THE RÔLE OF MINERAL SALTS IN THE METABOLISM OF INFANTS *

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It is the purpose of this paper to present, in rather broad outlines, the part which mineral salts play in carrying on the physiologic functions of the body, and in what manner they contribute to the various pathologic processes to which the infant and young child are subjected.

This field of metabolic research has been the last to be undertaken, and just now we are coming to realize its vast importance, not only in connection with their own functions, but in connection with the influence they have on the metabolism of fat, protein and carbohydrate. The chief reason for having failed to realize the importance of the mineral salts in metabolism is that it has long been thought that the salts contributed in no way to the nourishment of the child. It has been only recently that they have taken their rightful place as indirect energy producers.

HISTORICAL

The first investigator to concern himself with the value of mineral salts was von Liebig,¹ who, as early as 1840, studied the action of mineral salts both in animal and vegetable life, and many of his early deductions have become firmly fixed as laws in the field of mineral salts metabolism. C. Voit² is another investigator whose work on the action of sodium chlorid, as early as 1860, first gave to that salt its prominence above all others in the human economy. Vierordt was also an indefatigable worker, and as early as 1877, from meager data then present, had calculated absolute and relative heat and estimated child's metabolism. J. Forster,³ in 1873, added his convincing experiments on the necessity of the mineral salts to the continuance of life, and these were further reinforced by the work of Lunin⁴ in 1881. As time advanced, the roster of those who worked in the field of mineral metabolism contains the names of many

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1. Von Liebig, J.: *Chemie in ihrer Anwendung auf Agrikultur und Physiologie*, 1876, p. 332.

2. Voit, C.: *Ueber den Einfluss des Kochsalzes auf den Stoffwechsel*, München, 1860.

3. Forster, J.: *Ztschr. f. Biol.*, 1873, ix.

4. Lunin, N.: *Ztschr. f. physiol. Chem.*, 1881, v.

notable investigators, as G. v. Bunge, Michel, Keller, Loeb, Muller, Schlossman, Blauberg, Rubner, Huebner, Freund, v. Noorden, and in these latter days the work is being carried on enthusiastically by L. Langstein, L. F. Meyer, E. Schloss, J. A. Schabad and others abroad, and by Howland, Schwartz, Talbot, Veeder, and others in this country.

A GENERAL VIEW

In undertaking a problem of this kind, it is well at the beginning to take a general view, first of the physiologic action of the mineral salts as a whole, and then to study what has been definitely determined as to the action and influence of each of the mineral constituents. Then by inquiring into the mineral constituents of the new-born and of older children, one will be in position to learn the mineral needs of the growing organism, and, knowing them, to ascertain how best to supply them, and to study the factors which enter into the proper utilization of the salts ingested in the food and to determine whether or not this utilization is sufficient to meet the demands of the growing infant.

First, then, a general view of the physiologic action of the mineral salts as a whole. Physiologists are generally agreed, and their findings confirmed by physiologic chemists, that the important functions of the mineral salts are as follows:

1. They maintain the osmotic pressure in tissue cells, blood, and body fluids; controlling the flow of water to and from tissues; any deviation from normal causing a shrinking or swelling of tissue cells.
2. They regulate the reaction of the blood and tissue fluids. A deviation from this reaction inhibits the action of the various ferments, delays chemical processes, and if such reaction suffers much variation, death results.
3. Their presence in tissues and fluids gives rise to irritability of muscle and excitability of nerve through the action of their respective *ions*. Through this function the rhythmical contractions of the heart are maintained.
4. They act as catalysts for a large series of chemical reactions which take place during the processes of absorption, retention, utilization, and form combinations with waste products of metabolism in order to effect their elimination; for example, they act as carriers of excess acid materials in oxidation processes.
5. They share in the upbuilding and growth of the body, since they are a constituent of every cell; particularly do they take part in the changes which go on in the albumin bodies as they become intimately bound with the body proteins.
6. Their function in the intermediary metabolism of the ductless glands is very apparent from the large quantities of mineral salts found in these glandular organs.
7. Through a most excellent self-regulation, they protect against the acid poisons which the body is constantly producing.
8. Through the work of the various *ions*, electrically charged, some positively, some negatively, many important functions are being assigned to them, such as controlling body-weight, temperature, regulating the pulse, increasing leukocytes, etc. These and many more functions, not clearly defined, depend on the presence of the mineral salts in the body, and not on their presence alone, but their presence in definite relationships to one another.

ABSOLUTE NECESSITY OF SALTS

While physiologists have been busy defining the various functions of salts, other investigators have determined the absolute necessity to the maintenance of life of a certain quantity of mineral salts, and not only a certain quantity, but they have found that these salts must be in certain organic combination, as the following experiments will show:

Forster,⁵ in 1873, fed pigeons on approximately ash-free diet, and found their bones brittle, and they all died within a month. He also fed dogs on salt-poor diet, and they lived from twenty-six to thirty-six days.

Lunin⁶ showed by his classic experiment that the salts must be in organic combination to be available. He found that mice thrived well on dried whole milk, but that if the salts were extracted from the milk, and they were fed only the protein, fat and carbohydrate, they shortly died, and further, after abstracting the salts, if he substituted the same quantity of other mineral salts, adding them to the protein, fat and carbohydrate, the mice died. Furthermore, mice fed on ash-free food, plus sufficient sodium carbonate to take the place of the usual salts, lived twice as long as mice fed only on ash-free diet; nevertheless, they succumbed, demonstrating that even with the necessary amount of bases carbonates cannot supply the salt needed.

Rohmann⁶ added further confirmation to the value of salts. He fed mice a mixture of simple organic and inorganic food-stuffs. These mice lived and were able to produce young, but the latter could not be raised on artificial food, nor could they be made to produce living young.

It is evident from this latter experiment that artificial foods may be sufficient for the adult, whose supply of minerals is well established, but it is not sufficient to produce healthy offspring.

Abderhalden⁶ believes that the same physiologic importance of salts exists for the animal kingdom as has been shown by von Liebig and others to exist for the vegetable kingdom.

The salts have a very important bearing on the absorption and retention of other food constituents, e. g., in a large nitrogen retention there is usually a large ash retention, and when ash is eliminated in large quantities there is usually an accompanying loss of nitrogen.

T. B. Robertson⁷ points out how intimately the precipitation and coagulation of protein depends on the salts present in the solution as *ions*. Indeed it is becoming more and more to be appreciated that the various food constituents have a very intimate influence, the one on the other, and it is along this particular line that metabolism studies are directing themselves.

Recognizing, then, that the mineral salts are necessary to life, let us inquire what salts, and in what proportion in the body, Nature has stored

5. Rohmann: *Klin.-therap. Wehnschr.*, 1902, No. 40.

6. Abderhalden: *Physiological Chemistry*, p. 356.

7. Robertson, T. B.: *Jour. Biol. Chem.*, May, 1911.

them, by the action of which not only life is maintained, but energy developed and growth permitted. We are indebted to a number of investigators for information on the ash-content of the human organism both during fetal life and later.

Fehling⁸ gives us the following figures of the ash-content at different periods of fetal life:

Period of Life.	Ash Content; Per Cent. of Total Weight.
Fetus, 6 weeks	.001
Fetus, 4 months	.98
Fetus, 5th month, first half.....	1.4
Fetus, 5th month, second half.....	1.43
Fetus, 6th month.....	1.94
Fetus, 7th month.....	2.94
Fetus, 8th month.....	2.82
Fetus, 9th month.....	3.3
In the new-born.....	2.7
In the adult.....	4.4

It will be noted, therefore, that from the earliest observation of fetal life to those on adult bodies, there is a gradual increase of the ash-content. This increase is most rapid in terms of percentage of body weight during the fetal period, and thereafter the increase is much slower.

Let us now ask ourselves the question as to the mineral constituents contained in the total ash-content and study their relative amounts. Hugouencq⁹ has given us this information for fetal life, and Soldner¹⁰ for the new-born. Soldner found that there was 75 gm. of ash in a new-born child which was equal to 2.7 per cent. of its body weight, or 9.4 per cent. of the dry residue.

Period of Life.	Total Ash in Parts Per 100							
	Cl	P ₂ O ₅	SO ₃	CaO	MgO	K ₂ O	Na ₂ O	Fe ₂ O ₃
Fetus, 5 months.....	8.59	34.36	1.8	32.5	1.58	8.28	12.62	.4
Fetus, 6 months.....	7.75	34.94	1.78	34.6	....	7.21	10.62	.39
Fetus, 7 months.....	8.53	35.39	1.46	34.13	1.17	8.45	10.95	.398
New-born (Soldner), average of 6.....	6.61	.....	2.02	38.08	1.43	7.06	7.67	.83

Soldner, arguing from the average ash content of six new-born infants, concluded that there was a daily need of 1.4 gm. of mineral ash, and an infant should retain of the intake, chlorin 14 per cent., potassium 11 per cent., sodium 35 per cent., CaO, MgO and P₂O₅ at least 65 per cent. of the intake.

