The technical assistance of Mrs. John Hess is gratefully acknowledged.

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Received August 13, 1962. P.S.E.B.M., 1962, v111.

Gastrointestinal Sites of Absorption and Endogenous Secretion of Calcium and Phosphorus in Dairy Calves.* (27815)

P. T. CHANDLER AND R. G. CRAGLE (Introduced by F. R. Mraz)
Agricultural Research Laboratory, University of Tennessee, Oak Ridge,† and Dairy Department, University of Tennessee, Knoxville

Much work has been conducted concerning the total absorption of calcium and phosphorus. The sites within the gastrointestinal tract where absorption and secretion occur are not well known. The ideal method for studying gastrointestinal absorption and secretion is the use of non-absorbed indicators that move through the tract as does the nutrient in question. Absorption and secretion of calcium and phosphorus have been studied using reference markers of iron oxide(1), titanium dioxide(2,3,4), and insoluble ash of feed(5). Garner *et al.*(6) studied cerium-144 metabolism in the dairy cow and suggested its use as a marker in digestibility trials. In the present study, gastrointestinal absorption and secretion of calcium and phosphorus in the diary calf have been investigated using Ce^{144} as a non-absorbed marker.

Method. Eight Holstein male calves, 12 and 15 weeks of age, were used. The animals were raised on skim milk and calf starter ration. Reconstituted skim milk (13% solids) was fed at the rate of 10 lb per 100 lb of body weight per day until 4 weeks of age. Over the next 2 weeks the skim milk was gradually reduced to zero. The starter consisted of 15% alfalfa meal, 10% dried skim milk, 25% soybean oil meal, 10% oats, 38% yellow corn, 1% salt, and 1% vit. A and D supplement. The calves were fed this starter throughout the experiment, and at time of termination they were eating 3 lb per day.

The animals were divided into 2 groups of 4 each and trained to stand at ease in metabolism stalls. At 12 weeks of age, Group 1 was placed in the stalls and fed 1.5 lb of starter plus 50 μc of Ce^{144} twice daily. This feeding rate supplied an average of 8.05 g calcium, 6.44 g phosphorus and 10.08×10^6 cpm Ce^{144} per day per calf. After 7 days on this regime the tract contents approached equilibrium (Fig. 1). The animals were then slaughtered and digestive contents sampled. The contents sampled consisted of the rumen, omasum, abomasum, small intestines, cecum, coiled colon, and posterior colon. At 15 weeks of age, Group 2 was placed in stalls and dosed similarly to Group 1.

The Ce^{144} was blended into the starter by making a pre-mix of starter plus isotope and then mixing the pre-mix and feed together before feeding. The pre-mix was mixed by adsorbing the isotope on 50 g of anion exchange resin (Amberlite IRA-400, 20-50 mesh) and then mixing with 950 g of feed. An anion exchange resin was used to provide an adsorbing surface and to offer no competition for the cation. All mixing was carried out by tumbling the material in glass jars.

At slaughter, the gastrointestinal tract was tied off and removed from the animal as soon as possible. The tract was then dissected

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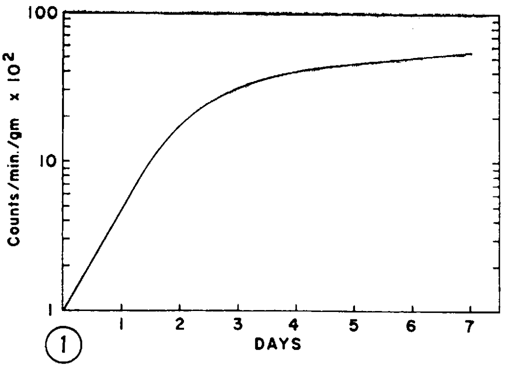

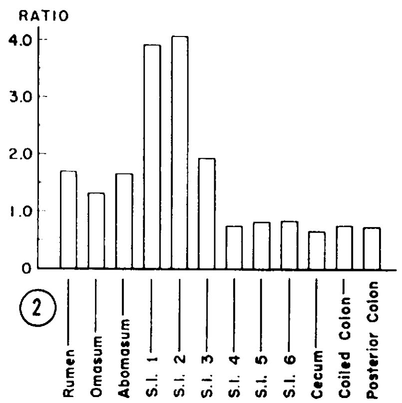

FIG. 1. Ce^{144} concentration in feces as affected by twice-daily continuous dosing (avg of Group 1).

