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Absorption of magnesium by the young steer

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1. Steers with rumen and simple duodenal cannulas were allowed to graze pasture or were given diets of dried grass or flaked maize with or without hay. For an experiment a solution or suspension of magnesium chloride, polyethylene glycol (molecular weight 4000) and either ^{144}Ce (as cerous chloride) or chromic oxide was added to the rumen with a morning feed. Conditions in the rumen were sometimes modified by adding sodium chloride or hydrochloric acid.

2. Changes in magnesium:marker in samples of strained rumen contents with time interval after adding the dose were due partly to changes in Mg distribution between different phases. Results indicated, but not unequivocably, that negligible amounts of Mg were absorbed in the first few hours.

3. Relative recoveries of Mg and markers at the duodenum indicated that proportions of Mg intake absorbed (net) varied from approximately zero for pasture to 0·2–0·5 for flaked maize. Significant correlations between absorption efficiency and sodium:potassium in rumen contents (positive) and rumen pH (negative) were observed.

4. Steers with simple duodenal and re-entrant ileal cannulas were given a diet of flaked maize and hay supplemented with different amounts of magnesium oxide. Little net change in Mg relative to an unabsorbed marker was found between these sites even for a diet containing an Mg supplement of 8 g/kg dry matter.

A number of workers have provided evidence that a major part of the magnesium absorbed by sheep or cattle is absorbed before the duodenum (Rogers & Van't Klooster, 1969; Grace, 1970; Dirksen, Kaufmann & Pfeffer, 1972; Strachan & Rook, 1975). More precise knowledge of the site of Mg absorption within the stomachs may help to determine how different dietary factors affect this absorption. Early conclusions that little absorption of Mg occurs from the rumen (Phillipson & Storry, 1965; Poutiainen, 1971) have recently been thrown into doubt by the results of Martens, Harmeyer & Breves (1976), Tomas & Potter (1976*a*) and Field & Munro (1977) and the relative importance of the different stomach compartments remains unclear. Part of the purpose of the present study was to try to assess the importance of the rumen in determining absorption up to the duodenum in the young steer. Observations were made also on absorption in the small intestine of this animal.

The dietary or other factors responsible for causing clinical hypomagnesaemia in sheep and cattle are still very poorly understood. Attempts to relate the occurrence of signs of Mg deficiency with specific dietary factors, other than a low Mg intake, have not generally been successful although a high potassium intake appears to be conducive to the condition (Suttle & Field, 1969). The efficiency with which Mg is absorbed from the stomachs of sheep or cattle has been shown to vary with different diets and different Mg intakes (Grace & MacRae, 1972; Kemp, Van't Klooster, Rogers & Gaurink, 1973; Grace, Ulyatt & MacRae, 1974) but there is little direct information on the mechanisms responsible. A further part of the present work, therefore, has been a study of possible associations between variations in the composition of rumen contents and the efficiency of Mg absorption from the stomachs of the young steer.

A preliminary report of part of this work has been published (Horn & Smith, 1976).

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Table 1. *Daily amounts of the main dietary components consumed by steers weighing 136–155 kg* and their approximate intakes of Na, K and Mg*

(Feeds, which included mineral and vitamin supplements, were given in two equal amounts at 09.00 and 17.00 hours. Estimates of mineral intakes included an allowance for drinking water)

	Diet			
	A	B	C	D
Hay (kg)	—	1·50	0·40	—
Flaked maize (kg)	2·06	1·56	1·94	—
Dried grass (kg)	—	—	—	1·50
maize starch (kg)	—	—	—	0·90
Na† (mol)	0·2	0·2	0·2	0·1
K (mol)	0·2	0·6	0·3	1·0
Mg† (mol)	0·2	0·2	0·2	0·2

* For animals of different weights, intakes were increased or decreased by approximately 12 % of those shown for each 20 kg difference in live weight.

† Supplementary amounts were sometimes varied as described in the text.

MATERIALS AND METHODS

Animals and feeding

Male Friesian calves were weaned at 6–8 weeks and provided with cannulas in the alimentary tract and castrated at 13–16 weeks of age. Steers nos. 1–4 were given simple rumen and duodenal cannulas and steers nos. 5–7 simple duodenal and re-entrant ileal cannulas as described by Smith & McAllan (1970, 1971) except that duodenal cannulas were made of polyacetal. After being weaned the animals received a diet of approximately equal weights of hay and a calf-rearing concentrate mixture until experiments were carried out at 26–57 weeks of age. They then received one of the diets shown in Table 1 for a period of at least 1 week and almost always of 2 weeks before an experiment was carried out. For a period of 1 month during May–June 1974, calves nos. 2–4 were allowed to graze pasture (permanent grassland composed mainly of ryegrass (*Lolium perenne*), cocksfoot (*Dactylis glomerata*), *Agrostis* spp. and *Festuca* spp.). Experiments were carried out at least 2 weeks after grazing began.

