

EFFECTS OF FEEDING BABY PIGS A DIET DEFICIENT IN SODIUM

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INTRODUCTION

A number of studies have been made of animals in a condition of acute or chronic sodium deficiency. In general, a sodium deficiency can be produced by feeding a low sodium diet, by acidosis, by extrarenal dialysis, or by induced diuresis.

A diet containing 7 mgs. sodium per 100 gms. of ration was fed to rats and caused a diminution of appetite which subsequently led to a decrease of fat and protein synthesis (Kahlenberg, *et al.*, 1937). A diet containing 2 mgs. sodium per 100 gms. ration fed to rats caused a loss of weight within a few weeks (Orent-Keiles, *et al.*, 1937). During the eighth to tenth week of feeding the low sodium ration many animals developed a thickening and bluish grey appearance of the corneae. Histological examinations showed the beginning of capsular cataracts. The female rats fed the low sodium ration became sexually mature later than control rats; vaginal smears indicated large, flaky cornified cells characterizing a period of estrus and ovulation which occurred about the same time as the initial changes in the eyes. Both male and female rats fed the low sodium ration had impaired reproductive function, and there was 100% mortality from the 18th to 21st week after the initiation of sodium deprivation. Rats fed a

low sodium diet decreased their urinary 17-ketosteroid excretion after the third week of deprivation (Danford and Danford, 1951). Rats fed a sodium deficient ration developed enlarged adrenals with a decreased ascorbic acid content between 30 to 150 days (Danford and Herrin, 1951). Three ten-week-old female puppies fed a ration containing 11 mgs. sodium per 100 gms. of ration exhibited a slight decrease of blood sodium and a slight increase in blood potassium (Turpeinen, 1939). The dogs lost weight continuously. They lived 50, 51, and 66 days when fed this ration.

The sodium requirement of growing swine whose initial body weights were approximately 32 lbs. was studied (Meyer, *et al.*, 1950). The low sodium ration contained 5 mgs. sodium per 100 gms. and was fed to the pigs for six weeks. During this time they gained an average of three lbs. per week. There were no significant differences in plasma sodium levels between control and sodium deficient pigs.

This laboratory has reported the effects of diarrhea on sodium retention by pigs (Reber and Whitehair, 1955; Reber and Yusken, 1956). These findings stimulated an investigation of the effects of feeding to pigs a ration containing a low level of sodium. This is a report of that investigation.

MATERIAL AND METHODS

Five healthy Hampshire pigs, 11 days of age, were placed in individual metabolism cages. Littermate pigs 3 and 4 were maintained on approximately 250 mgs. sodium per 100 gms. of ration until 41 days of age. Pigs 9, 10, and 12 were littermates from another sow. Pigs 9 and 10 were fed 250 mgs. sodium per 100 gms. ration while pig 12 was fed 700 mgs. sodium per 100 gms. ration until 41 days of age.

Salts were supplied as the USP XIV formula with added sodium chloride to supply varying amounts of sodium. The rations were fed as a "milk" containing 20% total solids.

When the five pigs were 41 days of age they were fed a ration containing only trace amounts of sodium. The composition of the ration is given in Table 1 and that of the salt mixture in Table 2. The ration contained 9.4 mgs. of sodium per 100 gms.

Collections of feces, urine, unconsumed feed, and vomitus were made twice each week. The urine was collected in bottles containing sulfuric acid. Samples were kept corked until used for sodium analyses. Feces, unconsumed feed, and vomitus were kept frozen at -10° C. All samples were wet-ashed with sulfuric and nitric acids.

Whole blood samples were taken by heart puncture with heparin used as an anticoagulant. One milliliter of whole blood was diluted with distilled water and frozen. These samples were later thawed and transferred quantitatively to volumetric flasks through filter paper to re-

TABLE 1.—Percentage Composition of Low Sodium Ration.

Lard.....	40.0
Casein.....	35.0
Lactose.....	10.0
Dextrose.....	8.4
Salt mix ¹	5.0
Wheat germ oil (2 I.U.E./gm.).....	1.0
Vitamin A and D oil (1000 U.S.P.A., 100 U.S.P.D./gm.).....	0.5
Vitamin mix ²	0.1

¹ See Table 2 for composition.

