Water Requirements of Men as Related to Salt Intake

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INGESTION of salt (sodium chloride), apparently requires the intake of sufficient quantities of water to dilute the salt to the level found in protein-free blood plasma. When, perchance, the amount of water drunk is insufficient even though the plasma levels of sodium and chloride remain constant, the urine becomes highly concentrated, and collapse may occur followed by a delay in recovery. Observations of these responses are described, the object being to indicate the smallest quantity of water intake needed to dilute the various amounts of dry salt consumed in certain rations.

PROCEDURE

Various experimental details, methods and identification of each subject were described earlier.[1] The diet, prepared from fresh foods, always provided 2,780 kilocalories (kcal.) and contained 133 mEq. of sodium, 85 mEq. of potassium and 123 mEq. of chloride. Water intake from the diet was 1.59 L.: 1.21 L. of water in the diet and 0.38 L. as the amount calculated to be supplied by dietary combustion in the body. Salt intake at meal times was increased every four days until a total of about 35 gm. of pure sodium chloride was ingested daily. Daily measurements were made of nude body weight, total water intake *ad libitum* and of the sodium, chloride and water output in urine and feces. Every fourth day, the amount of sodium and chloride present in the water of the blood plasma was measured and found to remain constant. Drinking water for each subject was prepared by deionization of tap water and was always available in glass vessels stored in a refrigerator at 5°c., which is the approximate temperature of unheated, running tap water in Denver.

Daily records were kept of water intake including that consumed in beverages such as coffee. Total intake included the amount of water consumed and that obtained from both sources in the diet. The barometric pressure was steady at 625 mm. Hg. The average dry bulb temperature of the ward was 23°c. when the vapor pressure of water ranged from 4 to 10 mm. Hg.

For each subject, records of the cumulative intake of sodium, chloride and water were prepared. From this was deducted the cumulative amounts of sodium, chloride and water excreted in urine and feces. This gave the balance representing the sodium, chloride and water lost from the body surfaces involved. These data were plotted on sheets of graph paper of a size large enough to note changes in the slopes with an accuracy of 2 mEq. per L. or better.

RESULTS

The results of this analysis are listed in Table I as sodium and chloride combined and expressed as milliosmols per liter of water involved during each of four periods. The first three periods were four days and the fourth period was ten days in duration. The daily total salt intake in each successive period was as follows: 393, 530, 803 and 1,104 mOsm. or 11.8, 15.8, 23.8 and 32.8 gm., respectively. The last figure (1,104 mOsm.) is an average, for in this period the salt load added to the diet was 24 gm. daily for nine days and 32 gm. for one day. Not shown in Table I is the fifth period of eight days (Fig. 1) during which the daily salt intake was 393 mOsm.; this is a recovery period to be discussed subsequently.

Figure 1, in which the urine osmolalities are plotted against the intake osmolalities, illustrates important details which are difficult

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TABLE I
Concentrations of Sodium and Chloride in Various Fluids During Increased Salt Intake*

Fluid	Period 1	2	3	4
Subject 1				
Intake	123	149	225	265
Urine	303	392	541	604
Balance	26	59	41	46
Plasma	271	268	267	278
Subject 2				
Intake	161	222	325	372
Urine	320	503	653	753
Balance	65	43	72	164
Plasma	267	267	272	273
Subject 3				
Intake	108	161	262	290
Urine	191	359	593	641
Balance	15	33	40	61
Plasma	280	273	260	267
Subject 4				
Intake	163	196	279	312
Urine	323	430	549	633
Balance	46	46	65	79
Plasma	269	268	267	274
Subject 5				
Intake	103	144	225	305
Urine	156	240	385	527
Balance	34	18	43	56
Plasma	269	264	263	267
Subject 6				
Intake	90	138	222	247
Urine	135	203	445	498
Balance	40	46	34	33
Plasma	271	272	271	273

* Values expressed as milliosmols per liter of water.

to perceive among the tabulated data. As judged from the slopes (Fig. 1), the urine excreted by these six subjects had, on the average, 2.04 times the osmolality of the intake. With