FIG. 2. Ratio of calcium to phosphorus absorption for Group 2. The ratio was obtained by dividing calcium ratio by phosphorus ratio in Table I. S.I. 1-6 = 6 equal sections of small intestine.

free and different sections tied so that mixing was prevented. The sections sampled are shown in Table I. In Group 1, the small intestine was divided into 3 equal sections while in Group 2 it was divided into 6 equal sections. Intestinal contents were collected and measured for Ce^{144}, calcium, and phosphorus. Cerium-144 was determined by placing a 2 g sample of material in a glass tube and counting in a well-type scintillation counter. Aliquots of contents were dried and then ashed overnight at 650°C. The ash was brought into solution in dilute HCl. Calcium and phosphorus in the ash solution were determined by the procedures of Kamal(7) and Fiske and Subbarow(8) respectively.

The results are expressed as a ratio of the indicator to mineral in gastrointestinal contents over that of the indicator to mineral in the feed.‡ Ratios greater than one indicate a net absorption of the mineral, and ratios less than one indicate a net endogenous secretion. The data $\left(\frac{Ce^{144}}{Ca} \text{ or } \frac{Ce^{144}}{P} \text{ ratios}\right)$ were subjected to analysis of variance and differences between sites, calves, and groups were tested.

Results. The concentration of Ce^{144} in feces as affected by twice-daily doses is shown in Fig. 1. The curve begins to approach a straight line with a slight positive slope between the fourth and fifth day.

The results of calcium and phosphorus absorption and secretion are given in Table I. Analysis of variance showed no significant differences between Groups 1 and 2 in calcium metabolism but a highly significant difference between groups in phosphorus metabolism.

There was little change in the calcium ratio from feed (equal to 1 by definition) to rumen contents (Table I). There was a net endogenous secretion in the omasum with a large net absorption present from the abomasum. The value dropped in the first part of the small intestine, then rose in the middle one-third and stayed fairly constant thereafter. There were significant differences ($P < .05$) in Group 1 between stomach to small intestine, rumen to omasum-abomasum, first one-third of small intestine, to last two-thirds, and omasum to abomasum. In Group 2 significant differences ($P < .05$) were found between rumen to omasum-abomasum, omasum to abomasum, and first one-third small intestine to the last two-thirds.

There was a definite change in the phosphorus ratio between feed and rumen (Table I). A small decrease was present in the omasum, with a large increase in the abomasum. This was followed by a large drop in ratio in the beginning of the small intestine. Absorption followed but a net absorption was not reached until the last half of the small intestine. The value remained practically constant over the remainder of the tract. Analysis of variance of the data from Group 1 indicated significant differences ($P < .05$)

‡ $\text{Ratio (contents-feed)} = \frac{Ce^{144}/\text{mineral of sample}}{Ce^{144}/\text{mineral of feed}}$

TABLE I. Ratios* of Calcium and Phosphorus Absorption in Dairy Calves.

	Calcium						Phosphorus					
	Group I (4 calves)		Group II (4 calves)		Total (8 calves)		Group I (4 calves)		Group II (4 calves)		Total (8 calves)	
Segments	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Rumen	.98	.35	.94	.09	.96	.26	.60	.27	.56	.17	.58	.20
Omasum	1.03†	.20	.42	.11	.62§	.33	.82†	.23	.32	.10	.49§	.28
Abomasum	1.99	.55	3.81	1.35	2.90	1.35	1.05	.30	2.32	1.51	1.68	1.22
Small intestine 1			.90	.27					.23	.10		
" " 2	1.44¶	.55	1.67	.30	1.36¶‖	.40	.35¶	.23	.41	.17	.33¶	.16
" " 3			2.01‡	1.27					.79‡	.55		
" " 4	2.59¶	.34	2.44	1.22	2.41¶	.37	1.41¶	.99	3.35	4.31	1.69¶‖	3.11
" " 5			2.74	.87					3.37	3.83		
" " 6	2.72¶	.29	2.10	.48	2.57¶	.47	2.89¶	1.76	2.55‡	.73	2.77¶‖	2.72
Cecum	1.97	.15	2.28	.83	2.12	.57	2.24	.69	3.47	1.68	2.86	1.29
Coiled colon	2.09	.21	2.37	.71	2.23	.50	2.31	.64	3.23	1.15	2.77	.99
Posterior colon	2.12	.43	2.21	.57	2.16	.47	2.31	1.25	3.07	.81	2.60	.84

* Ratio (sample − feed) $= \dfrac{Ce^{144}/\text{mineral of sample}}{Ce^{144}/\text{mineral of feed}}$. > 1 = net absorption; < 1 = net endogenous secretion. As value becomes smaller, endogenous secretion $>$ absorption. As value becomes larger, absorption $>$ endogenous secretion.

