.05$). This indicates that the longer the time spent at high altitude, body weight decreased for the WT group ($p < 0.05$). However, decrease in body weight did not differ significantly between the two groups.

Table 3 shows blood parameters. Hemoglobin concentrations and hematocrit values did not differ between the two groups, with no effect from length of stay at high altitude. Blood sodium and potassium concentrations were similar for the two groups ($p > 0.05$). Blood osmotic pressure did not change over

Table 2 Changes in body weight

		sea level	day2	day3	day4
Body weight, kg	WT	59.7 ± 6.6	59.6 ± 6.1	59.3 ± 6.3$^{\$}$	58.7 ± 6.2$^{\$\$,¥}$
	EC	61.0 ± 10.4	61.2 ± 10.5	60.8 ± 10.3	60.5 ± 10.3$^{\$}$
Change in body weight, kg	WT	-	-0.1 ± 1.1	-0.4 ± 1.1$^{\$}$	-1.0 ± 1.1$^{\$\$,¥}$
	EC	-	0.1 ± 1.1	-0.2 ± 1.0	-0.5 ± 0.9$^{\$}$
Change in body weight, %	WT	-	0.0 ± 2.0	-0.7 ± 2.0	-1.6 ± 1.9
	EC	-	0.2 ± 1.8	-0.4 ± 1.6	-0.8 ± 1.5

mean ± SD. $^{\$}P < 0.05$, $^{\$\$}P < 0.01$ vs. day2, $^{¥}P < 0.05$ vs. day3

Table 3 Changes in blood parameters

		sea level	day2	day3	day4
Hemoglobin, g/dL	WT	15.6 ± 1.3	15.5 ± 1.4	15.6 ± 1.2	15.8 ± 1.5
	EC	15.8 ± 0.7	15.8 ± 0.4	15.5 ± 0.5	15.5 ± 0.7
Hematocrit, %	WT	46.4 ± 2.6	46.9 ± 3.6	46.6 ± 2.8	46.8 ± 3.0
	EC	47.3 ± 1.9	48.2 ± 1.5	47.1 ± 1.5	46.2 ± 1.6
Sodium concentration, mEq/L	WT	141 ± 1	140 ± 1	141 ± 1	141 ± 1
	EC	141 ± 1	140 ± 1	141 ± 1	141 ± 1
Potassium concentration, mEq/L	WT	4.1 ± 0.2	4.1 ± 0.2	4.2 ± 0.2	3.9 ± 0.2
	EC	3.9 ± 0.2	4.1 ± 0.3	4.0 ± 0.2	3.9 ± 0.3
Osmolality, mOsm/L	WT	289 ± 2	286 ± 2	288 ± 2	288 ± 2
	EC	290 ± 3	287 ± 2	288 ± 2	287 ± 2
Aldosterone, ng/dL	WT	17.5 ± 5.0	13.5 ± 1.8	12.2 ± 3.0	13.3 ± 3.2
	EC	12.7 ± 2.0*	14.4 ± 1.8	11.7 ± 2.9	10.4 ± 3.4
Change in plasma volume, %	WT	-	-0.08 ± 7.25	-0.12 ± 7.42	-1.82 ± 5.61
	EC	-	-1.76 ± 5.07	2.56 ± 9.09	4.25 ± 8.55

mean ± SD. $^{*}p < 0.05$ vs. WT. $^{\$}p < 0.05$ vs. day2

the course of the stay for either group. Blood aldosterone concentrations were not significantly different. In the EC group, the longer the stay at high altitude, the more the aldosterone concentration decreased. The plasma volume in the WT group tended to decrease without significant difference ($p > 0.05$). However in the EC group, the plasma volume tended to increase, ($p > 0.05$).

