

ability of the human kidney to concentrate sodium in the water available for excretion. In column 4 of Table 3 is shown the effect in a dog of the experimental simulation of sea-water ingestion, that is the addition of sodium in excess of water. The concentration of extracellular sodium rose abruptly, water was rapidly withdrawn from body cells, and respiratory failure ensued. Too much, as well as too little, sodium in relation to water can be a bad thing!

Conclusion

My children once asked me what my colleague, Dr T. S. Danowski, and I were writing about when we were laboriously compiling a monograph under the title *The Body Fluids*. My answer was that our subject might just as well be entitled, *Peter Rabbit in the Pond and the Pond in Peter Rabbit*, a description independently arrived at by Dr Robinson. My share in this symposium has been to make the point that despite the predominantly watery character of ponds the health and happiness of Peter Rabbit depends on how those ponds are salted.

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Water equilibrium in health

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Dr Robinson (1957) and Dr Elkinton (1957) have described how all the chemical reactions of the body by which life is maintained take place in a watery medium, and made it clear that life without water is impossible. They have stressed how important it is that the extracellular fluids—the pond in fact—shall remain constant in volume and composition. Ponds, however, tend to dry up, and the one in the body is losing water every minute of the day and night; these losses must be made good if life is to proceed in the normal way.

Fresh supplies of water are obtained from three main sources. The first is fluids that we drink, and man generally drinks more than he needs. This is not true of an

animal like the laboratory rat, which seems to regulate its intake of water so that with a fully concentrated urine it is just able to excrete its waste products. The second source is water in the solid food. Nearly all foods contain some water, and many contain a considerable amount. Bread, for example, contains nearly 40% and a beef-steak more than 50%. The third source is the water formed by the oxidation of protein, fat and carbohydrate. A 3000 Cal. diet gives rise to about 350 ml. water. This quantity will not meet a man's requirements, but it will help.

Water is normally lost from the body by four different routes: the lungs, the skin, the intestine and the kidneys. Although the magnitude of the losses by each of these routes varies from one person to another and one set of conditions to another, some loss by each of them is absolutely inevitable.

A large intake of water presents no physiological problems to a healthy person, because the excess is readily excreted by the kidneys, but a shortage of water may have disastrous effects. Dehydration is always due to the losses of water from the body exceeding the intake. This usually happens because the losses increase but the intake does not keep pace, or because a real shortage of water prevents a person satisfying his normal requirement.

Losses by the lungs

The air breathed out is always saturated with water vapour, and the daily loss of water in this way amounts to about 400 ml. in an adult taking a minimum amount of exercise. The loss will be higher the more exercise a person takes or if he ascends to great altitudes, for he will then breathe more deeply and more frequently. On the 1953 Everest expedition it was found that losses of water by the lungs were four times as great at high altitudes as they were at sea level. One of the reasons for the exhaustion of members of some previous Everest expeditions, the Swiss one in 1952 for example, was probably lack of water. On the South Col over a period of 3 days the Swiss climbers drank less than 1 pt./man/day, which was certainly inadequate. On the 1953 British expedition the men drank 5-7 pt. daily (Hunt, 1953).

Losses by the skin

The loss of water from the skin as insensible perspiration is about 600 ml. a day by a person at rest in a temperate environment. This loss varies with body temperature and with the metabolic rate, with the temperature and humidity of the environment, and with the amount of clothes or bed clothes covering the body. Insensible water loss from the skin, like that from the lungs, plays an important part in the dissipation of heat generated by metabolism and hence in the regulation of body temperature, and it is essential for survival. It is quite distinct from the loss of water by sweating. Sweating is an accessory means of cooling the body by the evaporation of water when the temperature tends to rise. In a hot climate a man who is working may lose 10-14 l. by the skin in the course of a day (Hunt, 1912; Adolph (and associates), 1947), and all this loss is essential if he is to survive, for the evaporation of his sweat keeps him cool, and were he to stop sweating his temperature would

