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U. S. ARMY MEDICAL RESEARCH & NUTRITION LABORATORY



THE TRACE MINERAL LOSSES IN SWEAT

REPORT 284
18 AUG 1964

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UNITED STATES ARMY
MEDICAL RESEARCH AND DEVELOPMENT COMMAND

US ARMY MEDICAL RESEARCH AND NUTRITION LABORATORY
Fitzsimons General Hospital
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Report No. 284

18 August 1964

Report on

THE TRACE MINERAL LOSSES IN SWEAT

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Report No. 284
Project No. 3A012501A803 - Military Internal Medicine
Task No. 03 - Biochemistry
Sub-Task No. 00 - Mineral Metabolism

THE TRACE MINERAL LOSSES IN SWEAT

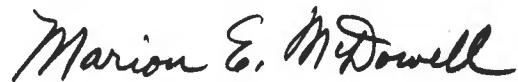
OBJECT:

The primary objective of this study was to evaluate the importance of the trace mineral losses in sweat, in relation to both normal dietary intakes and to the daily minimum allowances.

SUMMARY:

The results of this study show that considerable quantities of the trace minerals, including zinc, selenium, copper, cobalt, iodine, strontium, molybdenum, nickel, lead and chromium, are excreted in sweat, under conditions that produce profuse sweating. These losses are extremely important since they reflect losses that should be included in balance studies, which would greatly aid in evaluating more realistically the minimal daily requirements. As in previous studies, the excretion of these trace minerals in sweat decreases appreciably during acclimatization to hot environments.

APPROVED:



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THE TRACE MINERAL LOSSES IN SWEAT

The recommended daily mineral allowances established by the Food and Nutrition Board of the National Research Council ('58) and the Food and Agriculture Organization of the United Nations ('57) are based on data in the literature on balance and equilibrium studies. In most instances the accumulative losses in computing balance have included only the urine and fecal excretions, even though other losses are also observed in sweat, and can possibly be found in expired air. Recent studies by Consolazio, et al. ('62, '63a, '63b) have reaffirmed the observations of Cuthbertson and Guthrie ('34), Mitchell and Hamilton ('49) and more recently Mitchell and Edman ('62), that the nitrogen and mineral losses in sweat are quite appreciable. In one study, where the subjects consumed 441 mg of calcium/day for a 48 day period while living at temperatures of 21.1, 29.4 and 37.8°C, it was observed that 8.1, 11.6 and 20.2 mg of calcium/hour, respectively, was excreted in sweat. In a second study, the nitrogen excretion in sweat ranged from 1.8 to 2.6 gm/day on intakes of 12.6 gm of nitrogen/day. In both instances when sweat losses were included in the computation of balance, the subjects were in negative balance.

These fairly high mineral and nitrogen excretions in sweat, especially during profuse sweating conditions, indicated that these losses were sufficiently important to warrant further investigation. It is the opinion of investigators (Mitchell and Hamilton '49) (Mitchell and Edman '62) that unless these losses are included as part of the total daily output in balance studies, erroneous conclusions may be drawn.

Sweat samples collected in polyethylene bags covering one whole arm, were assumed to be representative of all the sweat excreted while the subject was in the chamber. The immediate question that comes to mind is the comparability of composition of arm sweat and total body sweat. It has been shown by some investigators that the composition of arm sweat is reasonably representative of the total body sweat. van Heyninger and Weiner ('52) on the other hand are in disagreement, observing that the arm sweat is more concentrated than the rest of the body. In a recent study by Consolazio, et al. ('64) it has been shown that the relationship between calcium excretion in arm sweat and in total body sweat is fairly good, especially under conditions where the arm sweat quantity is above 15 gm.

The primary object of this study was to evaluate the importance of the trace mineral losses in sweat in relation to a normal intake and in relation to the minimal daily requirement or allowance.