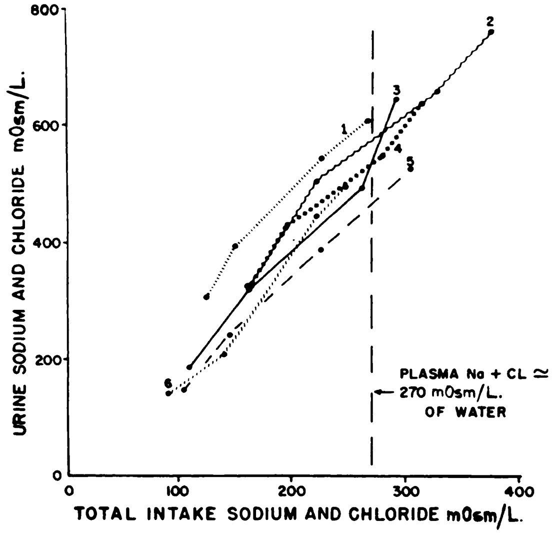

FIG. 1. (Six subjects.) As the ratio of salt to water intake increases, urine becomes increasingly concentrated.

a salt intake of 803 and 1,104 mOsm., four of these six subjects drank so sparingly as to have water intakes causing the intake osmolality to exceed that of plasma water, which deviated only slightly from the grand mean of 270 mOsm. per L. If this were the level of intake, the osmolality of the excreted urine would be 462, 534, 534 and 574 by interpolation, and 552 and 612 by extrapolation, giving an average value of 544 mOsm. of sodium and chloride per L. of urine water. This concentration is twice that of the sodium chloride osmolality of plasma water. Further, it is twice that of the maximum physiologic concentration of sodium in human urine (268 mOsm. per L. per day) inferred in the previous report of these experiments.[1] Assuming that errors were not made in the fairly involved and laborious collection of these data, it seems from this analysis of slopes and intercepts that the plasma level remains close to 270 mOsm. per L. of water even though the ratio of salt to water intake ranges widely from 90 to 372 mOsm. per L., while at the same time the kidneys respond by excreting almost exactly twice the osmolality as that representing the intake of sodium chloride.

Recovery from the overloading with salt of Subject 2 is shown in Figure 2. Following

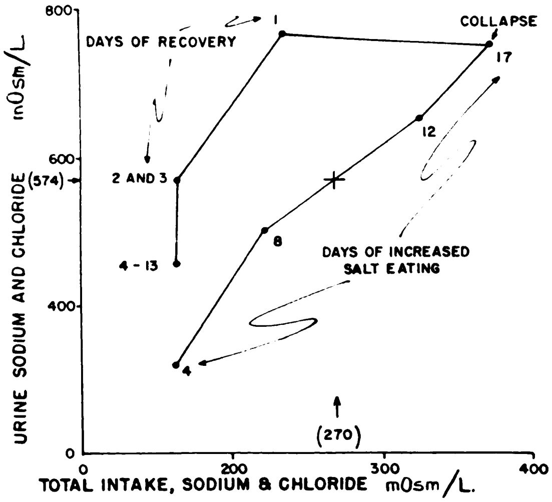

FIG. 2. Salt overloading and recovery in Subject 2.

the eighth day of increasing intake of salt, this subject's intake exceeded the plasma value of 270 mOsm. per L. Nine days later he collapsed for a brief period, suggesting tetany. On the first day of recovery, he consumed the same amount of salt (803 mOsm.) as he had eaten from the eighth to the twelfth day of increasing intake. In addition he was required to drink 1 L. more of water than he had taken previously. Although on the first day this treatment caused the intake osmolality to fall below that of the plasma (to a level of 235 mOsm. per L.), the amount of salt in the urine was even higher (770 mOsm. per L. per day) than on the preceding day (753 mOsm. per L. per day). On subsequent days, salt intake was reduced to 393 mOsm., the same as during the first four days of the experiment. With this low intake of salt, Subject 2 drank the same amount of water as at the start of the experiment. This was much less than for the other five subjects, possibly due to delayed gastric emptying which was later demonstrated on a roentgenogram. The sodium chloride osmolality of the urine during recovery, even after thirteen days, did not return to the starting level of 320 mOsm. per L. of urine water. The results of this experiment on overloading with salt showed that recovery was delayed. No more than nine days elapsed during the period of overloading; three days were required for recovery to the ordinary maximum salt osmolality of urine, but the pathway of recovery was different from that followed during the loading phase. The other five subjects showed a similar but less pronounced recovery lag—probably due to a smaller overload with salt.

The kidneys were the chief organ to respond to a salt overload. Under the present conditions of 23°c. with a water vapor pressure of less than 10 mm. at an ambient pressure of 625 mm. Hg, the kidneys, on the average, excreted 42.4 per cent of the total water intake and 90.7 per cent of the salt intake. Only 2.61 per cent of the water intake and 1.46 per cent of the salt intake were excreted in the feces. After deducting the materials excreted in the urine and feces from those taken into the body, the difference, the so-called balance, can be considered as the water lost from the skin and lungs together which amounts to 55.0 per cent of the total water intake. The salt presumably excreted by the skin amounts to 7.87 per cent of the total intake.

