Abstract  This study compared the body water turnover in endurance athletes and age-matched sedentary men. Eight competitive endurance athletes (20.8±1.9 yr) and age-matched eight sedentary men (21.6±2.5 yr) participated in this study. Total body water and body water turnover were measured using the deuterium (D₂O) dilution technique. Urine samples were obtained every day for 10 days after oral administration of D₂O. The day-by-day concentrations were used to calculate the biological half-life of D₂O and body water turnover. Maximal oxygen uptake (VO₂max) and oxygen uptake corresponding to ventilatory threshold (VO₂VT) as an index of aerobic capacity were determined during a graded exercise test. Both VO₂max and VO₂VT were higher in the exercise group than in the sedentary group (P<0.05). The biological half-life of D₂O was significantly shorter in the exercise group than in the sedentary group (5.89±0.81 days vs. 7.52±0.77 days, P<0.05), and the percentage of the body water turnover was significantly higher in the exercise group than in the sedentary group (11.99±1.96% vs. 9.39±1.21%, P<0.05). The body water turnover was correlated with VO₂max and VO₂VT, respectively (P<0.05). Based on these findings, this study speculates that a level of physical activity may induce a body water turnover higher in the healthy state, since the better trained subjects have a higher body water turnover. J Physiol Anthropol Appl Human Sci 22 (6): 311–315, 2003 http://www.jstage.jst.go.jp/en/

Keywords: body water turnover, deuterium dilution, aerobic capacity, exercise training, young men

Introduction

Body water homeostasis is tightly controlled under normal conditions. However, the changes of as little as 1–2% of body fluid levels can result in dehydration (Wilmore and Costill, 1994). Dehydration-mediated heat injuries can be the life-threatening for healthy exercisers (Guyton, 1984). Thus, the water homeostasis is a very important clinical consideration for the human body.

Several researchers had already reported the body water turnover (WT). WT studies have used a tracer to measure the rate at which the body water is turned over (Leiper et al., 2001), and WT is an indicator of the water homeostasis (Shimamoto and Komiya, 2000). Although several researchers indicated that it is very difficult to evaluate the daily fluid balance in unrestricted humans (Schoeller, 1990; Leiper et al., 2001), it remains advantageous to measure WT in humans who are not restricted. From the findings of previous studies, WT seems to be affected by several factors, such as the activity level of the subjects (Fusch et al., 1996; Fusch et al., 1998; Lane et al. 1997), climate (Singh et al., 1989) and age (Fusch et al., 1993; Shimamoto and Komiya, 2003).

To our knowledge, very few studies linking exercise and/or physical fitness to WT have been carried out. Among these previous studies, Leiper et al. (2001) reported that WT in the exercise group was faster for individuals undertaking the prolonged exercise compared to that in sedentary men of the age-matched subjects and compared on a mean basis (26–41 yr vs. 27–46 yr). However, we previously reported that WT decreases with age, and this decrease was about 20% over a 40-year period (Shimamoto and Komiya, 2003). The results by Leiper et al. (2001) were largely affected by the variability of subjects’ age. Therefore, a tight control of age is needed to investigate the relationship between WT and the exercise training. Furthermore, they did not evaluate the relationship between WT and the individual training volume.

With this in mind, we compared WT between an endurance exercise group and an age-matched sedentary group, and investigated the relationship between WT and physiological fitness level, which is evaluated by aerobic power, and between WT and training volume.

Methods

Subject

Eight endurance athletes (20.8±1.9 yr, range 19–24 yr) and age-matched eight sedentary men (21.6±2.5 yr, range
19–25 yr) participated in this study. The subjects of the exercise group (Group EXE) performed endurance running on average 131.8±23.4 km/month during the experimental period (10 days), but the subjects of the sedentary group (Group SED) did not do the regular exercise. All subjects were free of medical problems. Following a complete medical history, physical examination, and basic laboratory studies conducted at the beginning of the study, all subjects were recognized as free of severe medical problems. After being fully informed of the nature of the experimental protocol, the subjects gave an informed consent, and then were allowed to enter the study. During the experimental period, we asked each subject to follow his normal diet and avoid any changes in normal life style.

**Measurements Anthropometry:**

Body mass was obtained in light clothing without shoes, to the nearest 0.1 kg, and was measured on a calibrated balance-beam scale accurate to 0.1 kg. Stature was measured to the nearest 0.1 cm. Body mass index (BMI) was calculated using the formula: body mass (kg)/height (m)$^2$.

