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THE UTILIZATION OF CALCIUM[1]

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ONE FIGURE

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The dietary calcium needs of children are usually regarded as at least 1 gm. of calcium per day. During adult life, after the bones and teeth are fully formed, the daily amount required is less than this. The most widely used figure for the calcium requirements of adults is that of Sherman ('32) of 0.68 gm. per day. In a recent study, Leitch ('37) gives a figure in fairly close agreement, namely, 0.55 gm. per day. During pregnancy and lactation, however, these needs are markedly increased so that at least 1.5 gm. of calcium are required daily to insure calcium equilibrium.

In view of these comparatively large amounts of calcium required for optimum health and the scarcity of this mineral element in practically all foods ordinarily consumed, with the exception of milk and milk products, the question of the availability of calcium in different forms and in different foods is an important one. With this in mind, it was decided to test the availability of calcium in different forms including those compounds used for therapeutic purposes. The rat was used as the experimental animal.

The total amount of calcium and phosphorus in the bodies of approximately 3-week-old rats with the intestines discarded, ranging in weight from 46 to 62 gm., was determined. The results on twenty-seven of these animals are given in figure 1.

[1] Read at the Sixteenth Annual Meeting of the Canadian Society for the Study of Diseases of Children, held at Kingston, Ontario, June 3 and 4, 1938.

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This shows that there are variations not only according to the weight of the animal but also in different animals of the same weight. In an attempt to minimize these and other variations in the feeding observations to follow, the animals were matched according to weight, sex and litter. Six or more animals were used with each form of calcium tested.

The average total calcium and phosphorus in the bodies of 3-week-old animals, with the intestinal tract discarded, is

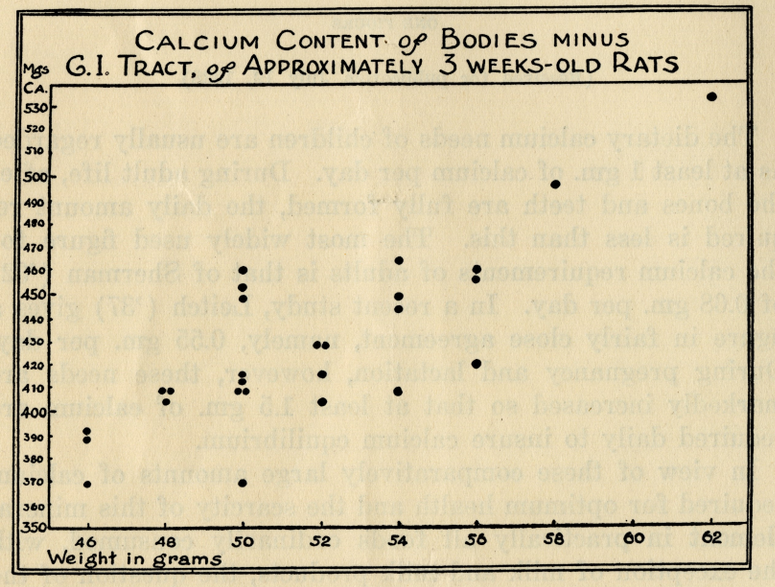

Figure 1

shown in table 1. A series of litter mates of these animals were fed for a further 4 weeks on the normal stock diet of the colony. These animals were then killed and the body calcium and phosphorus determined. A second matched series was fed 4 weeks on a low calcium but otherwise normal diet devised by Fincke and Sherman (see protocols). A third matched series was fed for 4 weeks on a low calcium diet devised by E. Chant Robertson (see protocols). The only deficiency in this diet as in the case of Fincke and Sherman's

diet, was the low calcium. The phosphorus and other elements were normal. This diet contained 2% cod liver oil. The animals in these two series were also sacrificed after 4 weeks and the body calcium and phosphorus determined. The results are given in table 1.

Protocols

Fincke and Sherman's low calcium diet:

	%
Whole wheat	65.0
Skim milk powder	11.0
Butterfat	9.0
Cornstarch	13.7
Sodium chloride	1.3

E. Chant Robertson's low calcium diet:

Casein A and B free (alcohol and acetic acid extracted)	18.0	
Cornstarch	62.2	
Crisco	10.0	
Yeast	6.0	
Cod liver oil	2.0	
Salt mixture	1.8	
Salt mixture:		
K_2HPO_4		219.72
KCl		125.29
NaCl		77.41
$MgCO_3$		33.43
$MgSO_4$ (anhydrous)		38.50
Fe Citrate $1\frac{1}{2}$ H_2O	94.18	
NaF	3.68	
$MnSO_4$	1.17	13.80
$K_2Al_2(SO_4)_4 \cdot 24\ H_2O$	0.67	
KI	0.30	
	100.00	

