A Quantitative Relationship Between the Absorption of Calcium and Phosphorus

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It is an established physiologic fact that the rate of phosphate loss is affected by the rate of calcium loss in the feces.[1] Likewise, it is accepted that the relative amounts of phosphorus and calcium in the diet, i.e., the Ca:P ratio, influence the absorption of both minerals from the human intestine.[2]

The quantitative association, however, between calcium and phosphorus absorption on the one hand, and its exact dependence on the calcium and phosphorus intake on the other, to our knowledge, has never been mentioned before and will be dealt with in this paper.

METHODS

Experimental Subjects

Our main group of subjects consisted of seventy-four clinically healthy adult Bantu living in the Feshi territory (former Belgian Congo). Biometric data and dietary habits of these people have been described before by one of us.[3–5]

The results obtained in the Congo experiments are compared to data obtained from the General Hospital in Pretoria (South Africa). In this case, the subjects were twenty infants, from six months to two years old, weighing from 5 to 10 kg. All these subjects suffered from acute kwashiorkor and on each patient a dietary balance was performed immediately after admission, and repeated two- and a half weeks later.

Diets

In the Congo experiments customary-type diets were used throughout; consequently the intakes of calcium and phosphorus were low. Cassava paste was the staple food, contributing 5 mg. per kg. per day of calcium and 7 mg. per kg. per day of phosphorus. All subjects received palm oil, sugar and spices, and, in addition, the foodstuffs, listed in Table I, were added for the respective groups.

In the Pretoria experiments the main source of calcium and phosphorus was milk which was prepared from dried skim milk plus added carbohydrate, dried whole milk, acidified dried whole milk, or dried skim milk plus added sunflower seed oil.

Technics

Each balance experiment lasted for three days. Food, stools and urine were analyzed daily and the results expressed in milligrams per kilogram per day.

In the Congo experiments the calcium content in the food and stools was estimated by the method of Tisdall and Kramer[6] after dry ashing, and phosphorus by the method of Fiske and Subbarow[7] after wet ashing. In the Pretoria experiments the calcium content in the stools and food was estimated by oxalate-permanganate method[8] after dry ashing, and phosphorus by the hydrazine sulfate method of Boltz and Mellon[9] after wet ashing.

Statistical correlations were computed by means of the correlation coefficient r, and their significance tested by means of the t test. Regression equations were calculated by the method of the least squares.

RESULTS

The results of the Congo experiments are given in Table II, and those of the Pretoria experiments in Table III. Statistical analysis of the results set out in Table II showed that

TABLE I

Group	Foodstuff
Mt	Caterpillars (insect larvae)
MM and Mm	Maize
FO	Whole egg
GA	Meat, fish and milk
MCB	Meat

From the Department of Physiology, University of Pretoria, Pretoria, South Africa.

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TABLE II

Intake and Fecal Excretion of Seventy-Four Calcium (Ca) and Phosphorus (P) Balances in Seventy-Four "Healthy" Adults in Feshi (former Belgian Congo)

