Study of Nutritive Utilization of Protein and Magnesium in Rats with Resection of the Distal Small Intestine. Beneficial Effect of Goat Milk

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ABSTRACT

The search for diets to improve the nutritive utilization of protein and magnesium in malabsorption syndrome led us to study goat milk, because of its particular nutritional characteristics, and to compare it with cow milk, which is most commonly consumed. We studied the nutritive utilization of protein and magnesium in transected rats (control) and in rats with resection of 50% of the distal small intestine. The diets used were the standard diet recommended by the American Institute of Nutrition and diets based on lyophilized goat or cow milk. The consumption of goat milk produces better protein efficiency ratio and food conversion efficiency values, particularly in rats with intestinal resection, together with a higher nutritive utilization of protein. Magnesium apparent digestibility coefficient is not modified by intestinal resection in rats fed with goat milk-based diet, on the contrary to the standard and cow milk diets. Magnesium apparent digestibility coefficient is greater for the goat milk group, which is reflected in the greater quantity of this mineral stored in bone. These results demonstrate the beneficial effect of goat milk on the nutritive utilization of protein and on magnesium bioavailability, especially in animals with resection of the distal small intestine.

(Key words: protein utilization, magnesium bioavailability, goat milk, resected rat)

Abbreviation key: ADC = apparent digestibility coefficient, DSI = distal small intestine, FCE = food conversion efficiency, PER = protein efficiency ratio, MCT = medium-chain triglycerides.

INTRODUCTION

Magnesium is an organism's second most prevalent intracellular cation, after potassium. Its metabolic importance is well known, having been identified as a cofactor in more than 300 enzymatic reactions, which affect the energetic metabolism and the synthesis of proteins and nucleic acids.

Several studies have demonstrated a clear relationship between nitrogen and magnesium balances, regardless of the absolute dietary intake of the mineral (Lo et al., 1980). Sufficient casein in the diet (16%) increases magnesium intake and retention (Wester, 1987).

Resection of the small intestine leads to a complicated pathological situation in which the organism is confronted with the malabsorption of protein, fat, and divalent cations (such as calcium, magnesium, iron, copper, and zinc; Barrionuevo et al., 1980; Barrionuevo and Campos, 1980; Campos et al., 1989; López-Aliaga et al., 1991; Hartiti et al., 1994). Intestinal resection can affect the rate of nutrient absorption by reducing the surface area available for nutrient transport and the transit time of food through the intestine, thus limiting the time nutrients are in contact with the absorptive surface (Ladefoged et al., 1996). This results in malabsorption, particularly as concerns proteins and minerals (magnesium), so when 50% of the distal small intestine is removed, the digestive utilization of magnesium is reduced, an effect reflected in bone mineral content (López-Aliaga et al., 1991), and there is a deterioration in the digestive utilization of protein, which improves with time (6 mo postsurgery) (Barrionuevo et al., 1985).

The search for natural foods that favor the nutritive utilization of protein and magnesium, particularly in cases of malabsorption syndrome, led us to study a goat milk diet. This milk has particular nutritional characteristics (Haenlein, 1996), being rich in me-

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dium-chain triglycerides (**MCT**) ($C_{6:0}$ caproic, $C_{8:0}$ caprylic, and $C_{10:0}$ capric), which are absorbed in the proximal small intestine and do not require bile salts in order to be absorbed (Vanderhoof et al., 1984). Goat milk contains large amounts of magnesium (140 mg/L) (Souci et al., 1989; Haenlein, 1996); the proteins in goat milk are digested readily, and their constituent amino acids are absorbed efficiently (Boulanger et al., 1984; Park, 1994). A comparative study was made with a cow milk-based diet (which is most commonly consumed) and with the standard diet recommended by the American Institute of Nutrition (AIN, 1977).

MATERIALS AND METHODS

Animals

We studied a total of 69 male albino Wistar rats with an initial BW of 177 ± 3 g (6 to 7 wk old), obtained from the University of Granada Laboratory Animal Service. All experiments and surgical procedures using rats conformed to the guidelines and legal requirements established in the United States for the proper care and use of laboratory animals. After surgery both the transected and resected animals were housed in individual metabolic cages kept in a room thermoregulated ($22 \pm 2^\circ\text{C}$) with a 12 h:12 h light-dark period. Food and distilled water were available ad libitum to all rats. At the start of the experimental period, the rats were 10 to 11 wk old.