rapidly rise to a level incompatible with life. In deserts and other hot places losses of water in the sweat may reach very high levels, but even in this country on a hot day we all know how thirsty we can feel. Mountaineers at high altitudes may lose a considerable amount of water by the skin as well as by the lungs, particularly when climbing on glaciers during the heat of the day. We tend to think of the heights of the Himalayas as rather chilly places, but on Cho Oyu in May 1952, for example, 'sun temperatures of 156°F were recorded at 19,000 feet' (Hunt, 1953). Every drop of water lost in the sweat must be replaced by drinking. In hot deserts and on high mountains thirst often fails to maintain a high enough intake of fluid. If good water is readily available people will drink it, but if snow has to be melted or if the water tastes warm or is in any way unpleasant there is a danger that they will not drink all they need to maintain full efficiency. Sweat is a dilute solution of sodium chloride, but since it contains less salt than the plasma the loss of water is proportionately greater than the loss of salt, so that sweating without drinking always leads to concentration of the body fluids. If the person now drinks water freely he may so dilute his body fluids that he is seized with severe cramps, which are due to a lowering of the concentration of sodium in his extracellular fluids. This can be prevented by adding a small quantity of salt to the drinking water of those who are working in hot atmospheres.

Losses by the intestine

The loss of water in the faeces varies with the rate of passage of material through the intestine, particularly the colon, and with the amount of 'roughage' to be excreted. It is generally of the order of 100 ml. a day. An increased loss of water by the bowel in diarrhoea does not come within my terms of reference, but I would like to emphasize the enormous turnover of water that goes on in the digestive tract every day in comparison with the amount that is eventually excreted in the faeces. An adult produces about 8 l. digestive juices a day (Rowntree, 1922). Of this water, 99% is reabsorbed in the intestine and only 1% is lost in the faeces.

Losses by the kidney

The function of the kidney may be stated to be the regulation of the volume and composition of the body fluids. The losses of water go on through the lungs and skin whatever the supply of water and the state of hydration of the body may be, but the volume of urine may be as little as 300 ml., or as much as several litres according to the intake and the amount excreted by the lungs and skin. Some urine must always be secreted, for in all circumstances, whether of starvation, dehydration or plenty, the kidney continues to excrete urea and salts, and with them water. The volume depends upon the intake of water, the losses by the lungs and skin, the amounts of urea and salts being excreted, and upon the concentrating power of the kidney.

Water equilibrium in the baby

A baby has a much larger turnover of water than an adult in proportion to its body-weight. It loses more by the lungs because it breathes a greater volume of air

per lb. of body-weight than an adult each minute (Smith, 1951), and more by the skin because it has a bigger surface area in proportion to weight; it also requires a larger volume of water to excrete the same amount of urea and salts because it cannot concentrate its urine to the same extent. A baby's fluid intake is, therefore, higher than that of an adult per lb. of body-weight. If it is reckoned that a baby takes $2\frac{1}{2}$ oz. milk/lb. body-weight/day it drinks about one-seventh of its own weight of water each day. This would correspond to 2 gal. for a 10-stone man. If an adult and a baby were deprived of all water the baby might be expected to succumb before the adult. Whether this would in fact be so I do not know. A baby can certainly tolerate a rise in the osmolar concentration of its body fluids better than an adult; perhaps it can also survive a bigger reduction in their volume.

Effects of dehydration

The effects of dehydration have been studied experimentally by several groups of workers. One investigation was made many years ago in our Department in Cambridge (Black, McCance & Young, 1943-4). Dr Black was one of the subjects, and he ate a dry diet consisting, as far as I remember, mostly of oatcakes, butter and marmalade, with nothing to drink. The volume of his body fluids was reduced by about 10% in 3 days, but there was at the same time a rise in the concentration of salts and urea in them. Three days without water were sufficient to make a big difference to the subjects' appearance and behaviour. 'Their mouths and throats had become dry, their voices husky, and they had begun to find it difficult to swallow. By the 3rd or 4th day their facies had become somewhat pinched and pale, and there was a suggestion of cyanosis about the lips, which was rather characteristic'.

Another experimental investigation of dehydration was carried out in rather different circumstances. It was made on a Buddhist bishop while he was occupied with religious duties in a temple in Japan (Yoshimura, Inoue, Yamamoto, Yamaji, Tanimura, Oohara, Takaoka, Koishi, Funaki & Hayashi, 1953). He neither ate any food, nor drank any water for 8 days, but during this time he 'performed his religious penances and prayed before a large sacred fire several times a day'. Apart from this activity he lay on his bed. During the whole experiment urine and faeces were collected and blood was taken at frequent intervals. 'The subject suffered from severe thirst, fatigue, palpitation, dizziness, etc. after the third or fourth day. The general appearance was worn out and the skin was dry . . . the subject lost about 23% of total body water (about 8 litres) after about 8 days'. In the experiments both on Dr Black and on the Buddhist bishop about one-third of the water was lost in the urine and faeces, and two-thirds from the lungs and skin. Again there was an increase in concentration of the urea and salts in the body fluids as well as a decrease in their volume. Which of these is the primary cause of death from dehydration is, I think, still not known for certain; it is possible that they are both involved.