It will be noted that phosphorus and calcium make up considerably over half; sodium about an eighth, and potassium and chlorin about a twelfth of the total ash-content, and that sulphur, magnesium and iron make up but a small part of the total.

8. Fehling: Cited by Freund, in Pfaundler and Schlossman, i, 363.

9. Hugouencq: *Compt. rend. Soc. de biol.*, li, 537.

10. Camerer and Soldner: *Ztschr. f. Biol.*, 1900-3, xxxix, xl, xlii, and xlii.

Bunge,¹¹ after a careful study of the mineral contents of the milk of lower animals and estimating the daily requirements of their offspring, attempted to show that the ash-content of the body was in correct proportion to the ash-content of the various animals. But when this was applied to the nursing infant his analogy failed, and the problem did not solve itself as readily as this hypothesis would indicate. It is evident that the main metallic elements are calcium, sodium, potassium and magnesium; the main acid salts being phosphoric, hydrochloric, carbonic and sulphuric, calcium phosphate being the most abundant of all the salts.

It should be further noted that the phosphorus and calcium content of the body increases in percentage, and that the other elements remain at the same or less percentage, but of course their absolute amount gradually increases.

The difference between the ash-content of a new-born and the ash-content of a 4-months' old child represents the change which must take place in the mineral salt storing. In actual figures the child must add to his weight, during the first four months, the following quantities of the various minerals:

	Gm.
K ₂ O	2.0
Na ₂ O	2.57
CaO	11.75
MgO	.31
Fe ₂ O ₃	...
P ₂ O ₅	10.48
Cl	1.12
S	...

It will be noted what really small quantities of the mineral salts are added to the body—extremely small when we consider the large quantity which a child during the first year must ingest. It is estimated that only about 4 per cent. of intake goes to growth in early months and later only half that amount. It is evident that a large quantity must be worked over. Taking mother's milk as a basis, during the first twelve months of life there is approximately 800 gm. of total ash ingested. This is divided among the various mineral salts as follows:

	Gm.
K ₂ O	276.
Na ₂ O	19.6
CaO	157.6
MgO	27.2
Fe ₂ O ₃	8.0
P ₂ O ₅	117.6
Cl	117.6
SO ₃	57.4
Total	791.0

If we take cow's milk as a basis, the picture is entirely different. Taking the average amount fed as outlined in Dr. Holt's text-book, an

11. Bunge: Cited by Freund, Pfaundler and Schlossman, Vol. i.

infant would ingest approximately 1,500 gm. of total ash during the first year of life, which would be divided among the various mineral constituents as follows:

	Gm.
K ₂ O	377.0
Na ₂ O	93.0
CaO	344.0
MgO	41.0
Fe ₂ O ₃	4.2
P ₂ O ₅	487.4
Cl	84.0
S	69.4
Total	1,500.0

This naturally leads us to a two-fold conception of the use which the body makes of the salts. First, a certain small per cent. is firmly bound with the tissues of the body and only escapes when such tissues are destroyed in oxidation; and a second group which are simply held in solution in the body fluids ready to be excreted, or to act as bases or alkalis to take up the products of cell destruction, or combine with acids set free in the processes of catabolism, or in the form of *ions* to subserve definite physiologic functions. It should be borne in mind that only a small part of the mineral salt intake in any day's feeding is added as an integral part of the tissue, and that by far the largest part is simply held in solution awaiting its excretion, either through the skin, urine or back into the intestinal canal. With sulphur and phosphorus the problem is a little more complicated, as these two substances are in exceedingly close chemical relationship with albumin, and before they can be set free the foreign albumin molecule must be torn down before it can be again rebuilt into the tissue substance and fluids of the host.

Having noted just what minerals and acids are present in the body at the end of fetal life, it behooves us to inquire into the method by which we can continue to supply the needs of the infant as relates to its mineral constituents so as best to foster its normal growth and aid in supplying its daily energy requirement. Nature has supplied us with a most excellent criterion by which we may reach a solution of this problem, viz., in normal mother's milk. Let us, therefore, address ourselves to a study of Nature's method of supplying the need of the growing infant by carefully considering the mineral constituents and their relative proportions in mother's milk.

In early mother's milk, i. e., colostrum, according to Camerer,¹² we have a marked increase from the first to the seventh day in the ash-content as follows:

Day after delivery	1	2	3	4	5	6	7
Ash content in per cents.....	0.1	0.5	0.7	0.9	1.0	1.1	1.3

12. Camerer: Cited by Freund in Pfaundler and Schlossman, i, 386.

Thus Nature provides in the early nursing period for a very rapid increase in the mineral constituents of the food. In mother's milk there is about 2.0 gm. of total ash to 1,000 gm. of milk. This 2 gm. of ash is divided among the various mineral constituents according to various authors, as follows:

In 1,000 gm. of mother's milk, there is, according to

	Bunge 1 ¹³ Gm.	Bunge 2 ¹⁵ Gm.	Camerer ¹³ and Soldner	Blauberg ¹⁴ Gm.
K ₂ O	0.780	0.703	0.884	0.69
Na ₂ O	0.232	0.257	0.357	0.049
CaO	0.328	0.343	0.378	0.394
MgO	0.064	0.065	0.053	0.068
Fe ₂ O ₃	0.004	0.006	0.002	0.02
P ₂ O ₅	0.473	0.469	0.310	0.294
Cl	0.438	0.445	0.591	0.294
SO ₃ .....	.....	.....	.....	0.143

The ash-content of mother's milk does not remain constant, as is shown by Soldner¹⁶ in his examinations of mother's milk on the eighth and seventieth days. In 1,000 gm. of mother's milk on the eighth day, there was 3 gm. of total ash, and in the same quantity on the seventieth day there was 2 gm. of total ash divided as follows:

	Eighth day Gm.	Seventieth day Gm.
K ₂ O	1.008	.259
Na ₂ O	.448	.176
CaO	.376	.381
MgO	.054	.052
Fe ₂ O ₃	.0022	.00125
P ₂ O ₅	.320	.288
SO ₃	.096	.063
Cl	.716	.342

From the above, it would seem that the fixed alkalies K and Na diminish greatly as does also the chlorin content of the milk, while the bone-forming constituents, viz., calcium, phosphorus and magnesium, remain nearly constant. In cow's milk the relations are entirely different as is shown by the exceedingly large ash-content of 7.8 gm. per 1,000 gm. of milk as against 2 gm. in 1,000 gm. of mother's milk. Not only does cow's milk contain more ash, but in vastly different proportion of mineral constituents than mother's milk, as will be seen by the following table when compared with the preceding table showing mineral contents of the ash of mother's milk. In 1,000 gm. of cow's milk there is:

13. Camerer and Soldner: Cited by Albu-Neuberg, *Mineralstoffwechsel*, p. 51.

14. Blauberg: Cited by Langstein and Meyer *Säuglingsernährung und Säuglingsstoffwechsel*, Wiesbaden, 1910, page 15.

15. Bunge: Cited by Albu-Neuberg, *Mineralstoffwechsel*, p. 51.

16. Soldner: Cited by Freund, in Pfaundler and Schlossman, p. 377.

	Bunge ¹⁵ Gm.	Soldner ¹³ Gm.	Hoobler Gm.	Soldner ¹⁷ Gm.
K ₂ O	1.766	1.720	.....	1.885
Na ₂ O	1.110	0.51	.....	0.465
CaO	1.599	1.980	1.600	1.72
MgO	0.210	0.20	0.167	0.205
Fe ₂ O ₃	0.004	.....	.....	0.021
P ₂ O ₅	1.974	1.82	2.140	2.437
Cl	1.697	0.98	1.86 (NaCl)	0.820
S .....	.....	.....	0.33638	....

It will be seen that in the same quantities of milk, that of the cow contains over twice as much potassium, five times as much sodium, phosphorus and calcium, four times as much magnesium and chlorin and six times as much sulphur. And, further, these salts are not in the same organic combination in one as in the other, as shown by Keller,¹⁸ and also by Schlossman,¹⁹ as relates to phosphorus, and when we consider that it is the organically bound salts only, as shown by Lunin,⁴ which are available, this factor is a very important one.