Diets

The diets and mineral and vitamin supplements were prepared according to the recommendations of the AIN (1977), except that the level of fat in the diets was 10% rather than 5%. The standard diet (diet S) was prepared using olive oil as the source of fat (10%) and casein as the protein source (20%). The milk-based diets were created with lyophilized cow or goat milk (diets C and G, respectively) (Table 1). These were analyzed to determine the fat content (cow milk: 35.23%; goat milk: 43.63%), protein content (cow milk 23.92%; goat milk: 25.27%), lactose content (cow milk: 37.55%; goat milk: 31.10%), and mineral composition (mg/100 g of lyophylate) (cow milk: Ca: 1031.5, P: 731.3, Mg: 76.3; Fe: 0.61; Cu: 0.11 and Zn: 3.72; goat milk: Ca: 1215.2, P: 843.3, Mg: 82.5, Fe: 1.13, Cu: 0.42 and Zn: 4.15). The necessary quantities of lyophilized goat or cow milk were taken to obtain a diet with a 10% fat content. To obtain the 20% protein content (as recommended by the AIN) (1977) the diet was supplemented with casein (Musal & Chemical, Granada, Spain) 12.53 g of casein/100 g for the diet of cow's milk and 14.05 g of casein/100 g for the diet of goat's milk,

Table 1. Composition of the experimental diets.

Component	g/kg diet (dry weight)
Diet S ¹	
Protein (casein)	209
DL-Methionine	3
Fat (olive oil) (MCT ² , 0 g)	112
Fiber (micronized cellulose)	50
Mineral supplement ³	36
Vitamin supplement ³	10
Choline chloride	2
Wheat starch	156
Sucrose	450
kcal/kg diet	4280
Diet C ¹	
Protein (casein + protein cow milk)	190
DL-Methionine	3
Fat (cow milk) (MCT ² , 20.6 g)	98
Fiber (micronized cellulose)	40
Mineral specific supplement ³	35
Vitamin specific supplement ³	10
Choline chloride	2
Wheat starch	152
Sucrose	487
kcal/kg diet	4210
Diet G ¹	
Protein (casein + protein goat milk)	194
DL-Methionine	3
Fat (goat milk) (MCT ² , 33.2 g)	92
Fiber (micronized cellulose)	46
Mineral specific supplement ³	36
Vitamin specific supplement ³	10
Choline chloride	2
Wheat starch	153
Sucrose	485
kcal/kg diet	4168

¹Standard diet (diet S), lyophilized cow and goat milk-based diets (diets C and G, respectively).

²Medium-chain triglycerides.

³Mineral and vitamin supplements were prepared according to the recommendations of the American Institute of Nutrition (1977).

as the protein provided by the lyophylate used for the milk-based diets was insufficient.

The mineral corrector was prepared according to AIN recommendations (1977) for the standard diet and to our own specifications for the milk-based diets. Magnesium was supplied as the oxide. These specific correctors were formulated taking into account the mineral content of the lyophilized milks supplied to the rats in order to meet the mineral-content recommendations of the AIN (1977). The lactose content of the milk diets was subtracted from the total carbohydrate content of the standard diet, and wheat starch and sucrose were added corresponding to the difference (Table 1).

Resection and Transection Procedures

The method described by Hartiti et al. (1994) was used to carry out the resection of 50% of the distal small intestine (**DSI**) and the transection.

Experimental Design

Six experimental groups were formed: 1) group T-S, transected rats, standard diet (n = 11); 2) group R-S, resected rats, standard diet (n = 13); 3) group T-C, transected rats, cow milk diet (n = 10); 4) group R-C, resected rats, cow milk diet (n = 11); 5) group T-G, transected rats, goat milk diet (n = 14); 6) group R-G, resected rats, goat milk diet (n = 10). All animals were fed up to the time of surgery, and were given access to water containing 50 g of glucose/L for 24 h after surgery. Thereafter, a period of 30 d was allowed for adaptation to the diet, during which feed and double-distilled water were available ad libitum to all animals. Beginning 30 d after surgery, feed intake (the amount of food consumed daily by each rat determined by weighing the amounts of diet given, refused, and spilled) was measured, and urine and feces were collected for a period of 7 d (Thomas and Mitchell, 1923) for subsequent analysis. Feces were dried, weighted, and homogenized. Urine was collected on 0.5% ClH (vol/vol), filtered (Whatman Filter Paper No. 40, Whatman, Maidstone, Kent, UK), and diluted for subsequent analysis. Body weight was recorded at the beginning and end of the experimental period. Throughout the experimental period, all rats had access to double-distilled water. At the end of this period, the rats were fasted for 24 h and killed after intraperitoneal anesthesia with sodium pentobarbital (5 mg/100 g of BW) and totally bled by cannulation of the abdominal aorta. Kidney, liver, heart, sternum, both femurs, and spleen were removed and frozen immediately at -80°C in liquid nitrogen, then stored at -40°C for magnesium analysis.

