ORIGINAL

Comparison of water balance among healthy young and old adults and handicapped adults

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Abstract : The body's water balance is changed by food and beverage intake, metabolism, and excretion. In this study, we performed a cross-sectional study that investigated the changes of water intake and water output in healthy Japanese young and elderly people and handicapped adults. Water balance was assessed by water intake from foods and beverages, metabolic water production, non-renal water losses (NRWL), and urine volume. Most of the parameters did not change with aging in healthy adults. Estimated total water intake (ml/kg/day) increased with aging. In the healthy men, healthy women, and handicapped adults, daily water intake (median [interquartile range]) accounted for 49.4 (41.4-59.9) ml/kg, 42.9 (38.7-51.8) ml/kg, and 50.9 (43.8-74.0) ml/kg, respectively. Water loss from the kidney accounted for 19.2 (16.2-29.2) ml/kg, 22.0 (16.2-26.6) ml/kg, and 27.5 (22.7-47.2) ml/kg, respectively. NRWL accounted for 26.6 (18.5-35.2) ml/kg, 22.4 (16.2-28.8) ml/kg, and 23.5 (19.8-28.5) ml/kg, respectively. Our findings suggest that a daily total water intake of more than 50-55 ml/kg is required to prevent dehydration in healthy and handicapped adults. J. Med. Invest. 70 : 195-199, February, 2023

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INTRODUCTION

Water is the main constituent of cells, tissues, and organs, and adequate hydration of body tissues is essential to health and life (1-3). The regulation of water balance is very precise. A loss of 1% of body water is usually compensated within 24 h. Elderly people have a higher risk of developing dehydration than young adults. Both diminution of liquid intake and increased liquid losses are involved in causing dehydration in the elderly (4). Caregivers should be aware of signs of dehydration in elderly individuals and should encourage water intake. However, detailed and representative data on water intake and hydration status of the Japanese population, which is a requirement to derive a reliable basis for intake recommendations, are missing. Furthermore, whether water requirements change with increasing age remains unclear.

Water balance constitutes clear evidence of how much water we really need. It can be assessed by water intake from foods and beverages, metabolic water production, and water losses from urine and non-renal water losses (NRWL). The aim of the present investigation was to quantify total fluid balance by assessing estimated total fluid intake and total fluid output over a 24-h period in healthy young and old adults and handicapped adults under moderate ambient temperature (18-20°C) and with a moderate activity level.

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MATERIALS AND METHODS

We conducted a cross-sectional study to investigate the changes of water intake and water output in healthy Japanese young to elderly and handicapped adults. We included healthy male and female subjects in the age groups of 20-39 years (17 and 14, respectively), 40-69 years (13 and 17, respectively), and 70 years and older (11 and 29, respectively) (Table 1). Among them, five males and 29 female subjects in nursing homes in the age group of 70 years and older had various levels of walking suppression and difficulty. These patients were being cared for mainly by registered care workers and dietitians. The seven male and one female handicapped patients were aged 20-28 years old. They were all bedridden and cared for in the medical and nursing care system. The handicapped patients were diagnosed as symptomatic epilepsy due to cerebral palsy (6), and acute subdural hematoma (1) and lissencephaly (1). The healthy subjects (67) were aged between 20-69 years old and consisted of registered care workers and physical and occupational therapists working in nursing homes. None of the healthy subjects were engaged in high levels of exercise or taking any medications just before or during the study. Height and weight measurements were performed with the participants wearing light clothing and no shoes. BMI was calculated as weight (kg) divided by the square of height (m).

The patients and caregivers were instructed by registered dietitians on how to weigh each food item and drink. They recorded their consumption on each recording day. Total water intake corresponded to the sum of beverages (including tea, coffee, milk, and soup), metabolic water, and water in food taken from the dietary record of the day of urine collection. All foods and beverages consumed were recorded using food scales for weighing or standardized containers and templates to estimate the consumed amounts. Dietary data were converted into water using the Standard Tables of Food Composition in Japan (5).