Not only are the salts organically bound, but there is a peculiar specificity about the whey containing the salts of mother's milk. Meyer²⁰ has shown that not only the protein and fat of mother's milk, but even the casein and fat of cow's milk, are well absorbed and retained when mixed with the whey of mother's milk. Children fed on the fat and protein of mother's milk mixed with the whey of cow's milk are not able to utilize these food products and do badly. It would seem that some constituent in mother's milk whey contains the essential dynamic force for making the casein and fat of both mother's and cow's milk available for nutritive purposes.

Having now considered separately the salts of the child's body and the salts of the two most common foods, let us study the processes which take place when these foods are ingested by the infant. It would contribute to a continuity of thought if we were to follow each individual salt through its various metabolic steps under perfectly normal conditions and discuss them under the heads of ingestion, absorption, retention and elimination, considering the results obtained by investigators in the use of mother's milk and cow's milk.

After having considered these steps in normal metabolism, I shall address myself briefly to abnormal conditions of metabolism, desiring rather to give most attention to the consideration of the normal. I shall take occasion to consider, along with the findings of literature, some results obtained by me in a series of metabolism studies which I have

17. Soldner: Cited by Langstein and Meyer, *Säuglingsernährung und Säuglingsstoffwechsel*, Wiesbaden, 1910, page 15.

18. Keller, A.: *Arch. f. Kinderh.*, 1900, xxix.

19. Schlossman: *Arch. f. Kinderh.*, 1905, xl.

20. Meyer, L. F.: Cited by Meara, *Problems of Nutrition in Early Life*, *Arch. Pediat.*, xxvii, 401.

		TOTAL ASH							
		Elimination		Absorption		Retention			
Food	Intake	Feces	Urine	Gm.	Percent.	Gm.	Percent.	Gm.	Percent.
Mother's milk (Blauberg)	1.13	0.193	0.373	0.937	82.9	0.56	49.5	0.56	49.5
Mother's milk (Blauberg)	1.32	0.24	0.47	1.08	81.8	0.61	45.9	0.61	45.9
Cow's milk (Soldner)	6.841	2.686	3.1341	4.15	60.7	1.013	14.8	1.013	14.8
Diluted cow's milk, 2.1% fat (Hoobler)	8.9691	4.2651	4.7966	4.7039	53.0	.....	....	.....	....
Cow's milk, 4% fat (Hoobler)	9.4808	3.1390	3.0834	6.3418	66.8	2.8917	43.5	2.8917	43.5
Cow's milk and cream, 5.4% fat (Hoobler)	8.7634	1.8675	4.1493	6.8959	78.6	2.7465	37.8	2.7465	37.8
Cow's milk (Blauberg)	6.84	2.68	3.13	4.15	60.7	1.01	14.8	1.01	14.8

Figures given above are in grams in 24 hours.

carried out in the wards and laboratory of the Presbyterian Hospital on a perfectly healthy infant of 9 months who had been fed on cow's milk from the time of his birth, details of the experiment, as relates to nitrogen metabolism, having already been published.²²

TOTAL ASH

I will first consider the figures covering the entire mineral metabolism as represented by total ash, and will then discuss its various phases.

INGESTION

First let us consider the intake. It should be remembered that mother's milk is relatively poor in ash-content while that of cow's milk is exceedingly rich, so that one is not surprised to note that the intake of total ash through breast feeding is very much less than with cow's milk feeding. From the figures of Blaubeurg, Soldner, and my own determinations, the ash intake in artificially fed children is from six to nine times greater than that of breast-fed children.

ABSORPTION OF TOTAL ASH

Various observers have recorded their findings of ash absorption in mother's milk, varying from 81.82 per cent. by Blaubeurg to 53 per cent. of intake by Schlossman; Biedert's determination was 77 per cent., and that of Rubner and Heubner 79.42 per cent., while the absorption of total ash of cow's milk by different authors is as follows (see also p. 115):

	Per cent.		Per cent.
Soldner	60.7	Biedert	65.1
Schlossman	70.	Hoobler.....	53.
Tangl	62.1	Hoobler.....	66.8
Blaubeurg	53.72	Hoobler.....	78.6

It will be seen that the absorption per cent. is 15 per cent. to 25 per cent. better on mother's milk, but because of the large intake the actual amount absorbed is very much larger in cow's milk feedings than in breast-fed. For example, 1.08 gm. was absorbed in twenty-four hours on mother's milk, while on cow's milk from 4 to 6 gm. were absorbed daily. Thus approximately four to six times more is absorbed in artificial feeding.

As we shall see later, this better absorption of mother's milk ash lies in the fact that calcium, magnesium and phosphorus are much better absorbed. As was demonstrated in my work on the various fat feedings, and now being published in the Presbyterian Hospital Report of this year, nitrogen, chlorin, sulphur and magnesium were absorbed in the same ratio as these elements existed in the food. The greatest variations from the ratio in the food occurred in calcium and phosphorus.

22. Hoobler: Arch. Pediat., 1910, xxvii, 853.

RETENTION

Without doubt the best criterion of availability and utilization of any given food-stuff is not its large per cent. of absorption, or even its large absolute amount of absorption; but rather the absolute amount retained. Literature does not yet contain reports which cover sufficient periods of investigation to feel quite sure that these so-called absolute retentions are permanent or simply transitory, since it takes weeks to utilize and eliminate the mineral salts. Therefore a prescribed diet should be carried out for weeks instead of days for most accurate results. However, the reports in literature show that the ash of mother's milk is well retained and this is but natural, for the salts come to the infant in much better form for utilization than in cow's milk.

In Blauberger's case on mother's milk (see total ash tabulation), the absolute retention was 0.61 gm., being 45.9 per cent. of the intake. In cow's milk feeding, the per cent. of retention is lower but the absolute amount is higher, owing to the much richer ash-content of the cow's milk. Blauberger's case on cow's milk feeding, having a retention of 14.8 per cent. of intake, represented an absolute amount of 1.013, being nearly twice the amount retained under mother's milk feeding. In my 9-month child there was retained 2.89 gm. or 43.5 per cent. intake. Blauberger found that with mother's milk feeding all the minerals were retained with the exception of sodium; in cow's milk there was a loss in Cl, S, and Na. It would seem that each child is a law unto itself so far as retention of mineral ash is concerned. It apparently takes it on just in accordance with the demands of physiologic growth.

In my determinations in connection with various strengths of fat in foods, I found that as compared with nitrogen retention, the retention of the mineral salts was relatively poorer. This poor retention was most marked on the lower fat food, better on the medium fat diet, and best as regards the absolute amount retained on the high (5.4 per cent.) fat diet. Retention of the salts in proportion to nitrogen was never in the same proportion as existed between the salts and nitrogen of the food.

ELIMINATION

The elimination through the feces and urine differs in amounts on mother's and cow's milk. In mother's milk feeding, one-third of the salts are eliminated through the feces and two-thirds through the urine, while in cow's milk feeding about half is eliminated by the urine and half by the feces, though the figures of different investigators vary. In my own figures the ash of the feces was three times as large on a 2.1 per cent. fat mixture as on a 5.4 per cent. mixture.

THE ANOMALIES IN THE METABOLISM OF TOTAL ASH

In the elaboration of Finkelstein's theory of food disturbances in infants and children, L. F. Meyer²³ has attributed to the mineral salts certain deleterious influences.

In each of Finkelstein's four stages of nutritional disturbance, Meyer finds that there is some anomaly in the salt metabolism. In the stage of "*Bilanzstörung*," there is decreased retention of the alkaline earths. There is also a lessened retention of other salts.

In the stage of dyspepsia, the salt elimination by the feces is increased but the ash balance is not markedly changed. In the stage of decomposition the entire picture is determined by the loss of the mineral salts, particularly through the loss of the fixed alkalies. Through the fatty acids in the stools, the Ca and Mg are used up. The diarrheal stools of this period are due largely to alkali loss. The condition of relative acidosis of Steinits (and of alkalipenia of Pfaundler) takes place during this stage, due to the loss of alkali.

In the fourth stage, of intoxication, the salt metabolism is little known. There is a negative balance of chlorin and probably of the other mineral constituents. Whether the salt loss controls the water loss or vice versa is still a question, but since the urine is much decreased and the output of water by the feces is increased, it would seem that the salts were accountable for this diversion of the water elimination. It is evident that salts play an important part in every digestive disturbance of the infant and young child.

CALCIUM

The calcium need of the growing infant is well met through the abundance of its salts in the milk, either of mother's or of cow's. Calcium makes up one-fifth of the ash of mother's as well as of the ash of cow's milk. Calcium is taken into the body in organic and inorganic form. The organic combination is present in milk, yolk of eggs and vegetables, and the inorganic form in water used as a diluent and for drinking.