Studies of Mg absorption from the stomachs

Experiments consisted essentially in observing changes in Mg : marker in digesta samples after adding these substances to the rumen. It was necessary to correct for Mg entering the digesta from other sources ('background Mg'). For the stall-fed calves this interference was minimized by withdrawing the Mg supplement from the diet for 4 d before starting the experiment (preliminary observations showed that the effects of a supplement on rumen Mg concentration disappeared in less than 3 d). This reduced daily Mg intake (Table 1) by about 40 %.

On the first day of an experiment 'background-Mg' was determined in samples of rumen and duodenal contents which were collected at intervals from 08.00 hours over a period of 24 h. On the second day the stall-fed steers were fed at 08.00 hours, rumen and duodenal samples taken at 08.45 hours and a mixture containing Mg and markers infused into the rumen at 09.00 hours. The mixture contained, in 0·24–0·50 kg water, 3·5–7 g Mg (as magnesium chloride), 30–50 g polyethylene glycol (PEG) (molecular weight 4000) to function as a water soluble marker and 50–100 μCi ^{144}Ce (as a tracer dose of cerous chloride in 1 M-hydrochloric acid; Radiochemical Centre, Amersham) to function as a solid-phase marker (Huston & Ellis, 1968). The effectiveness of ^{144}Ce as a solid-phase marker was

checked by adding 50 μCi $^{144}CeCl_3$ to the rumen of a steer consuming diet B and examining the distribution of radioactivity in rumen contents after 1 h. Approximately 90–95% was associated with the solid matter.

Steers at pasture were given at approximately 09.00 hours a similar infusion of $MgCl_2$ and PEG but with chromic oxide in suspension in place of $^{144}CeCl_3$ and they were allowed to graze freely.

Samples from the rumen were taken at intervals for up to 10 h after the infusion by inserting a flexible tube (i.d. 10 mm) into the rumen and sucking out successive small amounts of contents from different sites until approximately 200–500 g was collected. The bulked sample was strained through muslin. Samples from the duodenum were obtained at intervals for up to 56 h by unstoppering the cannula, allowing material present in the cannula to go to waste, and then only collecting digesta that appeared in rapid gushes; approximately 100 g was collected in approximately 5 min.

Some experiments were carried out after attempts to modify the properties of the rumen contents. On some occasions while steers nos. 2, 3 and 4 were receiving diet D, a daily supplement of 40 g sodium chloride was added to the diet for 2 weeks before observations were made. In other experiments, with steers nos, 2–4 receiving diet A, the infusion of Mg and markers into the rumen was accompanied by the addition of 100 ml 0·2 M-hydrochloric acid; further similar additions of acid were made at hourly intervals for the subsequent 8 h.

Studies of net Mg absorption from the small intestine

Each calf (nos. 5–7) was given essentially diet C but either with no supplementary Mg (low-Mg diet) or with 0·8 or 8·0 g Mg (as magnesium oxide)/kg dry matter ('normal'- and high-Mg diets respectively). Diet C was given for at least 2 weeks and then experiments were made with 'normal'-, high-, low-, 'normal'-, high-, low-Mg diets, in that order. At least 5 d were allowed after each change of Mg intake before an experiment was carried out. On the day before an experiment 200 g PEG were added to the evening feed. On the day of an experiment the calves were fed at 09.00 hours. At 12.30 hours approximately 100 g digesta were collected from the duodenal cannula and then 5 ml of a solution containing 20 g phenol red (sodium salt)/l and 9 g NaCl/l were injected at this site. A further 100 g sample of duodenal digesta was collected within 5 min and mixed with the first. Mg and PEG were determined in the pooled sample. Ileal effluent was observed until the phenol red appeared when a sample of ileal contents (approximately 150–250 g collected in 15–30 min) was obtained and analysed similarly. Net absorption of Mg between duodenum and ileum was estimated by comparing Mg : PEG in samples from the two sites.

In vitro studies

Samples of rumen contents (0·4–0·5 kg) from steers receiving diets A, B or C were obtained as described previously at 1–4 h after a morning feed but were not strained. A solution (10–15 ml) containing 12 g Mg (as $MgCl_2$) and 60 g PEG/l was added to such a sample, the mixture stirred rapidly (approximately 10 s) and part of the mixture immediately strained through muslin. The remainder was placed in a flask and a nitrogen–carbon dioxide (9:1, v/v) gas mixture passed into the flask for 2 min. The flask was sealed and incubated at 39°. Samples were taken after 0·5 and 1·0 h of incubation and strained through muslin. Mg and PEG were determined in the strained samples. Mg was also determined in a strained sample of rumen contents to which no $MgCl_2$ was added. This was used to calculate 'background-Mg'.

