Influence of a mixed and a vegetarian diet on urinary magnesium excretion and concentration

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Urinary Mg is suggested to be an effective inhibitor of the formation and growth of calcium oxalate stones. In order to examine the influence of variations in dietary Mg on urinary Mg excretion, ten healthy male subjects were kept on two different standard diets for 5 d each. In the course of the test period, 24 h urine samples were collected. Diets 1 and 2 were calculated according to the dietary recommendations of the German Society of Nutrition (Deutsche Gesellschaft für Ernährung, 1986). Diet 1 was established as a model of a balanced mixed diet, whereas diet 2 represented an ovo-lacto-vegetarian meal plan. Diets 1 and 2 were isoenergetic with equal amounts of the main nutrients, estimated from food tables, and a constant fluid intake. In contrast to the content of Mg (336 mg) and dietary fibre (28 g) of diet 1, diet 2 was rich in Mg (553 mg) and dietary fibre (52 g). On the ingestion of diet 1, renal Mg excretion was 5·09 (SEM 0·35) mmol on the control day and increased slightly but not significantly to 5·40 (SEM 0·52) mmol on the corresponding day on diet 2. Urinary Mg excretion as a percentage of estimated dietary intake was about double on the balanced mixed diet (37 %) than on the Mg-rich vegetarian diet (24 %). As both diets contained equal amounts of most nutrients, these results indicate a lower excretion rate of Mg from the vegetarian diet than from the mixed diet. This would appear to be primarily due to the higher Mg and fibre contents and to the lower Mg utilization, that are important factors in decreasing Mg absorption and consequently urinary excretion rate.

Mixed diet: Vegetarian diet: Magnesium: Calcium: Lithiasis

The importance of urinary Mg excretion as an inhibitory factor of the formation and growth of calcium oxalate urinary stones has been indicated by various experimental investigations. *In vitro* studies either with artificial or human whole urine revealed a marked reduction of both the nucleation and growth rates of calcium oxalate crystals at various concentrations (Hallson *et al.* 1982; Achilles & Ulshöfer, 1985; Li *et al.* 1985; Kohri *et al.* 1988).

The mechanism of action of Mg is most likely to increase the solubility of calcium oxalate, presumably by forming more soluble complexes (ion pairs) with oxalate ions that are then not available for precipitation by Ca (Desmars & Tawashi, 1973).

These findings indicate the importance of a sufficiently high 24 h excretion and concentration of Mg as an effective metaphylactic measure in preventing recurrent stone disease. Related clinical investigations of Mg therapy have been conducted on recurrent stone formers as on healthy subjects but with little success. Indeed, the oral administration of Mg supplements resulted in a significant increase in urinary excretion, but this benefit was counteracted by the associated increase in urinary Ca excretion (Heaton & Parsons, 1961; Briscoe & Ragan, 1966; Fetner *et al.* 1978; Tiselius *et al.* 1980). On the other hand, the effect of various dietary Mg supplies on urinary excretion of Mg is not well documented.

Table 1. *Study protocol*

Subjects:	10 healthy male subjects	
Test period:	phase 1	phase 2
Diet:	mixed diet	vegetarian diet
	diet 1	diet 2
Feeding period:	5 d	5 d
Material:	24 h urines	
Variables:	urinary volume, magnesium, calcium, oxalic acid	
Collection period:	5 d	5 d

In order to determine a recommendable diet for the prevention of recurrent calcium oxalate stone disease we studied the influence of a balanced mixed diet, that ensures an adequate Mg intake (approximately 350 mg/d), and a Mg-rich vegetarian diet (approximately 550 mg/d) on 24 h excretion and concentration of Mg in healthy men.

SUBJECTS AND METHODS

The present study was performed on ten healthy male subjects with a mean age of 28 years (range 21–32 years). The individuals had no history of renal calculus or other renal disorders. Before starting the test phases the subjects were fed on an adaptation diet, providing about 350 mg Mg/d for 5 d. The test series was divided into two consecutive phases of 5 d each. In the course of the test phases 1 and 2 the subjects received two different standard diets, diet 1 and diet 2. The protocol is summarized in Table 1.