Diet for 17-year-old child with milk omitted:

Breakfast:	Luncheon:	Dinner:
Orange juice	Cold lamb	Clear soup
Cornflakes and cream	Potato and lettuce salad	Beef and potato
Bacon and egg	Canned peaches	Cabbage and peas
Toast and honey	Bread and butter	Apple pie
Coffee and cream	Plain cake	Bread and butter
	Tea and cream	Coffee and cream

From the results given in table 1, it is seen that Chant Robertson's diet resulted in a much lower retention of calcium than Fincke and Sherman's low calcium diet; consequently, the rats fed Chant Robertson's low calcium diet should be more sensitive to any calcium addition. For this reason, in all the subsequent experiments this diet was used as the basic low calcium diet.

Six litters of rats, each animal weighing approximately 50 gm., and each litter containing six animals of the same sex, were divided into six groups so that each group was matched with the other groups according to litter, sex and weight. To the first group was fed the low calcium diet. To the other groups was fed the same low calcium diet with the addition

TABLE 1

Average body calcium and phosphorus of rat fed different diets

DIET	WEIGHT AT 3 WEEKS	WEIGHT AT 7 WEEKS	Ca	P
	gm.	*gm.*	*mg.*	*mg.*
Normal	52	...	430	267
Normal	53	148	1406	780
Fincke and Sherman's low Ca	53	137	968	592
E.C.R. low Ca	51	116	482	392

of varying amounts of calcium in the form of calcium carbonate. The animals ate the diet ad lib., careful records being kept of the amount of food consumed by each individual rat. At the end of 4 weeks on the diet the animals were killed, the gastro-intestinal tracts discarded, and the total calcium and phosphorus in the animals' bodies determined. The difference between the amount of calcium and phosphorus in the bodies of the animals on the low calcium diet and the amount in the bodies of the animals with calcium added to this diet will be due to retention of the added calcium.

Table 2 shows that as extra calcium was added to the diet the calcium retention increased. A striking feature, however, was that as increased calcium retention occurred the amount of phosphorus retained also increased, although no phosphorus had been added to the diet. The ratio of the calcium

and phosphorus retention closely approximates 2:1. This is of particular interest, as it indicates that in a diet adequate in phosphorus but low in calcium the retention of the phosphorus is dependent on the retention of calcium.

The availability of calcium in the form of calcium carbonate, calcium chloride, dicalcium phosphate, calcium lactate, powdered whole milk, casec and Pablum was studied by adding 200 mg. per cent calcium in these various forms to the

TABLE 2

Extra Ca and P retention on addition of $CaCO_3$ to low Ca diet

Ca ADDED TO DIET	EXTRA Ca RETAINED	RETENTION EXTRA Ca FED	EXTRA P RETAINED	RATIO OF EXTRA $\frac{Ca}{P}$ RETAINED
%	*mg.*	%	*mg.*	
0.115	306	85	185	1.65
0.150	355	81	185	1.92
0.200	454	73	228	1.99
0.250	595	74	308	1.93
0.300	755	79	354	2.13

TABLE 3

Extra Ca and P retention on addition of 0.200% Ca in different forms to low Ca diet

FORM	EXTRA Ca RETAINED	RETENTION EXTRA Ca FED	EXTRA P RETAINED	RATIO OF EXTRA $\frac{Ca}{P}$ RETAINED
	mg.	%	*mg.*	
Dica. phosp.	467	77.2	206	2.27
Ca carb.	454	74.0	228	1.99
Ca chlor.	470	74.7	215	2.19
Ca lact.	508	76.6	227	2.24
W. milk powder	459	72.9	249	1.84
Casec	458	77.6	233	1.97
Pablum	392	74.3	178	2.20

diet of rats for 4 weeks. The results given in table 3 show that the percentage retention of the extra calcium fed is approximately the same with all these different forms.

The various salts of calcium just studied were also fed at the level of 150 mg. per cent and 115 mg. per cent. Again the percentage of calcium retained was essentially the same with all these calcium salts. In these last series, calcium gluconate

was also fed and the amount of calcium retained did not differ from the other salts.