Water is also produced by the oxidative metabolism of hydrogen-containing substrates in the body ; thus, estimated total water intake was calculated by including an additional 250 ml of metabolic water.

When assessing water balance, estimated total water intake and total water loss, which is the sum of NRWL and 24-h urine volume, are assessed. Each subject provided two 24-h urine samples at inclusion on two consecutive days. Thus, NRWL corresponded to the difference of calculated total water intake and measured 24-h urine volume :

NRWL (ml/day) = total water intake (ml/day) - 24 h urine volume (ml/day).

The ratio of urinary ($Na^+ + K^+$) concentrations (mEq/L) to plasma 145 (mEq/L) (U[$Na^+ + K^+$]/145) was obtained to assess 24-h hydration status (6). A ratio of more or less than 1.0 suggested insufficient or sufficient water intake, respectively.

Statistical analysis

Continuous data are presented as the mean (standard deviation [SD]) or median (interquartile range [IQR]), and categorical data are presented as counts (%). Comparisons were performed using t-test or Mann-Whitney U test. The three stroke subtypes were compared using the Kruskal-Wallis test with a post-hoc Steel-Dwass test. All p-values were two tailed, and p-values < 0.05 were considered significant. JMP version 13.1.0 (SAS Institute Inc., NC, USA) and R version 3.1.1 (R Foundation for Statistical Computing, Vienna, Austria) were used for statistical analysis.

RESULTS

Parameters of water balance in healthy young to old adults

Estimated daily total water intake (median [IQR]) was 2529 (2310-2634) ml and 49.4 (41.4-59.9) ml/kg in men and 2381 (2323-3158) ml and 42.9 (38.7-51.8) ml/kg in women (Table 1). The percentage of water derived from foods and beverages was 35.0 (32.7-40.6) % and 54.5 (48.8-59.1) % in men and 39.9 (34.3-40.8) % and 50.1 (49.3-55.2) % in women, respectively. The proportion of urine and NRWL was 48.4 (39.8-59.6) % and 51.6 (40.4-60.2) % in men and 44.4 (33.7-52.8) % and 55.6 (47.2-66.3) % in women, respectively. Estimated daily total water intake (ml/kg) increased with age, whereas U($Na^+ + K^+$)/145 decreased with age in both men and women. Increments of water intake

Table 1. Parameters of water balance in different age groups of adult males and females

median (IQR)

