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# Concentrations of Trace Elements in Sweat during Sauna Bathing

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HOSHI, A., WATANABE, H., KOBAYASHI, M., CHIBA, M., INABA, Y., KIMURA, N. and ITO, T. *Concentrations of Trace Elements in Sweat during Sauna Bathing.* Tohoku J. Exp. Med., 2001, **195** (3), 163-169 —— Trace elements in sweat during sauna bathing were assessed. Sweat collected by the whole body method was compared with that collected by the arm bag method. The sweat samples were collected from ten healthy male adults aged 22-26 years, by heat exposure in dry sauna bathing (60°C, 30 minutes). Concentrations of major (Na, Cl, K, Ca, P and Mg) and trace (Zn, Cu, Fe, Ni, Cr and Mn) elements in sweat tended to be lower in the arm bag method than in the whole body method. It was found that Ca, Mg, Fe and Mn concentrations in the arm bag method were significantly lower than those in the whole body method. The amount of trace elements in sweat measured by the arm bag method was less than that by the whole body method; significant differences were observed in Fe and Mn amounts. These observations suggest that excretion of trace elements by sweating induces trace element decrease. Therefore, athletes and workers who work in a hot environment and sweat much habitually should ingest adequate amounts of trace elements.
———— trace elements; major elements; sweat; sauna bathing; sweat collection
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With heavy sweating during work or exercise in a hot environment, not only body water but also major elements such as sodium (Na) and chlorine (Cl) are lost (Nielsen and Nielsen 1965). Mercury, highly toxic metal to men, is excreted from the body by sweating. Therefore, heat exposure such as sauna bathing was used as a therapy for mercury poisoning

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(Putman 1972).

Recent studies have shown that nickel (Ni) concentration in plasma was at the lower level among workers who work in a hot environment (Hohnadel et al. 1973). There have been reported that iron (Fe), zinc (Zn), and copper (Cu) concentrations in plasma and blood cells were at the lower level in athletes (Dressendorfer and Sockolv 1980; Haralambie 1981; Campbell and Anderson 1987; Singh et al. 1990). Also, it has been reported that the presence of trace element deficiencies such as Fe (Pate et al. 1993; Cook 1994) or Zn (Nishiyama et al. 1996) deficiency anemia in athletes. A possible cause of these deficiencies is the loss of a large amount of essential trace elements.

For measurement of the sweat components, collection of sweat from the whole body is important. Because, the sweat rate and the contents differ among sweating areas of the body (Shvartz et al. 1974; Gutteridge et al. 1985; Aruoma et al. 1988). However, sweat collection during work is very difficult by this method. The arm bag method is a local sweat collection method, with which sweat can be collected easily during various activities (Van Heyningen and Weiner 1952).

In this study, the amount of trace element loss during sauna bathing was assessed, and also the contents of various elements were compared in sweat collected by the whole body method with the arm bag method.

## MATERIALS AND METHODS

### *Subjects and experimental design*

The subjects were ten healthy males whose mean ($\pm$S.D.) age, height, and weight were $23.3 \pm 1.3$ year, $173.2 \pm 3.3$ cm, and $71.14 \pm 6.62$ kg, respectively. They were given a detailed explanation of this study, and informed consent was obtained from all subjects. Heat exposure experiments were performed by dry sauna bathing at 60°C for 30 minutes. Sweat was collected by the whole body and arm bag methods. In the whole body method, a polyethylene sheet was placed in a polyethylene washtub (1 m in diameter) so that sweat could be collected on the sheet. In the arm bag method, sweat was collected in a polyethylene arm bag (circumference, 50 cm; length, 80 cm) from the nondominant arm of each subject. Subjects were weighed immediately before and after bathing (HW-100; A & M, Tokyo). The body was scrubbed with surfactant (Sunny safe; Daiichi Kogyo Yakuhin, Kyoto), rinsed copiously with distilled water, and dried by evaporation before and after sauna bathing. In addition, a shower cap was worn during sauna bathing. The whole sweat volume was determined by loss of weight during sauna bathing. The heart rate was continuously recorded (Canon, Tokyo).

