British Journal of Nutrition (1985), **54**, 713–718

The effect of potassium and magnesium infusion on plasma Mg concentration and Mg balance in ewes

BY A. F. McLEAN*, W. BUCHAN AND D. SCOTT†

Rowett Research Institute, Bucksburn, Aberdeen AB2 9SB

(*Received 22 May 1985 – Accepted 1 July 1985*)

1. Concentrations of magnesium in plasma, the ionic concentration in rumen digesta supernatant fractions, Mg balance and electropotential differences were measured in three ewes which were fed on grass and supplemented with potassium and Mg by intraruminal infusion.

2. Mean plasma Mg concentrations were unaltered by combined K and Mg treatments, but fell ($P < 0.001$) when K alone was infused.

3. The mean concentrations, in rumen digesta, of sodium and K varied reciprocally ($P < 0.001$) with each other when K was infused, but were unaffected by Mg infusion. The mean Mg concentrations in rumen digesta fell ($P < 0.01$) with K infusion but rose ($P < 0.001$) with Mg infusion.

4. Absorption and excretion of Mg rose ($P < 0.001$) when Mg intake was increased but was unaffected by K intake.

The association between hypomagnesaemia in ruminants and high potassium content of pastures has been known for many years (Sjollema, 1931; Brouwer, 1952; Butler, 1963). This association has led many workers to implicate an interaction between dietary K and magnesium in the aetiology of hypomagnesaemia (Suttle & Field, 1967, 1969; Newton *et al.* 1972; Tomas & Potter, 1976; Wylie *et al.* 1982). The effects of increasing K intake on plasma Mg concentration have not always been demonstrated, however. For example, increasing K intake did not result in a hypomagnesaemia in sheep (Eaton & Avampto, 1952), calves (Blaxter *et al.* 1960) or heifers (St Omer & Roberts, 1967). Other studies have demonstrated a depression in plasma Mg concentration combined with a reduction in dietary Mg absorption when sheep were given supplements of K (MacGregor & Armstrong, 1979; Wylie *et al.* 1982; Greene *et al.* 1983*a,b*). Suttle & Field (1969) have suggested that the susceptibility of sheep to hypomagnesaemia, following increases in K intake, may depend on dietary Mg intake *per se*. However, these authors gave a semi-purified diet of low Mg content and, at present, there are few studies which show such an effect when sheep are fed on grass. In the present experiment we have examined the effects of increasing K and Mg intakes on plasma Mg concentration and Mg balance in sheep fed on pelleted grass.

METHODS

Three adult (Suffolk × Greyface) ewes were used. Each was surgically prepared with a simple cannula (25 mm in diameter) into the rumen and a ‘T’-shaped cannula (10 mm in diameter) into the duodenum between 60 and 100 mm from the pylorus. The sheep were housed in individual metabolism cages which allowed the separate collection of urine and faeces. They were given 717 g dry matter of a pelleted grass diet supplying 1·86 g Na, 17·4 g K and 1·29 g Mg daily via a continuous-belt feeder. These intakes were sufficient to meet current requirements (Agricultural Research Council, 1980). Further variation in both K and Mg intakes was achieved by giving supplements of either KCl or $MgCl_2 \cdot 6H_2O$, or both, by continuous infusion into the rumen.

---

[*] Present address: The West of Scotland Agricultural College, Auchincruive, Ayr KA6 5HW.

[†] For reprints.

The experiment was of 60 d duration and was divided into six equal periods during which the following treatments were given sequentially: (1) basal diet, (2) basal diet + 19·6 g K/d, (3) basal diet + 39·1 g K/d, (4) basal diet + 2·86 g Mg/d, (5) basal diet + 19·6 g K/d + 2·86 g Mg/d, (6) basal diet + 39·1 g K/d + 2·86 g Mg/d. Collections were made over the last 6 d of each period to allow the sheep to become accustomed to changes in treatment. Urine and faeces were collected daily at 09.00 hours and samples of blood and rumen digesta and electropotential measurements were taken on the 5th and 9th days of each treatment period. The electropotential measurements and the preparation and analysis of samples for Mg were as described previously (McLean *et al.* 1984). In addition, the sodium and K contents of rumen digesta supernatant fractions were measured by flame photometry using a Technichon AutoAnalyzer (Technichon Instruments Corp., Basingstoke).