Total urine volume is shown in Table 4. The volume was significantly lower in the EC group than in the WT group ($p < 0.05$). Urine volume in daytime was significantly higher than at night for both groups ($p < 0.05$). For both groups, urine specific gravity significantly decreased with length of stay ($p < 0.05$), but was within the normal range. The osmolality of urine on the day 2-3 significantly decreased compared with that of the day 1 for both groups ($p < 0.05$). Urinary sodium concentration after the night of day 2 in the EC group was higher than that in the WT group ($p < 0.05$). Urinary potassium concentration decreased in both groups except for the night of day 2 and the day time of day 3 ($p < 0.05$). Sodium excretion in the night of day 3 was significantly higher in the EC group than in the

Table 4 Changes in urine parameters

		night of day1	day of day2	night of day2	day of day3	night of 3day	Total
Urine volume, mL	WT	903 ± 244	1845 ± 155	1298 ± 447	1994 ± 326	1078 ± 234	7118 ± 632
	EC	794 ± 312	1646 ± 299	1010 ± 262	1659 ± 424	1129 ± 356	6238 ± 939*
Urine specific gravity	WT	1.015 ± 0.004	1.006 ± 0.001$^{\#\#}$	1.008 ± 0.003	1.006 ± 0.001$^{\#\#}$	1.008 ± 0.002$^{\#}$	-
	EC	1.019 ± 0.007	1.007 ± 0.001$^{\#\#}$	1.010 ± 0.002$^{\#}$	1.007 ± 0.002$^{\#}$	1.009 ± 0.002$^{\#}$	-
Osmolality, mOsm/L	WT	527 ± 107	254 ± 29$^{\#\#}$	307 ± 83$^{\#}$	255 ± 31$^{\#\#}$	273 ± 58$^{\#\#}$	-
	EC	649 ± 216	288 ± 41$^{\#\#}$	346 ± 69$^{\#}$	286 ± 49$^{\#}$	287 ± 58$^{\#}$	-
Sodium concentration, mEq/L	WT	111 ± 20	65 ± 15$^{\#\#}$	64 ± 13$^{\#}$	66 ± 10$^{\#\#}$	52 ± 8$^{\#\#}$	-
	EC	135 ± 27	76 ± 9$^{\#\#}$	87 ± 15$^{**,\#}$	78 ± 12$^{*,\#}$	70 ± 14$^{**,\#\#}$	-
Sodium excretion, mg	WT	2322.6 ± 819.2	2736.9 ± 624.0	1848.8 ± 540.7	2975.0 ± 389.9	1252.0 ± 181.5	11135.3 ± 1285.0
	EC	2347.6 ± 716.2	2915.4 ± 791.3	1988.2 ± 473.1	2921.4 ± 616.8	1722.9 ± 273.3**	11895.5 ± 1733.0
Potassium concentration, mEq/L	WT	23.4 ± 5.1	14.0 ± 3.5$^{\#\#}$	14.8 ± 2.6	16.2 ± 3.9	11.3 ± 3.1$^{\#}$	-
	EC	30.9 ± 5.5*	17.2 ± 4.4$^{\#\#}$	16.9 ± 3.2$^{\#\#}$	18.1 ± 5.4$^{\#\#}$	12.6 ± 3.0$^{\#\#}$	-
Potassium excretion, mg	WT	413.4 ± 114.2	512.5 ± 109.4	368.0 ± 91.6	641.4 ± 160.0	235.1 ± 51.8	2170.6 ± 403.8
	EC	488.2 ± 203.3	553.0 ± 111.3	341.2 ± 125.9	579.5 ± 160.8	276.6 ± 83.6	2238.6 ± 510.7

mean ± SD. Night time was from 19 : 00 to 07 : 00 and included the urine gathered immediately after getting up. Day time was from 07 : 00 to 19 : 00.
$^{*}p < 0.05$, $^{**}p < 0.01$ vs. WT, $^{\#}p < 0.05$, $^{\#\#}p < 0.01$ vs. day1

WT group ($p < 0.01$). Total sodium and potassium excretions during the whole period were not different between the 2 groups ($p > 0.05$).

