Magnesium Absorption By Wethers Fed Potassium Bicarbonate in Combination with Different Dietary Magnesium Concentrations[1]

L. RAM,* J. T. SCHONEWILLE,* H. MARTENS,†
A. T. VAN'T KLOOSTER,* and A. C. BEYNEN*,[2]
*Department of Large Animal Medicine and Nutrition,
Faculty of Veterinary Medicine, Utrecht University,
PO Box 80.152, 3508 TD Utrecht, The Netherlands
†Department of Veterinary Physiology,
Freie Universität Berlin, Oerzenweg 19b, 14163 Berlin, Germany

ABSTRACT

We hypothesized that the decrease in the absolute amount of Mg absorbed in the total digestive tract, as induced by K, would remain constant if Mg intake by ruminants was increased. This hypothesis was based on earlier studies that used temporarily isolated rumens of sheep and the fact that the rumen is the major site of Mg absorption in ruminants. To test the hypothesis, six rumen-fistulated wethers were fed diets at two concentrations of K and three concentrations of Mg in a 6 × 6 Latin square design. Diets contained either 10 or 36 g of K/kg of dry matter and 1.3, 2.5, or 3.7 g of Mg/kg of dry matter. Extra K was added in the form of $KHCO_3$, and Mg was added in the form of MgO. For wethers fed the low K diets, absolute Mg absorption rose by 0.32 g/d for each 1 g/d of Mg intake that was in excess of requirements. The high K diets reduced absolute Mg absorption by a mean of 0.36 g/d; this reduction was independent of Mg intake. Magnesium intake and Mg concentrations in rumen liquid were positively related. Extra $KHCO_3$ in the diet increased K concentrations in rumen liquid, but the concentrations of Mg remained unchanged. Rumen pH was elevated by a mean of 0.45 units when the high K diets were fed. This study indicated that, in practical ruminant feeding, the supplementation of Mg to either low or high K diets increased absolute Mg absorption to the same extent. (**Key words:** magnesium, potassium, rumen, absorption)

INTRODUCTION

High intakes of K inhibit Mg absorption in ruminants, which increases the risk of hypomagnesemia. This relationship is essentially based on experiments that have shown that supplementation of the diet with either $KHCO_3$ or KCl decreases apparent Mg absorption (20). Potassium probably affects Mg absorption at the reticulorumen, the major site of Mg absorption in ruminants (19, 22), but the mechanism is not yet clear. Disappearance of Mg from the contents of a temporarily isolated rumen and the Mg concentration in rumen liquid are positively related (3). When Na ions were replaced by K ions in the buffer that was added to an isolated part of the rumen of sheep, there was a reduction in the rate of net Mg efflux; the absolute reduction was constant, and Mg concentrations ranged from 3 to 12 m*M* (3). In practical ruminant feeding, Mg concentrations in rumen liquid generally range from 0.5 to 6 m*M* (7). According to the observation of Care et al. (3), the Mg supplementation of Mg to a diet that was rich in K increased Mg absorption as effectively as the supplementation of Mg to a diet that was low in K. The decrease in the absolute absorption of Mg as induced by K would then be independent of Mg intake. This hypothesis was tested in the present study.

MATERIALS AND METHODS

Wethers and Experimental Design

Six rumen-fistulated, 1-yr-old wethers with a preexperimental BW of 55 kg (SE = 0.78) were used. The wethers had been fistulated at least 1 mo prior to the start of the study. The study had a 6 × 6 Latin square design including three concentrations of Mg (1.3, 2.5, or 3.7 g/kg of DM) and 10 g of intrinsic K/kg of DM either without or with added $KHCO_3$ to attain a K concentration of 36 g/kg of DM. Wethers were

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[2]Correspondence and reprint requests.

TABLE 1. Ingredient composition of the experimental concentrates.[1]

	Low K			High K		
	Low Mg	Medium Mg	High Mg	Low Mg	Medium Mg	High Mg
	(g)					
Constant components[2]	871.0	871.0	871.0	871.0	871.0	871.0
Cellulose	28.9	26.0	23.0	28.9	26.0	23.0
MgO	. . .	2.9	5.9	. . .	2.9	5.9
$KHCO_3$	. . .	. . .	. . .	91.1	91.1	91.1
Total	900.0	900.0	900.0	991.0	991.0	991.0

[1]Low K = 10 g of K/kg of DM, high K = 36 g of K/kg of DM, low Mg = 1.3 g of Mg/kg of DM, medium Mg = 2.5 g of Mg/kg of DM, and high Mg = 3.7 g of Mg/kg of DM.