Experimental Design

The study was conducted on three healthy men and consisted of four 4-day periods of exposure in an environmental chamber at 37.8°C and 50% relative humidity. The daily physical activity consisted of only 30 minutes of moderate activity on the bicycle ergometer with the remainder of the day spent in sedentary type activities.

Sweat rates were measured for each period using the method of Adolph, et al. ('47). These sweat rates were determined by measuring weight changes during the exposure periods and then adjusting for water intake, and weight loss due to urinary and fecal output. (Gaseous exchange of respiration contributes a small quantity to the change in weight, but usually less than 1% of the observed decrease in body weight.) Arm sweat samples were collected during both the morning and afternoon exposures, using the arm bag technique described in our previous studies. It should be emphasized that the sweat excretion data reported in this study was for an exposure period of only 7 1/2 hours. The daily food intake was constant during the entire study and consisted of 4 menus which were rotated to coincide with each period. The 4 menus contained a daily average of 3283 KCalories including 93.3 gm of protein, 171.1 gm of fat, 328.7 gm of carbohydrate, 12.46 mg of zinc, 3.52 mg of copper, 4.24 mg of manganese, 889 mcg of chromium, 172 mcg of molybdenum, 202 mcg of nickel and 404 mcg of lead.

Complete urinary and fecal collections were made for 4-day periods, coinciding with the repetition of the 4 menus utilized. Mineral balances were computed on each man for each period, based on the inclusion and exclusion of sweat losses.

The food composites, urine, feces and sweat samples were analyzed chemically for zinc (Vallee and Gibson '48) and iodine (ICNND '63). The other trace minerals were analyzed with the emission spectrograph (Jarell-Ash '60). They included copper, chromium, cobalt, strontium, molybdenum, manganese, selenium, tin, nickel, aluminum and lead.

Results

Table I represents the quantities of the various trace minerals that were excreted in sweat during the 16 day experiment at 37.8°C temperatures. These include cobalt, copper, manganese, iodine, chromium, selenium, zinc, molybdenum, tin, nickel, aluminum, lead and strontium. After acclimatization the copper excretion during a 7 1/2 hour period was fairly high, averaging 1.94, 1.79 and 1.04 mg for each of the last 3 periods at high temperatures. Selenium excretions in sweat averaged from 0.30 to 0.37 mg during a 7 1/2 hour collection period, and chromium averaged from 57 to 61 mcg during the same period.

The data in Table II represents the zinc intake, output and balance for 3 men exposed to temperatures of 37.8°C. The zinc excretion in sweat decreased appreciably after the first 4 days of acclimatization to heat dropping from 13.7 to 2.2 mg/day. These zinc excretions in sweat were approximately 18% of the total daily intake of 12.5 mg zinc.

The copper balance computed with and without the sweat losses are presented in Table III. When the losses in sweat were included, the men were in negative balance by 964 and 653 mcg/day during the last two periods of exposure to the hot environment. These copper losses in sweat were approximately 40% of the total daily intake.

Balance data for chromium, manganese, molybdenum, cobalt, nickel and lead are presented in Tables IV and V, respectively. Chromium in sweat amounted to approximately 6.9%, manganese approximately 2.3% and molybdenum 35.5% of the total daily intakes. A cobalt excretion in sweat of 18 mcg for a 7 1/2 hour exposure period was fairly high. Nickel excretion in sweat which ranged from 80 to 85 mcg for a 7 1/2 hour exposure period, was approximately 41% of the total daily intake and lead excreted in sweat at 195 to 317 mcg/7 1/2 hours accounted for approximately one-half of the daily intake. When the sweat losses of nickel and lead were included in the balance computation, both these metals were in negative balance.

The sweat and urinary excretion of iodine is presented in Table VI. Over a 7 1/2 hour exposure period, the iodine excretion in sweat ranged from 14 to 24 mcg during the last 3 exposure periods. The iodine intake was not computed but the iodine excretion in urine was considerable, ranging from 356 to 380 mcg/day for the same periods.