	Male					Female				
	Total	20-39 yr group (n = 17)	40-69 yr group (n = 13)	≧70 yr group (n = 11)	P for age	Total	20-39 yr group (n = 14)	40-69 yr group (n = 17)	≧70 yr group (n = 29)	P for age
Age (years)	63 (40.0-87.0)	33 (24.5-34.5)	46 (44.5-66.5)	74 (72.0-89.0)		41 (28.3-68.8)	21 (20.0-26.3)	53 (46.5-57.5)	87 (84.5-89.0)	
BMI (kg/m^2)	21.6 (19.7-24.3)	26.9^{a} (22.1-27.4)	25.3^{a} (24.0-26.2)	21.9^{b} (17.2-21.9)	<0.001	23.6 (19.9-26.2)	22.4 (20.0-25.9)	23.5^{a} (21.1-25.9)	20.6^{b} (18.8-21.6)	0.002
Estimated water intake										
total (ml/day)	2529 (2310-2634)	2397 (2194-3421)	3139 (2367-4222)	2374 (2360-2703)	0.162	2381 (2323-3158)	2443 (2019-3467)	2360 (2018-2529)	2592 (2529-2634)	0.077
(ml/kg/day)	49.4 (41.4-59.9)	38.4^{a} (28.9-43.2)	43.0^{b} (41.5-56.9)	47.9^{b} (42.2-61.8)	0.002	42.9 (38.7-51.8)	47.5^{a} (39.8-52.4)	34.1^{a} (32.0-45.8)	57.9^{b} (49.1-65.1)	<0.001
from food (ml/day)	1000 (817-1057)	897 (804-1033)	944 (823-1461)	946 (825-998)	0.768	942 (825-1051)	810^{a} (661-1012)	824^{a} (721-925)	1032^{b} (1030-1074)	<0.001
(%)	35 (32.7-40.6)	36.2 (26.2-41.1)	34.3 (30.4-38.8)	35 (34.3-39.9)	0.662	39.9 (34.3-40.8)	33.1^{a} (29.2-37.1)	34.9^{a} (34.0-39.9)	40.8^{b} (40.3-40.8)	<0.001
from beveages (ml/day)	1285 (1232-1310)	1384 (1107-2050)	1625 (1285-2231)	1310 (1285-1591)	0.302	1309 (1091-1761)	1353 (1126-2205)	1285 (1136-1312)	1285 (1247-1310)	0.231
(%)	54.5 (48.8-59.1)	53 (48.0-66.6)	55.2 (53.8-62.2)	54.5 (52.1-55.2)	0.384	50.1 (49.3-55.2)	56.6^{a} (53.5-63.6)	54.5^{a} (45.5-55.2)	49.6^{b} (49.3-49.7)	<0.001
metabolic (ml/day)	250	250	250	250		250	250	250	250	
Water output										
Urine (ml/day)	1080 (836-1385)	1160 (870-1570)	1460 (1095-1925)	1330 (1235-1600)	0.346	1260 (961-1600)	1070 (665-1820)	1050 (1000-1200)	1080 (814-1365)	0.943
(ml/kg/day)	19.2 (16.2-29.2)	16.1 (10.7-25.7)	20.5 (17.6-27.7)	25 (20.8-26.0)	0.063	22 (16.2-26.6)	18.3 (13.0-31.4)	16.7^{a} (15.0-19.0)	24.6^{b} (18.2-30.9)	0.049
(%)	48.4 (39.8-59.6)	44.4 (35.0-66.5)	46.5 (40.4-54.2)	55.5 (43.4-59.6)	0.754	44.4 (33.7-52.8)	41.7 (32.3-60.5)	49.1 (44.1-50.6)	41.8 (31.5-53.8)	0.395
Non-renal water loss (ml/day)	1300 (1067-1700)	1231 (798-2255)	1679 (1277-1957)	1093 (964-1716)	0.094	1215 (946-1734)	1373^{a} (865-1745)	1199^{b} (932-1387)	1534 (1182-1711)	0.079
(ml/kg)	26.6 (18.5-35.2)	17.2 (12.2-26.2)	23.5 (21.5-28.3)	26.8 (17.1-29.8)	0.051	22.4 (16.2-28.5)	25.7 (17.3-34.4)	17.5^{a} (15.3-24.6)	33.3^{b} (27.4-40.1)	<0.001
(%)	51.6 (40.4-60.2)	55.6 (33.5-65.0)	53.5 (45.8-59.6)	44.5 (40.4-56.6)	0.754	55.6 (47.2-66.3)	58.3 (39.5-67.7)	50.9 (49.4-55.9)	58.2 (46.2-68.5)	0.395
Urinary ($Na^+ + K^+$)/145	0.8 (0.6-1.2)	1.2^{a} (0.8-1.5)	0.7^{b} (0.6-0.8)	0.9 (0.7-0.9)	0.003	0.8 (0.7-1.1)	1.1^{a} (0.7-1.4)	1.2^{a} (0.9-1.5)	0.6^{b} (0.5-0.8)	<0.001

Steel-Dwass test

Different letters indicate significant differences ($P < 0.05$)

(ml/kg) from food and both urine and NRWL (ml/kg) with age were observed only in women. Water intake from beverages and loss from NRWL were slightly more than those from foods and from urine, respectively. However, most parameters of water balance did not show any significant changes among different sexes and age groups.