[2]The constant components were first prepared and then divided into three parts; two parts were supplemented with MgO. Subsequently, the three initial parts were each divided into two parts, of which one was supplemented with $KHCO_3$. The constant components consisted of 289 g of sugar beet pulp, 289 g of maize, 115.5 g of maize gluten meal, 87 g of extracted soybeans, 15 g of soybean oil, 51 g of beet vinasses, 3.6 g of NaCl, 2.9 g of $CaPHO_4$, 7.2 g of NH_4Cl, 3.6 g of $CaSO_4 \cdot 0.5H_2O$, and 7.2 g of premix. The premix consisted of 0.8 mg of $CoSO_4 \cdot 7H_2O$, 0.6 mg of $Na_2SeO_3 \cdot 5H_2O$, 0.2 mg of KIO_3, 107 mg of $MnSO_4 \cdot 2H_2O$, 232 mg of $FeSO_4 \cdot 7H_2O$, 80 mg of $ZnSO_4 \cdot H_2O$, 1.5 mg of $Na_2MoO_4 \cdot 2H_2O$, 1.7 mg of retinyl acetate, 0.03 mg of cholecalciferol, 15 mg of dl-α-tocopheryl acetate, and 6761 mg of $CaCO_3$.

randomly assigned to each of the six experimental diets. The study was preceded by a 14-d preexperimental period during which time the wethers became accustomed to a diet based on straw. The straw diet was then fed during the experimental periods. Each experimental period lasted 28 d. Wethers were weighed just before the evening meal on the last day of each dietary period. Wethers were housed individually in pens with a layer of wood shavings as bedding during the first 14 d of each experimental period and in metabolism cages with slatted floors during the last 14 d.

Diets

Appropriate dietary concentrations of Mg and K were attained by the addition of MgO or $KHCO_3$ to the basal diet. The ingredient and analyzed compositions of the experimental diets are presented in Tables 1 and 2. Wethers were fed a restricted amount of the experimental diets, which consisted of 500 g of pelleted straw and either 900 g/d of K concentrate (low K) or 990 g/d of K concentrate (high K). The amount of feed supplied was calculated to allow a growth rate of 100 g/d. During the preexperimental

TABLE 2. Analyzed composition of the experimental diets.[1,2]

	Low K			High K		
	Low Mg	Medium Mg	High Mg	Low Mg	Medium Mg	High Mg
DM, g/kg	872	872	867	875	874	870
	(g/kg of DM)					
CP	153.0	150.2	149.6	137.7	139.9	137.7
Crude fat	26.0	27.6	25.4	24.4	26.3	23.8
Crude fiber	231.8	231.3	229.1	221.0	216.1	214.6
Mg	1.35	2.58	3.81	1.27	2.45	3.66
Ca	7.85	7.85	7.80	7.41	7.46	7.47
P	2.77	2.81	2.77	2.71	2.67	2.80
K	9.83	10.01	9.84	36.49	35.79	36.43
Na	6.25	6.28	6.31	5.97	6.01	6.04

[1]Low K = 10 g of K/kg of DM, high K = 36 g of K/kg of DM, low Mg = 1.3 g of Mg/kg of DM, medium Mg = 2.5 g of Mg/kg of DM, and high Mg = 3.7 g of Mg/kg of DM.

[2]The analyzed composition of the pelleted straw component (875 g of DM/kg) was as follows (grams per kilogram of DM): CP, 26.8; crude fat, 20.5; crude fiber, 454.1; Mg, 0.8; Ca, 5.4; P, 0.9; K, 3.3; and Na, 12.1.

period, all wethers were offered the low K diet containing 2.5 g of Mg/kg of DM. Then, in balanced order, wethers were fed the six experimental diets, including the preexperimental ration. Diets were offered twice daily in two equal portions at 0800 and 1600 h.

Collection of Samples

The experimental feeds were sampled during each experimental period, dried at 60°C for 5 d, ground, and subsequently stored in a sealed jar at 18°C.