Discussion

The role of the trace minerals in human nutrition has frequently been associated with the enzyme systems and there now is increasing evidence that many of these trace minerals are essential for optimal nutrition (NRC '58). This evidence has shown that there are two major factors that may affect the zinc requirements, the source of dietary protein and the level of dietary calcium (Forbes '60). Even though the NRC Food and Nutrition Board's "Recommended Dietary Allowances" have not established minimal allowances for zinc, it has been observed that the normal daily intake usually ranges between 9 to 12 mg (NRC '58). Although very little information is available on zinc excretion in sweat, Prasad et al. ('63) presented data that averaged 115 mcg/100 ml. These values are in the same range as our reported values, where it was observed that approximately 18% of the average daily zinc intake was excreted in sweat during a 7 1/2 hour exposure period. If the 24 hour excretion in sweat was computed, these values could be considerable.

Copper is essential in mammalian nutrition, especially since it is a necessary requirement for optimal absorption and metabolism of iron, for normal erythropoiesis, for bone formation and for a number of oxidation-reduction reactions in tissues. Even though copper deficiency has never been clearly demonstrated in humans, there seems to be no question that it is essential for humans (Gubler '56). Copper deficiencies have never been demonstrated due to the fact that the copper intake throughout the world is fairly high and above the metabolic requirement (Scheinberg '61).

At the present time no minimal allowances have been established for the daily copper intake, but it has been observed that 2 mg of copper/day is sufficient to keep an adult in equilibrium (NRC '58). Mitchell and Hamilton ('49) reported copper excretion in sweat to be 6 mcg/100 ml, which is lower than our reported values. In this study, on an intake of 3.5 mg of copper/day the copper excretion in sweat accounted for approximately 40% of the average daily intake during a 7 1/2 hour collection period. The copper balances, exclusive of the sweat excretions were positive by 400 and 800 mcg/day during the last two periods but with the inclusion of the copper losses in sweat, the balances were negative by 650 and 950 mcg/day.

The iodine balance has been studied in normal humans and in patients with thyroid disease, by several investigators; and the importance of the skin losses as an avenue of excretion in attaining a true iodine balance and the increase in its dermal loss in exophthalmic

goiter has been recognized (Kuno '58). The iodine excretion in sweat observed in this study of 0.5 to 1.6 mcg/100 ml of sweat is in agreement with the published data of Spector et al. ('45). The minimal daily requirement has been established by Cole and Curtis ('35) to be between 100 to 200 mcg/day and by Underwood ('62) to be 60 to 120 mcg on an intake of 3000 KCalories. Assuming an iodine intake of approximately 150 mcg/day, the men were excreting an average of 20 mcg of iodine in sweat per 7 1/2 hours during the last 3 periods of exposure to high environmental temperatures. One must remember that these excretions were averages for only a 7 1/2 hour exposure period.

It has been shown that there is a relationship of molybdenum to at least two enzymes, xanthine oxidase, which is concerned with the essential metabolic processes, and aldehyde oxidase. Molybdenum may exert a stimulatory effect on hemoglobin regeneration when it is used concurrently with iron therapy in hypochromic anemia. This implies that molybdenum is an essential nutrient. There is very limited information on the average daily dietary intake of humans, but the intake may range from 0.20 to 0.50 mg/day (Underwood '62). It has been shown by Miller et al. ('59) that the protein intake will affect the molybdenum requirements. They reported that, in children having intakes of 75 mcg/day, the average molybdenum retention was increased 5 times when the protein intake decreased from an average of 2.5 gm to 0.7 gm/kg body weight. This supports the view that an adequate protein intake is essential for the elimination of excess dietary molybdenum. In the present study, the sweat losses accounted for approximately 30% of the average daily molybdenum intake of 172 mcg/day, which is extremely high, especially since one must consider that these excretions are for only a 7 1/2 hour exposure period. Even though no deficiencies have been reported in man as yet, there is no question that these sweat losses must be considered in future balance studies, under conditions of profuse sweating.