**Total body water and WT**

In the morning after an overnight fast, the subjects were allowed to rest for at least 30 min, and then ingested 1 g of D$_2$O per kilogram of body mass after discharging urine and evacuating the bowels. To measure the total body water (TBW) using the plateau method, in which a tracer enrichment is estimated from the value near a steady state after equilibration (Schoeller, 1996), urine samples were obtained 1, 2 and 3 hours after D$_2$O oral administration. Urine samples were distilled using the constructed standard laboratory glassware, heated at 100°C within 20 minutes. Each distilled sample was injected into a calcium fluoride cell with a light path of 0.125 mm, and absorbance was measured using an infrared spectrophotometer (SHIMADZU FTIR-8700). Standard solutions were prepared previously and the D$_2$O concentration was read from a calibration curve. TBW was calculated using the following formula (Komiya et al., 1981):

$$
\text{TBW(L)} = gD_2O_{\text{given}} \times \%D_2O \times 10
$$

To calculate WT, the urine samples were collected during 10 consecutive days. Daily urine samples were obtained from first the urine of the day. From the changes in D$_2$O concentration, the half-life of D$_2$O obtained from a semi-logarithmic plot of urine concentration against time in days, and the percentage of WT (WT, %) were calculated using the following formula (Schloerb et al., 1950):

$$
\text{WT (L/day)} = \text{TBW} \times \text{WT (\%)}
$$

$$
\text{WT (ml/kg/day)} = \text{WT (L/day)} \div \text{body mass}
$$

Lean body mass (LBM) was estimated using the following formula:

$$
\text{LBM} = \frac{\text{TBW}}{0.732}
$$

The fat mass was obtained by subtracting body mass from LBM.

**Aerobic capacity**

Maximal oxygen uptake (VO$_{2max}$) and oxygen uptake corresponding to the ventilatory threshold (VO$_{2VT}$) as an index of aerobic power were determined during a graded exercise test, using a cycle ergometer (Bodyguard-990; Jonas Øglænd A. S., Norway). Following 3 minutes of warming-up by unloaded cycling, the work rate was increased every 4-minutes by 50 W until exhaustion. The frequency of pedaling was 60 revolutions per minute. During exercise, the expired gas was analyzed continuously for O$_2$ and CO$_2$ concentration using a mass spectra gas analyzer (WSMR-1400, Westron Co., Japan) and an automatic respiratory gas analyser (RM-300i, Minato Ikagaku Co., Japan). VO$_{2VT}$ values were determined by defining the upward break point in the end-tidal O$_2$ partial pressure and the ventilatory equivalent for O$_2$ (VE/VO$_2$) with the plateauing of end-tidal CO$_2$ pressure and no change or continued fall in the ventilatory equivalent for CO$_2$ (VE/VCO$_2$) (Beaver et al. 1986).

**Statistical analyses**

All values were reported as mean±standard deviation (SD). Unpaired t-test was used to evaluate the significance of the difference between two groups. In all analyses, the significance level was set at $P<0.05$.

**Results**

Table 1 shows the physical characteristics of the subjects. There were no significant differences in the stature and body mass between the two groups. BMI was larger in Group EXE than in Group SED, but the result was not significant.

Table 2 shows the body composition, half-life and WT.

<table>
<thead>
<tr>
<th></th>
<th>Group EXE</th>
<th>Group SED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr.)</td>
<td>20.8±1.9</td>
<td>21.6±2.5</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>170.6±6.4</td>
<td>172.9±6.3</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>57.8±2.5</td>
<td>63.9±7.5</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>20.1±1.2</td>
<td>21.4±2.3</td>
</tr>
</tbody>
</table>
TBW and LBM were larger in Group SED than in Group EXE, but the result was not significant. The percent of the body fat and fat mass were significantly larger in Group SED than in Group EXE ($P < 0.05$). WT (%), WT (L/kg), and WT (ml/kg/day) were significantly higher in Group EXE than in Group SED ($P < 0.05$, respectively).

Table 3 shows the aerobic capacity of the subjects. Both $V\dot{O}_{\text{max}}$ and $V\dot{O}_{\text{VT}}$ were significantly higher in Group EXE than in Group SED ($P < 0.05$, respectively).

As shown in Fig. 1, the half-life of $D_2O$ concentration was longer in Group SED than in Group EXE (7.52±0.77 days vs. 5.89±0.81 days, $P < 0.05$). WT (%) was slower in Group SED than Group EXE (9.39±1.21% vs. 11.99±1.96%, $P < 0.05$).

Fig. 2 shows a significant correlation between WT with $V\dot{O}_{\text{max}}$ (A) and WT with $V\dot{O}_{\text{VT}}$ (B) in all subjects. The correlation coefficients between WT with $V\dot{O}_{\text{max}}$ in Group EXE and in Group SED were 0.735 and 0.760, respectively, and between WT with $V\dot{O}_{\text{VT}}$ in Group EXE and in Group SED were 0.713 and 0.747, respectively.