On d 17 and 28, prior to the morning meal, 70 ml of Cr-EDTA solution (100 g of Cr-EDTA/L) were injected into the rumen as a marker to estimate the rumen volume and passage rates of the liquid phase from the rumen. Samples of rumen liquid (approximately 30 ml) were taken at 0730, 0900, 1000, 1100, 1300, 1500, 1700, 1900, and 2130 h. After collection, the rumen liquid samples were centrifuged at 18°C at 2700 × *g* for 15 min, and the supernatant was stored in plastic bottles at –18°C. An aliquot of the supernatant from the samples of rumen liquid taken at 0900, 1100, 1300, 1500, and 1700 h was centrifuged at 20°C at 30,000 × *g* for 30 min, and the supernatant was stored at –18°C.

On d 19, an 8-d balance period was initiated during which time urine and feces were collected quantitatively. The 24-h urine collections were weighed, and 10% was removed and stored at –18°C in a bottle that contained 50 ml of 6*N* HCl. The 24-h feces collections were stored at –18°C in plastic bags. At the end of each experimental period, the feces collections were pooled per wether and mixed thoroughly. Two samples, each representing 10% of the total feces from each wether during each period, were removed and dried for 5 d at 60°C, ground, and stored in a sealed jar at room temperature (18°C). Similarly, urine collections were pooled, and two 100-ml samples were taken and stored at –18°C.

Blood samples were taken on the last day of each experimental period between 1500 and 1530 h. Blood was sampled from the jugular vein into evacuated heparinized tubes. The samples were centrifuged for 15 min at 2700 × *g*, and the plasma was collected and stored in plastic tubes at –18°C.

Chemical Analyses

Nitrogen contents were determined by the macro-Kjeldahl method (6); a factor of 6.25 was used to convert N into CP. Ether extracts of the feedstuffs were prepared according to the AOAC (1). The solvent was evaporated, and the crude fat residue was weighed. The crude fiber content of the feedstuffs was estimated using the Fibertec System M2 (Tecator, Stockholm, Sweden). Prior to the determination of the selected minerals in feedstuffs and feces, the samples were ashed (480°C for 6 h) and dissolved in 15 ml of 4 *M* HCl. Magnesium, Ca, and K were estimated by atomic absorption spectroscopy, and Na was estimated by atomic emission spectroscopy (Perkin Elmer 3110; Perkin-Elmer Corp., Norwalk, CT). Total P in feedstuffs was determined according to the method of Quinlan and DeSesa (17). The accuracy of each assay run was monitored using a commercial reference sample (hay powder, CRM 129; Community Bureau of Reference, Brussels, Belgium) and in-house reference samples and was found to be within a 5% deviation from the target values. Magnesium in plasma and urine was measured directly by atomic absorption spectroscopy. Chromium (III) in rumen fluid was measured directly by atomic emission spectroscopy. Potassium in the supernatants of ultracentrifuged samples of rumen liquid was estimated using an ion-selective electrode (Beckman Instruments B.V., Mijdrecht, The Netherlands). Magnesium in the supernatants was estimated directly by atomic absorption spectroscopy. The combined within- and between-run precision of the determinations was ≤3.0% (coefficient of variation).

Statistical Analyses

All data were checked for normal distribution using the Kolmogorov-Smirnov test (23). All data were subjected to ANOVA; wether, experimental period, concentrations of dietary K and Mg, and the interaction of K and Mg were factors (23). Data regarding minerals in rumen liquid were subjected to repeated measures analyses; wether, experimental period, and concentrations of dietary K and Mg were factors as were the interaction of K and Mg and rumen sampling time (23). When the influence of a dietary factor reached statistical significance, Bonferroni's *t* test was used to identify rations with different effects on the variable involved. Throughout, significance was declared at $P < 0.05$.

RESULTS

Feed Intake and BW Gain

Wethers consumed all of the supplied feed. During the study, wethers gained a mean 97 g/d (SE = 5); growth rate was not influenced by dietary treatments.