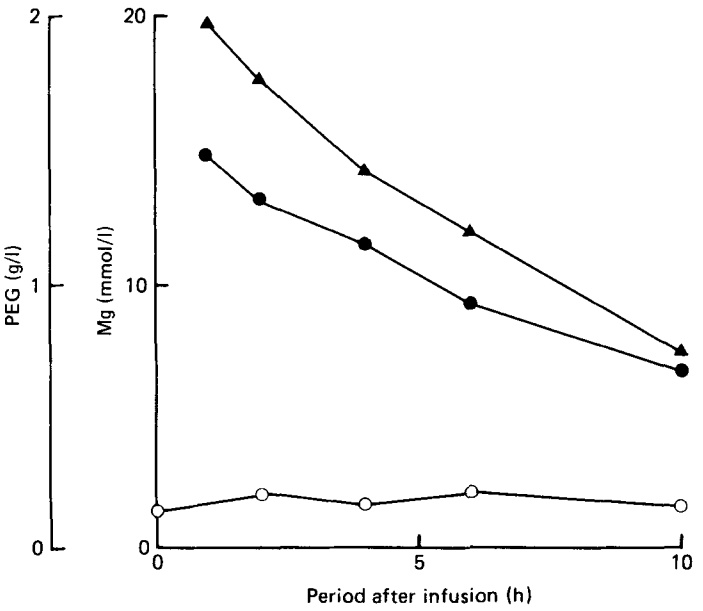

Fig. 1. Changes with period after infusion (h) in the concentration of magnesium (mmol/l) (○, ●) and polyethylene glycol (PEG) (g/l) (▲) in the rumen contents of steer receiving diet C with (solid symbols) and without (open circles) the infusion of 6 g Mg (as magnesium chloride) and 25 g PEG into the rumen 1 h after a morning feed. Diet composition is given in Table 1.

Analytical methods

Mg, Na and K. Samples (2–5 g) of digesta were boiled with 2 ml 16 M-nitric acid and 2 ml 9·4 M-perchloric acid for 2–3 h with further additions of HNO_3 if charring occurred. Heating then continued until white fumes of $HClO_4$ appeared and the solution was colourless or faintly yellow. The digest was suitably diluted with deionized water to give solutions with concentrations (mmol/l) of approximately 0·01–0·04 Mg, 0·04–0·40 Na and 0·02–0·25 K. Mg was determined as described by Smith & McAllan (1966) except that an A 3000 Atomic Absorption Spectrophotometer (Shandon Southern Instruments Ltd, Camberley, Surrey) was used. Na and K were determined using the same instrument in the flame emission mode at 585 nm for Na and 766 nm for K.

PEG. This was determined according to Smith (1962) except that a 20 min period was used for development of turbidity. When phenol red was present in the samples this was first removed as described by Smith (1964).

Cr_2O_3. Digesta samples were dried at 101° for 24 h and ashed at 600° for 48 h. Chromium was determined in the ash as described by Williams & Smith (1974).

^{144}Ce counting. This was done using a gamma counter (Panax Gamma one-sixty counter, Panax Equipment Ltd, Mitcham, Surrey).

RESULTS

Changes in Mg and marker concentrations in rumen contents

Fig. 1 shows an example of changes in concentrations of Mg and PEG in strained rumen contents after infusing these substances into the rumen and also shows changes in the corresponding 'background-Mg' concentration estimated on the previous day. When a value for Mg concentration in response to the infusion (observed value minus 'background

Table 2. *Magnesium (minus 'background-Mg'*): polyethylene glycol (PEG) concentrations in samples of strained rumen contents taken from steers at different periods of time after infusing doses of magnesium chloride and PEG into that organ*

(Results are based upon an assigned value for Mg:PEG in the dose of 1·0 and are mean values with their standard errors for *n* values between experiments for steer no. 1 and between animals for steers nos. 2–4. The latter values were often themselves means of two experiments. Main components of stall diets A–D are shown in Table 1 and ages of the steers in Table 3)

			Period after infusing dose (h)									
			1		2		3		5		8	
Steer no.	Diet	*n*	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1	A	3	0·67	0·04	0·70	0·04	—	—	0·67	0·03	0·62	0·04
	C	3	0·67	0·06	0·65	0·02	—	—	0·67	0·02	0·73	0·00
	D	2	0·84	0·05	0·76	0·01	—	—	0·82	0·04	0·74	0·06
2–4	A	3	0·83	0·08	—	—	0·83	0·03	0·78	0·80	0·70	0·07
	B	3	0·62	0·00	—	—	0·63	0·03	0·61	0·06	0·58	0·08
	D	3	0·84	0·05	—	—	0·85	0·04	0·78	0·05	0·76	0·07
	Pasture	3	0·83	0·05	—	—	0·79	0·00	0·75	0·05	0·85	0·26

* Mg entering digesta from other source, see p. 474.

