
Article

Magnesium butyrate is a readily available magnesium source in dairy cow nutrition

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Simple Summary: An adequate supply of magnesium is considered of great interest to prevent milk fever and grass tetany in dairy cows. Currently, magnesium oxide (MgO) is widely used to supplement dairy cows with magnesium. In dry cow nutrition, however, magnesium butyrate can be considered of interest as an alternative source of supplemental magnesium. This is because the use of magnesium butyrate, instead of MgO, is potentially advantageous because butyrate, but not oxide, may stimulate the growth of rumen papillae which is instrumental to prevent rumen acidosis. However, the bioavailability of magnesium from magnesium butyrate is not known. Therefore, an experiment was conducted with dairy cows to determine this. Six dairy cows were fed rations with or without magnesium butyrate supplementation, and feces was collected in order to enable magnesium absorption to be determined. The results showed that magnesium from magnesium butyrate was readily available for absorption. Using previously published data, magnesium butyrate was also indicated to be a superior source of magnesium relative to MgO. In conclusion, this study indicates that magnesium butyrate can be considered as an attractive alternative magnesium source to supplement dairy rations with magnesium.

Abstract: The aim of the present study was to measure the apparent absorption of magnesium (Mg) originating from Mg-butyrate. Six mid-lactation Holstein Friesian dairy cows were used with dietary treatments arranged in a cross-over design. Two different diets were fed during the experiment, consisting of a low Mg diet without Mg-butyrate (L-Mg, 3.1 g Mg/kg dry matter) or a high Mg diet with Mg-butyrate (H-Mg, 3.9 g Mg/kg dry matter). Cows offered the L-Mg diet ingested 54.7 g Mg/day while the cows fed the H-Mg diets ingested 66.3 g Mg/day ($P < 0.001$). The fecal excretion of Mg, however, was similar between the two experimental diets ($P = 0.174$). Consequently, apparent Mg absorption was found to be 7.9 percentage units greater ($P = 0.038$) when the cows were fed the diet supplemented with Mg-butyrate. The greater Mg absorption after feeding the H-Mg diet was, however, not reflected by a greater urinary Mg concentration ($P = 0.228$). These results indicate that the availability of Mg from the Mg-butyrate supplemented diet is high (34.1% of intake). The fractional Mg absorption from Mg-butyrate was calculated to be 71.6%. In conclusion, Mg-butyrate is an attractive alternative to supplement dairy rations with Mg.

Keywords: magnesium; absorption; rumen; butyrate; volatile fatty acids

1. Introduction

Magnesium (Mg) is an essential nutrient for cows. This means that dairy rations need to supply a sufficient amount of absorbable Mg to safeguard the cow's health. Currently, there is no experimental proof for any specific Mg regulating hormone [1]. This implies that Mg intake as such does not downregulate the efficiency of Mg absorption. Consequently, the amount of absorbed Mg in excess of requirement is excreted in the urine in order to maintain Mg balance. The efficiency of Mg absorption is considered the critical determinant in the Mg supply of dairy cows [2]. The amount of Mg that is available for metabolism depends on both the amount and source of Mg ingested by the animals, however, it is also dependent on the content of dietary potassium (K). It is well known that K

inhibits Mg absorption in the rumen of the cow [3]. This increases the risk of hypomagnesemia [4], and subsequently grass tetany or milk fever [5].

In many countries, grass and its co-products are usually rich in K. Consequently, it is common practice in such countries to supplement dairy rations with Mg. Magnesium-oxide (MgO) is currently widely used as a source of supplemental Mg. The effectiveness of MgO in terms of supplying Mg, however, is limited [6] and can vary greatly between different MgO sources [7,8]. As a consequence alternative Mg sources, such as Mg-butyrate, might be of interest.

Currently, supplemental butyrate has gained interest for ruminants in both practice and research. This interest is related to the evidence that butyrate is a main stimulator of papillae growth and epithelial cell proliferation in the rumen [9,10]. By increasing the size of rumen papillae, and thus the rumen surface area, absorption of short chain fatty acids is enhanced. This enhanced absorption increases the buffer capacity of the rumen content, leading to lower susceptibility to rumen acidosis [11]. In other words, supplemental butyrate may be instrumental in preparing the cow to adapt to high concentrate rations [12,13]. From this perspective, Mg supplementation in the form of Mg-butyrate can be considered opportune to use in the nutrition of dry cows. Thus, the use of Mg-butyrate instead of MgO seems an attractive alternative to supplement dairy rations with Mg. However, the availability of Mg from Mg-butyrate is not known. The aim of the current experiment was, therefore, to measure the apparent Mg absorption when Mg-butyrate is used as the Mg source.