Fig. 3 shows the relationship between WT with running.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Body composition and body water turnover</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group EXE</td>
</tr>
<tr>
<td>(n=8)</td>
<td>(n=8)</td>
</tr>
<tr>
<td>TBW (L)</td>
<td>35.5±1.2</td>
</tr>
<tr>
<td>LBM (kg)</td>
<td>48.4±1.7</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>9.4±2.6</td>
</tr>
<tr>
<td>Fat mass (%)</td>
<td>16.1±3.9</td>
</tr>
<tr>
<td>half-life (days)</td>
<td>5.89±0.81</td>
</tr>
<tr>
<td>WT (%)</td>
<td>11.99±1.96</td>
</tr>
<tr>
<td>WT (L/day)</td>
<td>4.25±0.66</td>
</tr>
<tr>
<td>WT (ml/kg/day)</td>
<td>73.5±11.0</td>
</tr>
</tbody>
</table>

* Significantly different between groups ($P < 0.05$)

TBW: total body water, LBM: lean body mass, WT: body water turnover

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Aerobic capacity</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Group EXE</td>
</tr>
<tr>
<td>(n=8)</td>
<td>(n=8)</td>
</tr>
<tr>
<td>$V\dot{O}_{\text{max}}$ (ml/kg/min.)</td>
<td>62.9±4.0</td>
</tr>
<tr>
<td>$HR_{\text{max}}$ (beats/min.)</td>
<td>186.6±4.0</td>
</tr>
<tr>
<td>$V\dot{O}_{\text{VT}}$ (ml/kg/min.)</td>
<td>46.9±3.3</td>
</tr>
<tr>
<td>$HR_{\text{VT}}$ (beats/min.)</td>
<td>155.6±8.5</td>
</tr>
</tbody>
</table>

* Significantly different between groups ($P < 0.05$)
distance during the experimental period. A significant correlation was obtained and the correlation coefficient was 0.791.

**Discussion**

In this study, we compared WT between the endurance exercise and age-matched sedentary men. The results of this study indicate that the differences in WT between groups corresponded to about 30% on a mean basis, and that WT increased with the physical activity level.

Previous studies indicated that WT seemed to be largely affected by the physical activity level (Fusch et al., 1996; Fusch et al., 1998; Lane et al. 1997; Leiper et al., 2001). Leiper et al. (2001) compared WT between the cycling exercising and sedentary men, and found that WT was faster in individuals undertaking prolonged cycling, who trained for 50 km per day, than in sedentary men. Fusch et al. (1996) measured WT in 11 men and 4 women during a trekking tour at high altitude, and reported WT was higher during trekking than before the tour. These previous studies suggested that WT is accelerated by the increased physical activity. Although these studies did not measure the metabolic water, respiration water formation or perspiration secretion directly, it was speculated that such accelerations were affected by the elevations of these factors. Thus, in this study, WT was faster in Group EXE than in Group SED, due to the habitual exercise in Group EXE.

Another study performed under special conditions showed results corresponding to our findings. Lane et al. (1997) compared WT in astronauts between the space flight period and ground-based period, and demonstrated lower WT during the space flight period than the ground-based period possibly due to the lower intake of fluids and metabolic water production during flight. This previous study shows that an increase in WT was affected by the augmentation in the physical activity level of subjects during the ground-based period. They mentioned that the reason for this augmentation in WT was partially accounted for by the higher intake of fluids and metabolic water production during the ground-based period, and if the water intake was adequate, WT could be expected to increase during the space flight period. It is suggested that our results may be affected by the same factors.

As shown in Fig. 2, a significant linear relationship between WT and the aerobic capacity was obtained. Furthermore, in the Group EXE, a significant relationship between WT and the running distance during the experimental period was acquired (Fig. 3). Fusch et al. (1998) reported that the increased WT was significantly correlated with the physical training state of the subjects: the better trained subjects had a higher turnover and could tolerate a greater loss of body water, suggesting that better trained subjects have an increased metabolic water production and insensible water loss due to a higher exercise intensity (pace, workload carried out) during exercise. Interestingly, they also indicated that the well trained subjects may have greater muscle glycogen and therefore more glycogen-bound water than less trained subjects, and thus a higher turnover of muscle glycogen during trekking may be related to a higher turnover of water (Fusch et al., 1998). The results of this study, which shows a significant relationship between WT with running distance during the experimental period, supported their findings. The increase in WT was larger in their study (about 50% higher than that during the control period) than in our study (about 30% higher than sedentary). It is speculated that this difference was due to the period and intensity of the physical activity of the day, excluding a routine exercise.

From the findings of this study and previous studies, the relationship between WT and the physical activity is clear. It is hypothesized that the higher aerobic power correlates with the higher physical activity, and thus induce WT higher. However, this argument requires a longitudinal intervention study measuring the physical activity throughout the day for all subjects.

In conclusion, the endurance exercise training increased WT corresponding to about 30% in young men, showing that WT and aerobic capacity were well correlated. Although the nature of this relationship is not yet fully understood and should be investigated in further detail, exercise training induces higher WT in young men. Furthermore, the results of this study suggest that a higher level of physical activity may induce a higher body water turnover in the healthy state.

**References**


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