² To 200 gms. of dry ration the following amounts (mg.) of vitamins were added: thiamine, 1.1; riboflavin, 1.8; nicotinic acid, 10.1; inositol, 26.8; choline chloride, 260; p-aminobenzoic acid, 5.0; folic acid, 0.13; biotin, 0.025; pyridoxin, 2.0; calcium pantothenate, 7.1; ascorbic acid, 130.0; vitamin B-12, 0.01; menadione, 0.29.

move any clots. Sodium and potassium analyses were made by flame photometry using lithium as an internal standard.

Hemoglobin was determined by a modification of the cyanomethemoglobin method (Crosby, 1954). Blood non-protein nitrogen and blood urea nitrogen were determined by the method described in the Beckman manual (Chaney and Lamar, 1955).

RESULTS AND DISCUSSION

Pig 3 died after it had been fed the low sodium ration for 40 days. The body weight of this pig was maintained until the last collection interval during which it lost 435 gms. Pig 4 was necropsied after being fed the low sodium ration for 32 days. It gained 1775 gms. during the first 28 days of sodium deficient ration. During the two days before it became comatose it lost 900 gms. Pig 9 lost 330 gms. over a 27-day period on the low sodium ration. There was a progressive increase in body weight up to the 14th

TABLE 2.—Sodium-Free Salt Mixture.

Constituent	Percent
Calcium carbonate.....	37.5
Potassium dihydrogen phosphate.....	28.4
Potassium chloride.....	18.9
Ferric citrate.....	9.5
Magnesium oxide.....	3.8
Copper sulfate.....	1.9
	100.0

day and a decline thereafter. There was a loss of 518 gms. during the 72-hr. period preceding death. Pig 10 showed little tendency to gain weight during the first 35 days. There was a loss of 670 gms. from the 35th to the 39th day and little change in body weight up to the end of the experiment. There was virtually no change in body weight of pig 12 up to the 21st day. Pigs 10 and 12 were killed after being fed the low sodium ration for 67 days. This period of time was deemed adequate to show physiological changes.

The average daily gain in weight, sodium intake and excretion, and sodium balance for each pig maintained on 9.4 mgs. sodium per 100 gms. of ration are presented in Table 3. This table also contains data obtained from baby pigs fed the rather high level of 920 mgs. of sodium per 100 gms. of ration (Reber and Yusken, 1956). Only pig 4 gained weight during the low sodium feeding. The feed and sodium intake values were very low. Pig 9 had a negative sodium intake which was presumed to be due to salivation, or possibly to some fecal or urinary contamination that was introduced into the feed bowl. The

average daily urinary losses of sodium by these pigs was about 17 mgs. per day. Their fecal loss was small and constant, and there was a rather constant negative balance of about 20 mgs. sodium per day.

In Table 4 is a summary of the very large negative sodium balances exhibited by these pigs during sodium deficiency. These large negative sodium balances occurred as early as the 7th to 11th day and as late as the 46th to 49th day of feeding the sodium deficient ration. In eight of ten balances the large daily negative sodium balance was accompanied by a loss of body weight. The fecal sodium level was not increased during these collection periods, and the large negative balances were a function of sodium losses in the urine. There was some tendency for the sodium to be concentrated in the urine. Urine volumes did not increase appreciably. There was no constant value of sodium loss per given value of body weight loss. The sodium losses varied from 22 to 227 mgs. per 100 gms. of body weight lost. It is tempting to postulate that some of these pigs may have lost sodium from some area of the body in which sodium was sequestered. There were two cases, *i.e.*, pig 4 during the 7th to 11th day of sodium deficiency and pig 10 during the 39th to 42nd day, in which there were no weight losses although there were marked negative sodium balances. These two cases strongly suggest a reserve area for sodium in the body.

Bergstrom and Wallace (1954), by using intraperitoneal dialysis against ammonium chloride in rats, found a decrease in the bone sodium

TABLE 3.—Average Daily Changes that Occurred When Pigs Were Fed Rations Adequate or Deficient in Sodium.

	Sodium per 100 gms. of ration					
	920 mgs. ¹	9.4 mgs.				
		Pig 3	4	9	10	12
Wt. changes, gm..	100 (12) ²	-36 (7)	50 (5)	-36 (6)	-20 (14)	-25 (14)
Na intake, mg....	768 (12)	3.9(8)	8.5(8)	-0.3(7)	1.4(16)	0.5(15)
Urinary Na, mg....	536 (12)	18.4(9)	18.1(9)	13.9(8)	14.8(17)	19.5(16)
Fecal Na, mg....	7.7(12)	1.5(9)	3.3(7)	3.6(7)	4.9(16)	3.0(16)
Na balance, mg....	215 (12)	-14.8(7)	-10.6(4)	-24.9(6)	-22.5(14)	-27.8(14)

¹ Reber and Yusken, 1956.