Whereas diet 1 was established as a model of a balanced mixed diet (Table 2), diet 2 represented an ovo-lacto-vegetarian meal plan, since vegetables, especially green leafy vegetables, fruits and cereals, are rich in Mg (Table 3). Diets 1 and 2 were calculated according to the dietary recommendations of the German Society of Nutrition (Deutsche Gesellschaft für Ernährung, 1986). Nutrient contents of the diets were estimated by use of the computer program PRODI III plus, which includes fifty different nutrients mainly according to the *Food Composition and Nutrition Tables, 1986/87* of Souci *et al.* (1986). The oxalic acid content of the diets was estimated from the data of Hodgkinson (1977).

Both diets were isoenergetic with equal amounts of the main nutrients and a constant fluid intake. The main components of the mixed diet 1 and the vegetarian diet 2 are specified in Table 4. In contrast to the normal contents of Mg (336 mg/d) and dietary fibre (28 g/d) of diet 1, diet 2 was rich in Mg (553 mg/d) and dietary fibre (52 g/d).

With diet 1, dietary fibre and Mg were supplied equally by cereals and fruits, whereas the intake of these nutritional components from vegetables was comparatively low. In comparison, the fibre and Mg intakes from vegetables and fruits in diet 2 were three times as much as with diet 1, whereas the intake of these dietary components from cereals remained unchanged compared with diet 1 (Table 5).

In the course of the test period, 24 h urine samples were collected each day. Mg concentration was determined by atomic absorption spectrophotometry and 24 h excretion of Mg was calculated from the concentration data and the urinary volumes. Other variables, such as urinary Ca (atomic absorption spectrophotometry), oxalic acid (ion chromatography) and creatinine (Jaffé-reaction), were also measured in 24 h urine samples.

The Wilcoxon signed-rank test (Sachs, 1984) was used to find significant differences

Table 2. *Menu for diet 1 (mixed diet)*

Breakfast:	100 g bread rolls 10 g margarine 25 g jam 30 g sausage
Snack:	150 g banana 25 g wholemeal biscuit bar
Lunch:	60 g roast pork with 90 g mustard sauce 120 g carrots 175 g rice 300 g apple purée
Snack:	150 g apple 150 g fruit yoghurt (minimum 3·5% fat content)
Dinner:	100 g wheat wholemeal bread 10 g margarine 40 g sausage 50 g tomato
Snack:	10 g crispbread 5 g margarine 17 g fresh cheese (minimum 60%, maximum 85% fat content in dry matter)
Beverages:	1250 ml fruit tea 450 ml coffee 500 ml apple juice 300 ml milk (minimum 3·5% fat content)

Table 3. *Menu for diet 2 (vegetarian diet)*

Breakfast:	50 g rolled oats 30 g raisins 20 g hazelnuts 150 g banana
Snack:	150 g orange 25 g wholemeal biscuit bar
Lunch:	200 g potato purée 240 g carrots 55 g egg 15 g margarine 150 g apple
Snack:	150 g apple 150 g banana
Dinner:	300 g potatoes 125 g quark, fresh cheese (20% fat content in dry matter) 100 g tomatoes
Snack:	50 g wheat wholemeal bread 10 g margarine 17 g fresh cheese (minimum 60%, maximum 85% fat content in dry matter) 150 g orange
Beverages:	1450 ml fruit tea 450 ml coffee 500 ml apple juice 100 ml milk (minimum 3·5% fat content)

Table 4. *Composition of the diets**

	Diet 1 (mixed diet)	Diet 2 (vegetarian diet)
Energy (MJ)	10·630	10·883
Protein (g)	65	65
Fat (g)	82	84
Carbohydrate (g)	370	386
Fibre (g)	28	52
Magnesium (mg)	336	553
Calcium (mg)	768	787
Phosphate (mg)	1283	1457
Oxalic acid (mg)†	74	129
Fluid intake (ml)	2500	2500

* Estimated by use of the computer program PRODI III plus, based on the *Food Composition and Nutrition Tables, 1986/87* of Souci *et al.* (1986).
† Estimated from the data of Hodgkinson (1977).