Manganese has not been shown to be required by humans and a manganese deficiency syndrome has yet to be reported (Underwood '62). Manganese is poorly absorbed since it has been shown and again reaffirmed in this study, that it is mainly excreted in the feces. In this study the subjects, consuming an intake of 4.24 mg/day, were in positive balance by 1.07 to 1.80 mg/day. Since the daily excretion in sweat was less than 5% of the total daily intake, the manganese losses in sweat are relatively unimportant in assessing the minimal requirements.

A true cobalt deficiency in humans is unknown (even though small quantities are contained in vitamin B₁₂) and as a result no human adult requirements have been established. In the present study the sweat excretion during a 7 1/2 hour exposure period averaged from 16 to 18 mcg of cobalt, which was higher than the reported adult intake value of 5 to 8 mcg/day (Harp '52).

There are no data in the literature on the sweat excretion of strontium, chromium, tin, aluminum, lead, and selenium, but the values observed in this study were fairly high. As mentioned previously these trace elements, with the possible exception of selenium, have not been found to be essential in human nutrition. Sweating may be an excellent means of reducing high concentrations of these elements in the body.

Underwood ('62) quotes the daily human adult intake of nickel to be between 0.3 and 0.5 mg/day. The nickel intake in this study was 202 mcg/day, with the sweat excretion being approximately 40% of the total daily intake. Since nickel has not been found to be an essential trace mineral in human nutrition, these high excretions may be unimportant, unless as a mechanism for reducing high concentrations in the body.

There seems to be no question that appreciable quantities of trace minerals are lost in sweat under conditions that produce profuse sweating. These fairly high sweat excretions of trace minerals have been reported for only a 7 1/2 hour exposure period. Excretion would be considerably higher if computed on a 24 hour basis. These losses are important in evaluating minimal requirements and must be considered as part of the total daily losses in computing balance studies, otherwise this would result in misinterpretation of the data.

As in past studies on sweat excretion, the trace mineral losses decreased after acclimatization to extreme heat.

ACKNOWLEDGMENTS

We wish to express our sincere appreciation and thanks to the University of Colorado and Dr. Norman F. Witt, and are especially thankful for the full cooperation of the test subjects, without whom this study could never have been performed. They included Frederick Eicher, Warren E. Kennel and Richard L. Sommer.

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TABLE I

Trace Minerals Excreted in Sweat*
 mg Excreted During 7 1/2 Hr Exposures at 37.8°C

<u>Days of Exposure</u>	<u>1 - 4</u>	<u>5 - 8</u>	<u>9 - 12</u>	<u>13 - 16</u>
<u>Trace Minerals</u>				
Cobalt	-**	0.018	0.017	0.015
Copper	-	1.94	1.79	1.04
Manganese	-	0.11	0.12	0.06
Iodine	0.038	0.024	0.014	0.021
Chromium	-	-	0.057	0.061
Selenium	-	0.37	0.34	0.30
Strontium	-	1.10	0.86	0.91
Zinc	13.70	2.18	2.16	2.41
Molybdenum	-	-	-	0.061
Aluminum	-	11.05	4.30	3.05
Lead	-	-	0.317	0.195
Nickel	-	-	0.080	0.085
Tin	-	2.21	2.49	1.98

* Average of 3 men exposed to temperature of 37.8°C for 16 consecutive days.

** Dashes mean that no samples were available for analysis.

TABLE II
Zinc Balance, mg/Day
Mean of 3 Men*

Days at 37.8°C	Intake	Daily Output			Balance	
	Food	Urine	Feces	Sweat**	No Sweat	+Sweat
1 - 4	12.46	0.75	12.45	13.70	-0.75	-14.45
5 - 8	12.46	0.57	7.67	2.18	+4.22	+2.05
9 - 12	12.46	0.57	7.48	2.16	+4.42	+2.26
13 - 16	12.46	0.75	7.40	2.41	+4.31	+1.90

* Average of 3 men exposed to temperatures of 37.8°C for 7 1/2 hours daily for 16 consecutive days.