The effects of K and Mg infusion and their interactions were statistically analysed using analysis of variance.

RESULTS

Mean values for urinary, faecal, total output, net absorption and apparent availability of Mg are shown in Table 1. Net absorption, urinary, faecal and total output of Mg all rose when Mg intake was increased but, with the exception of faecal Mg excretion, were unaffected by K infusion at either level of Mg intake. Mean retention and apparent availability of Mg were unaffected by either K or Mg infusion.

The mean values given in Table 2 show the effects of K and Mg infusion on the concentrations of Mg in plasma and Na, K and Mg in the rumen digesta supernatant fractions. Table 2 also shows the electropotential differences between blood and digesta contents of the rumen and indicates the minimum concentrations of ionic Mg in the digesta that would be necessary for transport of Mg across the rumen epithelium to occur by passive diffusion. These values were estimated as described previously (McLean *et al.* 1984).

The concentrations of Mg in rumen digesta supernatant fractions decreased during treatment periods 3 and 6 but rose when the Mg intake was increased. The mean concentrations in rumen digesta supernatant fractions of K increased whereas those of Na decreased following K infusion. Plasma Mg concentrations fell when K was infused during treatment periods 2 and 3 respectively. However, plasma Mg concentrations were apparently unaffected by K infusion when Mg intake was increased. There was a significant ($P < 0{\cdot}001$) interaction between Mg and K treatments on plasma Mg concentrations. Electropotential differences between blood and digesta in the rumen rose significantly ($P < 0{\cdot}001$) when K was infused but was unaffected by Mg intake.

DISCUSSION

The increase in the K concentration of the rumen fluid was associated with a decline in Na concentrations at both levels of Mg intake. Such a decline is consistent with enhanced Na absorption from the rumen in response to increases in K intake (Scott, 1975). It is unclear why the mean Na concentration of rumen digesta supernatant fractions during treatment period 4 was significantly ($P < 0{\cdot}05$) lower than that of treatment period 1. This may have been due to a 'carry-over' effect from the previous treatment (period 3) during which a high level of K was infused. The changes in Na and K concentrations were also accompanied by an increase in the electropotential difference when KCl was infused, although no such increase was apparent when $MgCl_2$ alone was infused (treatment period 4). Similar increases in the electropotential gradient across the rumen were found by Tomas & Potter (1976) in

Table 1. *Urinary, faecal, total output, retention, net absorption and apparent availability of magnesium in sheep given intraruminal infusions of either potassium chloride alone or in combination with magnesium chloride*

(Mean values with their standard errors for three sheep)

$MgCl_2$ infusion…	None			+2·86 g Mg/d				Statistical significance of:		
KCl infusion…	Grass alone	+19·6 g K/d	+39·1 g K/d	Grass alone	+19·6 g K/d	+39·1 g K/d	SEM	Mg effect	K effect	Mg–K inter-action
Mg (g/d):										
Intake	1·29	1·29	1·29	4·21	4·21	4·02	—	—	—	—
Urine	0·30	0·22	0·28	0·79	0·81	0·86	0·033	$P < 0·001$	NS	NS
Faeces	0·97	1·13	0·98	3·30	3·36	2·98	0·069	$P < 0·001$	$P < 0·05$	NS
Total output	1·27	1·35	1·26	4·09	4·17	3·84	0·088	$P < 0·001$	NS	NS
Retention	0·02	−0·06	0·03	0·12	0·04	0·19	0·088	NS	NS	NS
Net absorption	0·32	0·16	0·31	0·91	0·85	1·04	0·069	$P < 0·001$	NS	NS
Apparent availability (%)	24·8	12·7	24·0	21·6	20·2	26·0	32·1	NS	NS	NS

NS, not significant.