The importance of the calcium salts in the developing organism can hardly be overestimated. Physiologists²⁴ have shown that the calcium *ions* in the blood, though in small quantity, are yet absolutely necessary to the irritability of muscle. If calcium is present in too large quantities, as compared with Na and K *ions*, there is produced a tonic contraction known as calcium rigor.

Calcium has a definite specific action of its own and cannot be replaced by other earthy bases, as magnesium and strontium, as stated by Stewart.²⁵ The fact is well known that calcium is necessary to ferment action

23. Langstein and Meyer: Säuglingsernährung und Säuglingsstoffwechsel, Wiesbaden, 1910, pp. 111-166.

24. Howell: Physiology, Ed. 2, 1907.

25. Stewart: Physiology, Ed. 1910, p. 542.

as shown by the coagulation of blood and the precipitation of casein in milk. Calcium is much the largest mineral constituent of the body. Its most common salt is calcium phosphate, which makes up a large part of the bone salts.

Jacques Loeb²⁶ has shown the necessity of calcium salts for the development of the lower forms of life, and Blaumberg has shown that children who cannot metabolize calcium cannot survive.

Mother's milk contains only about 20 per cent. as much calcium as cow's milk; therefore we would expect a considerable variation in its absorption and retention, as is shown by the following:

CALCIUM AS CaO

The calcium of mother's milk is 0.394 grams in 1,000 gm. I found calcium of cow's milk to be 1.6 grams in 1,000 gm., or nearly four times as much in cow's as in mother's milk. (See also tabulation page 120.)

It will be noted first that the calcium intake in cow's milk feeding is about eight times greater than in mother's milk; that the amount actually absorbed and retained is four times greater on cow's milk than on mother's milk. However, a much larger percentage of mother's milk calcium is retained. It is evident, therefore, that the calcium of mother's milk is much better metabolized than the calcium of cow's milk, and since a healthy nursing infant shows no signs of a deficiency of calcium, we may well consider the amount which it gets as being the true calcium need. The absorption of calcium depends in part on the presence of accompanying salts; for example, if much alkali bases are present in the intake the absorption is diminished, whereas NaCl assists in calcium absorption. Calcium is more readily absorbed on flesh than on a vegetable diet.

ELIMINATION

It should be noted that the elimination of calcium is almost entirely through the feces; only 5 to 10 per cent. of the intake appears in the urine. This does not mean that the calcium is not well absorbed, but that it is excreted into the large intestine, as is proved by the fact that larger quantities of calcium are found in the large intestine than in the small intestine. It was Voit²⁷ who showed that 0.15 gm. of calcium per day was excreted from the inner surface of the intestine.

The amount of calcium excreted in the urine of infants fed on breast and cow's milk does not vary greatly, but the amount which appears in the feces varies greatly, being in some instances twenty times greater. Calcium makes up a quarter or a third part of the dried feces of cow's-milk-fed children, as against a much smaller portion in breast-fed. The

26. Loeb, J.: Cited by Meyer, *Jahrb. f. Kinderh.*, lxxi, 1.

27. Voit: Cited by Howell, *Physiology*, Ed. 2, p. 834.

CALCIUM AS CaO									
	Food	Intake	Elimination		Absorption		Retention		
			Feces	Urine	Gm.	Percent.	Gm.	Percent.	
			0.0952	0.0127	.....	....	0.176	62.4	....
Mother's milk 0.2884 (Blauberg)									
			0.0660	0.0310	0.2060	75.8	0.175	64.5	.026
Mother's milk 0.2720 (Blauberg 5 mos.)									
			1.142	0.0166	0.9370	45.1	0.924	44.4	.122
Cow's milk (R. & H. 7½) 2.0824									
			2.2687	0.0301	Negative	....	Negative	....	....
Diluted cow's, 2.1% fat 2.0536 (Hoobler)									
			1.6962	0.305	0.3538	17.2	0.3233	15.7	.041
Cow's whole milk, 4% fat 2.0500									
			0.9515	0.0085	1.1408	54.5	1.1322	54.1	.142
Cow's milk and cream, 5.4% fat ... 2.0923									

Figures given above are in grams in 24 hours.

form in which the calcium usually appears in the feces is that of the insoluble soaps, or in the form of calcium phosphate.

In my series of studies the elimination of calcium in the feces was greater on milk of lower fat content. As fat was increased in the food, the calcium was diminished in the feces. The calcium eliminated in the urine appears along with magnesium, bound with phosphoric, carbonic and uric acids. Iron is another mineral constituent which is excreted very poorly through the urine, and this leads one to group these two constituents together and to inquire if there are other characteristics. It should be noted that their presence in many organs, for example the thyroid gland, the liver, the spleen and the ovaries, suggests physiologic and chemical affinities as pointed out by Albu and Neuberg.²⁸ The internal secretions which play such a part in intermediary metabolism of the mineral salts, may be largely affected by the relationship of these two minerals. Calcium and phosphorus are closely allied in the bones, in the ovaries, and in the thyroid gland.

THE ANOMALIES OF CALCIUM METABOLISM

As a rule there is a great individual difference in the amount of calcium absorbed, and a further difference in the ability to retain the calcium absorbed. Rarely is such a condition due to the lack of calcium in the food, although many artificial foods are very poor in calcium. A diet containing less than 1 to 1.5 gm. CaO daily should be considered calcium-poor, except when on mother's milk feeding.

It has been shown that when calcium is purposely withheld from the diet of young puppies, rachitis develops, and the bones of young pigeons fed on calcium-poor diet are very fragile (Forster³). In the bones, in rachitis the mineral constituents are depleted, particularly calcium and phosphorus. The total ash of bones which normally is 65 per cent. falls to as low as 25 per cent. and the main loss falls on the calcium phosphate. The calcium loss in rachitis is largely through the intestine, with but little change in urinary calcium. In feces of rachitis, there is an increased elimination over that of healthy children, as shown by J. A. Schabad.²⁹ In rachitis particularly the weak point in the metabolism cycle may be the inability of the bones themselves to take up and build into bony tissue the calcium and phosphorus brought to them by the fluids, as has been pointed out by Albu and Neuberg.²⁸ The fact that calcium has much to do with the function of the nervous system has been shown by the calcium disturbances in tetany, as demonstrated by Schabad.³⁰ Further, the large proportional content of the brain tissue of the new-born in calcium

28. Albu-Neuberg: *Mineralstoffwechsel*, Berlin, 1906, p. 70.

29. Schabad, J. A.: *Arch. f. Kinderh.*, liii, 241.

30. Schabad, J. A.: *Monatschr. f. Kinderh.*, ix, No. 1; *Jahrb. f. Kinderh.*, I, No. 1.

(0.168 per cent. CaO), as compared with an 8-year-old child's brain (0.05 per cent.) speaks further confirmation of this. There is a very appreciable loss of calcium from the nerve structures during the first year of life. Quest³¹ found less calcium in the brains of children who died of tetany than of children of the same age without tetany.

Schloss³² has more recently shown that subnormal body temperature in some cases depends on the presence of calcium ions. In the symptom-complex which Finkelstein calls *Ernährungstörung*, during the stage of *Bilanzstörung*, Meyer²³ has shown that there is a decreased retention of calcium due in part to the fact that the fats of the stools are increased, and these demand the alkaline earth to neutralize the fatty acids. There may be such a demand that not only will no calcium and magnesium be retained, but there may be an actual withdrawal of these salts from the body. This may account for a portion of the loss of weight in this stage of food disturbance.

IRON

Cow's milk and mother's milk contain about the same amounts of iron. Each is very poor in iron, and were it not for the relatively large amount stored in the liver and blood of the new-born there would be a deficiency in the early months of feeding. The following table shows that the form in which the iron is present has a large bearing on its availability. The iron of goat's milk is poorly absorbed and poorly retained, while the iron of mother's milk is well absorbed and well retained. Iron is eliminated almost entirely through the feces but a very small quantity through the urine.

Iron plays an important part in metabolism. It is specially important in the formation of the hemoglobin molecule. It acts as a catalyst in oxidation processes, especially in the group of nucleoproteins, as has been shown by Spitzer⁴⁴ and by Manchot.⁴⁵ Iron is presented for consumption in both the organic and inorganic form. The organic forms occur in the nuclealbumins, in milk, yolk of eggs and in many vegetables.

IRON AS Fe_2O_3

In 1,000 gm. mother's milk, .02 gm. to .04 gm.

In 1,000 gm. cow's milk, .021 gm. (Abderhalden).