### *Determination of major and trace elements*

Sweat samples were centrifuged ($1000 \times g$, 10 minutes). The supernatants were removed and filtered through a 0.45 $\mu$m Millipore micro filter. Samples were stored frozen at $-20$°C until analysis. Sweat samples were diluted by 0.5% nitric acid solution. Fe, Cu, Zn, Ni, manganese (Mn), chromium (Cr), and magnesium (Mg) were determined by microwave induced plasma-mass spectrometry (P-7000; Hitachi, Tokyo) (Shinohara et al. 1994). Na, Cl, and Potassium (K) were measured by the electrode method (Saruta 1991), Calcium (Ca) was measured by the orthocresolphthalein complexone (O-CPC) method (Connerty and Briggs 1966).

### *Statistical analyses*

The Halbau statistical package was used for statistical analyses (Gendaiigakushoin, Kyoto). Values are expressed as a mean and the standard deviation ($\pm$S.D.). The paired $t$-test was used to compare the values between the whole body method and arm bag method. The level of significance was defined as $p < 0.05$.

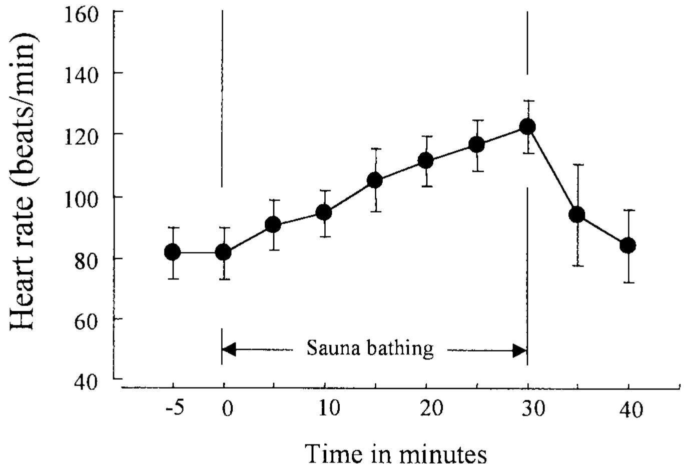

Fig. 1. Changes in heart rates during sauna bathing.

## RESULTS

*Sweat volume and heart rate*

Mean body weights were 71.14±6.62 kg before and 70.59±6.62 kg after sauna bathing, showing a significantly lower ($p<0.01$) weight after the sauna bathing. Thus, the mean whole sweat volume was estimated to be 0.55±0.16 liter.

Fig. 1. shows the changes of heart rates during sauna bathing, in which the heart rate increased with time and was 122.8±8.5 beats/minutes at the end of bathing, showing about a 40 beats/minutes increase compared with that at rest.

*Major and trace elements concentrations in sweat*

Table 1. shows the mean concentrations of major elements in sweat. They tended to be lower in the arm bag method than in the whole body method, with significantly lower ($p<0.01$) concentrations of Ca and Mg.

TABLE 1. *Concentrations of major elements in sweat during sauna bathing*

| Element | Whole body method | Arm bag method |
|---|---|---|
| Na (mEq/liter) | 63.1±35.9 | 49.7±13.7 |
| Cl (mEq/liter) | 53.0±30.0 | 41.6±12.1 |
| K (mg/liter) | 376.8±140.8 | 356.7±134.2 |
| Ca (mg/liter) | 40.3±24.1 | 20.7±8.0** |
| P (mg/liter) | 0.3±0.5 | 0.2±0.4 |
| Mg (mg/liter) | 5.2±3.0 | 1.9±0.4** |

**$p<0.01$ significant difference between whole body and arm bag methods.

Fig. 2. shows the trace element concentrations in sweat. Mean Zn concentrations in sweat were 366.9±378.1 μg/liter by the whole body method and 169.4±153.7 μg/liter by the arm bag method. Cu concentrations were 39.1±27.0 μg/liter and 27.4±12.5 μg/liter, respectively. Those of Fe were 33.0±15.3 μg/liter and 15.1±7.2 μg/liter, respectively. Those of Ni were 23.0±45.5 μg/liter and 11.8±11.5 μg/liter, respectively. Those of Cr were 10.7±25.1 μg/liter and 4.5±6.7 μg/liter, respectively. Those of Mn were 10.2±4.3 μg/liter and 5.1±2.1 μg/liter, respectively. Trace element concentrations in the arm bag method were less than those in the whole body method, with significantly lower ($p<0.01$) concentrations of Fe and Mn.

