Zinc Metabolism and Homeostasis in Ruminants as Affected by Dietary Energy Intake and Growth Rate[1] (37053)

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It is well established that the essential element zinc (Zn) is associated with and functions as an integral part of protein and enzyme systems in animal tissues (1, 2). Zinc-deficient animals consume less feed, grow more slowly, have a lower efficiency of feed utilization and a reduced nitrogen and sulfur balance compared to those given adequate dietary Zn (3). The reduced feed efficiency is due to lower utilization after digestion and not to decreased digestibility (4).

Zinc absorption and retention are regulated by homeostatic mechanisms (5) which respond to changes in dietary zinc level and probably is controlled at the cellular level. The exact nature of this control is unknown.

The relationship between energy intake and nitrogen utilization is well established (6). Reduced energy intake decreases growth and is reflected in reduced protein deposition and nitrogen retention. Thus it is hypothesized that if Zn homeostasis is controlled at the tissue level, and is associated with protein deposition, a reduced growth rate should decrease the absorption and retention of dietary Zn both in milligrams per day and as a percentage of intake. Likewise, nitrogen balance and Zn retention should be correlated. This study was designed to test this hypothesis by determining the effects of reducing dietary energy and protein intake on stable Zn and ^{65}Zn metabolism and their relationship to nitrogen balance.

Methods and Materials. Sixteen male Holstein bull calves, averaging 89 kg initial weight and 70 days of age, were randomly assigned to 4 treatment groups of 4 calves each. Each group was fed one of 4 diets (Table I) for 21 days. In treatment I (control, 34 ppm Zn) feed intake was 2.8% of body weight, with intake for the other 3 treatment groups restricted to 1.4% of body weight. Treatment II received approximately a maintenance level of intake, with treatment III identical to treatment II except that Zn, as ZnO, was added to provide 66 ppm and thus approxi-

TABLE I. Experimental Diets Utilized to Study Effect of Energy and Protein Intake on Zinc Homeostasis.

	Basal[a]	High fiber–low protein[b]
Ingredients (%)		
Corn grain	64.2	6.0
Soybean meal	22.1	4.0
Citrus pulp	5.0	
Cottonseed hulls	5.0	86.3
Vitamin–mineral–antibiotic premix[c]	2.7	2.7
Salt–trace mineral mix[d]	1.0	1.0
Analysis		
Crude protein (%)	16.7	6.0
Crude fiber (%)	6.0	41.5
Digestible energy (Mcal/kg)	3.63	2.02

[a] Treatments I and II consisted of basal diet (34 ppm Zn on D. M. basis) and treatment III consisted of basal diet plus 32 ppm Zn (total 66) as ZnO.

[b] Treatment IV consisted of high fiber–low protein diet plus 32 ppm Zn as ZnO for a total of 66 ppm on a D. M. basis.

[c] Vitamin A palmitate (20,000 IU/g), 100 g; vitamin D_3 (200,000 IU/g), 1.0 g; dicalcium phosphate (anhydrous, foodgrade), 454 g; $CaCO_3$ (marble dust), 650 g; oxytetracycline (5.5%), 40.0 g.

[d] 450 g of mixture consisting of: NaCl, 4.54 kg; $(Fe)_2(SO_4)_3 \cdot XH_2O$ (72% Fe by assay), 80.0 g; $MnSO_4 \cdot H_2O$, 14.0 g; $CuSO_4 \cdot 5H_2O$, 10.0 g; $CoCO_3$ (41% Co by assay), 120 mg; KI, 80 mg.

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TABLE II. Digestible Energy Intake, Nitrogen Balance, and Stable Zinc Intake and Retention of Calves Fed Different Levels of Energy and Protein.

	Treatment				
	I	II	III	IV	SE[a]
Digestible energy intake (Mcal/day)	8.4	4.3	4.3	2.5	
Wt change (g/day)	400	-190	-80	-355	
Nitrogen balance (g/day)	31[b]	9[c]	11[c]	-8[d]	3
Zinc intake					
mg/day	69.5	38.4	74.7	80.9	
% of control group	100	55	107	116	
Zinc retention					
mg/day	36.4[e]	11.9[f]	19.7[f]	17.0[f]	4.1
% of intake	52.4[g]	31.0	26.4	21.0	8.4
% of control group	100	59	50	40	

[a] Standard error; $N = 4$.