Food	Intake	Elimination		Absorption		Retention	
		Feces	Urine	Gm.	%	Gm.	%
Mother's milk	.00705	.00084	.00055	.00621	88.09	.00566	82.28
Goats' milk	.00344	.00259	.00009	.00085	24.71	.00076	22.09

Figures given above are in grams in 24 hours.

31. Quest: Cited by Freund, in Pfaundler and Schlossman, i, p. 235.

32. Schloss: Cited by Langstein and Meyer, *Säuglingsernährung und Säuglingsstoffwechsel*, Wiesbaden, 1910, p. 21.

44. Spitzer: Cited by Albu and Neuberger, *Mineralstoffwechsel*, Berlin, 1906, p. 151.

45. Manchot: Cited by Albu and Neuberger, *Mineralstoffwechsel*, p. 151.

MAGNESIUM AS MgO

In 1,000 gm. mothers' milk there is 0.068 gm. MgO.
 In 1,000 gm. cows' milk there is .205 gm. MgO.

Food	Intake	Elimination		Absorption		Retention	
		Feces	Urine	Gm.	Percent. Per Kilo	Gm.	Percent. Per Kilo
Mother's milk (Blauberg)	 0.047	0.0157	0.014	.....	....	0.0175	37.2
Cow's milk (Soldner)	 0.15017	0.0944	0.03718	.....	....	0.017	11.5
Diluted cow's milk, 2.1% fat..... (Hoobler)	0.10843	0.0058	0.0134	.10258	94.6 .123	0.0891	82.1 .011
Whole cow's milk, 4% fat..... (Hoobler)	0.07755	0.0300	0.04861	.04746	61.3 .045	Negative	....
Cow's milk and cream, 5.4% fat.... (Hoobler)	0.14999	0.0828	0.01909	.06719	44.7 .008	0.04809	32.0 .006

Figures given above are in grams in 24 hours.

MAGNESIUM

Magnesium and calcium are very closely connected in the metabolic function. They occur in the organism in much the same places and as salts of the same acids. Their proportion is $\text{CaO}:\text{MgO}::40:1$. Magnesium has a little wider distribution in the body tissues than does calcium. The latter occurs almost entirely—at least 99 per cent.—in the bones, while magnesium is found in muscle-tissue as high as 0.04 per cent. The part which magnesium plays in bone structure is important. Magnesium makes up about 10 to 15 per cent. of the total ash of bone. The relation of magnesium in these structures is about 1:9. The magnesium table on page 123 indicates that the Mg need of the growing infant on mother's milk is 0.047. Bunge, as cited by Albu and Neuberg, gives the magnesium need as 0.6. This seems rather high, for, since there is about 0.06 gm. Mg in a litre of mother's milk, it would require 10 litres to satisfy this need. Blauberg's breast-fed infant got but 0.047 gm. daily. The intake when fed on cow's milk varied; according to Soldner the daily intake was 0.15 gm., while my determinations showed intake varying from 0.07 to 0.15.

ABSORPTION

The absorption of magnesium which takes place through the small intestine is relatively very good. My determinations gave 94.6 as the per cent. of intake which was absorbed when feedings were low in fat. As the fat content of the food was increased, there was relatively poorer absorption, the percentages being 61.3 on a 4 per cent., and 44.7 on 5.4 per cent. fat mixture.

RETENTION

The retention of magnesium in my series was better on 2.1 per cent. fat mixture than on the 5.4 per cent. mixture. This retention varied inversely with the calcium retention so far as the amount of the fat in the food is concerned. In my findings for calcium, retention was poorest on lower fat mixtures and improved on the higher fat mixtures.

ELIMINATION

Excretion occurs both through urine and feces. On mother's milk in Blauberg's case, the excretion through either channel was about the same, while in cow's milk in some instances it was higher in urine and in others it was higher in the feces. In any event, the excretion is very small and that through the urine occurs as triple phosphates.

ANOMALIES OF RETENTION

There is more or less relation between Ca and Mg in the formation of oxalic acid concretions. It has been found that if the ratio of CaO to MgO be as 1 to 0.8 the concretion may be kept in solution. The smaller

PHOSPHORUS AS P_2O_5

Food	Intake	Elimination		Absorption		Retention	
		Feces	Urine	Gm.	Percent. Per Kilo	Gm.	Percent. Per Kilo
Mother's milk	0.2768	0.0363	0.0481	.....	.....	.192	69.13
Mother's milk, 5 mos.	0.2030	0.0220	0.088	0.1810	89.1	.093	45.9
Cow's milk	1.4429	0.5352	0.5003	.....	.....	.4074	30.7
Cow's milk (Keller's 2¾ mo)	0.8248	0.1073	0.4106	0.7174	87.1	.3068	37.2
Cow's milk (Blaug's 7½ mos.)	2.0605	0.9627	0.5899	1.098	53.28	.5079	24.2
Diluted cow's milk, 2.1% fat	2.2155	0.7648	1.152	1.4507	67.0	.3320	14.5
(Hoobler)							.040
Cow's milk, whole, 4% fat	2.7418	0.59914	2.009	2.1426	78.1	.1336	4.8
(Hoobler)							.0171
Cow's milk and cream, 5.4% fat	2.2346	0.3789	1.336	1.8556	83.0	.6196	27.7
(Hoobler)							.0657

Figures given above are in grams in 24 hours.

the calcium and the larger the Mg content the easier becomes the solution of calcium oxalate.

PHOSPHORUS

Of all the mineral elements, perhaps none has been studied more assiduously than phosphorus. Phosphorus is brought into the body in two very different forms, viz., that which is organically bound, occurring in milk, eggs and legumes, and a small part as phosphoric acid. When in organic combination it is found as nuclealbumin, nuclein, vitellin, casein and lecithin.

The source in which we are most interested is that of mother's and cow's milk, and these two foods differ considerably in the amount of organically bound phosphorus. Mother's milk contains 0.31 to 0.45 gm. per liter of P_2O_5 , while cow's milk contains 1.81 gm. P_2O_5 per liter. Keller³³ has shown that of the phosphorus of mother's milk 77 per cent. is organically bound, while in cow's milk only 27.9 per cent. is so bound. Of this organically bound phosphorus 54 per cent. occurs as nucleophosphorus in mother's milk, and but 13.4 per cent. in cow's milk, so that it is very evident that the phosphorus of cow's milk, though larger in actual quantity, is not in such form as to be available, as is the case of mother's milk. The nucleins of milk make up 41.5 per cent. of the total phosphorus of mother's milk, while of cow's milk only 6 per cent. is in that form. In mother's milk 35 per cent. of total phosphorus is in the form of lecithin, while the lecithin of cow's milk is but 5 per cent. according to Stocklasa.³⁴

The form in which the phosphorus reaches the organism is important for Salkowski has shown that the organism has not the power to build from phosphorus-free albumin, or from inorganic phosphates, cells which require as an integral part organically bound phosphorus.

Indeed, it has been shown that the phosphorus absorption is not in the least affected by the presence or absence of inorganic phosphates, but, on the other hand, the phosphorus absorption may be greatly increased when a child is fed on yolk of egg as shown by Cronheim and Muller.³⁵

Phosphorus is in demand in the body, particularly in glandular structures and bones, and for the central nervous system, and we should expect to find a considerable daily need on the part of the growing organism. This need seems satisfied in the healthy breast-fed infant on an intake varying from 0.7 to 0.8 gm. as a minimum and 1 to 2 gm. as a maximum. This is a wide variation, but we should consider that phosphorus is one of the minerals which becomes a definite part of the tissue structures throughout the body, and by virtue of its close connection

33. Keller, A.: *Arch. f. Kinderh.*, xxix, Stuttgart, 1900, p. 1.

34. Stocklasa: *Ebenda*, 1897, xxiii.

35. Cronheim and Muller: *Ztschr. f. diät. u. physik. Therap.*, 1903, vi.

with the albumin molecule must likewise suffer destruction along with the albumin, therefore it varies with the protein need.

The investigators who have determined phosphorus balances on infants are Blauberg, Michel, Keller, Cronheim and Muller and Schlossman. Let us consider some of their findings in comparison with the determinations which I have made.

ABSORPTION

It will first be noted that the intake of phosphorus is nearly ten times as great for cow's milk as for mother's milk and that in both forms of milk feeding the per cent. of intake absorbed indicates a very good absorption ability. In mother's milk, the absorption per cent. is 89.2 and that of cow's milk 53.2 in Blauberg's case. My determinations were 67.0 per cent., 78.1 per cent. and 83.0 per cent. on low, medium and high fat feeding. From this it would seem that phosphorus is more readily absorbed in the presence of increasing quantities of fat. The amount of the absorption depends more on the kind of phosphorus than on the quantity. The absorption of phosphorus is hindered when there is a relatively high ratio of accompanying alkaline earths and alkalis in the food; for example, when vegetables are fed a large calcium intake is present. This forms insoluble salts of phosphorus in the intestine and thus absorption is prevented. However, when these two elements meet within the body, they are joined in exceedingly close metabolic activity.

