MINIMAL SODIUM LOSSES THROUGH THE SKIN [1]

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The widespread administration of very low sodium diets makes it highly desirable to determine the amounts of sodium lost by each of the three excretory paths. It is a relatively simple matter to measure the urinary and fecal losses of sodium, and these values have been determined repeatedly in this laboratory (1) for normal subjects who are in balance on a daily intake of approximately 9 mEq. of sodium. Under these circumstances the urine values varied from 0.5 to about 2.5 mEq. and the fecal content of sodium was close to 1 mEq. These values make it evident that the largest of the three losses is from the skin. The outgo through the skin must be considered under two headings. *1*) The sodium content of the sweat, that is, the fluid delivered to the skin surface by the activity of the sweat glands. Normal sweat contains from 15 to 60 mEq. per liter (2). Sharp restriction of sodium intake results in a lessening of the concentration of sweat sodium but the values are still large from the point of view of balance. *2*) The loss of sodium from the skin in the total absence of sweating. Little information is available regarding the actual magnitudes of these latter losses, no doubt in part because of the laborious technique required to obtain reliable data. We have been able to find only one publication (3) in which a serious attempt was made to measure the losses from the skin in the absence of sweating. While their subjects were not aware of sweating during the experimental periods, but since they continued to perform their routine duties in the laboratory and were fully clothed there is no assurance that the sweat glands were completely inactive throughout the periods. The values reported under those circumstances vary from 2.6 to 9.1 mEq. per 24 hours.

Because of the paucity of data and of the great variation in the values cited above it seemed highly desirable to us to determine the losses from the skin in individuals whose activity was minimal and who remained in a cool room. Furthermore, since it was not known whether the skin losses, in the absence of sweating, are lessened by very low dietary sodium, these subjects were fed a diet that contained only 10 mEq. per 24 hours of sodium. After the urine values for sodium had become stabilized at low levels (1 to 2 mEq. per 24 hours) the actual losses from the skin were measured.

EXPERIMENTAL

Two normal adult male medical students were the subjects of this study. One, E. W., was 23 years of age and the other, W. B., 28 years. Both were placed on a diet that contained 10 mEq. of sodium, 40 gms. of protein and maintenance calories. The intake of tap water was unlimited since its sodium content was insignificant upon chemical analysis.

The study was divided into two periods: 11 preliminary days during which the subjects attained sodium balance and three subsequent days during which the losses from the skin were collected.

The subjects were weighed daily in the nude, before breakfast, and after emptying the bladder. A special human balance with a sensitivity of 5 gms. was used. A blood sample was taken on the first day for the determination of serum sodium, potassium and chloride. Daily 24 hour urines were collected for the analysis of sodium, potassium, chloride, nitrogen and creatinine, the latter being used as a check on the accuracy of the 24 hour collection.

The subjects were allowed to follow their daily routines up to the last three days when they were placed at rest in a cool atmosphere to prevent sweating. The evening before the collection of skin washings was begun, the subjects were directed to wash the whole skin surface with soap and water, and shampoo their hair followed by thorough rinsing.

All clothing and wash cloths were rinsed in five separate changes of distilled water, dried and wrapped in brown paper. This water contained less than 0.003 mEq. of sodium per liter.

Beginning with the first morning of the last three days and each subsequent morning the subjects were rinsed five times with the distilled water and the washings and wash cloths of the first morning discarded. The skin washings for the subsequent three 24 hour periods were collected. After drying themselves, the subjects dressed in medium-

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weight long underwear and socks that had been rinsed as described above. They then reclined in a bed whose mattress was covered with an impermeable plastic sheet and remained in the room where the temperature ranged between 15 to 22 degrees C. Activity was reduced to a minimum. They complained repeatedly of feeling uncomfortably cool, but never shivered. It is safe to assume that no sweating occurred.

The clothing and wash cloths were rinsed in five changes of the distilled water and this was added to the body washings.

The washings were then concentrated, and the insoluble material was removed by centrifuging and subsequently washed. The washings were added to the concentrated solution. It was then concentrated sufficiently to permit reliable analysis.

Twenty-four hour stool specimens were collected and fasting blood samples taken for the determination of sodium, potassium, and chloride during each of the last three days. The dried and blended stools were ashed in a muffle furnace at 400 degrees C.