No. of Experiment	Weight (kg.)	Calcium Intake (mg./kg./24 hr.)	Phosphorus Intake (mg./kg./24 hr.)	Ca:P in Diet	Fecal Ca (mg./kg./24 hr.)	Fecal P (mg./kg./24 hr.)	Fecal Ca / Ca:P in Diet
Mt1	38.0	9.9	20.3	0.49	7.6	8.6	15.5
Mt2	40.0	9.7	18.8	0.52	8.0	12.6	15.3
Mt3	50.0	7.4	14.8	0.50	7.7	10.4	15.4
Mt4	46.0	8.3	16.8	0.49	7.1	9.8	14.4
Mt5	40.0	9.5	19.3	0.49	5.1	10.4	10.4
MM1	43.0	4.2	29.7	0.14	1.1	2.6	7.8
MM2	48.0	4.0	27.3	0.15	0.5	1.6	3.3
MM3	36.0	4.2	28.4	0.15	0.1	0.2	0.6
MM4	48.0	3.4	24.2	0.14	0.5	0.7	3.5
MM7	36.0	5.2	36.2	0.14	2.1	13.6	15.0
MM8	40.5	3.8	26.6	0.14	4.4	13.9	31.0
MM10	32.0	5.1	34.2	0.15	4.4	12.3	29.0
Mm1	50.0	5.8	20.0	0.28	6.8	16.1	24.3
Mm6	38.0	6.0	19.0	0.32	7.0	16.3	21.9
Mm7	43.0	6.4	22.4	0.29	8.1	22.0	28.0
Mm8	38.0	6.8	23.9	0.28	6.8	15.0	24.3
Mm12	45.0	5.7	21.3	0.27	9.3	19.8	34.0
Mm14	40.5	6.8	23.2	0.29	7.4	18.3	25.5
ML1	51.0	6.6	10.9	0.60	4.7	5.4	7.8
ML2	45.0	6.7	10.8	0.62	7.1	7.6	11.4
ML3	46.0	5.4	10.2	0.53	3.2	3.7	6.0
ML4	48.0	6.1	10.0	0.61	5.6	6.7	9.2
ML5	42.0	7.7	10.8	0.71	4.6	5.3	6.5
ML6	38.0	7.0	12.1	0.58	5.5	8.4	9.5
ML7	40.0	8.5	14.8	0.57	5.5	10.0	9.6
ML8	38.0	8.1	14.7	0.55	8.2	10.2	14.9
ML13	50.0	5.6	9.6	0.58	0.5	0.5	0.8
ML14	40.0	5.9	9.5	0.62	4.8	4.8	7.7
ML15	32.0	8.1	12.9	0.63	7.9	10.5	12.5
ML17	40.0	6.4	10.4	0.61	9.1	11.3	14.9
ML18	43.0	5.6	9.3	0.60	5.3	7.0	8.8
FO75	44.0	4.7	15.0	0.31	4.7	15.0	15.2
FO76	44.5	6.2	17.0	0.36	3.5	4.0	9.7
FO77	39.0	5.8	18.0	0.32	7.1	7.0	22.2
FO78	37.0	5.6	18.5	0.30	1.9	3.0	6.3
FO79	38.5	4.7	16.0	0.29	5.1	5.5	17.6
GA1	47.0	21.9	30.1	0.73	7.9	9.6	10.8
GA2	47.5	21.9	31.7	0.70	17.1	9.6	24.4
GA3	46.5	29.1	46.4	0.63	12.6	10.3	20.0
GA4	55.0	19.0	26.1	0.73	10.5	7.7	14.4
GA5	38.0	30.6	42.5	0.72	18.4	15.8	25.5
GA6	55.0	21.5	30.0	0.72	12.7	8.5	17.6
GA7	43.0	23.9	34.0	0.70	15.5	10.6	22.0
GA8	45.0	25.6	36.5	0.70	17.0	14.3	24.3
GA9	41.0	28.8	38.5	0.75	16.5	12.7	22.0
GA10	54.0	21.0	28.5	0.74	13.0	10.0	17.6
GA11	49.0	22.3	33.4	0.69	20.3	14.8	29.4
GA12	47.0	21.5	28.6	0.75	23.2	17.2	30.9
GA13	54.5	19.5	30.2	0.65	10.6	12.4	16.3
GA14	52.0	20.5	28.0	0.73	14.5	12.0	19.9
GA15	44.5	23.0	32.7	0.70	14.4	10.4	20.6
GA16	57.5	22.5	30.3	0.75	18.6	17.4	24.8
GA17	51.0	21.8	28.9	0.75	22.4	15.7	29.9
GA18	47.0	26.8	37.5	0.71	22.1	14.9	31.1
GA19	47.0	26.8	36.2	0.74	19.0	14.8	25.6
GA20	51.5	22.1	28.8	0.77	25.0	19.5	32.5
GA21	62.5	21.1	28.4	0.74	13.9	7.6	18.7
MGB1	53.0	12.0	19.0	0.63	8.7	8.0	13.8
MGB2	36.0	14.0	22.0	0.63	8.4	10.8	13.1
MGB3	37.0	13.6	21.0	0.64	6.9	6.0	10.6
MGB4	40.0	15.8	24.0	0.66	18.0	15.0	27.2
MGB5	41.5	13.3	20.0	0.67	5.1	6.7	7.6
MGB6	48.0	14.2	20.9	0.68	7.2	5.9	10.6
MGB8	47.0	11.4	20.2	0.65	6.5	6.6	11.8
MGB9	42.0	16.0	22.0	0.73	11.4	8.3	15.6
MGB10	42.0	16.0	23.5	0.68	5.7	5.7	8.4
MGB11	54.0	12.6	18.4	0.69	12.3	8.9	17.8
MGB12	50.0	13.6	20.6	0.66	17.4	13.4	26.4
MGB13	51.0	13.4	19.0	0.70	11.7	11.3	16.7
MGB14	41.0	15.5	23.2	0.67	8.9	7.2	13.3
MGB15	43.5	12.3	20.2	0.61	14.4	15.1	23.6
MGB16	46.0	14.9	21.0	0.71	10.6	10.3	14.9
MGB18	43.0	15.5	23.2	0.67	8.8	9.2	11.4
MGB19	35.0	19.3	25.8	0.75	12.7	13.9	16.9