From my own determinations it appears that the phosphorus and nitrogen absorption varied considerably from the ratio in which these elements occurred in the food. Phosphorus absorption was relatively less than nitrogen absorption, during the low (2.1 per cent.) fat feeding, and was best in the medium fat feeding (4 per cent.), where it approximated the ratio which existed between nitrogen and phosphorus in the food.

RETENTION

The retention of phosphorus is one of great importance to the existence of life, for in conditions of starvation the organism clings tenaciously to its phosphorus—perhaps more so than to any other mineral constituent, except NaCl. This is probably due to its close connection with the central nervous system, for at the end of long periods of starvation the phosphorus content of nervous tissue is very little impoverished. This retention is, no doubt, in proportion to the need, and not only the present need, but it is stored up for an emergency; for the animal organism when fed on phosphorus-rich diet not only brings itself into phosphorus equilibrium, but retains a part of this excess phosphorus. The retention keeps step with the need and gradually diminishes when the skeleton is well formed.

As in the case of absorption, the phosphorus is retained not so much in proportion to its amount as according to the kind present. Its retention runs parallel with that of nitrogen in cases studied by Keller,³³ but L. F. Meyer³⁶ has been unable to confirm this finding, and in my determinations phosphorus and nitrogen were not retained in proportional amounts, i. e., 29.5 per cent. food-nitrogen was retained while only 4.8 per cent. of food-phosphorus was retained.

ELIMINATION

The elimination of phosphorus takes place both through the feces and through the urine. In most instances it is about equally divided between these two channels of excretion. However, great variations occur, for example, in children on a vegetable diet which contains much calcium, the phosphorus is largely excreted through the feces, since the calcium forms insoluble salts with the phosphorus and thus absorption is inhibited, while children on a generous flesh diet will excrete most of the phosphorus through the kidneys. The amount excreted through the urine on mother's milk varied from 0.04 to 0.08 gm., while on cow's milk it was much higher, being 0.589 gm. in Blauberg's case and as high as 2.009 gm. in one of my determinations. (See phosphorus tabulations.)

In the feces from mother's milk feedings, the elimination varied from 0.02 gm. to 0.036 gm., while on cow's milk it was 0.962 in Blauberg's case. My own determinations were 0.7648, 0.5991 and 0.3789 gm., the larger quantity appearing with the lower fat-content of feeding and diminishing as the fat was increased.

A number of investigators have tried to show that the elimination of phosphorus and nitrogen was parallel, arguing from the fact that with cell destruction both N and P were released; and, indeed, this is true for certain groups of tissues, and could we estimate their catabolism separately, this would be our result. However, since N is only influenced in the protein wear and tear of the body, and since phosphorus has many influences other than is brought about by its connection with nitrogen in the albuminous molecule, as a number of observers have shown—Ehrstrom, and more recently L. F. Meyer³⁶—there may be nitrogen retention with a phosphorus loss, and vice versa. The fact, too, that phosphorus is retained so tenaciously, while nitrogen is more readily given up, is another reason why the ratio of $N:P_2O_5$ in the urine is of little value as an index to cellular metabolism. The phosphorus balance obtained by considering the intake and elimination through feces and urine can only be depended on for correct interpretation of metabolic activity of phosphorus, and, indeed, the same may be held for any of the food constituents.

36. Meyer, L. F.: *Ztschr. f. physiol. Chem.*, 1904, xliii.

ANOMALIES IN PHOSPHORUS RETENTION

The anomalies related under the head of calcium retention are all shared in by phosphorus. Indeed, the pathologic conditions which affect one nearly always affect the other. As has been stated, in rachitis and osteomalacia there is a disturbance of retention of the phosphorus, particularly that part bound with calcium and magnesium. In these diseases the giving of calcium increases the retention of phosphorus and the giving of phosphorus increases the retention of calcium, proving undoubtedly their chemical and physiologic affinity.

Phosphorus has a close connection with intermediary metabolism, as shown by its large content in the thyroid gland, the ovaries and the testes. So great is the necessity for phosphorus in the functioning of the testes and ovaries that castration is sometimes employed in order to divert the phosphorus to the use of the bones, as has been done occasionally in osteomalacia.

In that anomaly known as phosphaturia, in which the ratio of P_2O_5 to CaO changes from 12:1 to 4:1, if a calcium-poor diet is given, the phosphates quickly disappear. Phosphorus may be retained in abnormally large quantities as pointed out by L. F. Meyer.³⁷

SODIUM AND POTASSIUM

The relationship of potassium and sodium to the maintenance of the alkalinity is a very interesting and important one. The study of the influence of their *ions* on muscle-contraction and nervous irritability is yielding valuable data. The power of their *ions* to influence body weight, body temperature, pulse and even leukocyte count is a most important contribution made by L. F. Meyer³⁷ and S. Cohn.²³

We will first discuss the problems of alkalinity into which Na and K enter, since these elements form the fixed alkalies. Under the anomalies of alkalinity we will discuss the problems which relate to variations of this alkalinity.

It should be remembered that both alkaline and acid solutions exist within the same body; that the blood, various secretions, as well as each body cell has a definite amount of alkali, and can vary only within very narrow limits in order that they may perform their proper functions. This automatic regulation of alkalinity of the tissues and fluids is one of the marvels of the human mechanism, and it is remarkable how rarely it varies sufficiently to produce a pathologic condition. It is for the maintenance of this stupendously important work that the fixed alkalies, sodium and potassium, are used. Albu and Neuberger²⁸ have explained this self-regulation thus: Through the tearing down of the albumin of the body and the albumin taken in in the food, sulphuric and phosphoric

37. Meyer, L. F.: Deutsch. med. Wehnschr., 1905, No. 37.

acids are set free and must be neutralized by the alkalies of the blood. These acids would draw out the fixed alkalies were it not for the supply of carbonate derived from the carbonic acid and from the vegetable salts taken in the food. At certain times when the breaking down of albumin is excessive, ammonia is also set free and this is used along with the carbonates for the fixing of the acids. By means of this sort of neutralization, the acids become a constituent of the body, the fixed alkalies remain untouched, and the alkalinity of the tissues is unchanged. Should this reaction suffer the least change, either through a lessening of the bases or an increase of the autogenous acids, the organism becomes at once in danger.

The constant chemical reaction is also necessary for the ferment action which takes place throughout the body. The alkalies act also as carriers of the carbonic acid in the blood-stream.

The *ions* of potassium and sodium have an important bearing on the heart action, as shown by Overton.³⁸ *K ions* do not seem an absolutely necessary accompaniment of rhythmical action, but if present in too large numbers they cause a depression, even to complete inhibition. On the other hand, *Na ions* are necessary to contractility and irritability of heart-muscle. If present alone they produce muscular relaxation.

Jacques Loeb²⁶ has shown how closely developing life is dependent on exact proportions of NaCl in solution as shown by his experiments in sea-water, physiologic salt solution and in water with no NaCl in it.

Let us, therefore, study the sources of supply of these important elements, and see if we can determine the daily need for the growing infant. (See tabulation on page 131.)

In mother's milk there is much less sodium and potassium than in cow's milk. There is more potassium than sodium in each of these milks. The daily need of the nursing infant as represented by the intake is for sodium 0.5877 gm., and for potassium 1.1032 gm. In cow's milk feeding the sodium intake was below the intake on mother's milk and the potassium intake was considerably above that on mother's milk.

ABSORPTION

The absorption is relatively good on both milks. On absorption the Na salt takes its place in the blood and tissue fluids, while the potassium, displaying its selective action, takes its place in the various body-cells and in the blood-cells. Its most common salts are potassium phosphate, which is the chief mineral constituent of red blood corpuscles, and potassium chlorid, which is found in the body-cells. The potassium salts make up 0.4 per cent. of the total blood and 0.65 to 0.8 per cent. of fresh muscle tissue. It is evident therefore that for the production of

38. Overton: Arch. f. d. ges. Physiol. Bonn (Pflüger), 1902, xcii, 346.

POTASSIUM AS K₂O

In 1,000 gm. mother's milk 0.69 gm. K₂O.
In 1,000 gm. cow's milk 1.885 gm. K₂O.