[bcd] Means not sharing common superscript are significantly different ($p < .01$).

[ef] Means not sharing common superscript are significantly different ($p < .05$).

[g] The treatments were statistically different at the following percentages: I vs II, III, or IV ($p < .025$); II vs III ($p < .38$); II vs IV ($p < .17$); and III vs IV ($p < .39$).

mate the total Zn intake (mg/day) of controls. Treatment IV was a submaintenance, low protein–high fiber diet, with added ZnO to total 66 ppm. An oral tracer dose of ^{65}Zn was administered on Day 8, with total daily collection of feces and urine from Days 8–21.

Fecal ^{65}Zn activity was determined with an automatic gamma test tube changer with a NaI (TI) well crystal. Feed, fecal, and urinary nitrogen were determined by the Kjeldahl method. Fecal and feed zinc were determined by atomic absorption spectroscopy, with nitric–perchloric–sulfuric acid wet-ashing of samples.

Results. The reductions in energy and protein intake of treatments II, III, and IV were reflected in the expected lower daily weight changes and nitrogen balances (Table II). These were accompanied by lower stable Zn (as percentage of intake) and average ^{65}Zn absorption and retention (Tables II and III). When feed intake was reduced by 50% and the dietary Zn content remained the same (34 ppm), stable Zn retention, as a percentage of intake, was substantially reduced, with a further reduction in retention when total Zn intake was raised to equal that of controls (treatment III). A further reduction in energy and protein intake to a submaintenance level (treatment IV) resulted in even lower zinc absorption and retention. The decrease in percentage of stable zinc retained with additional dietary Zn (treatments III vs II) no doubt was due to homeostatic control, and is in agreement with previous work (5).

Comparison of the other 3 treatments with the controls shows a reduced ^{65}Zn retention associated with decreasing the energy intake to near maintenance, with further reductions in retention on the high fiber–low protein submaintenance diet (Table III).

Correlation coefficients were determined between stable Zn retention (as a percentage of intake) and ^{65}Zn retention (as a percentage of dose) with nitrogen balance. Nitrogen balance and stable Zn retention were highly correlated ($r = 0.67$). ^{65}Zn retention and ni-

TABLE III. Effect of Different Energy and Protein Intake on ^{65}Zn Retention from a Single Oral Dose (% of Dose).

	Treatment			
After dose (days)	I	II	III	IV
1–4	56.4	58.0	52.8	48.1
1–7	48.6	42.8	35.8	32.9
1–10	45.5	36.4	30.2	27.6
1–14	43.6	32.7	27.0	25.4
Decrease from control, % for 1–14 day period		25	38	42

trogen balance had a lower, yet definite, correlation ($r = 0.49$).

Discussion. As growth rate and nitrogen balance decreased, both stable Zn and ^{65}Zn retention declined. Thus, the homeostatic control mechanism(s) for Zn metabolism was influenced by growth status of the animals, which was a function of energy and protein intake. The homeostatic control mechanism shown previously (2, 5) was evident since ZnO addition to a diet of the same energy and protein (treatment III vs II) further decreased the percentage of the zinc retained. In this study, Zn deposition was directly correlated with protein deposition as demonstrated by the correlations of Zn retention and nitrogen balance.

These data support the hypothesis that Zn homeostatic control is dependent upon metabolic changes occurring at the cellular level and that these are related to protein deposition. This phenomenon may provide an explanation for some previously unexplained results. For example, a metabolic load of cadmium (Cd) greatly reduced ^{65}Zn absorption in calves and goats, but did not reduce tissue Zn content (7). However, the Cd treatment substantially reduced feed intake and, undoubtedly, also growth and protein deposition. The current studies suggest the Cd effect probably was indirect, operating through Zn homeostasis and the relationship to protein deposition shown here.

Summary. Decreasing energy and protein intake in young ruminants resulted in lower weight gain and nitrogen balance. This was accompanied by reduced stable zinc absorption and retention both as milligrams/day and as a percentage of intake. Similarly, ^{65}Zn absorption and retention were reduced. Nitrogen balance was well correlated with stable zinc and ^{65}Zn retention ($r = 0.67$ and 0.49, respectively). These data support the concept that regulation of zinc homeostasis is controlled at the tissue level and is closely related to protein deposition changes.

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