The Excretion of Trace Metals in Human Sweat

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ABSTRACT

The concentrations of zinc, copper, iron, nickel, cadmium, lead, manganese, sodium and chloride in the sweat of six males and three females were determined after collections utilizing a total body washdown technique. From our results, sweat appears to be an important excretory pathway for zinc and copper. The mean concentrations of nickel and cadmium in sweat were higher than those reported for urine, that of lead was similar to urine. The loss of manganese in sweat is insignificant. Levels of zinc and iron were lower in sweat from females, possibly reflecting compensation for menstrual and other losses.

Collections were made in six subjects simultaneously utilizing a total body washdown method and collections from one arm in an occlusive arm-bag. The arm-bag collection method gave higher and more variable results and is not recommended as an indicator of loss from the entire skin surface.

Introduction

This study was undertaken in order to determine the importance of excretion in human sweat of certain trace metals. The excretion of essential trace metals in sweat is of potential significance in nutrition and in the consideration of heat stress. The loss of non-essential or toxic trace metals in sweat could be of toxicologic and therapeutic importance. Balance studies to date have given little attention to the amount of trace metal excreted via sweating. As with other excretory pathways, the relative importance of the sweat will differ depending on the trace metal under study. Human studies are particularly important as there is no good animal model for total body human eccrine sweating.

It is important to obtain a specimen which will be representative of the total loss in sweat of the substance in question. To date investigators who have studied the concentrations of trace elements have usually collected the sweat from the forearm in an occlusive bag. It has been shown for chloride, lactate, urea, sodium, potassium and creatinine that collection in such a manner leads to a misleadingly high estimate of total body sweat concentrations. The difference has been attributed either to elevations in local skin...
temperature or humidity. It has been shown that there are regional variations in the concentration of such elements as sodium and chloride in body sweat. Additionally, arm-bag sweat is primarily of eccrine gland origin while whole body sweat is a variable mixture of eccrine and apocrine secretions. The eccrine contribution rises sharply with vigorous muscular activity or with emotional factors such as anxiety or fear. The two types of sweat are known to differ in composition.

In this study, the concentrations were determined of sodium, chloride, zinc, cadmium, lead, iron, copper, nickel and manganese in male and female sweat by a total body washdown method. The results obtained by the simultaneous use of the standard total body washdown method of sweat collection were also compared with those obtained by collecting sweat in an occlusive arm-bag.

Materials and Methods

Whole Body Sweat Collection

Sweat was collected from six males and three female healthy, adult volunteers, aged between 23 and 33 years, using a modification of the method described by Kuno. None of the subjects was taking drugs or medications, including oral contraceptives. Informed consent was obtained after the nature of the procedure had been fully explained.

Sweat collections took place in a controlled temperature chamber at 37.8°C and 35 percent relative humidity, conditions under which the sweat rapidly evaporated. Prior to entering the chamber each patient showered and rinsed with distilled, deionized water. Analysis of the water used for rinsing showed no significant detectable trace metals. Polyethylene film was used to prevent contact between the subject's skin and garments. After entering the chamber the polyethylene film and garments were removed and the subject weighed on a polyethylene covered counter-beam scale (accuracy ± 10g). For a 90 minute period, subjects exercised on a bicycle ergometer with alternating 10 minute exercise and rest periods. The ergometer work load was 600 kgm per minute for males and 400 kgm per minute for females. Pedals, handles and seat of the ergometer were covered with polyethylene film to prevent contamination. The minimal amount of dripped sweat was collected on polyethylene sheeting. Rectal temperature was monitored continuously and pulse taken every 10 minutes. Tap water at the same temperature as the chamber was provided for drinking ad lib.

At the end of the period, the subject was rinsed down from the hairline of the forehead with distilled, deionized water into a large, acid-washed, plastic basin. After drying, the subject was reweighed. The volume of sweat was assumed to be the difference between the weight of the subject before and after the experimental period, after allowing for water consumed or urine passed. The relatively considerably smaller amount of water loss through the lungs was ignored.

The volume of the washings was recorded before transfer to acid-washed glass bottles and storage at 4°C until analysis. After filtration to separate the liquid from the dermal detritus, a 300 ml aliquot was analyzed for zinc, iron, lead, nickel, copper, manganese, cadmium, sodium and chloride using atomic absorption spectroscopy by the methods of Slavin.

Arm-bag Sweat Collection

Six subjects, three male and three female, simultaneously wore polyethylene bags over one forearm in order to compare levels of trace metals in whole-body sweat and sweat collected in an occlusive arm-bag. These specimens were handled as described previously.

* Quinton Instrument Corp., Uniwork Ergometer Model 844.
with the exception that the entire specimen was filtered and used for analysis. Student's "t" test was used to determine the statistical significance of differences in results.

Results

The mean sweat loss over a 90 minute period was 899 ml (range 620 to 1090 ml) for males and 847 ml (range 775 to 915 ml) for females. A rise in the rectal temperature occurred in all subjects shortly after commencing the first period of ergometer work and reached a plateau (99° to 100.8°F) after either the third or fourth exercise period. A rise in pulse rate to between 114 and 156 beats per minute accompanied the rise in temperature. Only one male experienced any obvious discomfort during the experiment and required an additional 20 minute rest between the first and second work periods. He recovered and completed the experiment without ill-effects.

The concentrations of metals obtained for total body sweat are given in table I. Under the study conditions, the concentrations of sodium and chloride were somewhat higher in sweat from the females. Concentrations of other elements were similar in both sexes, except for zinc and iron which were lower in females perhaps because of reduced body stores as a result of losses in menstruation, pregnancy and lactation. The mean cadmium concentration in females was affected by one very high value (230 μg per l), which was rejected for the purpose of determining the mean.