2. Materials and Methods

2.1. Experimental Design

Six, multiparous, mid-lactation cows (approx. 120 days in milk) producing around 30 kg of milk per day were used in the experiment. The experiment was designed as a cross-over with 2 experimental periods of 14 days each, preceded by a 14 day pre-experimental period to allow the cows to become adapted to the experimental rations. The cows were individually fed in a stanchion barn with unrestricted access to fresh water.

2.2. Experimental Rations

During the pre-experimental period all six cows were fed a basal ration (Table 1) supplemented with 2.7 kg dry matter (DM) commercial compound feed and 1.8 kg DM low sugar beet pulp without any additives. During the experimental periods, the beet pulp was replaced by experimental beet pulp i.e., beet pulp with or without supplemented Mg-butyrate (Rumen-Ready®, Palital Feed Additives, Velddriel, The Netherlands), i.e., high Mg and low Mg beet pulp, respectively (Table 1). The supplemental Mg-butyrate used, Rumen-Ready®, was in the form of a micro pellet with a diameter of ~ 1.2 mm and consists of (as fed) 70% Mg-butyrate encapsulated in a fat matrix. The Mg-butyrate from Rumen-Ready® is completely released and solubilized within the rumen, i.e., it is 100% available for absorption. Both types of experimental beet pulp contained titanium oxide (TiO_2), which was used as an inert marker for determination of fecal output. The cows were randomly assigned to the order of the two experimental treatments.

2.3. Feeding Procedure

At 9:00 h the daily individual feed refusals, if any, were collected. These were then weighed and stored at -18 °C. The rations were offered twice daily in two equal portions starting at ~ 9:15 h and ~ 16:30 h. At each feeding time, cows were first offered their allocated amounts of compound feed and beet pulp and then ~ 30 min later, half of the daily portion of the basal ration was offered (Table 1).

Table 1. Ingredients and calculated chemical composition of the experimental rations.

Parameters	Treatment	
	Low Mg	High Mg
Ingredient composition (kg DM):		
Basal ration ¹	13.6	13.6
Compound feed	2.7	2.7
Experimental beet pulp		
Low Mg ²	1.8	-
High Mg ³	-	1.8
Total (kg DM)	18.1	18.1
Calculated composition of the whole experimental ration		
NEL, MJ/kg DM	6.91	6.91
Mg, g/kg DM	3.1	3.9
K, g/kg DM	23.7	23.7
Ca, g/kg DM	6.0	6.0
P, g/kg DM	3.3	3.3

¹ Basal ration consisted of (% DM): grass silage, 67.0; corn silage, 26.5; bypass soybean meal, 5.9; mineral premix, 0.7.

² Low Mg beet pulp; pellet containing 99.2% low sugar beet pulp and 0.8% TiO₂

³ High Mg beet pulp; pellet containing 91.7% low sugar beet pulp, 0.8% TiO₂ and 7.5% Rumen-Ready®

2.4. Sampling Procedure and Chemical Analysis

During the last 4 days of each 14 d experimental period, all spontaneously voided feces and urine were collected between 9:00 and 17:00. At the end of each collection day, the individual feces collections were stored at -18 °C whereas the individual urine collections were stored at 5 °C. At the end of each experimental period, the individual feces collections were thawed. Then, all individual feces and urine collections were pooled per cow and mixed thoroughly. Thereafter, the pooled fecal and urine samples were stored at -18 °C pending chemical analysis. All samples were air dried at 60 °C for 24 h and the dry matter (DM) content of the air-dried samples was determined with the use of a forced-air oven (105 °C, 24 h) according to ISO standards [14]. The Mg content of feces, urine, feed and feed refusals was measured by means of inductively coupled plasma mass spectrometry. The titanium concentration of the experimental beet pulp and feces was analyzed according to the method of Myers et al. [15] with modifications. Ti was determined using a spectrophotometer (Beckman Coulter Inc., Brea, USA) equipped with sipper module for 408 nm instead of 410 nm as reported by Myers et al. [15].

2.5. Statistical Analysis

All data were subjected to analysis of variance with the general linear model procedure in SPSS, using the model:

$$Y_{ij} = \mu + PERIOD_i + TREATMENT_j + e_{ij}$$

where Y_{ij} = a response variable (e.g., Mg intake, fecal Mg excretion, etc.); μ = overall mean; PERIOD_i = experimental period ($i = 1$ or 2); TREATMENT_j = level of dietary magnesium ($j = \text{low}$ or high); and e_{ij} = residual error. Both, the PERIOD and TREATMENT were set as fixed factors in the statistical model. Throughout, the level of statistical significance was pre-set at $P \leq 0.05$.