Biological Indices

The following indices and parameters were determined for each group, according to the formulas given below: intake (expressed as dry weight), BW, protein efficiency ratio (**PER**, eq. 1), food conversion efficiency (**FCE**, eq. 2), apparent digestibility coefficient (**ADC**, eq. 3) and retention for protein and magnesium (balance, eq. 4) and percent nitrogen or magnesium retention/nitrogen or magnesium intake (% R/I, eq. 5).

$$\text{PER} = \text{weight gained (g/rat/day)} / \text{protein intake (g/rat/day)} \quad [1]$$

$$\text{FCE} = \text{diet intake} / \text{weight gained} \quad [2]$$

$$\text{ADC} = (\text{I} - \text{F}) \times 100/\text{I} \quad [3]$$

$$\text{Balance (retention)} = \text{I} - (\text{F} + \text{U}) \quad [4]$$

$$\% \text{ R/I} = \text{I} - (\text{F} + \text{U}) \times 100/\text{I} \quad [5]$$

The factors used were I = intake, F = fecal excretion, and U = urinary excretion.

Analytical Methods

Water contents of diet, feces, kidney, liver, heart, sternum, femur, and spleen were determined by drying the materials at $105 \pm 2^{\circ}\text{C}$ until the weight remained constant. An appropriate amount of the resulting material was ashed at 450°C , and the residue was extracted with 5 M HCl and brought up to an appropriate volume with double-distilled water. Atomic absorption spectrophotometry (Perkin-Elmer 1100B) was used for magnesium determination.

Total nitrogen content was determined according to the Kjeldahl method, and the CP content was calculated ($\text{N} \times 6.25$).

Total plasma protein was measured with a colorimetric combination test based on the method of Biuret Urea Enzymatic colorimetric test and the cleavage with urease and Berthelot's reaction (Fawcett and Scott, 1960).

Quality Control

Given the importance of accurate determination of the various parameters studied, the measurement of these was subjected to a quality control procedure. This consisted of analyzing a skim milk powder (certified reference material CRM 063R, Community Bureau of References, Brussels, Belgium), which yielded Mg value of 1.19 ± 0.08 mg/g (means $\pm$ SEM of five determinations) (certified value of Mg, 1.26 ± 0.02 mg/g).

Statistical Analysis

We calculated the mean and the standard error of the mean for each parameter studied. Statistical evaluation was performed by the two-way ANOVA method using a model with two main effects (animal group and type of diet) (SPSS 2002, PC Software package, Chicago, IL). Values of $P < 0.05$ were considered significant.

RESULTS

Intake, PER, FCE, ADC, and Protein Balance

The three diets assayed all contained the same level of protein (approximately 20%). Protein intake was not affected by intestinal resection for the different diets studied (milk diets, cow or goat, and standard

Table 2. Food intake and weight change in transected and resected rats fed on standard nonmilk or milk diets (cow or goat).¹

Group	n	BW gain (g/d)	DMI (g/d)	Protein intake (g/d)	PER ²	FCE ³
T - S ⁴	11	3.21 ± 0.30	18.62 ± 0.59 ^a	3.90 ± 0.12	0.81 ± 0.06	6.43 ± 0.81
R - S ⁴	13	2.85 ± 0.48	19.18 ± 0.64 ^b	4.02 ± 0.13	0.72 ± 0.09	10.18 ± 2.69 ^b
T - C ⁴	10	2.51 ± 0.57	20.71 ± 0.50 ^c	3.95 ± 0.10 ^c	0.63 ± 0.13	11.34 ± 3.40
R - C ⁴	11	2.81 ± 0.22	22.16 ± 0.58 ^d	4.22 ± 0.11 ^d	0.66 ± 0.04 ^d	8.23 ± 0.50 ^d
T - G ⁴	14	2.71 ± 0.21	16.24 ± 0.34 ^e	3.15 ± 0.07 ^e	0.85 ± 0.05	6.35 ± 0.41
R - G ⁴	10	2.86 ± 0.32	16.85 ± 0.62 ^f	3.27 ± 0.12 ^f	0.98 ± 0.07 ^f	5.58 ± 0.51