Food	Intake	Elimination		Absorption		Retention	
		Feces	Urine	Gm.	Per cent.	Gm.	Per cent.
Mother's milk (Klotz)	1.1032	0.2842	0.1591	....	....	0.6598	74.2
Cow's milk (Meyer)	1.9605	0.2033	1.4411	....	....	0.8161	16.12
Cow's milk (Blauberg)	1.57	0.271	1.12	1.30	82.8	0.180	11.5

Figures given above are in grams in 24 hours.

SODIUM AS Na₂O

In 1,000 gm. mother's milk there is .049 gm. Na₂O.
In 1,000 gm. cow's milk there is .465 gm. Na₂O.

Food	Intake	Elimination		Absorption		Retention	
		Feces	Urine	Gm.	Per cent.	Gm.	Per cent.
Mother's milk	0.5877	0.1924	0.1481	....	....	0.2471	67.2
Cow's milk	0.478	0.075	0.3305	....	....	0.0725	15.27
Cow's milk (Soldner)	0.409	0.098	0.343	.311	75.9	Negative	....

Figures given above are in grams in 24 hours.

the muscle of the growing child an adequate supply of potassium salts must be given.

RETENTION

The retention in per cent. of intake in mother's milk is very good, being 67.0 per cent. for sodium and 74 per cent. for potassium, while the retention on cow's milk is relatively poor, being 15.27 per cent. for sodium and 16.12 per cent. for potassium.

ELIMINATION

K and Na are eliminated through the urine and feces. The potassium in the urine is bound with Cl and with phosphorus and the sodium chiefly as NaCl. The sodium of the urine largely depends on the sodium intake in the food, while the potassium in the urine depends on the destruction of tissue; hence K metabolism is parallel with tissue destruction. This is explained by the fact that K is in the cells and is more closely bound, while Na is held in solution in the blood and tissue fluids and, therefore, more readily excreted. The normal ratio of Na to K in the urine is 3:1, 2:1 and some authors place it as 5:3.

ELIMINATION THROUGH THE FECES

About 15 to 25 per cent. of the intake of K and N are eliminated through the feces. These amounts vary considerably with the kind of diet, whether it is rich in alkali or not, or whether it is vegetable or made up of a considerable part of meat.

ANOMALIES OF RETENTION OF FIXED ALKALI

There is at times an over-retention of potassium salts to the point of potassium intoxication, and some authors²⁸ have attempted to build a theory for uremia on this fact. In such cases the potassium salts are retained in the blood-stream rather than taking their places in the tissue structure. But the most common anomaly is not that of over-retention but of marked withdrawal of the fixed alkalies. Against such a contingency the organism of the carnivora has builded up a strong resistance. First in the use of the carbonate of the tissue fluids and blood, and, as a last resort, in the production of ammonia. As has been previously stated, under normal conditions the carbonates with the help of a small amount of ammonia, are sufficient to care for the normal production of acids in the body. Under abnormal production of acids, as occurs in diabetes and in conditions of acidosis in certain infants fed on high fat mixtures, and in some older children fed on a mixed diet containing a quart or more of rich milk, there is a demand for a large quantity of ammonia to protect the fixed alkali.

A vast number of researches have been carried on covering the field of conditions of acidosis. It was Salkowski in his experiments on dogs

CHLORIN AS NaCl

In 1,000 gm. mother's milk, 0.294 gm. Cl.
 In 1,000 gm. cow's milk, 0.82 gm. Cl.
 In 1,000 gm. cow's milk (Hoobler), 1.8678 gm. NaCl.

	Food	Intake	Elimination		Absorption			Retention		
			Feces	Urine	Gm.	Percent.	Per Kilo	Gm.	Percent.	Per Kilo
	Mother's milk	0.3297	0.0135	0.1776	0.3162	95.4	....	0.1386	58.0	....
	Diluted cow's milk, 2.1% fat (Hoobler)	2.3178	0.042	2.2421	2.2758	98.1	.274	0.0337	1.4	.004
	Whole cow's milk, 4% fat (Hoobler)	2.3926	0.1567	2.3328	2.2359	93.4	.286	Negative	....	....
	Cow's milk and cream, 5.4% fat (Hoobler)	2.3428	0.06031	2.1340	2.2824	97.3	.288	0.14849	6.3	.018

Figures given above are in grams in 24 hours.

who first pointed out that the self-produced body acids were bound by the withdrawal of the fixed bases of the body, and thus there would be impoverishment of these indispensable mineral constituents were it not for the fact that the carnivora are protected by this increased ammonia excretion; but this protection is only within narrow limits.

Not only is the withdrawal of alkali accomplished through the overproduction of acids, but it has been shown that a diet rich in fats will cause a withdrawal of alkali for the purpose of combining with the fatty acids of the stools. The fatty acids will first utilize such alkaline earths (Ca and Mg) as are available, and then for further neutralization will call on the fixed alkali of the body. This in turn demands the production of ammonia for the protection of the fixed alkali. This often occurs in healthy infants when on a high fat mixture, but it takes place pre-eminently, as shown by L. F. Meyer,²³ in the stage of decomposition of Finkelstein's *Ernährungstörung*. In this condition not only does the fat cause loss of alkali, but even sugar produces the same result.

SODIUM CHLORID

Of all the mineral constituents, sodium chlorid has the most varied and important functions to perform. The function of maintaining osmotic pressure has been the one most studied, and its relation to the retention and excretion of water is well known. In recent years to the Na ions and the Cl ions, acting either separately or in conjunction, have been assigned various results. L. F. Meyer²³ has shown that the intake of Na ions, especially when bound with the halogen group, particularly with chlorin, when in certain concentration, viz., 3 gm. NaCl to 100 c.c. water, always produced an increase of temperature in a young infant. There is a marked decrease in the body weight when fed on milk freed of salts; also the pulse and leukocyte count are affected. Just what the daily need of this salt is depends largely on the kind of food ingested. There is a certain demand for this salt and when the intake is cut off the body retains with great tenacity what it has until further intake occurs.

The chlorin intake in mother's milk is 0.3297 gm., while on cow's milk the chlorin intake in terms of NaCl was 2.3926. The tabulation on page 133 shows the chlorin metabolism in terms of NaCl.

The demand for NaCl is greater in herbivora than in carnivora, because of the greater consumption of K carbonates, as was pointed out in the classic observation by Bunge.³⁹ His concise explanation of this phenomenon is that with a large intake of K carbonate there is formed in the blood the salts of sodium phosphate and potassium chlorid. Both being foreign, they are eliminated, leaving a loss of NaCl which must be replenished.

39. Bunge: Cited by Albu and Neuberg, *Mineralstoffwechsel*, p. 164.

NaCl is ingested in large quantities. It being well absorbed, there is an increased quantity in the blood, hence its isotonicity is disturbed and either there must be a holding back of water until the solution is isotonic, or an increased elimination of the NaCl. Both of these processes may take place.

ABSORPTION

The absorption of salt is found to be excellent—usually above 90 per cent. of the intake is absorbed. The retention of NaCl is only sufficient to cause a balance to be maintained under normal conditions. In my determinations I found that there was utilized but 1.4 per cent. to 6.3 per cent. of the intake.

ELIMINATION

The elimination takes place almost entirely through the kidneys. But a very small quantity appears in the feces, so well is it absorbed. In my determinations there was a little over 2 gm. excreted through the urine daily, while less than 0.1 gm. appeared in the feces.

It has been observed that salt solution when injected subcutaneously is more quickly eliminated than when taken by mouth. With the excretion of NaCl there must accompany it a certain amount of water, and, therefore, the intensity of diuresis depends on the molecular concentration within the body. Not only does salt affect the retention and withdrawal of water, but it holds a very close relation to nitrogen.

Voit's original work seemed to show that with increasing retention of NaCl there was an increased retention of nitrogen; later investigations have not agreed with this. Belli⁴⁰ sums up his findings with the statement that in small amounts, as in the food normally, it hastens and increases protein retention, but in greater quantities it tends to lessen the nitrogen retention.

THE ANOMALIES OF NaCl RETENTION

There are a number of conditions which seem markedly affected by sodium chlorid. The most important is that of nephritis. Von Noorden⁴¹ was the first to work on this important condition. He noted a variation in different cases. Some retained and others did not retain NaCl. Halpern⁴² has shown that both in acute and chronic nephritis the salt content of the urine is dependent on the salt content of the food. In cases in which there is edema there is marked lessening of the edema when the patient is put on a salt-free diet, and there appears in the urine an increase in the NaCl elimination. The use of salt-free diet, whether

40. Belli: Cited by Albu and Neuberg, *Mineralstoffwechsel*, Berlin, 1906, p. 170.

41. Von Noorden: *Lehrbuch d. Pathologie d. Stoffwechsels*, Berlin, 1893.

42. Halpern: Cited by Albu and Neuberg, *Mineralstoffwechsel*, Berlin, 1906, p. 174.

with or without edema, brings about more or less of a dechloruration of the body. It would seem that in these cases the NaCl retention always precedes the water retention and that the edema consequent on water retention is due to the NaCl retained. However, no hard and fast rules can be laid down in regard to use of salt-free diet, as in some cases it will not reduce edema, and in some cases a salt-rich diet will not always produce NaCl retention.