Table 5 shows the mean heart rate during sleep at high altitude. It was similar at low and high altitude ($p > 0.05$). SpO_2 decreased over the stay at high altitude in both groups ($p < 0.05$).

Significant difference was not observed between the total urine volume and the changes in plasma volume in the day 4 ($r = -0.421$, $p = 0.104$) (Fig. 2). There was a significant negative correlation between the blood aldosterone and the changes in plasma volume in the day 4 ($r = -0.623$, $p < 0.05$) (Fig. 3).

Table 5 Changes in peripheral oxygen saturation (SpO_2) and heart rate during sleep

		sea level	night of day1	night of day2	night of day3
Heart rate, bpm	WT	62.1 ± 3.9	65.3 ± 4.8	64.7 ± 5.1	64.7 ± 4.1
	EC	64.2 ± 4.1	64.7 ± 5.3	64.4 ± 4.9	64.8 ± 5.1
SpO_2, %	WT	97.1 ± 0.3	91.5 ± 1.7$^{\#\#\#}$	92.5 ± 1.6$^{\#\#}$	92.2 ± 1.2$^{\#\#\#}$
	EC	96.9 ± 0.2	92.8 ± 1.3$^{\#\#\#}$	92.8 ± 1.5$^{\#\#\#}$	93.0 ± 1.7$^{\#\#}$