The quantities of water and salt in the body pools involved could have fluctuated only to a slight extent. This opinion was based on the findings that sodium and chloride in plasma water were constant at a level of 269.6, with $\sigma = 3.7$, mOsm. per L. The mean fluctuations in body weights among each period compared to the first period, 0.108, −0.241, −0.076 and −0.614 kg., were not statistically significant except in the final period. Further, a similar slight decrease in body weight also occurred six months later when the six men were fed the same quantity of food, 2,780 kcal. of metabolizable energy, in experiments during which salt intake was not controlled. Most of the change in body weight, −0.614 kg., took place during the period of recovery from salt overloading. Perhaps the body weight changes could have been the result of two processes; first, slight continuous loss of body substance due to mild caloric insufficiency of the diet and, second, fluid retention during salt overloading with loss of this extra fluid during recovery. Even so, the maximum quantity of fluid that might have been retained was insufficient to account for the apparent salt retention, assuming that such fluid has the same salt osmolality as in the blood plasma.

COMMENTS

Salt always has been sought after and prized, especially by those who ate no flesh. Eaters of "bread and salt" wrote, drew and carved records of this commodity. Cakes of salt are bartered among people, taxed by officials and offered with prayers. In the living body, ions of salt are variously distributed and engage in many processes.[2,3] Further, many studies have been made of salt and water intakes in man. Excellent examples of this are the studies of Ladell.[4,5] When the salt intake of healthy men is reduced by fasting or by the consumption of salt-poor food, it is generally conceded[6] that the kidneys almost stop the excretion of sodium and chloride although the levels of sodium and chloride in the blood plasma may remain unaffected during several weeks of such experiments. Thus, it is difficult to deplete the body of its sodium and chloride content unless the deprivation is severe and prolonged. The results of the present tests show that it is also difficult to overload the body with sodium chloride provided the amount of water ingested and supplied in foods is adequate.

The smallest quantity of water required to prevent overloading with salt is that which is sufficient to dilute the salt ingested to the same level as sodium and chloride normally occur in the water of blood plasma. At this ratio of salt to water intake, the kidney excretes highly concentrated urine and thus handles 90.7 per cent of the salt intake for as long as ten days without apparent harm to the body. To dilute the maximum tolerable salt intake of 270 mOsm. per L. requires 127 ml. of water for each gram of sodium chloride. This provides a basis for estimating the minimum amount of water required at different levels of salt intake. Figure 3 was prepared by noting that for six men the average rate of water lost from the skin, lungs and bowel was 1.90 L. per day throughout a period of thirty days while eating salt at various daily rates. It was of interest to note that the loss of water from the skin, lungs and bowel of 1.90 L. per day was relatively constant throughout the study irrespective of salt intake. It must be emphasized that water intake was *ad libitum*

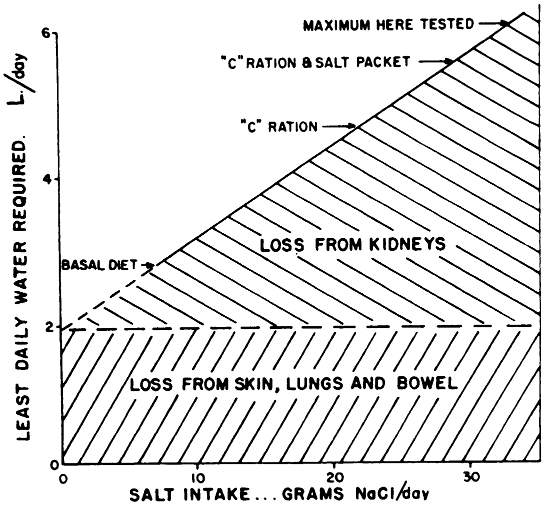

FIG. 3. Sedentary man weighing 70 kg. and maintained at an ambient temperature of 75°F. Least amount of water required in proportion to salt intake (based on mean values for the six men). Relative humidity, 19 per cent.

and increased as salt intake increased. If, in addition, the kidneys were to excrete maximally tolerable concentrations of salt, the entire loss rate can be stated. To balance such a total loss of water requires 2.84 L. per day when eating the basal diet. A military ration containing 22.0 gm. of sodium chloride would require at least 4.69 L. per day to counterbalance the loss. If the contents of the salt packet in the ration were also eaten, 5.60 L. per day would be needed as total water intake. The presently tested maximum load of salt of 32.8 gm. per day would require 6.06 L. of water per day.

These water requirements are for a man of average size (70 kg. wearing clothes) and leading a sedentary existence in a warm, arid environment with an *ad libitum* water intake.

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