Table 2. *Effects of intraruminal infusion of either potassium chloride alone or in combination with magnesium chloride on the concentration of Mg in the plasma and on the concentration (mmol/l) of sodium, potassium and Mg in rumen digesta and supernatant fractions and electropotential difference between blood and rumen digesta*

(Mean values with their standard errors for three sheep)

$MgCl_2$ infusion...	None			+2·86 g Mg/d				Statistical significance of:		
KCl infusion...	Grass alone	+19·6 g K/d	+39·1 g K/d	Grass alone	+19·1 g K/d	+39·1 g K/d	SEM	Mg effect	K effect	Mg–K interaction
Rumen										
Na	96·6	42·3	29·4	78·6	31·5	27·9	4·40	$P < 0·05$	$P < 0·001$	NS
K	41·6	109·7	132·5	43·2	112·4	130·6	3·30	NS	$P < 0·001$	NS
Mg	3·7	4·1	2·5	12·2	13·4	10·2	0·44	$P < 0·001$	$P < 0·01$	NS
Mg concentration required for passive absorption (mmol/l)	6·1	14·2	10·2	7·1	15·7	19·7	—	—	—	—
Plasma Mg (mmol/l)	0·89	0·78	0·53	0·93	0·98	0·88	0·023	$P < 0·001$	$P < 0·001$	$P < 0·001$
Electropotential difference (mV) blood positive	34·0	47·2	47·9	35·3	45·4	49·9	2·12	NS	$P < 0·001$	NS

NS, not significant.

sheep which were intraruminally infused with 19·1 and 31·3 g K/d. They suggested that such increases in electropotential difference were sufficient to reduce passive diffusion of Mg across the rumen epithelium (Tomas & Potter, 1976). However, there is considerable evidence now to show that absorption of Mg from the rumen is achieved by an active-transport process which becomes saturated at high Mg concentrations (Brown *et al.* 1978; Martens & Rayssiguier, 1980; Martens, 1983; McLean *et al.* 1984). Furthermore, we found that the Mg concentrations in the rumen fluid were, in most periods, too low to support absorption of Mg by passive diffusion. It seems unlikely, therefore, that an increase in the electropotential difference across the rumen epithelium could have any direct effect on Mg absorption from this organ. A rise in the potential difference would, on the other hand, favour the increased passive diffusion of Mg from blood to rumen and as such might be expected to lead to a reduction in net Mg absorption (Care *et al.* 1984). The fact that we were unable to show any adverse effect of K on overall net Mg absorption (Table 1) would suggest that this effect on rumen secretion either did not occur or was compensated for elsewhere in the gut.

It is interesting to note that the Mg concentrations of rumen digesta supernatant fractions rose slightly during treatment periods 2 and 5 but fell during treatment periods 3 and 6 respectively. Net absorption and excretion of Mg was unchanged during all periods, however. It seems unlikely, therefore, that the changes of Mg concentration in the rumen fluid we observed had any direct effect on plasma Mg concentration *per se*.

In the present study plasma Mg concentrations fell in response to K infusion only when no supplementary Mg was given. Moreover, this fall occurred despite any change in either Mg absorption or excretion. Depressions of plasma Mg concentration following increases in K intake have been reported previously and were attributed to a reduction in Mg absorption proximal to the pylorus (Tomas & Potter, 1976; MacGregor & Armstrong, 1979; Wylie *et al.* 1982). In one of these studies, however, Mg concentrations in plasma were also depressed when K was infused into the duodenum (Tomas & Potter, 1976). This was interpreted as evidence for K having exerted a 'general' effect on the whole animal (Tomas & Potter, 1976). Similarly, Larvor (1976) demonstrated a depression in plasma Mg concentrations and the release of Mg from the slow Mg exchanging pool, but with no significant change in Mg absorption in ewes given 'tetany-prone' grass. This led Larvor (1976) to suggest that a shift in body Mg from the blood to some other tissue could result in lowered plasma Mg levels. The results of our study are consistent with such a shift.

In contrast to the effects of infusing K alone, we found no lowering of plasma Mg level when both Mg and K treatments were combined. The significant ($P < 0{\cdot}001$) Mg effect of plasma Mg concentrations was due to Mg–K interaction since plasma Mg concentrations were found to be similar when the basal diet alone (treatment period 1) was compared with basal diet+supplementary Mg (treatment period 4). The apparent lack of response to combined Mg and K treatments may be due to a masking effect caused by the greater fluxes of Mg into and out of the plasma, since ruminants appear to absorb Mg in relation to intake but not according to physiological requirement (Field & Munro, 1977; Field & Suttle, 1979; Martens & Rayssiguier, 1980). Suttle & Field (1969) have demonstrated that the hypomagnesaemic effect of K supplementation in sheep was lessened when their Mg intake was increased. The greater effectiveness in maintaining plasma Mg concentration of the supplementary Mg administered in our study was probably due to the larger quantity of the supplement given rather than its different chemical form.