In 1871 a book was published entitled *The Welsh Fasting Girl* (Fowler, 1871). This book tells the story of a certain Sarah Jacob who, it was alleged, took no food or water and yet remained plump and in good health. After she had been going on

in this supposedly miraculous way for about 2 years Dr Robert Fowler, a London doctor, happened to be staying in the neighbourhood where the girl lived and he went to see her and was allowed to examine her. As a result he wrote a letter to *'The Times'* making it clear that in his opinion the whole thing was a fraud and that the girl, then aged 12 years, was being fed in secret all the time. This letter excited much feeling in the locality, where these aspersions on the 'Welsh wonder' were much resented. So strongly did some people believe that the girl was living without food or water that it was decided, with the willing co-operation of the parents, that she should be watched night and day for a fortnight, so that the world should know that what was alleged was true.

For this purpose 'four reliable nurses from Guy's Hospital' were sent to the village in Wales where Sarah Jacob lived and on Thursday, 9 December 1869, their watch began. It was not their duty to keep food or drink from the child, or to feed her, unless she wished for anything or her parents wished her to be given food or drink. Their duty was to observe what happened. In 8 days the girl was dead. The doctors who came to see her, and the nurses, all seem to have realized that she was going to die but, because neither she nor her parents asked for her to be given food or water, nobody did anything to save her life. Although it does not seem to have been appreciated at the time, there is no doubt now that this girl died of dehydration. The description of her appearance by the nurses fits in with this. 'Her eyes were sunk, and her nose pinched, and the cheek-bones more prominent . . . Her lips were very dry, and her mouth seemed parched'. She would certainly not have died of starvation in 8 days, for a previously well-nourished person lying in bed would probably survive for many weeks without food, provided she was given a plentiful supply of water.

Survival at sea

Dehydration is a serious problem in situations where there is a real shortage of water. This is particularly so among men adrift on the sea in lifeboats and rafts after shipwreck. Men have survived for many weeks without food, but survival for as much as 2 weeks without water is unlikely, even under favourable conditions. One might conclude that where space for rations is limited only water should be carried. This is not quite true. During complete starvation the amount of body protein broken down is quite large, and the nitrogen produced by the breakdown of this protein has to be excreted as urea, which means that the minimum urine volume is not quite as small as it might be. It has been found that giving a small amount of sugar reduces the breakdown of protein to well below the level found in starvation (Gamble, 1944; Hervey & McCance, 1952).

The question as to whether people adrift on rafts should drink sea-water has come up again and again, and interest has been revived in this problem since Dr Bombard succeeded in crossing the Atlantic in his small dinghy. Sea-water is a more concentrated salt solution than any urine that was ever produced by man, and it is four times as concentrated as the extracellular fluid. If a person drinks sea-water he may excrete the salt in it, in which event he will have to part with some of the water

from his body fluids along with it, or he may retain the salt. In either event the result must be a concentration of his body fluids and an accentuation of his dehydration. We may safely say that Dr Bombard, and those who have emulated him, survived in spite of drinking sea-water, not because of it.

A convincing argument against the drinking of sea-water by castaways is provided by figures for the mortality rate among members of the Merchant Navy who were shipwrecked during the last war (McCance, Ungley, Crosfill & Widdowson, 1956). In those life-craft where sea-water was recorded as having been drunk by one or more of the men the mortality from all causes was 39%. Where no positive statement was made the mortality was 3%. Drinking sea-water was sometimes reported as having caused delirium, madness, suicide or death; in no instance was it reported to have prolonged life.

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The breakdown of the water equilibrium in disease

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If the subject delineated by my allotted title is to be reduced to manageable proportions, it will be necessary to exclude from consideration a number of topics which are either too general to warrant discussion here, or which fall within the territory of other speakers in this symposium. It is difficult to conceive of a disease process which is not attended by some local change in tissue hydration, but such changes are mostly secondary effects, and for our present purpose can be omitted. Moreover, the physiological aspects of body water have been discussed by Robinson (1957) and Widdowson (1957), so it will not be necessary for me to discuss normal water balance. Many of the most notable alterations in water content of the body are really determined by primary changes in its content of electrolytes, certainly of sodium