¹All data are expressed as mean ± SEM values.²PER = weight gained/protein intake.³FCE = diet intake/weight gained.⁴T = Transected, R = Resected, S = Diet S, C = Diet C, G = Diet G.^aT-S and T-C; ^bR-S and R-C; ^cT-C and T-G; ^dR-C and R-G; ^eT-S and T-G; ^fR-S and R-G.

diet, without milk). In both the animal groups studied (T and R) consumption of the goat milk-based diet was lower than that of the other two diets ($P < 0.001$). There was no difference between the latter two, so the intake of proteins and nitrogen was lower with the goat milk diet. However, no significant differences in weight gain were found due to the resection or to the effects of the diet. The goat milk diet produced increased values for the PER, especially in resected rats with respect to the standard diet ($P < 0.05$) and to the cow milk-based diet ($P < 0.01$) (Table 2).

Intestinal resection had no effect on food conversion efficiency. With regard to the diets supplied, consumption of the goat milk diet led to a better food conversion efficiency than the diet based on cow milk ($P < 0.001$) (Table 2).

The protein ADC was lower in animals with intestinal resection fed the cow milk-based diet, compared with the control (transected) animals ($P < 0.001$); however, there were no differences in protein ADC between the two animal groups fed the standard or goat milk-based diets (Table 3).

In relation to the type of diet employed, the goat milk-based diet showed highest values of protein ADC,

followed by the standard diet and finally by the cow milk-based diet, in both the animal groups studied ($P < 0.001$) (protein ADC: $G > S > C$) (Table 3).

With respect to protein balance, there were no significant differences due to intestinal resection effect or the type of diet assayed, although we observed a tendency for more nitrogen to be retained in the animals fed the goat milk-based diet in relation to the other two diets. However, when retention is expressed as nitrogen retained with respect to nitrogen intake, this biological index was found to be significantly higher in the transected and resected rats fed the goat milk-based diet with respect to the other two diets ($P < 0.001$), the latter two producing similar results (% R/I for protein: $G > S = C$) (Table 3).

Biochemical Parameters Related to Protein Metabolism

Serum total protein levels were lower in rats with intestinal resection than in their controls (transected) when they were fed the standard or the cow milk-based diet ($P < 0.001$), although there were no differences when the animals were fed the goat milk-based diet.

Table 3. Digestive and metabolic utilization of protein in transected and resected rats fed on standard nonmilk or milk diets (cow or goat).¹

Group	n	N intake (mg/d)	Fecal N (mg/d)	Absorbed N (mg/d)	ADC ² (%)	Urinary N (mg/d)	N balance (mg/d)	% R/I ³
T - S ⁴	11	611.03 ± 19.51 ^a	35.45 ± 0.81 ^{a,e}	575.59 ± 18.94 ^a	94.17 ± 0.13 ^{a,e}	381.46 ± 11.69 ^a	194.13 ± 11.69	31.76 ± 1.60 ^a
R - S ⁴	13	629.50 ± 21.14 ^b	39.04 ± 1.89 ^{b,f}	590.46 ± 21.41 ^b	93.71 ± 0.39 ^{b,f}	405.75 ± 17.25 ^b	184.71 ± 12.55	29.18 ± 1.67 ^b
T - C ⁴	10	618.29 ± 14.89 ^c	39.75 ± 1.17 ^{c,g}	578.54 ± 14.95 ^c	93.54 ± 0.24 ^{c,g}	378.26 ± 10.87 ^c	200.28 ± 12.37	31.75 ± 1.59 ^c
R - C ⁴	11	664.29 ± 17.27 ^d	50.30 ± 1.68 ^d	613.89 ± 16.20 ^d	92.44 ± 0.20 ^d	433.64 ± 20.24 ^d	180.35 ± 11.94	27.33 ± 2.40 ^d
T - G ⁴	14	493.61 ± 10.27	21.14 ± 1.00	472.47 ± 9.67	95.73 ± 0.16	261.79 ± 7.82	210.68 ± 7.86	44.56 ± 1.24
R - G ⁴	10	512.01 ± 18.74	25.12 ± 2.46	486.89 ± 16.55	95.19 ± 0.36	281.99 ± 16.85	204.86 ± 13.33	40.29 ± 2.40

¹All data are expressed as mean ± SEM values.²Apparent digestibility coefficient.³Retention/intake.⁴T = Transected, R = Resected, S = Diet S, C = Diet C, G = Diet G.^aT-S and T-G; ^bR-S and R-G; ^cT-C and T-G; ^dR-C and R-G; ^eT-S and T-C; ^fR-S and R-C; ^gT-C and R-C.