In the present study we fed our sheep on grass that was typical in Mg content of most pastures grazed by ruminants. In addition, we have shown that the Mg intake *per se* may be a major factor in determining the susceptibility of ruminants to hypomagnesaemia and that by increasing the Mg intake the depressant effect of K on plasma Mg could be offset.

However, the sheep we used had a low requirement for Mg and the effect of K may be more marked in pregnant and lactating ruminants. Our findings, therefore, indicate the possible benefits of giving supplementary Mg to grazing ruminants at critical periods when their Mg intake is low and their K intake is high.

REFERENCES

Agricultural Research Council (1980). *The Nutrient Requirements of Ruminant Livestock*. Farnham Royal: Commonwealth Agricultural Bureaux.

Blaxter, K. L., Cowlishaw, B. & Rook, J. A. F. (1960). *Animal Production* **2**, 1–10.

Brouwer, E. (1952). *British Veterinary Journal* **108**, 123–131.

Brown, R. C., Care, A. D & Pickard, D. W. (1978). *Journal of Physiology* **276**, 62–63.

Butler, E. J. (1963). *Journal of Agricultural Science, Cambridge* **60**, 329–340.

Care, A. D., Brown, R. C., Farrar, A. R. & Pickard, D. W. (1984). *Quarterly Journal of Experimental Physiology* **69**, 577–587.

Eaton, H. D. & Avampto, J. E. (1952). *Journal of Animal Science* **11**, 761.

Field, A. C. & Munro, C. S. (1977). *Journal of Agricultural Science, Cambridge* **89**, 365–371.

Field, A. C. & Suttle, N. F. (1979). *Journal of Comparative Pathology* **89**, 431–439.

Greene, L. W., Fontenot, J. P. & Webb, K. E. (1983*a*). *Journal of Animal Science* **56**, 1208–1213.

Greene, L. W., Webb, K. E. & Fontenot, J. P. (1983*b*). *Journal of Animal Science* **56**, 1214–1221.

Larvor, P. (1976). *Cornell Veterinarian* **66**, 413–429.

MacGregor, R. C. & Armstrong, D. G. (1979). *Proceedings of the Nutrition Society* **38**, 66A.

McLean, A. F., Buchan, W. & Scott, D. (1984). *British Journal of Nutrition* **52**, 523–527.

Martens, H. (1983). *British Journal of Nutrition* **49**, 153–158.

Martens, H. & Rayssiguier, Y. (1980). In *Digestive Physiology and Metabolism in Ruminants*, pp. 447–466. [Y. Ruckebusch and P. Thivend, editors]. Lancaster: MTP Press.

Newton, G. L., Fontenot, J. P., Tucker, R. E. & Polan, C. E. (1972). *Journal of Animal Science* **35**, 440–445.

St Omer, V. V. E. & Roberts, W. K. (1967). *Canadian Journal of Animal Science* **47**, 39–46.

Scott, D. (1975). In *Digestion and Metabolism in Ruminants*, pp. 205–215. [J. W. McDonald and A. C. Warner, editors]. Armidale, NSW: University of New England Publishing Unit.

Sjollema, B. (1931). *Landbouwkundig Tijdschrift* **43**, 793–815.

Suttle, N. F. & Field, A. C. (1967). *British Journal of Nutrition* **21**, 819–831.

Suttle, N. F. & Field, A. C. (1969). *British Journal of Nutrition* **23**, 81–90.

Tomas, F. M. & Potter, B. J. (1976). *Australian Journal of Agricultural Research* **27**, 873–880.

Wylie, M. J., Fontenot, J. P., Greene, L. W. & Rahnema, S. H. (1982). *Virginia Technical Livestock Research Report* pp. 104–111.

Printed in Great Britain