Mg') and a corresponding value for PEG concentration are each expressed as a proportion of dose infused, then Mg : PEG indicates the recovery of infused Mg in that sample. Results calculated in this way are shown in Table 2 for samples taken up to 8 h after the infusion from steers given different diets.

After only 1 h Mg : PEG was always considerably less than unity but little or no further change occurred in the next 2–4 h and even up to 8 h after the infusion the additional change was generally small and, for any one calf and diet, not significant. Student's *t* test was used to examine the significance of these and other relations reported. The lack of significance was probably due to the small numbers of observations and when all experiments with the stall-fed calves were considered together (there were no significant differences in the trends shown with time between diets or calves) and paired comparisons made between 1 and 8 h samples (16 df) it was shown that the latter were significantly ($P < 0·02$) lower than the former. Conclusions about the steers on pasture are uncertain as these animals continued to graze after the infusion so that a greater variability and potential error in the correction for 'background-Mg' can be expected.

Net absorption of Mg up to the duodenum

Changes in concentration of Mg in duodenal contents are exemplified in Fig. 2 for collections with and without infusion of a solution containing 5 g Mg as $MgCl_2$ into the rumen. The latter provided estimates of 'background Mg' and enabled corrected values indicating the response in concentration to Mg infusion, to be calculated. The diagram shown in Fig. 3 shows an example of changes with the period after infusion for such corrected Mg concentrations expressed as proportions of the infused dose/l. It also shows parallel changes in concentrations of infused markers expressed in a similar way.

Steers given feeds once or twice/d showed a reasonably constant rate of flow of digesta into the duodenum (J. L. Black, I. J. F. Stobo, J. H. B. Roy, P. Ganderton & E. F. Smith, unpublished results) so that comparisons of areas under curves such as those shown in Fig. 3 enable estimates of Mg flow as proportions of marker flow to be made. If observations continue for a sufficient period of time then such values should indicate proportional

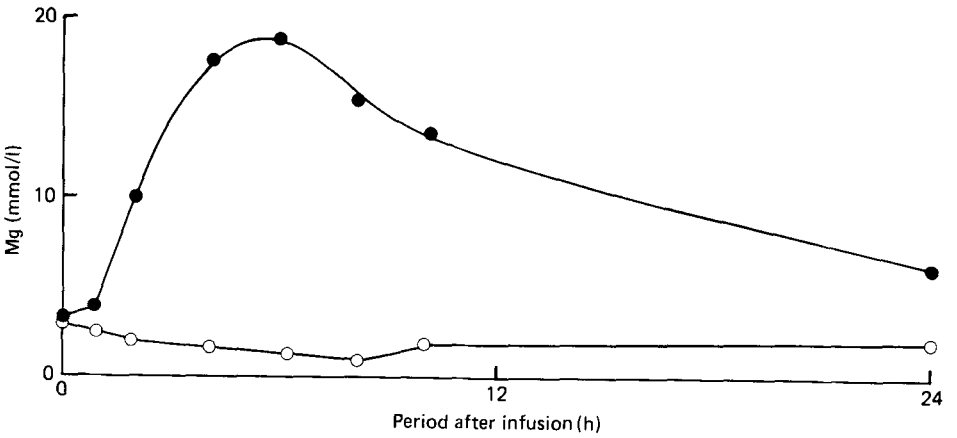

Fig. 2. Changes with period after infusion (h) in the concentration of magnesium (mmol/l) in the duodenal contents of a steer receiving diet B with (●) and without (○) the infusion of 5 g Mg (as magnesium chloride) into the rumen 1 h after a morning feed. Diet composition is given in Table 1.