Table 4. Parameters relationed with protein metabolism in transected and resected rats fed on standard nonmilk or milk diets (cow or goat).¹

	T – S ² (n = 11)	R – S ² (n = 13)	T – C ² (n = 10)	R – C ² (n = 11)	T – G ² (n = 14)	R – G ² (n = 10)
Total protein (g/L)	0.60 ± 0.011 ^{a,b,c}	0.56 ± 0.006 ^{d,e}	0.56 ± 0.013 ^{f,g}	0.51 ± 0.006 ^h	0.64 ± 0.010	0.64 ± 0.008
Urea (mg/L)	3.39 ± 0.15	3.38 ± 0.13	3.16 ± 0.098	3.10 ± 0.14	3.24 ± 0.097	3.29 ± 0.15

¹All data are expressed as mean ± SEM values.

²T = Transected, R = Resected, S = Diet S, C = Diet C, G = Diet G.

^aT-S and R-S; ^bT-S and T-C; ^cT-S and T-G; ^dR-S and R-C; ^eR-S and R-G; ^fT-C and R-C; ^gT-C and T-G; ^hR-C and R-G.

Moreover, this diet produced the highest levels of total protein, followed by the standard diet and finally the cow milk diet, in both groups of animals (total protein G > S > C) (Table 4).

On the other hand, the urea serum levels did not show any significant differences in the intestinal resection effect or in the type of diet assayed and were within the range reported by other investigators (Table 4).

ADC and the Magnesium Balance

The magnesium ADC was lower in rats with intestinal resection than in the control group (transected) when standard ($P < 0.05$) or cow-milk based diets ($P < 0.01$) were consumed. However, when rats were fed the goat milk diet, there were no differences for magnesium ADC between the two animal groups (Table 5).

Comparison of the different diets assayed shows that the magnesium ADC was higher for the two animal groups (T and R) fed the goat milk-based diet with respect to the standard (T and R: $P < 0.001$) and cow milk (T: $P < 0.05$ and R: $P < 0.001$) diets, which showed similar magnesium ADC values (magnesium ADC: G > C = S) (Table 5).

With regard to the magnesium balance, there were no differences between the transected and resected animals for any of the three diets assayed or for the

type of diet given (magnesium balance: G = S = C) (Table 5).

Magnesium Content in Different Organs

The magnesium content in the femur and sternum was not affected by intestinal resection in the animals fed the goat milk-based diet. However, when rats were given the standard diet, the magnesium content in the femur decreased due to the resection effect ($P < 0.01$), and when animals were fed the cow milk diet resection diminished magnesium content in the sternum ($P < 0.01$). Consumption of the goat milk diet favored magnesium storage in bone (femur and sternum) in animals with intestinal resection with respect to the other diets assayed ($P < 0.001$, except RS-RG; $P < 0.05$ in sternum) (Table 6). The same tendency was observed in the transected animals group.

In general, the magnesium content in the other organs studied (testes, kidney, *longissimus dorsi* muscle, heart, spleen, liver, and brain) was scarcely affected by intestinal resection, although among the rats fed the goat milk-based diet, the group with intestinal resection had higher levels of magnesium in the testes, kidney, muscle, and brain (Table 6).

The magnesium content in the blood was similar in all the control animals (transected) for the three types of diets assayed, but in the resected rats, it was lower

Table 5. Digestive and metabolic utilization of magnesium in transected and resected rats fed on standard nonmilk or milk diets (cow or goat).¹