Mg Balance

Intake of Mg was ≤2.1% higher for wethers fed the high K diets than for wethers fed the corresponding

TABLE 3. Balance of Mg in wethers (n = 6) fed the experimental diets.[1]

	Low K			High K				P		
	Low Mg	Medium Mg	High Mg	Low Mg	Medium Mg	High Mg	Pooled SEM	K	Mg	K × Mg
Intake, g/d	1.64	3.14	4.66	1.66	3.20	4.76	ND[2]	ND	ND	ND
Feces, g/d	1.06[f]	1.97[d]	3.10[b]	1.39[e]	2.39[c]	3.62[a]	0.034	<0.001	<0.001	0.045
Urine, g/d	0.58[d]	1.08[b]	1.38[a]	0.37[e]	0.82[c]	1.14[b]	0.039	<0.001	<0.001	0.791
Absorption, g/d	0.58[d]	1.17[b]	1.56[a]	0.27[e]	0.81[c]	1.14[b]	0.034	<0.001	<0.001	0.297
Absorption % of intake	35.32[a]	37.37[a]	33.36[a]	16.54[c]	25.46[b]	24.00[b]	1.322	<0.001	0.002	0.006
Balance, g/d	0.00[bc]	0.09[ab]	0.18[a]	–0.10[c]	–0.01[bc]	0.00[bc]	0.034	<0.001	0.002	0.368

[a,b,c,d,e,f]Values in the same row with different superscripts differ ($P < 0.05$; Bonferroni t test).

[1]Low K = 10 g of K/kg of DM, high K = 36 g of K/kg of DM, low Mg = 1.3 g of Mg/kg of DM, medium Mg = 2.5 g of Mg/kg of DM, and high Mg = 3.7 g of Mg/kg of DM.

[2]Not determined because the wethers were fed a restricted amount of feed.

low K diets (Table 3). Magnesium intake and absolute Mg absorption were positively related. Extra K in the diet diminished absolute Mg absorption; the magnitude of the effect was similar for the three concentrations of Mg intake (Figure 1). The addition of $KHCO_3$ to the diet significantly increased fecal Mg excretion and reduced urinary Mg excretion, regardless of the concentration of dietary Mg. Magnesium excretion in feces and urine was significantly increased when the dietary Mg concentration was increased. Absolute Mg absorption and urinary Mg excretion were positively related (Pearson's r = 0.925; $P < 0.001$; n = 36). Magnesium absorption expressed as a percentage of intake was reduced by a high K intake, and there was a significant effect of dietary Mg concentration. The interaction of K and Mg intake was significant.

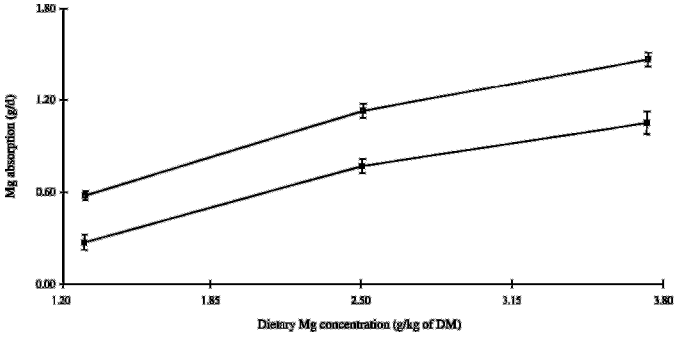

Figure 1. Magnesium absorption in wethers fed the experimental diets with two concentrations of K (10 and 36 g/kg of DM) and three concentrations of Mg (1.3, 2.5, and 3.7 g/kg of DM). For both the low (□) and high (■) K concentrations, Mg intake and Mg absorption were positively related. For the low, medium, and high Mg concentrations, the decrease in Mg absorption as induced by K was 0.31 ± 0.17, 0.36 ± 0.15, and 0.41 ± 0.17 g/d ($\bar{X}$ ± SD; n = 6), respectively.

Plasma Mg

Dietary treatments did not affect plasma Mg concentrations. For all treatments combined, plasma Mg concentration was 0.98 mM (SE = 0.015; n = 6).

Rumen Mg and K

Concentrations of Mg and K in the rumen liquid phase did not differ between the two sampling days and, thus, were pooled.

The Mg concentration in the rumen liquid rose as dietary Mg concentrations increased (Table 4). At 1 h after feeding, Mg concentrations were higher than those at 3, 5, or 7 h after feeding. The repeated measurement test showed that the Mg concentration in rumen liquid decreased ($P < 0.001$) according to time after feeding. Decreases ($P = 0.004$) in the Mg concentration depended on Mg intake; the decline was greater at higher Mg concentrations. No effect of dietary K on Mg concentrations in rumen liquid was found.