An attempt was made to estimate the availability of calcium in a number of vegetables, as prepared and canned for infant feeding. For practical reasons, it was necessary to feed the vegetables in dried form.[2] Due to the difficulties of drying these vegetables, it was necessary to add to the vegetables a certain amount of starch. In each animal experiment, the amount of dried vegetable added was such that the animal's diet contained the equivalent of 70 parts per 100 of the canned sieved vegetables undergoing test. Due to the fact that calcium is present in most vegetables in comparatively small amounts, the added calcium in most instances was comparatively small in relation to the control low calcium diet test. For this reason, no definite statement is made at the present time as to the availability of the calcium in the vegetables, except that there is some evidence that the calcium in vegetables does not seem to be utilized as efficiently as that of milk.

In another series of experiments, 10% dried spinach was added to the rat's diet, which is equivalent to about 210 parts of fresh spinach. At the same time, in a second series of animals, 115 mg. of calcium, which is the calcium content of 10 gm. of dried spinach, was added as calcium carbonate to each 100 gm. of the low calcium diet. To the diet of a third series of animals was added exactly the same amount of calcium carbonate, plus the amount of oxalic acid calculated to be present in the 10% dried spinach.

The results obtained, which are given in table 4, confirm the results previously reported by us (Tisdall, Drake, Summerfeldt and Jackson, '37) that the feeding of large amounts of spinach actually decreases the calcium retention. These results also show that this adverse effect of spinach on calcium retention is probably due in part at least to its oxalic acid content.

The effect of feeding 10% of the diet in the form of farina, oatmeal and Pablum on the calcium retention was studied.

[2] We are indebted to Dr. E. R. Harding of the H. J. Heinz Company, who kindly dried these vegetables for us.

The addition of 10% farina to the diet resulted in an increase of 14 mg. calcium; oatmeal, 36 mg., and Pablum, 209 mg. (table 5).

The effect of feeding human diets was studied. A diet for a 17-year-old child (see protocol) with the milk omitted was dried. It should be noted that this diet is such as might be consumed by many people who are not fond of milk. This dried material was used to replace the starch of the low

TABLE 4

Effect of adding 0.115% calcium as $CaCO_3$, as spinach and as $CaCO_3$ plus oxalic acid

MATERIAL ADDED	EXTRA Ca RETAINED	EXTRA P RETAINED
	mg.	*mg.*
$CaCO_3$	306	185
Dried spinach	−81	−82
$CaCO_3$ plus oxalic acid	141	61

TABLE 5

Effect of adding 10% farina, oatmeal and Pablum on Ca retention

MATERIAL ADDED	EXTRA Ca RETAINED	EXTRA P RETAINED
	mg.	*mg.*
Farina	14	43
Oatmeal	36	25
Pablum	209	119

TABLE 6

Effect of human low milk diet and high milk diet on Ca and P retention

DIET	EXTRA Ca RETAINED	RETENTION EXTRA Ca FED	EXTRA P RETAINED	RATIO OF EXTRA $\frac{Ca}{P}$ RETAINED
	mg.	*%*	*mg.*	
Low milk	50	62.7	20	2.5
High milk	215	88.0	102	2.1

calcium diet, so that each gram of the final mixture contained the equivalent of 1 gm. wet weight of the human diet. In another series of animals, the diet was constructed so that each gram contained the equivalent of 1 gm. wet weight of the 17-year-old child's milkless diet plus the appropriate amount of whole milk which would be present if 1 quart of milk (40 ounces) had been added to the child's milkless diet. In these two experiments, any extra retention of calcium and

phosphorus over the control animals is due to the consumption of the milkless diet in the one case and the same diet plus 1 quart of milk daily in the other case. The results given in table 6 show that not only is the average human diet without milk not a good source of calcium, but the percentage of the calcium retained is less than in the same diet with added milk.

SUMMARY

Studies have been made of the retention in the rat's body of calcium fed in various forms.

When calcium was added to a low calcium but otherwise normal diet, including cod liver oil, in the form of calcium carbonate, calcium chloride, dicalcium phosphate, calcium gluconate, calcium lactate, whole milk powder, casec and Pablum, the percentage of the added calcium retained was essentially the same in each instance.

With an adequate phosphorus and low calcium diet, the retention of calcium and phosphorus increases approximately in the ratio of 2:1 when extra calcium retention is brought about by the addition of calcium to the diet. In other words, in a diet adequate in phosphorus, the amount of phosphorus retained is dependent on the amount of calcium retained.

The addition of calcium in the form of large amounts of spinach to a low calcium diet resulted in a reduction rather than an increase in the body calcium. This effect is probably due in part to the oxalic acid content of the spinach.

The increase in the body calcium produced by the addition of different cereals has been studied.

The inadequacy of an averaye human diet low in milk, as a source of calcium, has been biologically demonstrated. Not only is the calcium retention on this diet low but the percentage of the calcium retained is less than in the same diet with added milk.

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