Parameters of water balance in handicapped adults

The estimated daily water intake (ml/kg) and urine (ml/kg) in bedridden handicapped adults were more than those in the healthy adults (Table 2). The percentages of water derived from foods and beverages were 52.8 (43.1-67.0) % and 35.1 (18.0-44.1) %, and the proportions of urine and NRWL were 60.0 (49.2-65.7) % and 40.0 (34.3-50.8) %, respectively. Water intake from foods and loss from urine were higher than those from beverages and NRWL, respectively. The mean ratio of U(Na^+ + K^+)/P145 in handicapped adults was lower than that in healthy adults.

DISCUSSION

There is little information on suitable liquid intake and hydration in elderly (7) and handicapped adults. In the present study, dietary weighed records and 24-h urine samples (n = 109) were used to estimate individua1 24-h hydration status in young, old, and handicapped adults. Water inputs are composed of three major sources : the water we drink, the water we eat, and the water we produce. The water we drink is essentially composed of water and other liquids with a high water content (85 to > 90%). The water we eat is derived from various foods with a wide range of water content (40 to > 80%). The water we produce results from the oxidation of macronutrients (endogenous or metabolic water).

Metabolic water production varies depends on the rate of energy expenditure : higher metabolic rates produce more water. Comparing men and women above 65 years to those aged 18-24 years old, the proportion of metabolic water decreased slightly (-1.4% in men and -2.3% in women) (8). Theoretically, for l g of glucose, palmitic acid, and protein, 0.6 ml, 1.12 ml, and 0.37

Table 2. Comparison of water balance parameters in healthy and handicapped adults and by sex and age matched healthy subjects

median (IQR)

	Healthy (n = 8)	Handicapped (n = 8)	P value Welch's t test
Sex (Male), n (%)	7 -87.5	7 -87.5	
Age (years)	24.5 (21.0-27.8)	25.5 (22.3-28.0)	0.732
BMI (kg/m²)	25.1 (21.5-31.2)	15.8 (13.9-18.0)	<0.001
Estimated water intake			
total (ml/day)	2434 (2211-3322)	1880 (1734-2173)	0.007
(ml/kg/day)	37 (30.2-40.8)	50.9 (43.8-74.0)	0.01
from food (ml/day)	1020 (876-1114)	967 (837-1272)	0.976
(%)	41.3 (35.2-47.6)	52.8 (43.1-67.0)	0.032
from beverages (ml/day)	1213 (907-1735)	675 (300-900)	0.011
(%)	48.4 (41.5-56.1)	35.1 (18.0-44.1)	0.017
metabolic (ml/day)	250	250	
Water output			
Urine (ml/day)	1100 (790-1220)	1115 (846-1438)	0.592
(ml/kg/day)	15.2 (8.9-19.1)	27.5 (22.7-47.2)	0.006
(%)	43.8 (24.7-56.7)	60 (49.2-65.7)	0.031
Non-renal water loss (ml/day)	1305 (944-2468)	783 (705-922)	0.017
(ml/kg/day)	20.1 (13.2-27.4)	23.5 (19.8-28.5)	0.335
(%)	56.2 (43.3-75.3)	40 (34.3-50.8)	0.031
Urinary (Na^+ + K^+)/145	1.5 (1.1-1.7)	0.7 (0.5-1.2)	0.024

ml water is endogenously produced, respectively. For l00 kcal of energy, 15 ml, 13 ml, and 9 ml of water is produced, respectively. The standard Japanese diet in daily three meals contains carbohydrate, fat, and protein consisting of 50-65%, 20-30% and 15-20% of total energy, respectively. Since daily metabolic expenditure in this study was approximately 1800-2100 kcal, 230-270 ml of metabolic water was produced. Therefore, a constant of 250 ml was used to estimate metabolic water (Table 1).