Concentrations of K in rumen liquid differed significantly between the two dietary K concentrations (Table 5). A decrease ($P < 0.001$) in the K concentration in rumen liquid was found in relation to time after feeding; the decline was greater ($P < 0.001$) when the high K diets were fed.

Rumen Liquid pH

At 1 h (0900 h) and 2 h after feeding (1100 h), rumen liquid pH was slightly, but significantly, increased as dietary MgO concentrations increased (Table 6). The rumen liquid pH was significantly increased by a mean of 0.45 units when $KHCO_3$ was added to the diet. The highest pH values were found

TABLE 4. Concentrations of Mg in rumen liquid in wethers fed the experimental diets.[1]

	Low K			High K				P		
	Low Mg	Medium Mg	High Mg	Low Mg	Medium Mg	High Mg	Pooled SEM	K	Mg	K × Mg
	(mmol/L)									
Mean[2]	3.75	6.48	9.71	3.37	5.95	9.57	1.11	0.226	<0.001	0.858
0900 h	4.43[b]	8.61[ab]	12.69[a]	4.13[b]	7.04[ab]	11.38[a]	1.20	0.293	<0.001	0.857
1100 h	3.65[b]	6.53[ab]	9.55[a]	3.09[b]	5.68[ab]	8.86[a]	0.88	0.341	<0.001	0.986
1300 h	3.21[b]	5.19[ab]	8.10[a]	2.84[b]	4.81[ab]	7.90[a]	0.86	0.655	<0.001	0.993
1500 h	2.91[ab]	4.42[ab]	6.85[a]	2.64[b]	4.56[ab]	7.71[a]	0.86	0.735	<0.001	0.800
1700 h	4.55[b]	7.64[ab]	11.34[a]	4.18[b]	7.64[ab]	11.98[a]	1.28	0.929	<0.001	0.924

[a,b]Values in the same row with different superscripts differ ($P < 0.05$; Bonferroni t test).

[1]Low K = 10 g of K/kg of DM, high K = 36 g of K/kg of DM, low Mg = 1.3 g of Mg/kg of DM, medium Mg = 2.5 g of Mg/kg of DM, and high Mg = 3.7 g of Mg/kg of DM.

[2]Mean values for samples taken at the different time points. Wethers were given a restricted amount of feed at 0800 and 1600 h.

after the morning meal when the meal consisted of the high K diet plus any concentration of Mg. Rumen liquid pH decreased ($P < 0.001$) according to time after feeding.

Passage of Rumen Contents

A difference in both absolute and fractional rumen outflow between the 2 d on which these variables were estimated was observed. The differences between d 17 and 28 were 84 ± 27.0 ml/h and 1.3 ± 0.38%/h, respectively ($\bar{X}$ ± SE; n = 6). Because no interactions were found between sampling day and dietary treatment, the data for the 2 d were pooled. Rumen volume and absolute outflow, but not fractional outflow, were significantly increased for wethers fed the high K diets (Table 7). The dietary Mg concentration tended to be negatively associated with the absolute outflow. Rumen volume was not affected by Mg intake.

DISCUSSION

Quantification of apparent Mg absorption as a percentage of intake rather than as the absolute amount absorbed is a common practice. In this study, relative Mg absorption data are reported, but, in the context of our hypothesis, only absolute Mg absorption is relevant. In previous studies that examined temporarily isolated rumens (3) and rumen epithelia (13), which described the fundamental aspects of Mg absorption, absolute Mg absorption was measured. Furthermore, for concerns regarding Mg requirements and metabolism by ruminants, the absolute amount of Mg absorbed, not the percentage of ingested Mg, is of importance. When Mg intakes differ,

TABLE 5. Concentrations of K in rumen liquid in wethers fed the experimental diets.[1]