*Amounts of trace elements loss to sweat*

Fig. 3. shows the amounts of trace elements loss to sweat, which were calculated from the sweat concentration and whole sweat volume. The amounts of loss of Zn to sweat were 186.9±170.4 μg by the whole body method and 83.3±

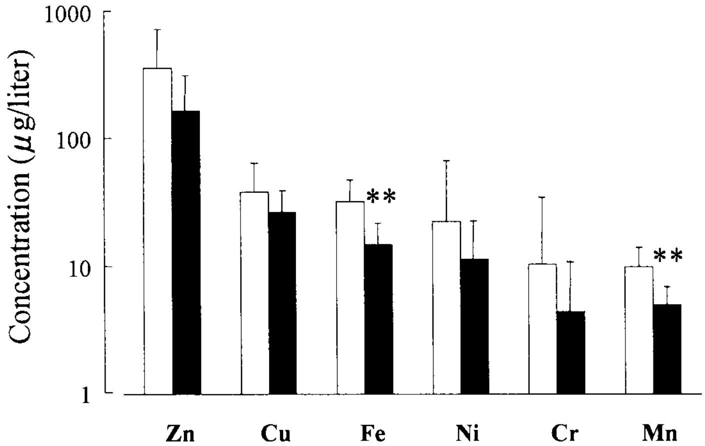


Fig. 2. Concentrations of trace elements in sweat during sauna bathing.
□, whole body method; ■, arm bag method.
$^{**}p<0.01$, significant difference between whole body and arm bag method.

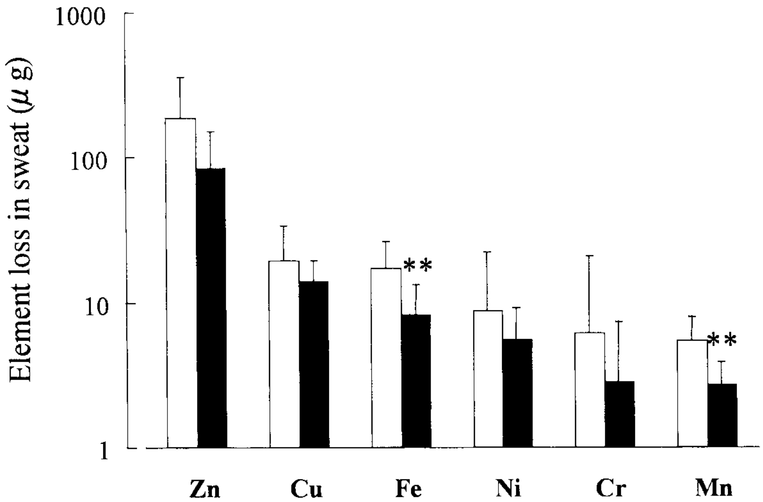


Fig. 3. Amounts of trace elements loss to sweat during sauna bathing.
□, whole body method; ■, arm bag method.
$^{**}p<0.01$, significant difference between whole body and arm bag method.

66.7 μg by the arm bag methods. Cu was 19.6±14.2 μg, 13.9±5.5 μg, respectively. Fe 17.4±9.0 μg, 8.2±5.2 μg, respectively. Ni 8.7±13.8 μg, 5.5±3.7 μg, respectively. Cr 6.1±14.9 μg, 2.8±4.5 μg, respectively. Mn 5.4±2.5 μg, 2.7±1.2 μg, respectively. The amounts of loss of trace elements in the arm bag method were less than those in the whole body method; significant differences ($p<0.01$) were observed for Fe and Mn.

## DISCUSSION

During sauna bathing, the heart rate increased with time and was 122.8±8.5 beats/minute at the end of bathing, showing about a 40 beats/minute increase compared with that at rest (Fig. 1). However, no subject showed an increase to 150 beats/minute, which is considered to be the caution limit during heat exposure (Miura and Saito 1952). It have been suggested that the dehydration of about 1% of body weight induces the thirst (Yurugi 1980).

However, the sweat volume in this study was about 0.55 litter, which was less than 1% of the body weight. Therefore, the degree of the physical stress during heat exposure by sauna bathing in this study was considered to be slight.