L. F. Meyer²³ believes that many of the symptoms present in food disturbances of infants may be traced to the deleterious influence of sodium chlorid, acting not only as salt, but also in the capacity of the respective *ions*. He believes particularly that the rises of temperature during the stage of intoxication of Finkelstein's *Ernährungstörung* is due to the action of these *ions*. In children with food disturbances smaller quantities of NaCl solution will raise temperature more quickly than in healthy children.

Fisher⁴³ has shown that the injection of salt solution of one-sixth molecular strength may produce glycosuria, and that this glycosuria may be stopped by injecting a calcium chlorid solution.

Abderhalden⁶ believes that every cell has particular salts in specific apportionment and that a disturbance of this relation, as would take place in Fisher's experiment just quoted, would cause considerable trouble in the life processes of the cell.

SULPHUR

Of all the mineral salts, sulphur has been the last to receive due attention at the hands of investigators. What we know of sulphur metabolism is largely due to Freund⁴⁶ and his pupils. Sulphur presents itself for ingestion in the food in two different forms, viz., in the inorganic salts, and organically bound with albumin. The inorganic salts have little or no effect on metabolism and need not be considered. It is that sulphur which is organically bound which is the important part and which supplies the daily need of the growing infant.

Whether or not sulphur is necessary for the maintenance of life is still a question, but any substance so closely associated with nitrogen may be assumed to have a distinct function, though as yet this function is obscure.

The total sulphur intake of infants fed on mother's milk is .04 gm., while on cow's milk the daily intake is about 0.44 gm., according to my recent researches. The sulphur of mother's milk is very well absorbed, as is also that of cow's milk. My determinations show that it is absorbed in from 88.2 to 95.7 per cent. of intake. This absorption is quite in

43. Fisher: Cited by Abderhalden, *Lehrbuch d. physiolog. Chemie*, Berlin, 1909, p. 358.

46. Freund: *Zeit. f. phys. Chem.*, Strassburg, 1900, xxix, 24-46.

SULPHUR IN TERMS OF S

In 1,000 gm. mother's milk, total sulphur .0572 gm.
In 1,000 gm. cow's milk (Hoobler), total sulphur .33538 gm.

Food	Intake	Elimination			Absorption			Retention		
		Feces	Urine		Gm.	Percent.	Per Kilo	Gm.	Percent.	Per Kilo
Mother's milk	.0396	.0096	.026		.0298	75.5	....	.0039	9.8	....
Cow's milk	.5832	.01484	.2019		.0436	74.5	....	Negative	....	....
Diluted cow's milk, 2.1% fat (Hoobler)	.46308	.0542	.3777		.4089	88.2	.491	Negative	....	....
Whole cow's milk, 4% fat (Hoobler)	.4411	.02430	.26589		.4168	94.2	.531	.15091	34.2	.019
Cow's milk and cream, 5.4% fat (Hoobler)	.4444	.01901	.30585		.42546	95.7	.533	.11961	26.9	.015

Figures given above are in grams in 24 hours.

keeping with the facility with which nitrogen is absorbed, and this is probably due to the fact that its connection with the albumin molecule is so close. (See tabulation, page 137.)

The absorption takes place through the small intestine, and some of it is again eliminated into the large intestine, making up the sulphur found in the feces.

Schwarz⁴⁷ found in a 5-year-old child on a mixed diet that the absorption was very good, being 92.2 per cent. of the intake. My normal child on a milk diet had an absorption of 92.4 per cent. of the intake. Identical methods of determination were used by both of us.

RETENTION

The retention of sulphur in mother's milk feeding is very good, while with cow's milk the retention is relatively poor. In one of my determinations there was a negative balance and in two others 34.2 and 26.9 per cent. of the intake was retained. Schwarz,⁴⁷ in a normal 5-year-old child on a mixed diet found that sulphur retention was relatively poor, being 31.1 per cent. of the intake.

ELIMINATION

The elimination of sulphur occurs mostly through the urine. In cow's milk feeding ten times as much appeared excreted through the urine as through the feces.

The sulphur in the feces appears as iron sulphate and alkali sulphate, while in the urine there are recognized four different forms, viz., the inorganic sulphate sulphur, the ethereal sulphate sulphur, neutral sulphur and basic sulphur. The first named is by far the most abundant in the urine, making up about 80 per cent. of the total sulphur. Ethereal sulphate sulphur makes up about 8 per cent. of the total sulphur and the neutral and basic sulphurs the balance.

Just what significance should be assigned to total sulphur and to each of the various sulphurs making up the total, has been the subject of much speculation.

Because of the connection between sulphur and albumin in tissues, the sulphur metabolism has been taken as the index to protein metabolism. The normal ratio is $N : H_2SO_4 : : 5 : 1$.

The relative amount of ethereal sulphate sulphur has been taken as an index of the degree of albuminous putrefaction going on in the intestine, and also for the breaking down of albuminous cells in the body.

The neutral sulphur appears to be increased on a vegetable diet and decreased on a meat diet. Investigators have shown that in periods of starvation, as well as in other conditions of protein break-down, there is an increase in the per cent. which neutral sulphur holds to total sulphur.

47. Schwarz: *Jahrb. f. Kinderh.*, 1910, lxxii, p. 549.

Lepine⁴⁸ is the authority for believing that neutral sulphur has its origin partly from the taurin of the bile. This is first excreted into the intestine, reabsorbed, and again eliminated through the urine. In those conditions of disturbed oxidation, if below normal, neutral sulphur is low; if above normal, then the neutral sulphur is increased. In my determinations of neutral sulphur it appears that on cow's milk containing 2.1 per cent. fat the neutral sulphur averaged 7.2 per cent. of the total sulphur, but that on feeding 4 per cent. and 5.4 per cent. fat mixtures the neutral sulphur was increased to as high as 15 per cent., more than doubled. This might be explained by the fact that during these higher fat feedings small amounts of acetone, diacetic acid and beta-oxybutyric acid were found in the urine, forecasting an impending acidosis, in which already tissue albumin had begun to disintegrate.

ANOMALIES OF SULPHUR RETENTION

Schwarz has shown that in rachitis the total sulphur absorption in two cases was 76.9 and 83 per cent., which was somewhat lower than in his normal case, which showed 92.2 per cent. absorption. The retention in one case was 30.9 per cent. and in the other 26.1 per cent. of the intake. This was about the same as in his normal case, viz., 31.1 per cent.

There was eliminated through the urine 55 per cent. of the total sulphur in one case and 54.1 in the other, while in the urine of his normal case 61.1 per cent. was thus eliminated. The elimination by the feces in two of his cases of rachitis showed a marked change from his normal case—23.1 per cent. and 17 per cent. in rachitis and but 7.8 per cent. in the normal.

Of the various forms of sulphur in the urine, the only one which showed much variation from the normal was that of the neutral sulphur, which in two of his cases was considerably increased, being 18.5 per cent. and 18.6 per cent., while his normal showed 7.8 per cent. of the total sulphur. In one of his rachitic cases no variation from the normal occurred.

A further anomaly of sulphur metabolism is that of cystinuria. Bunge has shown that in the catabolism of cystin, albumin, which has sulphur in it, sets sulphur free, which usually unites with bases and is eliminated as sulphates; but if the bases are lacking, then alkali is drawn from the cells of the body.

SUMMARY

1. Salts are necessary to maintain life.
2. Salts are best absorbed and utilized when in organic combination with food stuffs.

48. Lepine: Cited by Albu and Neuberg, *Mineralstoffwechsel*, Berlin, 1906, p. 148.

3. There are marked differences in the salt content of mother's and cow's milk which should be considered in artificial feeding.

4. Certain pathologic conditions arise in which certain of the salts are not absorbed, even though in abundance in the food.

5. In certain other pathologic conditions salts are actually withdrawn from the body to such an extent as to impoverish the organism and produce grave disturbances of nutrition.

6. The various salts, with the exception of iron, are present in sufficient quantities and proper proportions in mother's milk. In most of the dilutions of cow's milk there is an excess of salts which may be neglected in feeding normal infants, but which plays an important rôle in the feeding of children already suffering from nutritional disturbances. The conditions under which the salt content of feedings should be altered and in just what degree each or all should be varied, are still unsolved problems.

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