	Low K			High K				P		
	Low Mg	Medium Mg	High Mg	Low Mg	Medium Mg	High Mg	Pooled SEM	K	Mg	K × Mg
	(mmol/L)									
Mean[2]	35.0	36.1	37.7	102.0	102.4	106.9	7.9	<0.001	0.272	0.831
0900 h	41.6[b]	43.7[b]	46.2[b]	131.8[a]	129.3[a]	133.0[a]	5.4	<0.001	0.818	0.907
1100 h	33.0[b]	35.6[b]	36.8[b]	92.5[a]	94.2[a]	96.8[a]	7.7	<0.001	0.663	0.987
1300 h	29.6[b]	31.3[b]	33.2[b]	86.5[a]	89.1[a]	92.6[a]	5.9	<0.001	0.375	0.932
1500 h	28.9[b]	28.2[b]	30.2[b]	80.2[a]	80.6[a]	88.3[a]	3.0	<0.001	0.209	0.487
1700 h	41.8[b]	41.6[b]	42.0[b]	119.2[a]	118.9[a]	124.0[a]	6.5	<0.001	0.896	0.920

[a,b]Values in the same row with different superscript differs ($P < 0.05$; Bonferroni t test).

[1]Low K = 10 g of K/kg of DM, high K = 36 g of K/kg of DM, low Mg = 1.3 g of Mg/kg of DM, medium Mg = 2.5 g of Mg/kg of DM, and high Mg = 3.7 g of Mg/kg of DM.

[2]Mean values for samples taken at the different time points. Wethers were given a restricted amount of feed at 0800 and 1600 h.

TABLE 6. Rumen pH in wethers fed the experimental diets.[1]

	Low K			High K				P		
	Low Mg	Medium Mg	High Mg	Low Mg	Medium Mg	High Mg	Pooled SEM	K	Mg	K × Mg
Mean[2]	5.95	6.00	6.06	6.41	6.45	6.50	0.08	<0.001	0.001	0.933
0900 h	6.13[c]	6.24[bc]	6.30[b]	6.74[a]	6.81[a]	6.81[a]	0.04	<0.001	0.008	0.364
1100 h	5.84[b]	5.80[b]	5.97[b]	6.31[a]	6.40[a]	6.44[a]	0.05	<0.001	0.023	0.324
1300 h	5.97[b]	5.96[b]	6.03[b]	6.28[a]	6.27[a]	6.35[a]	0.04	<0.001	0.116	0.873
1500 h	6.08[b]	6.15[b]	6.08[b]	6.33[a]	6.35[a]	6.35[a]	0.04	<0.001	0.369	0.559
1700 h	5.77[d]	5.88[cd]	5.97[c]	6.44[b]	6.51[ab]	6.59[a]	0.03	<0.001	<0.001	0.767

[a,b,c,d]Values in the same row with different superscripts differ ($P < 0.05$; Bonferroni t test).

[1]Low K = 10 g of K/kg of DM, high K = 36 g of K/kg of DM, low Mg = 1.3 g of Mg/kg of DM, medium Mg = 2.5 g of Mg/kg of DM, and high Mg = 3.7 g of Mg/kg of DM.

[2]Mean values for samples taken at the different time points. Wethers were given a restricted amount of feed at 0800 and 1600 h.

as was the case in this feeding study, the percentage of Mg absorption is misleading. Therefore, in this study, we focused on apparent Mg absorption expressed as an absolute amount.

This study confirmed earlier experiments (4, 5, 9, 15, 16, 20, 24) that showed that the addition of $KHCO_3$ to the diets of ruminants lowered apparent Mg absorption. The novel observation was that the decrease in the absolute amount of Mg absorbed, which was induced by K, was almost identical when dietary Mg concentrations ranged from 1.3 to 3.7 g/kg of DM (Figure 1). In contrast to the data in Figure 1, data in Table 3 point to an interaction of the dietary concentration of Mg and K with regard to fecal Mg excretion and the percentage of Mg absorption. However, the tendency toward greater increases in fecal Mg excretion as Mg intake increased when the dietary K concentration was high can be explained almost completely by differences in Mg intake for wethers fed the low and high K diets. The significant interaction of dietary Mg and K on the percentage of Mg absorption appeared to be caused by the aberrantly low value (16.54%) for the low Mg, high K diet. Thus, we concluded that, within the range of dietary Mg concentrations studied, there was no clear interaction of Mg and K intake on Mg absorption.