mean ± SD. $^{\#\#}p < 0.01$, $^{\#\#\#}p < 0.001$ vs. sea level

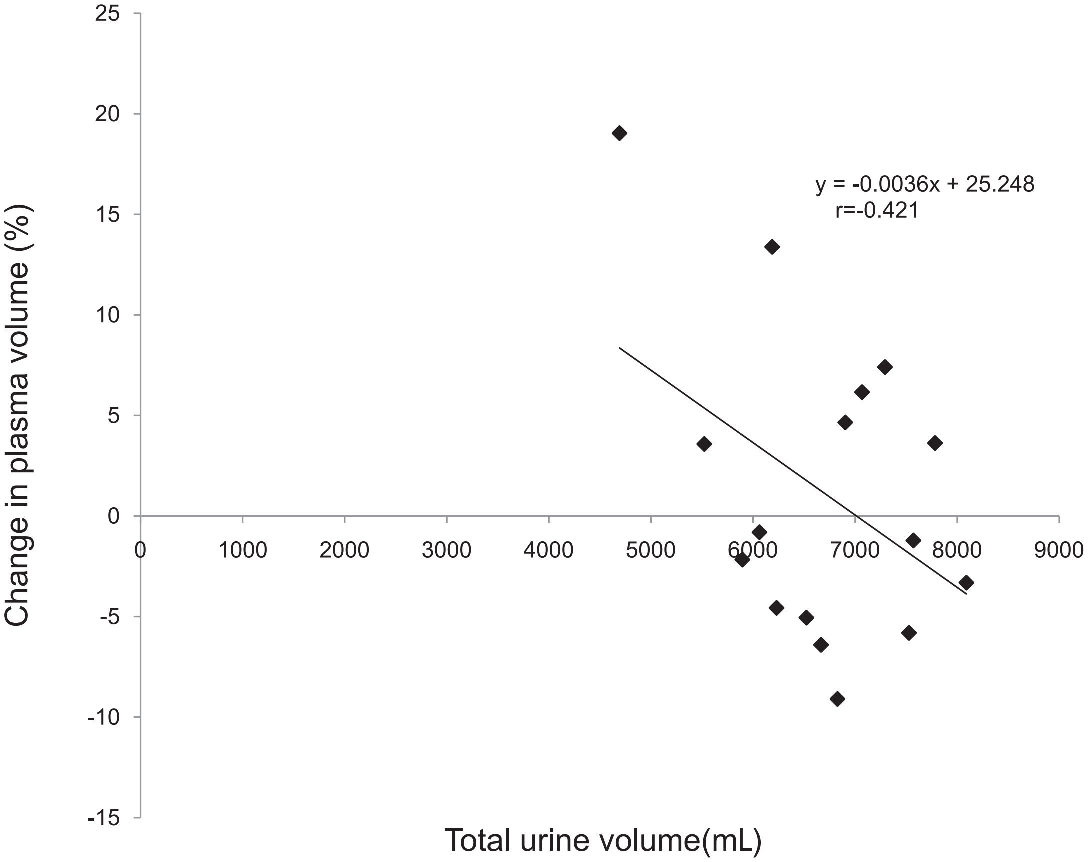

Figure 2 Correlation between change in plasma volume and total urine volume

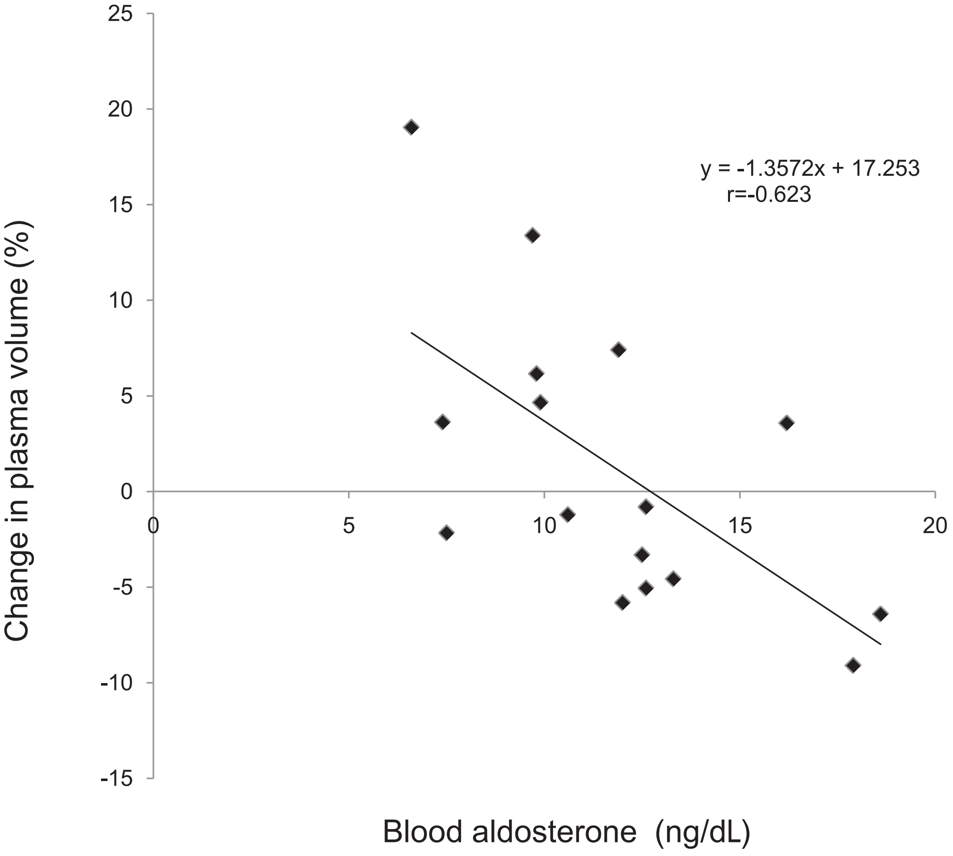

Figure 3 Correlation between change in plasma volume and blood aldosterone at day4