TABLE III

Intake and Fecal Excretion of Calcium (Ca) and Phosphorus (P) in Twenty Infants Suffering from Acute Kwashiorkor (No. 1 to 20) and after Two and a Half to Three Weeks of Treatment (No. 21 to 40) in Pretoria

No. of Experiment	Weight (kg.)	Calcium Intake (mg./kg./24 hr.)	Phosphorus Intake (mg./kg./24 hr.)	Ca:P in Diet	Fecal Ca (mg./kg./24 hr.)	Fecal P (mg./kg./24 hr.)	Fecal Ca / Ca:P in Diet
1	5.7	97	90	1.08	49	26	45
2	8.3	144	102	1.43	98	53	69
3	6.5	161	113	1.44	170	68	118
4	8.8	135	113	1.31	133	52	100
5	7.8	132	101	1.31	106	36	81
6	5.5	115	96	1.22	77	24	63
7	8.4	120	105	1.15	81	57	71
8	8.8	117	108	1.08	81	56	75
9	8.5	131	102	1.29	137	78	106
10	7.2	100	86	1.17	71	23	61
11	8.9	121	97	1.25	70	32	57
12	9.1	129	83	1.55	83	37	54
13	7.0	143	111	1.30	101	48	78
14	9.7	124	100	1.24	96	51	77
15	8.7	148	105	1.40	128	60	91
16	7.0	133	103	1.30	81	56	62
17	11.0	121	93	1.27	66	30	52
18	10.8	119	79	1.50	55	26	36
19	10.9	107	86	1.24	91	33	72
20	6.4	135	103	1.30	112	65	85
21	6.4	140	107	1.31	168	54	127
22	7.3	160	122	1.31	102	33	78
23	6.4	169	157	1.07	169	87	156
24	8.5	135	110	1.23	112	46	91
25	6.9	150	109	1.37	100	15	73
26	5.7	119	106	1.12	126	38	111
27	7.0	153	126	1.21	141	68	115
28	9.3	123	104	1.18	204	76	176
29	6.6	134	119	1.12	143	62	128
30	8.8	124	100	1.24	76	34	62
31	8.4	147	119	1.24	110	38	89
32	8.5	141	111	1.27	72	23	57
33	7.0	142	110	1.29	114	37	88
34	9.5	128	108	1.19	127	62	108
35	9.1	137	105	1.30	101	47	78
36	7.0	156	123	1.27	144	66	113
37	9.7	126	95	1.32	86	52	65
38	10.9	117	89	1.31	96	52	73
39	10.3	121	96	1.26	105	58	83
40	6.3	143	105	1.36	91	48	67

fecal phosphorus, taken as a dependent variable, was unrelated (i.e., r not significantly different from 0) to the following: (1) phosphorus intake, (2) fecal calcium, and (3) the Ca:P ratio in the diet. All these were taken successively as independent variables.

A close relationship, however, existed between fecal phosphorus in the one hand, and, on the other, the fecal calcium divided by the Ca:P ratio in the diet. This correlation is illustrated in Figure 1. Its regression equation is

$$Y = 1.48 + 0.515 X \quad \text{(formula 1)}$$

The correlation coefficient r equals 0.88, which is, of course, highly significant.

In the Pretoria infants, the values for intake and, accordingly, for fecal excretion of calcium and phosphorus were much higher than in the Congolese subjects. The values in the