Group	n	Mg intake (mg/d)	Fecal Mg (mg/d)	Absorbed Mg (mg/d)	ADC ² (%)	Urinary Mg (mg/d)	Mg balance (mg/d)
T – S ³	11	8.79 ± 0.28 ^a	3.80 ± 0.31 ^e	4.99 ± 0.26 ^{a,e}	57.00 ± 2.73 ^{h,e}	1.25 ± 0.31 ^{a,e}	3.74 ± 0.37
R – S ³	13	8.99 ± 0.31 ^b	4.40 ± 0.17 ^{b,f}	4.59 ± 0.24 ^{b,f}	50.89 ± 1.53 ^f	1.24 ± 0.10 ^{b,f}	3.35 ± 0.19
T – C ³	10	10.62 ± 0.26 ^c	4.10 ± 0.25 ^{c,g}	6.51 ± 0.24 ^c	61.43 ± 2.01 ^{c,g}	3.14 ± 0.42	3.37 ± 0.40
R – C ³	11	11.33 ± 0.27 ^d	5.28 ± 0.21 ^d	6.05 ± 0.29	53.32 ± 1.74 ^d	3.07 ± 0.34	2.98 ± 0.35
T – G ³	14	8.53 ± 0.18	2.77 ± 0.16	5.76 ± 0.19	67.55 ± 1.74	1.98 ± 0.20 ⁱ	3.78 ± 0.22
R – G ³	10	8.84 ± 0.32	2.68 ± 0.31	6.16 ± 0.14	70.42 ± 2.84	2.67 ± 0.16	3.49 ± 0.21

¹All data are expressed as mean ± SEM values.

²Apparent digestibility coefficient

³T = Transected, R = Resected, S = Diet S, C = Diet C, G = Diet G.

^aT-S and T-C; ^bR-S and R-C; ^cT-C and T-G; ^dR-C and R-G; ^eT-S and T-G; ^fR-S and R-G; ^gT-C and R-C; ^hT-S and R-S; ⁱT-G and R-G.

Table 6. Magnesium concentration in several organs (mg/g dry weight) and blood in transected and resected rats fed on standard nonmilk or milk diets (cow or goat).¹

	T - S ² (n = 11)	R - S ² (n = 13)	T - C ² (n = 10)	R - C ² (n = 11)	T - G ² (n = 14)	R - G ² (n = 10)
Femur	5.01 ± 0.11 ^a	4.46 ± 0.15 ^b	4.96 ± 0.08	4.72 ± 0.19 ^c	5.31 ± 0.23	5.56 ± 0.25
Sternum	2.31 ± 0.04 ^d	2.29 ± 0.04 ^b	2.51 ± 0.04 ^e	2.36 ± 0.03 ^c	2.49 ± 0.02	2.48 ± 0.03
Testes	1.01 ± 0.10	0.83 ± 0.05 ^b	0.96 ± 0.02	0.91 ± 0.02 ^c	0.95 ± 0.02 ^h	1.10 ± 0.07
Kidney	0.76 ± 0.01	0.75 ± 0.01 ^f	0.76 ± 0.02 ^e	0.71 ± 0.01 ^c	0.82 ± 0.02	0.87 ± 0.03
Muscle L.D.	0.74 ± 0.03	0.71 ± 0.03 ^b	0.72 ± 0.02	0.71 ± 0.02 ^c	0.78 ± 0.02	0.81 ± 0.01
Heart	0.83 ± 0.01 ^{d,g}	0.79 ± 0.02 ^f	0.76 ± 0.01 ^e	0.72 ± 0.02 ^c	0.73 ± 0.01 ^h	0.78 ± 0.01
Spleen	0.74 ± 0.02 ^d	0.73 ± 0.02	0.66 ± 0.01 ^e	0.73 ± 0.01	0.74 ± 0.01	0.75 ± 0.01
Liver	0.66 ± 0.02	0.69 ± 0.02	0.65 ± 0.01	0.68 ± 0.02	0.65 ± 0.01 ^h	0.71 ± 0.01
Brain	0.59 ± 0.02	0.58 ± 0.02 ^b	0.55 ± 0.02	0.60 ± 0.02 ^c	0.60 ± 0.01 ^h	0.66 ± 0.02
Blood (mg/dL)	8.33 ± 0.31	8.35 ± 0.32 ^f	7.80 ± 0.22	7.33 ± 0.16 ^c	8.58 ± 0.39	9.08 ± 0.48

¹All data are expressed as mean ± SEM values.²T = Transected, R = Resected, S = Diet S, C = Diet C, G = Diet G.^aT-S and R-S; ^bR-S and R-G; ^cR-C and R-G; ^dT-S and T-C; ^eT-C and R-C; ^fR-S and R-C; ^gT-S and T-G; ^hT-G and R-G.

for the animals fed the cow milk diet in comparison with those consuming the goat milk diet ($P < 0.001$) and the standard diet (without milk) ($P < 0.05$). In this respect, no differences were found between the latter two diets (Table 6).