Aliquots of a sample diet were analyzed for sodium, potassium, chloride and nitrogen. The dietary calories were obtained from U. S. Department of Agriculture Circular Number 549. The values for sodium, potassium, chloride and nitrogen are from our own analysis.[2]

Sodium and potassium determinations were carried out on urine, serum, stool, body washings and diet by means of the flame photometer (6). Chlorides were determined on serum by the method of Van Slyke and Sendroy (7), and on the urine, stool, body washings, and diet by a modification of the Volhard-Harvey titration (8). Urinary and dietary nitrogen were determined by the Kjeldahl method for macro analysis (9). The urinary creatinine was determined by the modification method of Bonsnes and Taussky (10).

RESULTS

Tables I and II show a progressive fall in the amount of sodium in the urine in response to a diet that contained approximately 10 mEq. of sodium. In the case of subject E. W. the 24 hourly urinary sodium had fallen to less than 3 mEq. by the fifth day and subsequently reached values of 1 mEq. or less. W. B. showed higher values throughout and even by the 11th day, which was the last day of the preliminary period, the value was still 2.86 mEq. In both cases the concentrations of serum sodium and potassium were in the normal range throughout the whole

[2] Comparison of our chemical analyses with values reported in tables published by Bills and Associates (4), and by McCance and Widdowson (5) are as follows: In subject E. W.'s diet the calculated and analyzed composition was respectively: nitrogen 6.14 gms. and 5.91 gms.; sodium 9.9 and 10.4 mEq.; chloride 19.8 and 24.8 mEq.; and potassium 84.8 and 76.8 mEq. For W. B. the calculated and analyzed composition was respectively: nitrogen 6.16 and 5.81 gms.; sodium 9.8 and 9.5 mEq.; chloride 19.2 and 20.7 mEq.; and potassium 92.8 and 96.7 mEq.

TABLE I

Subject E. W., Male, Age 23, Height 5′ 10″

Exp. day	Weight	Skin loss			Serum			Urine							Stool			
		Na	K	Cl	Na	K	Cl	24 hr. volume	Na	K	Cl	Total nitrogen	Creatinine	Creatinine coeff.	Dry weight	Na	K	Cl
	Kg.	*mEq./24 hrs.*	*mEq./24 hrs.*	*mEq./24 hrs.*	*mEq./L*	*mEq./L*	*mEq./L*	*cc./24 hrs.*	*mEq./24 hrs.*	*mEq./24 hrs.*	*mEq./24 hrs.*	*gms./24 hrs.*	*gms./24 hrs.*		*gms./24 hrs.*	*mEq./24 hrs.*	*mEq./24 hrs.*	*mEq./24 hrs.*
1	67.485						99.6	1315	74.3	63.4	83.9	10.17	1.48	21.9				
2	67.507				144.8	4.9		890	22.3	76.5	44.4	8.05	1.67	24.8				
3	67.435							1260	13.5	65.6	25.3	7.04	1.53	22.7				
4	67.489							1020	7.0	68.0	19.1	5.94	1.51	22.4				
5	67.187							800	2.9	71.5	14.1	6.32	1.52	22.6				
6	67.310							925	3.0	72.4	13.8	6.50	1.54	22.8				
7	67.500							910	1.7	61.5	9.3	5.76	1.42	21.1				
8	67.565							600	0.8	53.5	9.2	5.51	1.43	21.1				
9	67.615				144.3	4.8	101.1	670	0.7	65.2	8.7	5.32	1.40	20.7				
10	67.345							1060	1.2	74.0	8.9	5.76	1.47	21.9				
11	67.435				142.0	5.1	98.0	680	1.0	63.9	9.9	5.17	1.39	20.6				
12	67.113	4.3	6.2	3.68	142.8	5.5	98.8	1110	19.4	69.0	20.6	5.89	1.52	22.7	39.5	8.2	12.0	0.72
13	66.863	4.2	5.6	4.05	142.5	4.8	98.9	1013	8.8	66.4	20.6	5.35	1.44	21.5	23.0	8.2	12.0	0.72
14	66.828	3.7	5.4	3.72	143.0	5.2	100.0	980	11.5	72.2	17.6	5.28	1.46	21.8	40.5	8.2	12.0	0.72

Dietary intake was constant daily and consisted of:

Calories	3232	Potassium	76.8 mEq.
Nitrogen	5.91 gms.	Chloride	24.8 mEq.
Sodium	10.4 mEq.		