DISCUSSION

In this study we found that the administration of an electrolyte-carbohydrate beverage in the early stage of high altitude training in young adults was effective in decreasing urinary output and preventing loss of plasma volume. Dehydration through the increase of urine volume is common in the early stage of a high altitude stay, due to the low oxygen concentration. Because of the low oxygen concentration, the supply of oxygen to the body becomes insufficient and various adverse effects appear in the tissue and organs. Swenson *et al.* (22) compared the urine volume for 6 hours in subjects put in a chamber with the oxygen concentrations at sea level or at 4,000 m altitude and observed higher urine excretion and urinary sodium excretions at the lower concentration. With regard to the mechanism for this effect, he suggests that hyper-breathing at low oxygen concentration reduces carbon dioxide partial blood pressure, which heightens the pH of body fluid. To compensate for this, the absorption of bicarbonate is reduced and urine volume increases. Other researchers have also observed a similar phenomenon and have suggested various mechanisms. Bärtsch *et al.* (23) reported that a stay at 4,559 m for 4 days increases plasma norepinephrine concentration and increases urine volume. Okazaki *et al.* (24) reported that low oxygen concentration stimulates adrenocorticotropic hormone and increases serum aldosterone concentration.

When we compare urine volume, we can not ignore water intake. In this study, the subjects were given the same amount of beverage (6.0 L/60 hours). Since they took the same meals throughout the study, the metabolic water from nutrients was similar for all of them. Body weight can be a good indicator of short-term changes in body fluid (25, 26). It is known that body weight decreases at high altitudes due to decreases in water intakes (14, 27). In this study the decrease in body weight was significant on the 3rd and 4th day in the WT group, but only on the 4th day in the EC group ($p < 0.05$). Since all the subjects ate the same foods (same energy intake) and engaged in similar physical activities (similar energy expenditure), the difference in body weight between the two groups may support the hypothesis of the prevention of water loss by the electrolyte-carbohydrate beverage. Results similar to ours have been reported ; body water in dehydrated rats recovered to normal levels by providing water with 0.2-0.9% NaCl but not by water alone. Okuno *et al.* (28) reported that a beverage containing sodium is useful in recovery from dehydration and loss of body fluid by sweating. On the basis of these findings, the Japan Sports Association recommends 0.1-0.2% NaCl solution (29). Greenleaf *et al.* (30) studied the effect of electrolyte beverages on body fluid at an altitude of 2,800 m. After 10 hours, plasma volume increased only in subjects administered sodium 185.0 mEq/L but not in those administered sodium 21.6 mEq/L. The urinary excretion rate was slower when the electrolyte was given than when water alone was given.

An electrolyte solution with carbohydrate was more effective for sodium and water absorption than a solution with electrolyte alone (31). This is because intestinal glucose uptake is mainly performed by a Na^+-dependent glucose transporter in the intestinal epithelial cells. In this study, although the sodium concentration was low (15 mEq/L), loss of water into urine was reduced. Its favorable effects might be obtained by the mixture of electrolytes and carbohydrates. A similar result was observed during long flights when subjects were given either a solution of sodium (21.0 mEq/L) and 6.7% carbohydrate or water alone (20). In this study, although water intake was similar when either the electrolyte-carbohydrate beverage or water was given, urine volume was lower and water retention was higher in the former group than in the latter group. The tendency of the negative relationship between total urine volume and the changes in plasma volume were observed but without significant difference (Fig. 2). In other words, the decrease of urine volume means the possibility of plasma volume.

Aldosterone is an important hormone for the control of body water. In this study changes in this hormone were not observed. There was a significant negative correlation between the blood aldosterone and the changes in plasma volume (Fig. 3), which suggests that maintenance of body water is controlled not by aldosterone but rather by the electrolyte-carbohydrate beverage.

In our study the osmotic pressure and specific gravity were low in both groups (1.006-1.010), suggesting that 2.5 L/day of beverage was enough for the stay at the altitude of about 1,800 m. The Australian Institute of Sport defines normal specific gravity for athletes as less than 1.020 (32). Armstrong *et al.* (33, 34) reported that the normal range in specific gravity for healthy adults was 1.013-1.029. Although 4-5 L/day is usually recommended (18), our results indicate that even a smaller quantity is enough.

In conclusion, the study showed that electrolyte-carbohydrate beverage may be effective in preventing water loss in early stage high altitude training. To confirm our findings further studies including physical activity, performance test and the period of the electrolyte-carbohydrate beverage administration are desired.

CONFLICT OF INTERESTS

None of the authors have any conflicts of interest to declare.

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