Results from our feeding study with wethers supported the data of Care et al. (3), who used temporarily isolated rumens. Those researchers (3) showed that the reduction in Mg efflux as induced by K was constant at Mg concentrations between 3 and 12 m*M*. In our study, Mg concentrations in rumen liquid were in that range. Thus, under practical conditions, supplemental Mg apparently does not affect the inhibitory effect of K on Mg absorption but increases Mg absorption simply by increasing the amount of Mg available for absorption in the rumen. Currently, two mechanisms are thought to be involved in the process of Mg absorption from the rumen: a transport mechanism that is insensitive to K and a transport mechanism that is sensitive to K (10). The component that is sensitive to K is influenced by the transmural potential difference (14). Magnesium transport that is insensitive to K is a process mediated by the carrier (i.e., the exchange of 1 Mg^{2+} ion for 2 H^+ ions) (14). The component that is insensitive to K

TABLE 7. Rumen volume and passage rate of rumen liquid in wethers fed the experimental diets.[1,2]

	Low K			High K				P		
	Low Mg	Medium Mg	High Mg	Low Mg	Medium Mg	High Mg	Pooled SEM	K	Mg	K × Mg
Rumen volume, L	7.3	6.9	6.9	7.5	7.6	7.8	0.5	0.033	0.888	0.550
Passage rate, %/h	9.5	9.7	9.1	9.8	10.0	8.3	0.8	0.916	0.135	0.622
Passage rate, ml/H	671	659	581	721	748	658	57	0.032	0.079	0.886

[1]Low K = 10 g of K/kg of DM, high K = 36 g of K/kg of DM, low Mg = 1.3 g of Mg/kg of DM, medium Mg = 2.5 g of Mg/kg of DM, and high Mg = 3.7 g of Mg/kg of DM.

[2]Mean values for samples taken on 2 different d.

may become saturated at Mg concentrations greater than 4 m*M* (2, 3, 11, 13); however, the component that is sensitive to K remains dependent on the Mg concentration. In this study, Mg concentrations in rumen liquid ranged from 3 to 13 m*M* (Table 4). When both K and Mg concentrations in the rumen are high, the component of Mg transport that is sensitive to K is, at least partly, blocked, and the component that is insensitive to K is saturated and transports an invariable amount of Mg. Figure 1 shows that supplemental $KHCO_3$ did not affect the quantity of Mg absorbed per unit of Mg ingested but lowered Mg absorption by a constant amount. Extra K probably altered the transmural potential difference (12), which, in turn, would have reduced Mg transport across the rumen epithelium so that, in our feeding study, two parallel lines were observed for the relationship between dietary Mg concentration and absolute apparent Mg absorption.

That the rise in the pH of rumen contents as induced by $KHCO_3$ lowers the solubility of Mg and thereby reduces the amount of Mg available for transport across the rumen epithelium has been suggested. The Mg concentration in rumen liquid has been shown to decline progressively when pH increases from 6 to 7 (7, 21). In this study, supplemental $KHCO_3$ produced an increase in rumen liquid pH from about 6.0 to 6.5. However, the Mg concentration in rumen liquid was not affected by supplemental $KHCO_3$. Other researchers (7, 8, 9) have reported variable associations between rumen liquid pH and Mg concentrations in rumen liquid. In any event, it appears from this study that supplemental $KHCO_3$ did not reduce Mg absorption through a decrease in Mg solubility in rumen contents.

The transit time of rumen contents could theoretically affect Mg absorption. If the rumen outflow increases, less Mg is available for absorption in the rumen. The absolute rumen outflow was increased by the addition of $KHCO_3$ to the diet, which is consistent with an earlier observation that the addition of NaCl or $NaHCO_3$ to the diets of steers also resulted in increased rumen outflow (18). However, as mentioned previously, $KHCO_3$ ingestion did not affect Mg concentrations in the liquid phase of rumen contents. Thus, it is difficult to conclude that the increase in rumen outflow induced by $KHCO_3$ had any impact on Mg absorption.

In conclusion, this study extended our knowledge on the inhibition of Mg absorption as induced by $KHCO_3$. We observed that Mg absorption is independent of dietary Mg concentrations in the range of 1.3 to 3.7 g/kg of DM. We speculated that our observation is explained by a reduction in Mg absorption that is sensitive to K; however, the transport component that is insensitive to K was saturated. For practical ruminant feeding, Mg supplementation of a diet that is rich in K is equally as effective as Mg supplementation of a diet that is low in K in increasing Mg absorption.

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