DISCUSSION

The rats with intestinal resection (50% DSI) consumed practically the same quantity of diet as did the transected animals. This seems to be due to the fact that resected animals tend to satisfy their caloric requirements by increasing food intake and thus compensate for the absence of half of the small intestine. These findings coincide with those of Coves et al. (1991). The type of diet given influences intake, and so the goat milk diet is consumed in smaller volumes. This might be because of the special organoleptic characteristics of this milk, which has an intense aroma, a strong flavor and a slightly salty taste (Jandal, 1996). Despite the lower food intake by the rats given the goat milk diet, there were no differences in weight gain between the different experimental groups. This fact is explained not only by the greater PER found in the two groups of animals fed the goat milk diet, but also due to their greater food conversion efficiency (FCE), particularly among the resected group. The latter could be a consequence of the better digestive utilization of the fat in the goat milk diet (Alfrez et al., 2001). Previous studies (Barrionuevo et al., 1980) have shown that resection of 50% DSI leads to a decrease in the digestive and metabolic utilization of protein. In the present study, however, the control and resected animals presented the same protein ADC for the standard and goat milk diets, with slightly lower values being recorded for the resected animals given

the cow milk diet, with respect to the control group. The proportion of protein supplied (20%) was higher than the 12% used by Lpez-Aliaga (1989). According to Alfrez et al. (1990), increased levels of protein in the diet led to increased absorption rates, up to the level at which they stabilize. On the other hand, the animals with intestinal resection present a strong degree of adaptation of the remaining segments (the duodenum and part of the jejunum), increasing the percentage of nutrients absorbed per centimeter and gram of intestinal mucosa, as also occurs with some minerals (magnesium and calcium) (Lisbona et al., 1994; Alfrez et al., 1996). Furthermore, there is an increase in the absorption of macronutrients such as fat (Alfrez et al., 2001) and possibly, too, the protein. These effects could explain why, in animals with intestinal resection, the protein ADC is similar to that of the control animals when dietary protein increases. Thus, the goat milk diet favors digestive utilization and balance protein, with respect to the other two diets, and this is reflected in the higher PER, because these rats consume a lower quantity of the diet, and thus less protein; nevertheless, they grow at the same rate as do the animals given the other two diets and which consume greater quantities. The protein in goat milk is mainly casein, as is the case in cow milk and in the standard diet; however, the casein in goat milk is more soluble than that in cow milk (Boza and Sanz-Sampelayo, 1997) and therefore is absorbed more easily. This is of interest because it indicates that the protein quality of goat milk is better than that of cow milk, as is also shown in the different parameters studied.

With respect to the biochemical parameters related to protein metabolism, the serum levels of total protein were lower in the resected than in the transected animals when the standard and the cow milk diets were

consumed, possibly as a consequence of the lower rate of nitrogen retention with respect to nitrogen intake. This, however, did not occur when the animals consumed the goat milk diet.

The digestive utilization of magnesium was affected by resection of 50% DSI among the rats given the standard and the cow milk diets. So, the magnesium ADC decreased among the resected animals with respect to their controls by almost 11% for those given the standard diet and by 13% for the cow milk diet. However, among the animals that consumed the goat milk diet, the magnesium ADC was of the same order for the two groups of animals (T and R). Previous studies by López-Aliaga et al. (1991) showed that intestinal resection (50% DSI) reduces the ADC for magnesium by 42% with respect to the control group. Several factors might explain this lower effect of intestinal resection on magnesium ADC for the standard and the cow milk diets, and the nil effect for the goat milk diet. Firstly, it should be taken into account that the level of protein (20%) and fat (10%) provided by the three diets assayed is practically double that used in previous studies (12% protein and 4% fat) (López-Aliaga et al., 1991). According to Pallarés et al. (1996), increased proportions of protein in the diet favor magnesium absorption. Furthermore, the magnesium in the small intestine is preferentially absorbed in the distal zone, but especially in the proximal colon (Lisbona et al., 1994; Shiga et al., 2001), and the latter segment remains after resection of 50% DSI. Moreover, previous studies (Lisbona et al., 1994) have found that after resection of the distal small intestine, the proximal colon undergoes an adaptation process that leads to an increase in the absorption capacity per unit of length (cm) and per gram of intestinal mucosa, especially when the animals are given a diet in which the fat source comprises 33% MCT and contains a supplement of vitamin D₃. Thus, these animals may present an increased magnesium absorption capacity both because of the greater quantity of protein in the diet (20%) and because of the higher quality resulting from its animal origin (Pérez-Llamas et al., 2001). These facts could contribute to improved digestive utilization of magnesium among the rats with intestinal resection.