Sweating is enhanced during exercise or heat exposure (Nielsen and Nielsen 1965), and major elements such as Na and Cl are lost (Ogawa 1983; Nishimuta and Suzuki 1989). In this study, the major element concentrations in sweat (Table 1) were almost the same levels as those of previously reported values (Ogawa 1983; Nishimuta and Suzuki 1989).

Recent studies have shown that Ni concentration in plasma was at the lower level in a workers who work in a hot environment (Hohnadel et al. 1973). There have been reported that Fe, Zn, and Cu concentrations in plasma and blood cells were at the lower level in athletes (Dressendorfer and Sockolv 1980; Haralambie 1981; Campbell and Anderson 1987; Singh et al. 1990). Also, it has been reported that the presence of trace element deficiencies such as Fe (Pate et al. 1993; Cook 1994) or Zn (Nishiyama et al. 1996) deficiency anemia in athletes. A possible cause of these deficiencies is the loss of trace elements from the body. In fact, this study confirmed the loss of trace elements to sweat (Figs. 2 and 3).

The "6th revision of recommended dietary allowances for the Japanese" (Healthy Nutrition Information Workshop 1999) shows the following intake standards in adult males: Fe, 10 mg/day; Zn, 11-12 mg/day; Cu, 1.8 mg/day; Mn, 4.0 mg/day; Cr, 30 $\mu$g/day, etc. The mean sweat volume in this study was 0.55 litter, less than 1% of the mean body weight. The ratio of the loss of each trace element in this study to its dietary allowance for the adult Japanese can be estimated to be 0.1-2.0%. During marathon races, 5 litter body water is lost due to sweating (Paugh et al. 1967), and the sweat rate in athletes who perform strenuous training is estimated to be about 7-10 litter/day (Fallon et al. 1998; Rehrer 2001). The percentage of the trace element loss in sweat to its daily allowance in athletes is more than 20 times that observed in this study, indicating a marked loss of trace elements in athletes. Therefore, athletes and workers in a hot environment who sweat much habitually should ingest adequate amounts of trace elements.

The amount of loss of each element determined by the arm bag method was less than that determined by the whole body method; the differences were significant in the mean Fe and Mn ($p<0.01$) (Fig. 2). In addition, no association was observed between the values determined by the two methods.

Wheeler et al. (1973) reported that lower concentration of Fe in sweat were associated with higher sweat rates, they would be diluted according to the large amount of sweat. Also, Aruoma et al. (1988) observed that concentrations of trace elements were tended to be lower in the arm site than in the other sites. In this study, on the other hand, concentrations of trace elements in sweat were lower in the arm bag method than in the whole body method. Therefore, the higher concentration of trace elements in the whole body method seems to be other factor.

It has been reported that concentrations of Fe in sweat was higher in the sweating latter half sample than in the first half sample (Brune et al. 1986; Waller and Haymes 1996). The higher sweat Fe concentrations in the first half sample was due to cellular debris and external contamination (e.g., dust), which was lodged in the sweat pores (Waller and Haymes 1996). Also, the large amount of Fe and Mn are included the air born dust (Valerio et al. 1988). In the whole body method, sweat discharged from the whole body was collected in a washtub, whereas, in the arm bag method, sweat was collected in a polyethylene arm bag covering an arm. Therefore, sweat collected by the whole body method was in contact with the skin and air for a longer time than that collected by the arm bag method. As a result, trace elements in the air and from exfoliated skin may have been mixed with or eluted into sweat collected by the whole body method. Therefore, in this study, the higher concentrations of trace elements, especially Fe and Mn in the whole body method were probably due to cellular debris and external contamination.

As another reason, since this study was performed at a temperature of 60°C, the sweat collected by the whole body method may have been concentrated by evaporation. On the other hand, it was reported that sweating gradually decreases during use of an arm bag for a long time because saturation to sweat vapor occurs, and sweat cannot evaporate (hidromeiosis) (Myhre and Robinson 1977; Ogawa et al. 1982). In this study, the higher major and trace element concentrations in sweat determined by the whole body method than those determined by the arm bag method as well as no definite association between the concentrations determined by the two methods may be a complex effect of the above factors.

It is possible that a large volume of sweating due to daily exercise and/or work in a hot environment causes trace element loss in the body, and the resulting trace element deficiency reduces the blood trace element concentration or induces Fe or Zn deficiency anemia. Therefore, athletes and workers in a hot environment who sweat much habitually should ingest adequate amounts of trace elements.

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