Comparative results for the sweat collected simultaneously by whole body washing and by occlusive arm-bag collection are given in table II. Significant differences were found between values obtained by the two different collection methods (p < 0.05) in all cases. The concentrations in arm-bag sweat were from 1.4 to 5.3 times higher than the concentrations in sweat collected by whole body washing depending on the particular metal analyzed. In addition, arm-bag sweat concentrations were more variable from subject to subject than were the concentrations obtained by the whole body washdown method.

No correlation between the concentrations of sodium and chloride and that of any trace metal was found in the limited number of subjects studied, nor could any correlation be made between the concentrations of one trace metal and another. The inverse relationship between sweat volume and trace metal concentrations reported by Hohnadel12 was not seen over the limited range of sweat volumes observed in this study.

Discussion

Any study addressing the loss of solutes in human sweat is made difficult by the marked variations in rates of excretion and in solute concentrations under different conditions. Many of the variables for sodium and chloride excretion have been studied. These include the region of the body, rate and duration of sweating and degree of acclimatization.21 The latter two factors are intimately related, the rate of sweating being inversely proportional to the degree of acclimatization. The concentration of NaCl in sweat falls with acclimatization10,17 and has been reported as low as 5 Eq per L2,8,11,19,33 or as high as 148 Eq per
Comparison of Sweat Volumes and Concentrations of Trace Metals, Sodium and Chloride Between Sweat Collected by Whole Body Washdown Method and Sweat Collected Simultaneously in an Occlusive Arm-bag

<table>
<thead>
<tr>
<th></th>
<th>Whole Body Sweat</th>
<th>Arm-bag Sweat</th>
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<tbody>
<tr>
<td></td>
<td>Mean ± S.D.</td>
<td>Range</td>
</tr>
<tr>
<td>Sweat-volume (ml)</td>
<td>919 ± 142</td>
<td>775-1090</td>
</tr>
<tr>
<td>Zn (µg/L)</td>
<td>773 ± 332</td>
<td>400-1200</td>
</tr>
<tr>
<td>Pb (µg/L)</td>
<td>60 ± 33</td>
<td>40-120</td>
</tr>
<tr>
<td>Fe (µg/L)</td>
<td>258 ± 203</td>
<td>40-550</td>
</tr>
<tr>
<td>Cu (µg/L)</td>
<td>1360 ± 314</td>
<td>860-1600</td>
</tr>
<tr>
<td>Ni (µg/L)</td>
<td>55 ± 16</td>
<td>40-80</td>
</tr>
<tr>
<td>Mn (µg/L)</td>
<td>20 ± 9</td>
<td>10-30</td>
</tr>
<tr>
<td>Na (mEq/L)</td>
<td>17 ± 6</td>
<td>10.6-28.6</td>
</tr>
<tr>
<td>Cl (mEq/L)</td>
<td>15 ± 7</td>
<td>8.5-26.31</td>
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Women on the average have a higher temperature threshold for sweating than men. In this study, carried out in summer, it was likely that all subjects were at least partially acclimatized which would account for the comparatively low sodium values.

The excretions in sweat of copper, zinc, lead, cadmium, nickel and manganese have not previously been determined using a total body washdown method. The results of previous studies of trace metal concentrations in sweat using limited sweat collection including occlusive bag collection have resulted in highly variable results. For example, mean sweat copper concentrations have been reported to be as high as 4.9 mg per L or as negligible. The levels of sweat copper excretion (1.3 ± 0.3 mg per L) found in this study appear nutritionally significant in terms of the estimated daily dietary intake of two to five mg and urinary excretion of five to 25 µg per day. These findings suggest that important excretion of copper may take place in sweat as well as in bile.

The sweat zinc excretion observed was significantly higher than the reported mean daily urinary zinc excretion of 643 µg per L. Our results are consistent with the contention of Prasad that zinc excretion in sweat may have played a major role in the development of hypogonadic dwarfism in certain areas of Egypt and Iran. A higher mean concentration of copper than zinc was observed by us in the sweat of both males and females. This does not support the postulate that the lower risk of coronary heart disease in men who exercise regularly may be due to the greater loss of zinc over copper in sweat.

After several hours of maximal sweating, the sweat rate will fall and profuse sweating day after day normally results in acclimatization with decreased sweat rates and solute concentrations. The influence of acclimatization and of continued heavy sweating on copper and zinc concentrations has not yet been determined. However, extrapolating from the results obtained by us in the first 90 minutes of exercise to a total sweat excretion of from three to six liters per day sweat losses of 4.5 to 9 mg of copper and three to six mg of zinc appear possible. It is even possible that zinc, copper and perhaps other losses in sweat are important in the pathogenesis of heat stroke.

Our results for sweat iron excretion are considerably lower than those reported for four adult males by Mitchell et al of 1.91 mg per L at sweat rates of less than 200 ml per hour and 1.64 mg per L at sweat rates of from 200 to 900 ml per hour. However, these authors studied whole sweat rather than cell-free sweat. Cell-rich sweat is rich in desquamated cells which contain relatively large amounts of iron.
In Table III the mean concentrations of lead, cadmium, nickel and manganese found by us in sweat are compared with published values for the usual adult dietary intake average and urinary concentrations. In the case of lead, urinary and sweat concentrations appear similar. Sweat concentrations of cadmium and magnesium appear higher than those in urine whereas in the case of manganese both urinary and sweat excretion appear physiologically insignificant.

Our results indicate that the collection of sweat in an occlusive arm-bag, as practiced in a number of previous investigations, can lead to high and quite variable results for trace metal concentrations when compared with results obtained using the body washdown technique. This is unfortunate as the former is a more convenient method of sample collection. On the basis of our findings, it is our recommendation that the washdown method is generally preferable.

References