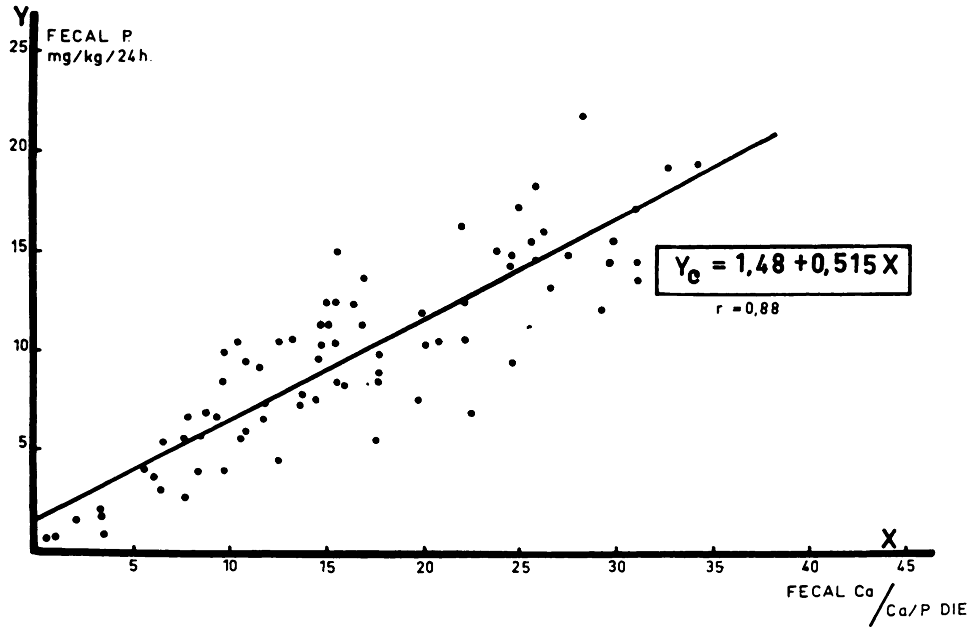

FIG. 1. This figure illustrates the highly significant correlation between fecal phosphorus and the fecal calcium divided by the Ca:P ratio in the diet of Congo adults. The values were taken from Table II.

Pretoria experiments are represented in Figure 2 which illustrates, on a reduced scale, the correlation between the same variables as represented in Figure 1. The regression line in Figure 2 is the same as that in Figure 1 and was computed for the Congolese subjects only, but it can easily be appreciated that the correlation for the patients with kwashiorkor in Pretoria corresponds closely with that existing for the Congolese adults.

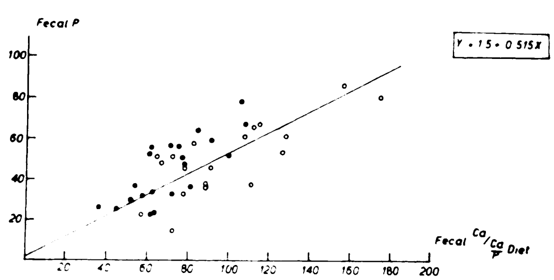

FIG. 2. This graph represents results obtained in patients with kwashiorkor in Pretoria (South Africa). Circles indicate balance results obtained two and one-half weeks after admission. The values were taken from Table III, but the regression line was calculated from the results obtained in the Congolese adults (Table II).

COMMENTS

Since a rather close relationship was found between four variables in two distant places in Africa, it seemed worthwhile to compare this relationship with results reported from outside Africa. From the numerous results published by Macy[10] in America, we have plotted fifty arbitrary values, together with the Congo results, in Figure 3.

In this graph again, the regression line is calculated for the Congo series only (formula 1), but it is nevertheless evident that the American values cluster closely around that regression line. We believe, therefore, that formula 1 is the expression of a general relationship between the absorption of calcium and phosphorus, respectively.

Although no statistical tests were carried out, we believe that for the sake of simplicity, formula 1 can be changed to

$$Y = 0.5\ X \qquad \text{(formula 2)}$$

and if we substitute for X and Y in this formula, we obtain

$$\text{fecal P} = 0.5\ \frac{\text{fecal Ca}}{\text{Ca:P in diet}} \qquad \text{(formula 3)}$$