† Avg of 2 calves. ‡ Avg of 3 calves. § Avg of 6 calves. ‖ Avg of 7 calves. ¶ Represents one-third segments.

between stomach to small intestine, first one-third of small intestine to the last two-thirds, and middle one-third of small intestine to the last one-third. Analysis of Group 2 indicated differences ($P<.05$) between the first one-third of small intestine to the last two-thirds.

Absorption ratios of calcium and phosphorus (Fig. 2) indicate different points of metabolism of calcium and phosphorus along the digestive tract. The most significant fact is the higher absorption of calcium than phosphorus in the first part of the small intestine. The similarity of the values from the last third of the small intestine to the posterior colon indicates that there was no significant change in relative calcium and phosphorus absorptions over this section of the tract.

Discussion. The metabolism of Ce^{144} in the calf and the mature cow is similar. Garner *et al.*(6) reported that equilibrium conditions were reached after 5-6 days on twice-daily doses. This is very close to the time required for equilibrium in calves. They also reported a small percentage of the dose (0.20%) occurring in the urine. There was no significant amount of activity in the urine of the calves in the present study. The activity of the blood was close to background at all measurements. Therefore it is logical to assume that the isotope was not absorbed in appreciable amounts by the dairy calf.

The indicator method for determining absorption depends upon the movement of the indicator with the ingesta. Moore and Tyler(5) indicate that the results obtained by Fournier(2) and Fournier and Dupuis(3,4) are a result of unequal flow between calcium and phosphorus and the indicator. The indicator used in these studies was titanium dioxide. However, our results with calves are in close agreement with those obtained by these workers with rats. Fournier(2) and Fournier and Dupuis(3,4) are of the opinion that absorption of calcium and phosphorus from the stomach of the rat is of considerable importance. In all 8 of the calves, the ratios for calcium were larger for the abomasum than for the previous compartments. In 7 of the 8 calves reported this was true for phosphorus. The possibility of an uneven flow of indicator to mineral may be ruled out when one compares the values of the omasum to abomasum and then abomasum to the first part of the small intestine. If an uneven flow was present, the rates of flow between indicator and mineral would have to reverse as the ingesta went from one compartment to another.

The endogenous secretion of phosphorus into the rumen has been observed by Smith *et al.*(9) with sheep. It was concluded that a significant amount of phosphorus came by way of saliva but a larger amount crossed the rumen wall. These data also support their work in that there is a definite secretion of phosphorus into the omasum. Average absorption ratio value of the rumen for Group 2 of the present study was 0.56 and the value for the omasum was 0.32 indicating a greater secretion than absorption for phosphorus.

Bergeim(1) in working with rats stated that there is a larger secretion of phosphorus in the first part of the small intestine with a later absorption in the terminal portion. He has also stated that the secretion of phosphorus seems to be associated with calcium absorption. The data on calves indicate a large secretion of phosphorus in the first part of the small intestine followed by absorption in the terminal part. A large calcium absorption is associated with the mid-portion of the small intestine. However, there was no calcium absorption associated with the large secretion of phosphorus in the rumen and omasum.

These results support the findings of Moore and Tyler(10) in that the secretions of calcium and phosphorus in the lower tract are small. The ratios observed for calves indicate that the absorption was equal to the secretion for this section of the tract. Wallace *et al.*(11) found an appreciable quantity of Ca^{45} in the lower tract of rats 6 hours after intramuscular dose. This would indicate a rapid secretion of calcium into the small intestine with the major amount of activity obtained at 6 hours due to movement from the small intestine to the large intestine.

Analysis of variance of the data indicates that there was significant difference due to age for phosphorus metabolism. The major differences between groups are between values obtained for omasum and abomasum (Table II). The younger calves in Group 1 have larger ratios for omasum and smaller ratios for abomasum than the older calves of Group 2. This indicates that the endogenous secretion of phosphorus in the omasum and the absorption of phosphorus from the abomasum are greater in the older calf. At slaughter, it was observed that all calves in the study were ruminating. The omasum was larger and more functional in the 15-week-old group.

Summary. An indicator method using Ce^{144} to determine calcium and phosphorus absorption and secretion in dairy calves has been described. Definite secretions of phosphorus into the rumen and omasum and absorption of calcium and phosphorus from the abomasum have been demonstrated. The points of calcium absorption are not always associated with phosphorus secretion. Appreciable secretions of calcium and phosphorus in the lower tract are not present or they are balanced by an equal absorption. There was no difference noted with age as to the metabolism of calcium; however, a significant difference was found in phosphorus metabolism with age.

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Received August 13, 1962. P.S.E.B.M., 1962, v111.