Table 5. *Dietary fibre and magnesium intakes from a mixed diet and an ovo-lacto-vegetarian diet**

	Diet 1 (mixed diet)		Diet 2 (vegetarian diet)	
	Fibre (g/d)	Magnesium (mg/d)	Fibre (g/d)	Magnesium (mg/d)
Total	28	336	52	553
Cereals	11	129	7	116
Vegetables	6	26	23	172
Fruits	11	101	21	195

* Estimated by use of the computer program PRODI III plus, based on the *Food Composition and Nutrition Tables, 1986/87* of Souci *et al.* (1986).

($P < 0.05$) between corresponding days of phases 1 and 2. As control day the fifth day of phase 1 and as comparative day the fifth day of phase 2 were chosen, because by then conditions of steady state had been reached.

RESULTS

The results are summarized in Table 6. Mean Mg excretion was 5·34 mmol/d on the normal-Mg-containing diet 1 and increased to 5·69 mmol/d on average on consumption of the Mg-rich vegetarian diet 2. The difference between the Mg excretion on the mixed diet 1 (days 1–5) and that on the vegetarian diet 2 (days 6–10) was not statistically significant.

To estimate the approximate excretion rate of Mg from both diets, the Mg input and output on the last day of each phase had to be compared (Table 7). The Mg content of the mixed diet 1 amounted to 13·8 mmol/d, whereas 22·8 mmol Mg/d were supplied by diet 2, corresponding to an increase of Mg intake of 65%. On the other hand, 5·09 (SEM 0·35) mmol Mg were excreted on the control day during the ingestion of diet 1, compared with 5·40 (SEM 0·52) mmol on the comparative day during the intake of diet 2, which is an increase

Table 6. *Urinary volume, oxalic acid and mineral excretion by healthy male subjects consuming a mixed diet (diet 1) and an ovo-lacto-vegetarian diet (diet 2)*†

(Mean values with their standard errors for ten subjects)

	Diet 1					Diet 2				
Day...	1	2	3	4	5	6	7	8	9	10
Urinary volume (litres/d)	2·54	2·40	2·41	2·30	2·30	2·80	2·58	2·36	2·65	2·45
SEM	0·21	0·13	0·23	0·14	0·12	0·16	0·16	0·16	0·11	0·24
Magnesium (mmol/l)	2·09	2·33	2·41	2·47	2·25	2·16	2·25	2·47	2·26	2·31
SEM	0·18	0·17	0·17	0·16	0·16	0·20	0·13	0·18	0·17	0·24
Magnesium (mmol/d)	5·07	5·49	5·54	5·51	5·09	5·84*	5·66	5·63	5·91	5·40
SEM	0·34	0·38	0·36	0·27	0·35	0·36	0·26	0·32	0·39	0·52
Calcium (mmol/d)	4·26	3·93	3·54	3·36	3·09	2·99*	2·70*	2·58*	2·84*	2·46*
SEM	0·49	0·53	0·47	0·49	0·44	0·40	0·40	0·43	0·49	0·42
Oxalic acid (mmol/d)	0·290	0·325	0·298	0·297	0·287	0·378*	0·407	0·414*	0·411*	0·376*
SEM	0·020	0·021	0·019	0·016	0·018	0·030	0·022	0·031	0·028	0·039

* Mean values were significantly different from those of diet 1 on the corresponding day, $P < 0·05$.

† For details of diets and procedures, see Tables 2–5 and pp. 784–786.