² Numbers in parentheses represent the number of three- or four-day trials.

and potassium. Their experiment implicated bone as a reservoir for sodium and potassium. Edelman, *et al.*, (1954) found that 45% of the bone sodium was exchanged with radioactive isotopic sodium within four hours in both man and dog, which indicated a great lability of bone sodium.

Whole blood sodium and potassium, hemoglobin, blood urea nitrogen, and blood non-protein nitrogen were determined on the five pigs used in this experiment, both while they

were fed an adequate sodium ration and a deficient sodium ration (Table 5). The average sodium levels of whole blood did not decrease during sodium deprivation, while whole blood potassium did. However, sodium deficiency caused an elevated blood urea nitrogen and blood non-protein nitrogen. Pig 3 had an abnormally high blood non-protein nitrogen during the last collection interval which was probably a reflection of the changes preceding death. Pig 12 consistently had an

TABLE 4.—Summary of Large Daily Negative Sodium Balances.

Pig	Days of sodium deficiency	Weight change, gms.	Urinary sodium, mgs.	Urine volume, mls.	Sodium balance, mgs.
3	7-11	-16			
3	35-39	-109	34.5	180	-37.0
4	7-11	0	53.7	158	-215.0
9	14-18	-99	15.4	190	-28.3
9	25-27	-173	43.8	196	-54.5
10	35-39	-168	12.0	150	-37.0
10	39-42	+57	61.0	223	-66.7
10	46-49	-37	96.3	250	-95.7
12	25-28	-93	70.0	90	-79.0
12	46-49	-75	87.7	133	-98.3
			34.7	68	-37.3

TABLE 5.—Blood Changes in Baby Pigs Fed a Diet Adequate or Deficient in Sodium.

	Adequate sodium diet	Deficient sodium diet
Hemoglobin, gm. %	10.9 (12) ¹	11.9 (25)
Blood urea nitrogen, mg. %	20.9 (11)	30.0 (29)
Non-protein nitrogen, mg. %	20-45 ²	56.4 (23)
Whole blood sodium, MEQ./l. . . .	94 (26)	93 (32)
Whole blood potassium, MEQ./l. . . .	47 (26)	41 (32)

¹ Numbers in parentheses are number of trials.
² See Dukes (1953).

elevated blood urea nitrogen and non-protein nitrogen which was highest on the 25th day of sodium restriction. The blood urea nitrogen rose to 89 mg.% and blood non-protein nitrogen rose to 100 mg.%. This may have reflected some transitory kidney impairment, because the blood levels returned to normal values by the end of the experiment at which time no gross kidney pathology was observed.

The post-mortem examination of the three pigs that died in this experiment did not reveal any specific pathology. Pig 3 was found to have an enteritis with free blood in the lumen. There appeared to be a fatty infiltration of the liver and some degenerative changes of the nephron. Pig 4 had a gastritis, a pulpy kidney, and other characteristics depicting a uremic state. This uremia was verified by the abnormally large blood non-protein nitrogen. Pig 9 was found to have excessive and bloody pericardial fluid along with a flaccid myocardium of the left

side, probably due to heart puncture. There also was an enteritis and lymph node congestion. Pigs 10 and 12 were sacrificed after 67 days on the sodium-deficient ration and they had no gross pathological conditions.

SUMMARY

Five apparently healthy Hampshire pigs were fed a synthetic ration which contained 9.4 mgs. of sodium per 100 gms. of ration, from 7 to 15 weeks of age. Sodium balances and blood chemistries were obtained to assess the effects of sodium deprivation. The pigs did not thrive, ate poorly, drank little water and either showed poor gains in body weight or losses. The tendency for high blood urea nitrogen or non-protein nitrogen seen in these pigs indicated endogenous protein breakdown with an inability to remove these nitrogenous wastes. Negative sodium balances persisted during sodium restriction with intermittently large negative sodium balances and urinary sodium losses usually accompanied by large losses of body weight. Although large amounts of sodium were lost in the urine, the level of blood sodium did not change from standard values, and blood potassium concentration decreased. Some large negative sodium balances were neither accompanied by losses of body weight nor changes in blood sodium, which was postulated to indicate a loss from some reserve area in the body such as bone. It was also concluded that the level of blood sodium *per se* does not appear to be adequate to assess sodium nutrition.

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