TABLE II

Subject W. B., Male, Age 28, Height 6′ 0½″

Exp. day	Weight	Skin loss			Serum			Urine							Stool			
		Na	K	Cl	Na	K	Cl	24 hr. volume	Na	K	Cl	Total nitrogen	Creatinine	Creatinine coeff.	Dry weight	Na	K	Cl
	Kg.	*mEq./24 hrs.*	*mEq./24 hrs.*	*mEq./24 hrs.*	*mEq./L*	*mEq./L*	*mEq./L*	*cc./24 hrs.*	*mEq./24 hrs.*	*mEq./24 hrs.*	*mEq./24 hrs.*	*gms./24 hrs.*	*gms./24 hrs.*		*gms./24 hrs.*	*mEq./24 hrs.*	*mEq./24 hrs.*	*mEq./24 hrs.*
1	81.780				143.0	4.6	102.3	1160	54.8	98.1	66.5	11.58	1.81	22.2				
2	81.310							1310	36.4	96.2	48.6	11.62	2.07	25.4				
3	81.047							1580	21.8	72.4	30.8	10.51	1.96	24.2				
4	81.050							820	13.4	82.8	22.7	8.61	1.80	22.2				
5	80.722							1220	7.7	89.6	18.2	8.43	1.90	23.5				
6	80.565							1410	10.2	73.6	22.2	7.82	1.85	23.0				
7	80.785							1230	10.2	47.5	12.7	6.60	1.60	19.8 *				
8	80.620							1520	15.8	86.9	17.8	7.95	2.30	28.5 *				
								(1375	12.7	67.2	15.3	7.28	1.95	24.2) †				
9	80.670							1270	4.1	72.3	11.7	6.46	1.87	23.2				
10	80.775				147.5	5.6	102.1	1110	7.1	58.8	11.0	5.95	1.65	20.4				
11	80.790				144.7	5.1	94.7	1020	2.9	72.4	12.6	6.01	1.81	22.4				
12	80.806				147.5	5.1	100.7	1580	36.2	78.4	24.2	6.92	1.79	22.1	42.5	0.9	10.9	1.16
13	80.511	4.4	3.1	3.19	147.3	4.9	101.1	1620	20.3	68.9	29.1	6.15	1.76	21.8	27.0	0.9	10.9	1.16
14	80.681	4.4	2.8	3.28	147.7	4.8	100.1	1518	17.0	77.7	28.5	5.61	1.77	21.9	60.5	0.9	10.9	1.16

* Subject ended 24 hour collection of seventh day in container reserved for eighth day's collection.
† Average values for the seventh and eighth day.
Dietary intake was constant daily and consisted of:

Calories	3559	Potassium	96.7 mEq.
Nitrogen	5.81 gms.	Chloride	20.7 mEq.
Sodium	9.5 mEq.		

study. The urinary output of potassium varied somewhat from day to day and amounted to roughly 80 per cent of the intake. The urinary chloride diminished in the case of both subjects during the preliminary period to about half of the dietary intake. Both subjects achieved nitrogen balance by the seventh or eighth day. The 24 hourly urinary creatinine was determined daily to check the accuracy of the collection, and the ratio between this value and body weight in kilograms was calculated (creatinine coefficient). For E. W. the ratio varied from 20.6 to 24.8 and in the case of W. B. the range was from 20.4 to 25.4. The normal range for creatinine coefficient is 20 to 26 (11). The weight for E. W. at the end of the preliminary period was within 50 gms. of the initial weight. In regard to W. B., if one compares the weight on the second morning with that on the last day of the preliminary period a loss of one-half Kg. occurred.

Coming now to the three final days of the study during which the losses through the skin were measured, the following changes were recorded. The urinary sodium in both cases was strikingly great. There were no significant changes in regard to potassium, but the chloride, like the sodium, was increased as compared to the preliminary period. There was no significant variation in urinary nitrogen and the creatinine coefficient was unchanged. The weight in both cases diminished somewhat, about 600 gms. for E. W. and only about 220 gms. for W. B.