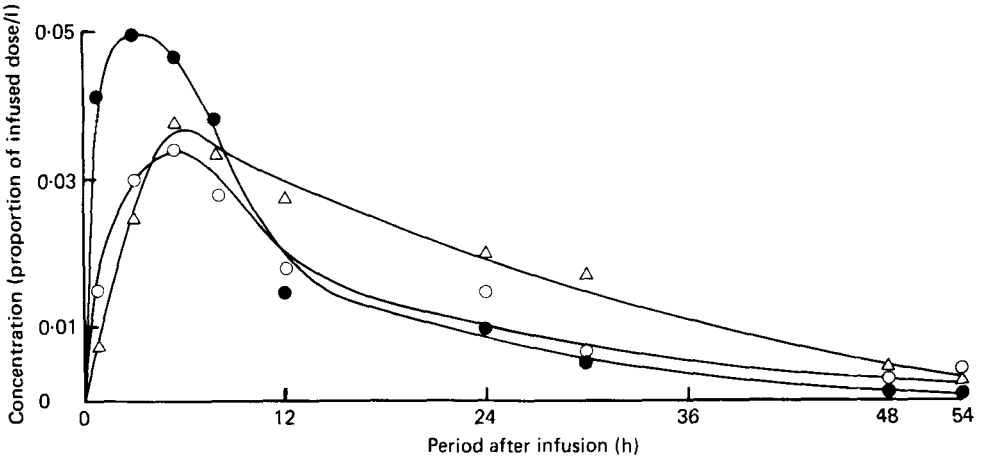

Fig. 3. Relative recoveries (proportion of infused dose/l) at the duodenum of magnesium (○), polyethylene glycol (PEG) (●) and ^{144}Ce (△) after 3·5 g Mg (as magnesium chloride), 30 g PEG and 100 μCi ^{144}Ce (as a tracer amount of cerous chloride) were infused into the rumen of steer no. 3, 1 h after a morning feed of diet B. Diet composition is given in Table 1.

recovery of the infused Mg dose even though Mg and marker may leave the rumen at different rates. To check on the validity of the method results are presented in Table 3 based upon two markers, one which moved more and the other less rapidly than Mg. With one or two exceptions agreement was fairly good but because the pattern of Mg movement was always much more like that of PEG than of either ^{144}Ce or Cr_2O_3 the former is regarded as the more reliable marker and conclusions have been based upon this unless otherwise indicated.

Estimates of Mg absorption up to the duodenum differed markedly between periods in which different diets were given. For both steer no. 1 and steers nos. 2–4 markedly higher values were observed when diet A rather than diet D was given and the difference was significant ($P < 0{\cdot}02$) for steers nos. 2–4. It appeared that there was no net absorption of Mg for animals at pasture. The fact that experiments were done with the animals at differ-

Table 3. *Proportions of magnesium doses infused into the rumen which disappeared up to the duodenum, estimated using polyethylene glycol (PEG) (molecular weight 4000) and ^{144}Ce or chromic oxide as markers*

(Results are mean values with their standard errors for *n* values between experiments for steer no. 1 and between animals for steers nos. 2–4. The latter values were often themselves means of two experiments. Main components of stall diets A–D are shown in Table 1)

				Marker used in estimation					
				PEG		^{144}Ce		Cr_2O_3	
Steer no.	Age (weeks)	Diet	*n*	Mean	SE	Mean	SE	Mean	SE
1	36–41	A	3	0·49	0·08	0·46	0·12	—	—
	37–42	C	3	0·20	0·10	0·31	0·08	—	—
	54–58	D	2	0·05	0·09	0·29	0·12	—	—
2–4	21–26	A	3	0·24	0·05	0·25	0·09	—	—
		A+HCl*	3	0·58	0·04	0·61	0·05	—	—
	30–32	B	3	0·20	0·01	0·31	0·07	—	—
	41–43	D	3	0·11	0·05	0·13	0·08	—	—
		D+NaCl†	3	0·05	0·03	0·15	0·04	—	—
	36–37	Pasture	3	−0·06	0·10	—	—	−0·05	0·14

* 100 ml 0·2 M-HCl added with infusion and at hourly intervals for the next 8 h.
† 40 g NaCl/d added to the diet for at least 2 weeks before and during an experiment.

ent ages may have influenced the results although, over intervals of 5 weeks, no consistent effects of age were apparent for replicate experiments with diets A and C given to calf no. 1. If, as seems probable, differences in diet were, at least, partly responsible for the differences in Mg absorption it is of interest to consider factors which might mediate the effect.

Na : K in digesta

None of the steers showed very marked diurnal variation in Na : K in rumen or duodenal digesta (Horn, 1975) but there were marked differences between animals which had received different diets for 1 or 2 weeks. The total [Na]+[K] molar concentrations in rumen contents did not, however, show consistent changes with changes in ratio and were virtually always within the range 110–150 mmol/l (Horn, 1975). Thus, for example, mean values ± SE for concentrations (mmol/l) of Na and K respectively for three calves transferred from diet B to pasture were 119 ± 6 and 20 ± 2 just before the transfer and 87 ± 6 and 41 ± 6, 5 d after it. Ingestion of a feed had only a small and transient direct effect on N : K in rumen contents; it appeared that the ratio was determined mainly by secretion and exchange of Na and K within the animal.