** The sweat excretions are for the 7 1/2 hour collection periods during 16 consecutive days exposure to hot environments.

TABLE III
Copper Balance, mcg/Day
Mean of 3 Men

Days at 37.8°C	Intake	Daily Output			Balance	
	Food	Urine	Feces	Sweat*	No Sweat	+Sweat
1 - 4	3516	158	2900	No Value	+458	
5 - 8	3516	303	3000	1940	+213	-1727
9 - 12	3516	303	2387	1790	+826	-964
13 - 16	3516	229	2900	1040	+387	-653

* The sweat excretions are for the 7 1/2 hour collection periods during 16 consecutive days exposure to hot environments.

TABLE IV

Chromium, Manganese and Molybdenum Balances*
mcg/Day

Days at 37.8°C	Intake	Output			Balance	
		Urine	Feces	Sweat**	No Sweat	+Sweat
<u>Chromium</u>						
1 - 4	889	20	870	No Value	-1	
5 - 8	889	31	600	No Value	+258	
9 - 12	889	5	580	57	+304	+247
13 - 16	889	17	627	61	+245	+184
<u>Manganese</u>						
1 - 4	4240	11	2320	No Value	+1909	
5 - 8	4240	9	2285	110	+1946	+1836
9 - 12	4240	8	2559	121	+1673	+1552
13 - 16	4240	37	3071	61	+1132	+1071
<u>Molybdenum</u>						
1 - 4	172	53	73	No Value	+46	
5 - 8	172	272	68	No Value	-168	
9 - 12	172	70	106	No Value	-4	
13 - 16	172	188	82	61	-98	-159

* Mean of 3 men during exposures to environmental temperatures of 37.8°C for 16 consecutive days.

** The sweat excretions are for the 7 1/2 hour collection periods during 16 consecutive days exposure to hot environments.

TABLE V

Cobalt, Nickel and Lead Balances*

mcg/Day

Days at 37.8°C	Intake	Output			Balance	
		Urine	Feces	Sweat**	No Sweat	+Sweat
<u>Nickel</u>						
1 - 4	202	13	179	No Value	+10	
5 - 8	202	10	213	No Value	-21	
9 - 12	202	12	272	80	-21	-160
13 - 16	202	13	221	85	-32	-117
<u>Lead</u>						
1 - 4	404	11	226	No Value	+167	
5 - 8	404	54	120	No Value	+230	
9 - 12	404	8	298	317	+98	-219
13 - 16	404	16	262	195	+126	-69
<u>Cobalt</u>						
1 - 4	No Value	5		-	-	
5 - 8	No Value	7		18	-	
9 - 12	No Value	8		17	-	
13 - 16	No Value	20		15	-	

* Mean of 3 men during exposures to environmental temperature of 37.8°C for 16 consecutive days.

** The sweat excretions are for the 7 1/2 hour collection periods during 16 consecutive days exposure to hot environments.

TABLE VI

Iodine Excretion, mcg/Day*

Days Exposure at 100° F	Sweat		Urine	
	mcg/100 ml	mcg/7 1/2 hr	mcg/100 ml	mcg/Day
1 - 4	1.65	38.4	38.0	401.4
5 - 8	0.90	23.7	42.0	368.0
9 - 12	0.48	13.8	42.0	355.6
13 - 16	0.70	21.3	46.4	380.0

* Mean of 3 men during daily 7 1/2 hour exposures to high environmental temperatures. No analytical values for food and feces.

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1. Trace Mineral Excretion
2. Trace Mineral Balance
3. Trace Mineral Requirements

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