3. Results

3.1. Feed Intake and Milk Yield

The amount of DM offered was not fully consumed by the cows and the mean amounts of DM refused were 1.1 kg DM and 0.7 kg DM for the cows fed the high- and low Mg rations, respectively. Consequently, DM intakes were found to be 16.9 kg (SE ± 0.51) and 17.4 kg (SE ± 0.43) for high- and low Mg treatment groups ($P = 0.543$), respectively. The mean milk production was similar ($P = 0.836$) between the two treatments, i.e. 26.5 kg/day (SE ± 2.39) and 27.2 kg/day (SE ± 2.04) for the high- and low Mg treatments, respectively.

3.2. Mg Absorption and Urinary Mg Concentration

The intake of Mg increased ($P < 0.001$) from 54.7 g/day to 66.3 g/day when the cows were fed the high- instead of the low Mg ration (Table 2). However, fecal Mg excretion was found to be similar ($P = 0.174$) between the two experimental rations. Consequently, Mg absorption, either expressed as g/day or as a % of intake, were greater ($P \leq 0.038$) when the high Mg ration was fed. The urinary Mg concentration in the animals fed the low Mg ration (Mean, 10.6 mmol/L, Standard Error (SE) 1.81) and high Mg ration (13.9 mmol/L, SE 1.80) was found to be similar ($P = 0.228$).

Table 2. Mg intake, fecal Mg excretion and Mg absorption in cows fed the experimental rations with or without Mg-butyrate supplementation (i.e., high and low Mg, respectively).

Parameter	Low Mg	High Mg	SEM	P value
Mg intake, g/day	54.7	66.3	1.40	<0.001
Fecal Mg excretion, g/day	40.4	43.7	1.58	0.174
Apparent Mg absorption				
g/day	14.3	22.6	1.66	0.006
% of intake	26.2	34.1	2.30	0.038

4. Discussion

In the current study, the amount of absorbed Mg was found to be 14.3 g/day when the low Mg ration, containing 23.7 g K/kg DM, was fed. The value on Mg absorption observed in the current study is 13.4% greater than predicted based on the regression formula reported by Schonewille et al. [16], i.e., Mg absorption (g/day) = $3.6 + 0.2 \times \text{Mg intake}$ (g/day) – $0.08 \times \text{Dietary K}$ (g/kg DM). Thus, when the low Mg ration was fed, absolute Mg absorption (g/day) was more or less in line with expectation. When the cows were fed the ration supplemented with Mg-butyrate, predicted Mg absorption [16] was calculated to be 15.0 g/day but observed Mg absorption was found to be ~1.5 times greater than predicted (Schonewille et al., 2008). This indicates that Mg from Mg-butyrate is readily available for absorption. Indeed, the absolute difference in Mg absorption ($\Delta\text{Mg absorption}$) between the current low- and high Mg diet was 8.3 g/day while the absolute difference in Mg intake between the diets ($\Delta\text{Mg intake}$) was 11.6 g/day. Thus, the fractional Mg absorption from Mg-butyrate was calculated to be 71.6% (i.e., calculated as $\Delta\text{Mg absorption} / \Delta\text{Mg intake} \times 100\%$). The calculated fractional Mg absorption from Mg-butyrate is much greater compared to the likewise derived values on the fractional Mg absorption from MgO (Table 3). Thus, it appears that Mg-butyrate, relative to MgO, is superior in rendering Mg available for absorption.

Table 3. Mg intake, Mg absorption, Δ Mg intake, Δ Mg absorption in cows fed increasing amounts of Mg in the form of MgO [6].

Ration _i	Mg intake	Mg absorption	Δ Mg intake ¹	Δ Mg absorption	
	(g/day)	(g/day)	(g/day)	(g/day) ²	(% of intake) ³
1 ⁴	27.1	3.4	-	-	-
2	44.6	7.0	17.5	3.6	20.6
3	64.6	11.9	20.0	4.9	24.5
4	83.5	17.1	18.9	5.2	27.5
5	100.4	20.2	16.9	3.1	18.3
6	124.3	22.0	23.9	1.8	7.5

¹ Δ Mg intake is calculated as the difference in Mg intake between ration_{i+1} and ration_i. For example, the difference in Mg intake between ration 2 and ration 1 = 44.6 – 27.1 = 17.5 g Mg/day.

² Δ Mg absorption (g/day) is calculated as the difference in Mg absorption between ration_{i+1} and ration_i. For example, the difference in Mg absorption between ration 2 and ration 1 = 7.0 – 3.4 = 3.6 g Mg/day

³ Δ Mg absorption expressed as % of intake is the percentage absorption of Δ Mg intake, i.e. (Δ Mg absorption / Δ Mg intake) × 100%.

⁴ Ration 1 is the control ration, not supplemented with MgO.