The sodium losses through the skin during these three days when the sweat glands of the subjects were presumably entirely inactive were gratifyingly uniform and ranged from 3.67 to 4.28 mEq. for E. W. and from 4.38 to 4.41 mEq. for W. B. When referred to the surface area of the body the values per square meter were respectively 2.22 mEq. and 2.18 mEq. The potassium losses for E. W. were close to 6 mEq. and not far from one-half this value for W. B. The chloride losses were somewhat smaller than the sodium losses and varied only slightly.

The feces for the three days were blended and the values recorded in the tables are the 24 hourly averages. In the case of W. B. they contained less than 1 mEq. of sodium per 24 hours. However, the values for E. W. are strikingly larger.

DISCUSSION

The study demonstrates that approximately 4 mEq. of sodium were lost through the skin per 24 hours, under conditions in which the subjects were presumably not sweating and after they had achieved balance on an intake of 10 mEq. of sodium per day. This is at the rate of about 2 mEq. per square meter of surface area per 24 hours and is presumably the smallest loss through this channel that can be achieved by the normal individual. Since there is always a desquamation of surface epithelium, these minimal quantities of sodium would appear to be merely a normal constituent of this epithelial loss.

With this irreducible loss of sodium from the skin and an additional outgo of about 1 mEq. per 24 hours in the feces, the urinary excretion of sodium must be reduced to 5 mEq. if the individual maintains sodium balance on an intake of 10 mEq. It seems unlikely that individuals whose activity is not restricted will completely avoid sweating. Since this secretion, even in the case of persons acclimatized to heat, and on an intake of about 40 mEq. of sodium contains 4 to 6 mEq. of sodium per liter (12) it is probably true that the sodium losses from the skin are frequently greater than these minimal values we have recorded. This must certainly be the case during warmer periods of the year when on some days even the nude recumbent individual produces a considerable amount of sweat.

However, since the urinary sodium can be reduced to negligible quantities, balance can probably be established even though the skin loss is about twice the minimal value provided that the individual has kidneys whose functional capacity regarding sodium is adequate. Many patients suffering from chronic nephritis no longer possess this high functional capacity and in them a progressive depletion of body sodium may take place on very low sodium diets. It is always essential to examine the state of the kidneys in hypertensive subjects before prescribing diets containing minimal amounts of sodium since it has been demonstrated that the renal damage in such individuals may be so great that the urine will always contain considerable amounts of sodium (13).

It will be noted that the amounts of sodium in the 24 hourly urines during the three final days when the subjects were in a definitely cool room, lightly clad, and recumbent, were strikingly large as compared with the preceding days. In the case of E. W. the stool losses also were unexpectedly large. The total outgo of sodium for this subject was 86.66 mEq. for the three days and the intake was 32.2 mEq., making a negative balance of 54.46 mEq. For W. B. the urinary loss for the three days was 73.46 mEq. but the stool losses were only 2.79 mEq. and the skin loss was 13.2 mEq., giving a total loss of 89.45 mEq. and a negative balance of 60.95 mEq. The amount of sodium represented by these negative balances would be distributed in about 400 ml. of extracellular fluid at the existing serum concentrations of sodium. The increased outgo of sodium would be accounted for if a shrinkage of the extracellular space of this extent had taken place. Both subjects lost a little weight during this period. It has been established that a shrinkage of the extracellular space occurs when an individual is transferred from a warm to a cool environment (14), and this might be the cause of the augmented sodium loss. However, a lessening of the body weights which can be accepted as indicative of a loss of body water does not correspond closely with the prediction based upon the negative sodium balance. This lack of correspondence might have occurred because loss of water vapor from the body surface was somewhat less under the cool conditions than previously. In the face of an expected lessening of evaporative loss of water and a possible slight diminution in extracellular volume one would scarcely expect a net loss of body water that conformed with a loss of sodium. This point is being investigated further.

CONCLUSIONS

Two normal male subjects who had achieved sodium balance on an intake of 10 mEq. of sodium daily lost respectively 4.06 and 4.40 mEq. of sodium per 24 hours through the skin when precautions had been taken to avoid all activity by the sweat glands. When these sodium losses are calculated on the basis of surface area the values are respectively 2.22 mEq. and 2.18 mEq. per square meter of body surface per 24 hours.

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