Table 7. *Intake and excretion of magnesium by healthy male subjects consuming a mixed diet (diet 1; day 5) or an ovo-lacto-vegetarian diet (diet 2; day 10)**

(Mean values with their standard errors for ten subjects)

	Diet 1 (mixed diet)		Diet 2 (vegetarian diet)		
	Mean	SEM	Mean	SEM	Δ (%)
Mg intake (mmol/d)	13·8		22·8		65
Mg excretion (mmol/d)	5·09	0·35	5·40	0·52	6
Mg excretion rate (%)	37		24		

* For details of diets and procedures, see Tables 2–5 and pp. 784–786.

of only 6%. At a value of 5·09 mmol Mg on the last day of phase 1, renal Mg excretion amounted to 37% of the intake. Although Mg supply by diet 2 was considerably higher than with diet 1, Mg excretion increased only by 0·31 mmol/d, which corresponds to 24% of the ingested amount.

Furthermore, urinary Mg concentrations were similar to a large extent on the ingestion of both diet 1 and diet 2. The additional water intake from fruits and vegetables of the vegetarian diet 2 resulted in an increase in urinary volume from 2·39 litres/d on average on diet 1 to 2·57 litres/d on diet 2, an average of 180 ml/d, that equalized the relatively low differences in Mg excretion between the comparable test days with regard to the concentration.

The 24 h urinary excretion of Ca was highest on the ingestion of the mixed diet 1 and then decreased on the intake of the vegetarian diet 2. The differences were statistically significant.

On diet 1, mean oxalic acid excretion amounted to 0·299 mmol/d and increased significantly by 33% to 0·397 mmol/d on average on diet 2.

DISCUSSION

Magnesium is suggested to be an important inhibitor of calcium oxalate stone formation. If its renal excretion and concentration could be sufficiently enhanced, Mg might increase the solubility of calcium oxalate by complexing oxalate (Desmars & Tawashi, 1973).

In order to investigate the importance of a Mg-rich diet as an effective metaphylactic measure in calcium oxalate urolithiasis, a vegetarian diet has been tested in relation to a mixed diet in the expectation that the high Mg content of fruits, cereals and vegetables would increase urinary Mg excretion and concentration.

In spite of the use of short-term periods, a tendency in Mg excretion was noted in the course of the present study. The results indicate that increasing the Mg intake by more than half, the excretion rate, i.e. urinary excretion as a percentage of the intake, clearly diminishes. On consumption of diet 1, 37% of the ingested amount was excreted compared with 24% on diet 2.

The main factor that influences Mg excretion in the urine is the amount of Mg ingested. The urinary excretion of Mg in an individual in Mg balance is a close function of dietary intake and intestinal absorption. As Mg balance is assumed under standardized conditions the availability can be determined from the renal Mg excretion.

At average dietary Mg intakes, Mg absorption has been found to be approximately 35–40% of the intake (Wacker & Parisi, 1968; Wilkinson, 1976; Danielson *et al.* 1979; Elin, 1987). On extremely low or high dietary Mg intakes an inverse relationship to the absorption rate has been observed. Graham *et al.* (1960) showed that 76% of the ingested Mg was absorbed with a very low dietary intake of Mg (0·95 mmol), while a high intake (23·5 mmol) resulted in a decrease in the absorption to 24%.

These findings suggest that Mg absorption at high dietary Mg levels, as on the vegetarian diet 2 which supplied 22·8 mmol/d, is much lower than on normal intakes. The experimentally determined values of the present study agree with the findings of Jahnen *et al.* (1991). On a diet containing 16·45 mmol Mg/d 4·34 mmol Mg/d were excreted on average, which corresponds to 26% of the supply. On an intake of 34·96 mmol Mg/d (16·45 mg with the diet + 18·51 mg Mg with effervescent tablets) a mean excretion of 6·1 mmol Mg/d resulted, which is 17·4% of the intake.