With respect to the effect of the fat content in the diet (20%), this is practically double that recommended for rats by the AIN (1977). According to Van Dokkum et al. (1983), the level of fat in the diet influences magnesium ADC because fatty acids have a greater tendency to form soaps with calcium than with magnesium. Furthermore, the recent study by Alférez et al. (2001) found that an increased lipid proportion of the diet improves the digestive utilization of fat in animals

with resection of 50% DSI, approaching the ADC of the control animals. In the light of these results, the resected rats have easier access to the ATP necessary in absorption mechanisms due to the active transport of magnesium, which lead to an increase in its digestive utilization. Concerning the type of diet used, the goat milk diet gave the best results for ADC and magnesium balance, both among the resected animals and the control group (transected) with respect to the cow milk and standard diets. The magnesium content in goat milk is slightly higher (140 mg/L) than in cow milk (120 mg/L) (Souci et al., 1989). The bioavailability of magnesium in goat milk could be greater than that of cow milk, for various reasons: first, goat milk contains greater quantities of vitamin D than does cow milk (Jandal, 1996; Souci et al., 1989) and taking into account the results obtained by Lisbona et al. (1994), this might contribute to the higher magnesium ADC in animals fed the goat milk diet. Furthermore, considering the quality of the fat in the different diets (standard diet: olive oil; cow milk diet: cow milk fat; goat milk diet: goat milk fat), the MCT content in the goat milk is higher (36%) in comparison with the 21% of the cow milk and the 0% of the standard diet. According to Tappenden et al. (1997) short-chain fatty acids favor intestinal adaptation after resection, probably due to the increased quantity of the other nutrients transported through the basolateral membrane of the enterocyte. It is possible that medium-chain fatty acids (abundant in goat milk), which are absorbed into the intestinal cells without reesterification, directly entering portal circulation, have the same effect on intestinal adaptation. Thus, not only is energy retention favored directly by the presence of MCT in the diet, but it could also increase as a consequence of the greater absorption of the other nutrients in the diet, such as magnesium.

Additionally, according to Lutz (1991), long-chain fatty acids slightly reduce the magnesium absorption, but short-chain fatty acids stimulate its absorption in the colon, and MCT probably have a similar effect.

The bone (femur and sternum) is the preferential organ for the deposit of magnesium among the transected and resected animals given the three types of diet, which is in accordance with results given in the literature (Shils, 1996). Intestinal resection reduces the level of magnesium in the femur for animals given the standard diet, as found in earlier studies (López-Aliaga et al., 1991); however, the milk-based diets (cow or goat milk) minimize the differences between transected and resected animals, and the values are practically of the same order. Milk, therefore, and dairy products in general, favor the deposit of divalent cations such as calcium and magnesium (Boza and Sanz-Sam-

pelayo, 1997), which agrees with the results obtained in the present study, particularly those for goat milk, possibly due to its special characteristics concerning lipid composition (rich in MCT) and the vitamin D content. Both factors favor the absorption and deposit of magnesium in the femur, in transected and resected animals (López-Aliaga et al., 1991; Lisbona et al., 1994).

With respect to the levels of magnesium found in the other organs studied (testes, kidney, liver, spleen, brain, heart, and *longissimus dorsi* muscle), these show that intestinal resection, as well as when the standard or the cow milk-based diets are consumed, hardly affects the deposit of magnesium; however, when the rats consumed the goat milk-based diet, the magnesium deposited in the testes, kidney, muscle, and brain was higher in the resected animals, probably due to the greater digestive utilization of this mineral, as described previously.

With respect to the levels of magnesium in the blood, the animals given the goat milk diet presented a higher quantity of magnesium in the erythrocytes, particularly so the resected animals, due to its greater digestive utilization, which again reveals the beneficial effect of consuming this type of milk, which prevents magnesium deficiency after intestinal resection.

In our experimental conditions, the magnesium content in organs and blood remains within the range reported by Pallarés et al. (1996).

CONCLUSIONS

In conclusion, this study reports the beneficial effect of goat milk on the nutritive utilization of protein and magnesium, especially in rats with resection of the distal small intestine.

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