For obvious reasons, the current study does not provide clues to explain the difference in Mg absorption between Mg-butyrate and MgO, but it is well known that the particle size of MgO is of critical importance for proper solubilization of MgO. Results from various studies [7,8,17] have clearly indicated that the solubility of MgO is inversely related with its particle size. However, the data presented in Table 3 from Jittakhot et al. [6] is based on a highly soluble MgO source [7]. Thus, the difference in fractional Mg absorption between Mg-butyrate and MgO is difficult to explain by a difference in particle size. It is speculated that, the greater Mg absorption from Mg-butyrate versus MgO may be related to the anion moiety of the Mg-butyrate.

To the best of the authors' knowledge, there are currently no published data reporting on the availability of Mg from Mg-butyrate. However, Ross et al. [18] reported that supplemental Mg in the form of either calcined magnesite or Mg-acetate prevented hypomagnesemia in grazing cows. Unfortunately, Mg intakes were not kept constant between supplemental Mg sources and Mg absorption was not measured in the Ross et al. [18] study, thereby hindering proper interpretation of the data. Interestingly, Giduck and Fontenot [19] reported on the stimulatory effect of readily fermentable carbohydrates on Mg absorption in sheep. This observation in sheep fuels the idea that short chain fatty acids (SCFA) are instrumental in stimulating Mg absorption in ruminants. This notion is in line with the outcome of fundamental *in-vitro* research on Mg transport across the rumen epithelium.

The process of Mg uptake by rumen epithelial cells [20] consists of two components, one sensitive and one insensitive to K [21]. It was shown by Leonhard-Marek et al. [22] that SCFA can stimulate Mg absorption *in-vitro* with butyrate, relative to acetate and propionate, being most effective. These results prompted the authors [22,23] to propose that a K-independent transporter was located at the apical membrane of the rumen epithelial cell, which exchanges one Mg ion for two hydrogen ions. It can, therefore, be speculated that Mg butyrate provided the protons to stimulate the K-independent transport across the apical membrane of the epithelial cells in the rumen. However, Schweigel and Martens [24] were not able to demonstrate a Mg²⁺ / 2 H⁺ exchanger in isolated rumen epithelium cells and these authors suggested the involvement of H⁺-ATPase activity to explain the

butyrate induced stimulation in Mg transport across rumen epithelial cells. The involvement of H⁺-ATPase activity implicates that SCFA mediated Mg transport may also involve a voltage dependent pathway [24]. Clearly, the mechanism underlying the stimulatory effect of SCFA/butyrate on Mg absorption is not settled yet [25].

Magnesium transport across the basolateral membrane of rumen epithelial cells depends on a carrier mediated process based on the exchange of a Mg ion for two Na ions [23,26]. Thus, it can be speculated that the transport of Mg across the rumen epithelium can become saturated. Jittakhot et al. [6] however, reported that the apparent Mg absorption in dry cows, became saturated when a ration was fed containing ~12 g Mg/kg dry matter. It can thus be speculated that the process of Mg absorption was not saturated in the current feeding experiment due to the rations containing a much lower amount of Mg.

Despite the numerical increase in the urinary Mg concentration after the feeding of supplemental Mg-butyrate, the difference in the urinary Mg concentration did not reach statistical significance. This observation is not easy to explain because both DM intake and milk yield were found to be similar between the two experimental rations. It can be speculated that both Mg excretion with milk and the intake of electrolytes (i.e., Na and K), was similar between the two rations. In view of the latter, the volume of urine produced is likely to have been similar between the two treatments. It seems, therefore, fair to assume that the lack of response in urinary Mg excretion cannot be explained by a difference in urine volume. Thus, the probability of type-1 error was most likely unfavorably affected by the high variation in the urinary Mg concentration.

5. Conclusions

Mg-butyrate is a readily available Mg source and can be considered an attractive alternative to MgO to supplement dairy rations with Mg.

Author Contributions: Conceptualization, J.E.E. and J.T.S.; methodology, J.T.S.; formal analysis, J.T.S.; investigation, B.M.G.; resources, J.T.S.; data curation, B.M.G.; writing—original draft preparation, J.T.S and B.M.G.; writing—review and editing, J.T.S, B.M.G., J.E.E.; visualization, B.M.G.; supervision, J.T.S.; project administration, J.T.S; funding acquisition, J.T.S.. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Utrecht University with partial financial support from Palital Feed Additives, Velddriel, The Netherlands.

Institutional Review Board Statement: The animal study protocol was approved by the Institutional Review Board of the Faculty of Veterinary Medicine, Utrecht University (approval number 10803-2020-05).

Acknowledgments: The authors thank the animal caretakers of the department of farm animal health for their technical assistance and excellent care of the cows.

Conflicts of Interest: The authors declare no conflict of interest.

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