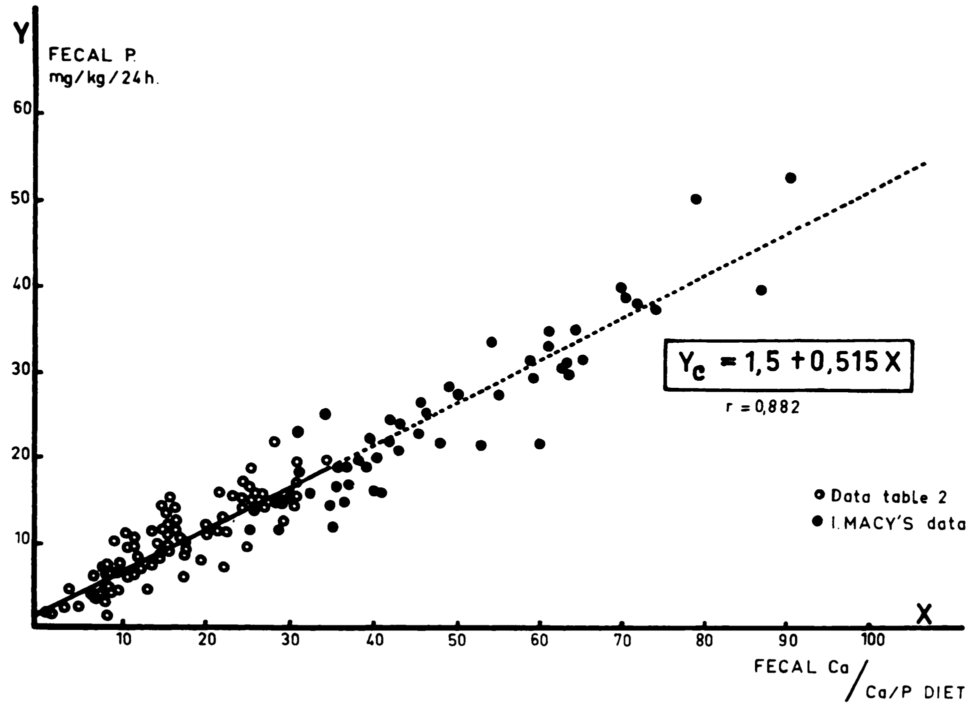

FIG. 3. Results obtained in Congolese adults (circles, values taken from Table II) and same regression line as in Figure 1. The dots represent fifty arbitrarily selected data from Macy.[10] They cluster closely around the regression line calculated for the results obtained in the Congolese adults only.

An association such as represented by formula 3 (or formula 1) is useful only if it serves some practical purpose. From it we can, in fact, deduct several well established facts related to the physiology of calcium and phosphorus:

(1) According to formula 3, if the normal calcium absorption is, for example, 30 per cent of the intake, the phosphorus absorption must be 65 per cent. Indeed, formula 3 can be written:

$$\text{fecal P} = 0.5\ \frac{\text{fecal Ca}}{\text{Ca intake}} \times \text{P intake} \qquad \text{(formula 4)}$$

If calcium absorption is 30 per cent, the ratio fecal Ca:Ca intake equals 0.7, and formula 4 becomes

$$\text{fecal P} = 0.5 \times 0.7 \times \text{P intake} \times \text{P intake}$$

In other words, in this instance, fecal phosphorus is 35 per cent of the intake, or phosphorus absorption is 65 per cent of the intake.

(2) Impaired calcium absorption is accompanied by impaired phosphorus absorption. According to formula 4, if the ratio fecal Ca: Ca intake increases (impaired Ca absorption), the fecal phosphorus becomes a larger fraction of the phosphorus intake. It can be seen, however, in formula 4, that even with fecal calcium exceeding the calcium intake (negative absorption) phosphorus absorption can still take place unless fecal calcium amounts to twice the calcium intake, since in the latter event formula 4 can be written

$$\text{fecal P} = 0.5 \times 2 \times \text{P intake} = \text{P intake}$$

(3) The inversion of the ratio urinary P: fecal P, normally larger than 1, has been proposed and used as a criterion for vitamin D deficiency or resistance, especially in adults.[11] One can deduct from formula 4 that an inversion of this ratio is likely to take place if calcium absorption is seriously impaired. In that case, indeed, the ratio fecal Ca: Ca intake will exceed 1, and formula 4 shows that fecal phosphorus will then amount to more than half

the phosphorus intake. If more than half of the phosphorus intake is lost in the feces and phosphorus balance is to be maintained, urinary phosphorus can only be less than half of the intake.

(4) Phosphorus deficiency without accompanying calcium deficiency is clinically unknown. This fact also can be deducted from formula 4: fecal phosphorus does not exceed half of the intake if the intestinal calcium balance is positive, since in that event, the ratio fecal Ca : Ca intake does not exceed 1.

SUMMARY

A relationship between calcium and phosphorus absorption, not previously described, was found to exist in balances performed in Feshi (former Belgian Congo), in Pretoria (South Africa) and in America. This relationship can be expressed by the formula

$$\text{fecal P} = 0.5 \frac{\text{fecal Ca}}{\text{Ca:P in diet}}$$

from which several known physiologic and clinical facts can be deduced.

ACKNOWLEDGMENT

We are indebted to Dr. P. J. Pretorius for allowing us to study the patients under his care and for using his data.

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