Examples of mean Na : K values observed after different diets had been given for at least 1 week are shown in Table 4. When estimates of Mg absorption up to the duodenum were plotted against values for Na : K (Fig. 4) it was apparent that there was a highly significant ($P < 0{\cdot}001$) correlation between them. An attempt to show directly the effect of increased Na status by adding 40 g NaCl/d for 2 weeks or more to diet D given to steers nos. 2–4 was unsuccessful. The supplement increased Na intake from approximately 0·1 to 0·9 mol/d but failed either to affect appreciably apparent Mg absorption (Table 3) or Na : K in rumen contents (Table 4).

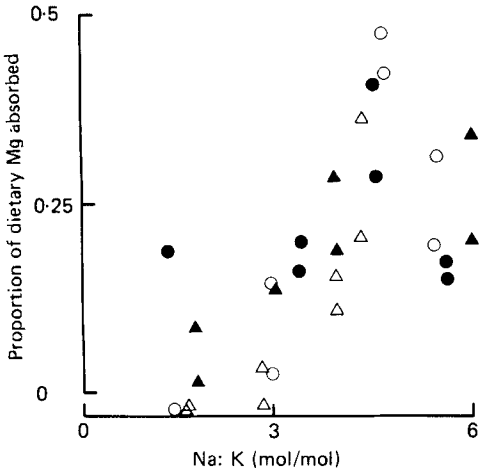

Fig. 4. Relationship between sodium:potassium (mol/mol) in rumen contents (average values 0–8 h after feeding) and estimated proportions of dietary magnesium absorbed up to the duodenum for steers nos. 1 (○), 2 (●), 3 (△) and 4 (▲) given different diets. r 0·68.

Table 4. *Sodium: potassium (mol/mol) and pH values of rumen contents from steers given different diets and treatment*

(Results are mean values with their standard errors for n values between experiments for steer no. 1 and between animals for steers nos. 2–4. Individual values on which these means were based were themselves means for samples taken between 0–8 h after feeding* for Na:K and between 2–6 h after feeding† for pH. Main components of stall diets are shown in Table 1 and ages of the steers in Table 3)

Steer no.	Diet	Na:K n	Na:K Mean	Na:K SE	pH n	pH Mean	pH SE
1	A	3	4·98	0·09	1	6·23	—
	C	3	5·30	0·23	1	6·52	—
	D	2	2·72	0·23	2	6·44	0·06
2–4	A	3	4·28	0·18	3	5·50	0·16
	A+HCl‡	3	4·80	0·37	3	5·34	0·13
	B	3	5·81	0·43	3	6·65	0·16
	D	3	3·31	0·36	3	6·70	0·08
	D+NaCl§	3	3·46	0·42	3	6·54	0·10
	Pasture	3	1·61	0·05	3	7·20	0·27

* From approximately 09.00–15.00 hours when steers were at pasture.
† From approximately 11.00–13.00 hours when steers were at pasture.
‡ 100 ml 0·2 M-HCl added with infusion and at hourly intervals for the next 8 h.
§ 40 g NaCl/d added to the diet for at least 2 weeks before and during an experiment.

pH

For the stall-fed steers, the pH values of samples of rumen contents taken before a morning feed did not vary very greatly (from approximately 6·7 for diet A to 7·3 for diet B) and were similar to those shown by steers at pasture. After a feed, however, there were considerable differences between stall diets in the decrease in pH which occurred (Table 4). Differences in rumen pH after feeding were negatively correlated with Mg absorption efficiency up to the duodenum (Fig. 5). In an experiment in which 0·2 M-hydrochloric acid (100 ml at hourly intervals) was added directly to the rumen the pH values in rumen contents were only slightly decreased (Table 4) (although at 6 h after feeding the difference

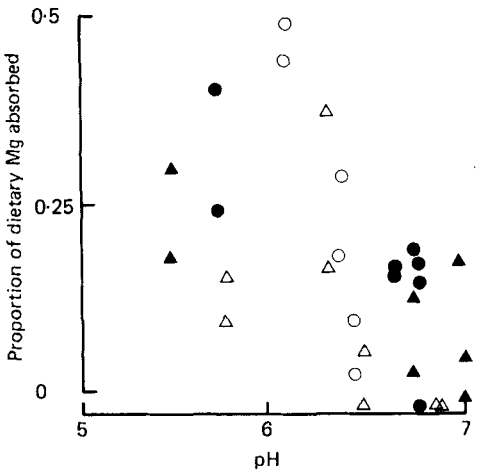

Fig. 5. Relationship between rumen pH values (average values for 2–5 h after feeding) and estimated proportions of dietary magnesium absorbed up to the duodenum for steers nos. 1 (○), 2 (●), 3 (△) and 4 (▲) given different diets. r −0·72.