A number of nutritional factors have been indicated to influence Mg absorption and excretion, e.g. the carbohydrate, fat, protein, Ca and phosphate contents of the diet (Wilkinson, 1976; Seelig, 1981).

Whereas in the present study both diets contained similar amounts of the main nutrients and of Ca, the ingested amount of phosphate with diet 2 (1457 mg) was greater than with diet 1 (1283 mg). As a mechanism of action, the ability of phosphate to form a complex with Mg in the gastrointestinal tract, which makes Mg unavailable for absorption, is assumed (Wilkinson, 1976; Pak *et al.* 1985).

Another food component that is suggested to be effective in decreasing Mg absorption is phytic acid. Phosphate in phytic acid is able to bind Mg, thus interfering with the bioavailability and absorption of this essential mineral (Hartmuth-Hoene, 1985; Franz, 1989). Phytic acid is widely found in whole grains and legumes (Franz, 1989), but with regard to the vegetarian diet 2 the influence of phytic acid on Mg absorption is of minor interest, since the diets did not differ greatly in the proportion of phytic-acid-rich foods they contained.

Recently, attention has been focused towards a possible role of a high intake of dietary fibre in impaired Mg absorption. Whether intake of fibre may exert an effect on Mg absorption from the diet is still debated (Kelsay *et al.* 1979; McHale *et al.* 1979; Slavin & Marlett, 1980), since chemical determinations of Mg in the food do not indicate the amount available for absorption (Frølich, 1986). Fruits and vegetables in diet 1 supplied 39% of total dietary Mg and 60% of total dietary fibre. In diet 2, 66% of the Mg and 84% of the fibre were provided by fruits and vegetables, representing an increase in both dietary Mg and fibre supply from fruits and vegetables by about 25%.

The higher fibre intake from fruits and vegetables with the vegetarian diet 2 than that with the mixed diet 1 might have influenced the Mg excretion, possibly by decreasing Mg utilization and absorption. This may correspond to losses of Mg in the faeces. Further studies on this question should therefore incorporate collection and analysis of faeces. Moreover, longer feeding periods may be necessary if adaptation by the intestine to higher dietary Mg and fibre levels is to be considered.

On the other hand, Mg has been suggested to influence the excretion of Ca. Balance studies in man (Heaton & Parsons, 1961; Briscoe & Ragan, 1966) have shown that oral administration of Mg causes a substantial fall in the faecal excretion of Ca, suggesting that the increased urinary excretion of Ca may result from an increased intestinal absorption of Ca and not necessarily from competition for reabsorption between Ca and Mg in the renal tubule. Raising Mg intake with diet 2 compared with diet 1 did not increase Ca excretion. Here, the effect of an excess Mg supply on Ca excretion is mitigated by several other factors such as the dietary fibre and oxalic acid contents of the vegetarian diet.

Furthermore, it has been suggested that Mg decreases the oxalate excretion either by affecting its absorption (Berg *et al.* 1986), or by regulating the endogenous synthesis as the Mg ion is a cofactor in the decarboxylation of glyoxylate. However, a reduction in oxalic acid excretion on Mg administration was only reported by Brundig *et al.* (1981) and Berg *et al.* (1986). The majority of investigations have revealed no significant differences in oxalic acid excretion on Mg therapy (Elliot & Ribeiro, 1971; Gregory *et al.* 1977; Tiselius *et al.* 1980; Nordenvall *et al.* 1985). On the contrary, ingestion of the Mg-rich vegetarian diet 2 resulted in a significant increase in oxalic acid excretion, predominantly caused by the high oxalate content of the plant foods.

The influence of a Mg-rich ovo-lacto-vegetarian diet on urinary Mg excretion and urinary concentration was not as great as expected. Moreover, on the basis of the high oxalic acid excretion caused by the oxalic acid content of the plant foods, calcium oxalate stone formers with a mild hyperoxaluria, due to intestinal hyperabsorption of oxalate, should be advised to avoid an excess of fruits, vegetables and cereals.

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