For men and women, the estimated daily total water intake was 2529 ml (49.4 ml/kg) and 2381 ml (42.9 ml/kg). Water intake from foods and beverages accounted for 35.0% and 39.9%, and 54.5% and 50.1%, respectively. Water loss from kidneys and from skin and the respiratory tract (NRWL) were 48.4% and 44.4%, and 51.6% and 55.6%, respectively. These parameters of water balance did not show significant differences between the sexes and among different healthy age groups.

It was reported that the water content of food can vary within a wide range, and consequently the amount of water contributed by foods can vary between 500 ml and 1 L a day (9). Endogenous or metabolic water represents about 250-350 ml a day in sedentary people. Over a 24-h period, a sedentary adult produces 1-2 L of urine. Water is lost as NRWL by evaporation through the skin (about 450 ml of water per day in a temperate environment) and the respiratory tract (about 250-350 ml per day). The adequate total water intake for sedentary adults is an average of between 2 and 2.5 L per day in women and men, respectively (10). Therefore, total water inputs for sedentary adults are an average of between 2 and 3 L. All the parameters of water balance in this study were similar to previous studies, except NRWL, which was more than previously reported.

U($Na^+ + K^+$)/145 values decreased with age in both men and women. This suggests lower osmolarity urine in elderly men because of lower urinary concentration capability. There is increasing evidence that even mild dehydration (defined as a 1-2% loss in body mass caused by fluid deficit) may play a role in various morbidities such as urolithiasis, constipation, and hypertension (11). Therefore, it is speculated that more than 50-55 ml/kg of water intake is required to maintain positive water balance in elderly men and women (Table 2). In contrast, the population < 69 years old needs more than approximately 45 ml/kg of water supply in the sedentary condition. These water intakes may induce urine of at least 1200 ml/day in men and 1000 ml/day in women.

Few previous studies measured water intake and water output in bedridden handicapped adults. Mean estimates of daily total water intake were 1880 (1734-2137) ml and 50.9 (43.8-74.0) ml/kg for handicapped adults (Table 2). Water intake from foods, beverages, and metabolic production accounted for 52.8%, 35.1%, and 12.1% of total water intake, respectively. The amount of water loss from kidneys and NRWL were 27.5 (22.7-47.2) ml/kg and 60.0 (49.2-65.7) %, and 23.5 (19.8-28.5) ml/kg and 40.0 (34.3-50.8) %, respectively. Thus, our findings suggest that water turnover rate in handicapped adults was faster than healthy adults in the same age group because more water intake and more urine excretion were observed. Previous studies have shown that electrolytes—particularly sodium—enhance fluid retention in the extracellular space, restore fluid homeostasis, and maintain plasma concentrations of vasopressin and aldosterone (12-15). Because U($Na^+ + K^+$)/145 values in handicapped adults were significantly lower than healthy adults (Table 2), more sodium intake is required to control water turnover rate. Furthermore, more than 50 ml/kg of water intake in handicapped adults may also be necessary, as elderly people in the 70 years and older group required this much water.

This study has several limitations. First, mild excessive water loss may not have been detected in this study, because water balance is regulated within 0.2% of body weight over a 24-h period (16). Under usual conditions of moderate ambient temperature (18-20°C) and with a moderate activity level, body water remains relatively constant. Second, large between- and within-subject variances made it difficult to determine the water requirement for all persons within a life stage (17). Individual energy expenditure and respiratory quotient were not measured. Because individual metabolic water production could not be obtained, estimated total water intake was used.

Dehydration is the most common fluid problem among the elderly. It has a greater negative outcome in this population than in younger adults and increases mortality, morbidity, and disability. The present study suggests that daily water intake of more than 50-55 ml/kg that keeps the daily urine amount more than 1000 to 1200 ml is necessary to prevent dehydration.

CONFLICT OF INTEREST AND ACKNOWLEDGEMENT

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