Table 5. *Changes in magnesium:PEG between duodenum and ileum and estimates of net Mg absorption between these sites for steers receiving diet C with different supplements of Mg (as magnesium oxide)*

(Results are mean values with their standard errors for observations in steers nos. 5, 6 and 7; with one exception there were two observations/steer. Main components of the diet are shown in Table 1)

Mg supplement in diet (g/kg dry matter)	No. of observations	Mg in duodenal contents (mg/l)		Mg:PEG (mg/g)				Estimated proportional net absorption	
				Duodenal contents		Ileal contents			
		Mean	SE	Mean	SE	Mean	SE	Mean	SE
0	5	52	3	19·8	2·3	21·4	2·4	−0·082	0·107
0·8	6	102	9	38·0	5·8	35·7	3·8	0·026	0·066
8·0	6	470	48	158	18	146	16	0·065	0·050

from the control approached significance ($P < 0·1$)) but estimated Mg absorption up to the duodenum was markedly and significantly increased ($P < 0·01$) compared to the control (Table 3).

Net exchange of Mg in the small intestine

Results are given in Table 5 for Mg : PEG in samples of duodenal and related ileal contents from steers given diet C. Comparisons of Mg : PEG indicated that, on average, there was little net absorption of Mg between the two sites. When Mg concentrations were increased by giving dietary Mg supplements the average net absorption increased slightly but not significantly.

Distribution of Mg added to rumen digesta in vitro

The results given in Table 6 show that there were appreciable differences in distribution between Mg and PEG after these substances were added to rumen contents in vitro, even when the mixture was examined immediately after the addition. After the mixture was incubated for 1 h it appeared that the effect was sufficiently great to account, to a consider-

Table 6. *Magnesium (minus 'background Mg'*) : polyethylene glycol (PEG) concentrations in samples of rumen contents strained at different periods of time after incubating a solution of magnesium chloride and PEG with whole rumen contents in vitro anaerobically at* 39°

(Samples were taken 1–4 h after feeding and a solution added which provided approximately 0·3 g Mg (as $MgCl_2$) and 1·5 g PEG/l mixture. Results are mean values with their standard errors and are based on an Mg:PEG assigned value of 1·0 in this added solution. Main components of the diets are shown in Table 1)

		Period of incubation (h)					
		0		0·5		1·0	
Diet	No. of observations	Mean	SE	Mean	SE	Mean	SE
A	2	0·90	0·06	0·88	0·03	0·91	0·06
B	6	0·88	0·013	0·83	0·028	0·80	0·023
C	2	0·86	0·04	0·91	0·02	0·84	0·05

* Mg originally present in digesta, see p. 475.

able extent, for the finding (Table 2) that Mg : PEG observed in strained rumen contents taken 1 h after these substances were added to the rumen were lower than in the dose.

DISCUSSION

A number of recent studies have shown the importance of Mg absorption in the stomachs of the sheep (Grace & MacRae, 1972; Pfeffer & Rahman, 1974; Strachan & Rook, 1975; Tomas & Potter, 1976*a*; Field & Munro, 1977). The bovine has had less attention but Kemp *et al.* (1973) and Dirkson *et al.* (1972) have reported considerable absorption of Mg at this site in the dairy cow also. From present findings it appears that the same is true of the young steer and that such absorption may considerably exceed that in the small intestine. The low net absorption of Mg that was observed for the small intestine accords with previous findings in this animal (Smith, 1969) and in the sheep (Grace *et al.* 1974).

For the sheep the abomasum does not appear to be an important site of Mg absorption (Care & Van't Klooster, 1965; Tomas & Potter, 1976*a*; Field & Munro, 1977) and there was an slight net secretion rather than absorption of Mg when an $MgCl_2$ solution entered the abomasum of the preruminant calf (Smith, 1969). Thus, although it has not been demonstrated directly, it seems probable that Mg absorption in the ruminating bovine must occur in the omasum, reticulo-rumen or both.

Attempts to measure net Mg absorption from the rumen at normal concentrations have generally led to the conclusion that this is very small (Care & Van't Klooster, 1965; Phillipson & Storry, 1965; Perry, Cragle & Miller, 1967; Poutiainen, 1971). Results are, however, difficult to interpret in an unequivocal manner because, under normal conditions, Mg is not distributed uniformly in digesta; part of the Mg is ultrafilterable (Smith & Horn, 1976), another part is bound to bacteria or other particulate matter (Fitt, Hutton & Otto, 1974) and another part is precipitated as insoluble salts. Such precipitation was shown to occur as Mg ammonium phosphate or, more often, as mixed Mg, calcium phosphates under conditions likely to exist in the rumen (Smith & McAllan, 1967). The present results (Table 6) indicated that Mg in a solution added in vitro to rumen contents, rapidly became partially associated with coarse particles and such redistribution undoubtedly accounted, at least in part, for the Mg : PEG in strained rumen contents being substantially lower than that in an added dose. The subsequent lack of change in Mg : PEG for the next 3–5 h (Table 2) indicates little absorption of Mg but the possibility of a small amount of absorp-

tion being compensated by redistribution of Mg between different phases cannot be ruled out. There was, in fact, often a small decrease in Mg : PEG between 1 and 8 h after an infusion; for the stall diets, as a mean effect, the decrease was approximately 7% and was significant. The importance of this should not be over-stressed as errors due to the need to correct for 'background-Mg' became more likely the longer the period of study and in four similar experiments in which ^{28}Mg was infused the ^{28}Mg : PEG was virtually unchanged even after 8 h in the rumen (Smith & Horn, 1976). Although the weight of our evidence indicates that Mg absorption in the reticulo-rumen of the steer is small (with the corollary that absorption in the omasum is considerable) it does not show this unequivocably. For the sheep the view that the omasum may be the main site of Mg absorption has been questioned by Martens *et al.* (1976) from studies of Mg transport in vitro across preparations of stomach wall and by Tomas & Potter (1976*a*), who observed evidence of Mg absorption when an Mg solution was infused into the rumen but not when it was infused into the omasum. In similar infusion experiments Field & Munro (1977) detected some absorption from the omasum but concluded that this was less than from the rumen. There is, however, a possibility that a solution infused into the omasum via a catheter may be treated abnormally. It should also be stressed that findings for the sheep omasum do not necessarily apply to that of the bovine (Edrise, Smith & Buttle, 1977). It appears that the relative roles of the reticulo-rumen and omasum in Mg absorption are still uncertain and require further investigation.

However, whether absorption occurs primarily in the reticulo-rumen or in the omasum any variation in Mg absorption with dietary change is likely to be associated with differences in composition of digesta in the rumen. There is little published information on such associations. Two factors which might be related to Mg absorption efficiency, Na–K status and rumen pH have been considered in the present work.

It has been shown that high K intakes increase the electrical potential across the rumen wall of the sheep which opposes cation movement from mucosa to serosa (Sellers & Dobson, 1960). It is likely that the same is true of the omasum so that a decreasing Na : K in rumen contents might be expected to be associated with a reduction in Mg absorption whether from reticulo-rumen or omasum or both. Considering all the present findings there was indeed a strong positive correlation between Na : K in rumen contents and Mg absorption efficiency between mouth and duodenum (Fig. 4). However, the differences in Na : K were induced by major diet changes and were inevitably associated with other compositional differences. The apparent relation between Mg absorption and Na : K may not therefore have been causal. The attempt to check this by simply adding an Na salt to a low-Na (dried grass) diet was unsuccessful presumably because the change in intake was inadequate but K supplementation was reported to reduce the absorption of Mg infused into the rumen of the sheep (Tomas & Potter, 1976*b*).

Amongst speculations on possible factors implicated in the aetiology of clinical hypomagnesaemia in ruminants Wilcox & Hoff (1974) included a high rumen pH. A possible mechanism to explain such an association might be the reduced ultrafilterability of Mg in rumen contents at higher pH values (Smith & Horn, 1976). In the present experiments rumen pH values tended to be highest in steers consuming pasture and lowest in animals receiving mainly concentrates and they showed a significant negative correlation to Mg absorption efficiency between mouth and duodenum (Fig. 5). It is clear that possible pH effects were confused by other changes induced by the diets and although some support for it being a causal relationship was provided by the fact that adding hydrochloric acid to the rumen significantly increased Mg absorption, it is difficult to explain this effect in terms of changes in Mg ultrafilterability.

It must be concluded that the results provide evidence in favour of the view that condi-

tions leading to low Na : K in rumen contents and high rumen pH lead to a depression in Mg absorption from the stomach of the young steer but neither effect has been proved unequivocably.

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