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Bone Mobilization in Transition Cows

This article is written in the spirit of **June is Dairy Month**.

Calcium and phosphorus are essential nutrients in the diet of dairy cows. Research since the mid-20th century has more precisely defined the daily dietary mineral requirements for lactating dairy cows. The factorial approach used looks at the total of maintenance, lactation, pregnancy and growth requirements of dairy cows corrected for nutrient absorption coefficients (NRC, 2001). However, the 2001 NRC requirements did not consider calcium and phosphorus mobilization from bones in its models.

Calcium and phosphorus are nutrients many studies have looked at when determining nutrient requirements for maintenance, production/lactation, reproduction and health, particularly in high-producing dairy cows. Phosphorus homeostasis (balance) is closely related and secondary to calcium homeostasis. The hormonal control of phosphorus is not entirely understood. Calcium metabolism is regulated by parathyroid hormone and vitamin D metabolites. The hormone and metabolites stimulate bone resorption of these two nutrients in response to hypocalcemia (low blood calcium).

In the intestine these nutrients are primarily passively diffused across the intestinal membrane when diets contain sufficient amounts of the nutrients. Hypophosphatemia (low blood phosphate) and hypocalcemia along with the parathyroid hormonal control can independently induce vitamin D metabolites to be broken down. The metabolites promote active transport of the nutrients across the intestinal epithelial cells. Lactation studies with marginal dietary phosphorus concentrations assume cows function adequately with nutrient deficiency during the early stages of lactation.

Regardless of the cause for a calcium absorption (physiological or dietary), it is thought that between 0.8 and 1.3 kg of calcium can be mobilized from bones to cope with the absorption deficiency and with nutrient demands of high milk production in early lactation. During the first 10 days of lactation, most cows are in negative calcium balance. This is due to the slow adaptation of calcium absorption mechanisms in response to the sudden increase in the calcium demand for milk production after calving. The balance is usually restored between 45 and 60 DIM.

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Most body calcium is stored in bones and most phosphorus in the body is stored as hydroxyapatite and calcium phosphate in the bones as well at a ratio of 1.67:1 calcium to phosphorus. Just as calcium is mobilized from the bones, we can assume phosphorus is mobilized along with calcium at a similar rate. The estimate is that 0.5 to 0.8 kg of phosphorus may be mobilized from bone resorption during the first few weeks of lactation. This mobilized phosphorus may result in 26 to 42 kg of milk per day having phosphorus secreted into it during the first 21 days of lactation.

Research methodology:

Researchers at Louisiana State University conducted a study to understand the influence of dietary calcium and phosphorus levels on performance and bone metabolism markers of cows during the first month of lactation. The study involved 52 multiparous cows (3 lactations or more) grouped by calving date in 13 blocks of four cows each. The cows were brought into the barn at least 20 days before their expected calving date and stayed in the study until the last cow in the block reached 30 DIM. The treatment diets were fed to the cows beginning 3 days after calving.

The treatment diets were high calcium-high phosphorus (**HCaHP**), high calcium-low phosphorus (**HCaLP**), low calcium-high phosphorus (**LCaHP**) and low calcium-low phosphorus (**LCaLP**). The high and low descriptors indicate the nutrient concentrations were above and below the respective predicted requirements. Based on the actual ingredient analyses, the average nutrient contents were calculated on a dry matter basis to be 0.64% (high) and 0.46% (low) for calcium and 0.47% (high) and 0.38% (low) for phosphorus. Calcium, magnesium and potassium were determined in the feed samples and the calcium content of collected fecal samples was recorded. During the dry period, the basal diet (LCaLP) was fed. Most of the usual feed ingredients supplied all the phosphorus requirements for the early lactation cows on the basal diet (LCaLP).

On a daily basis, the researchers collected TMR, dry matter intake, feed refusals and corn silage samples. The samples were processed and analyzed for nitrogen, phosphorus and fiber content. Milk production was recorded at each milking. Milk samples were collected and analyzed for fat, true protein and somatic cell content from six consecutive milkings when cows in each treatment block averaged 28 days in milk. Blood samples were collected at 10 days before expected, and day one (calving date), 15 and 30 postpartum. The blood was processed and blood serum (plasma) was stored and frozen for analysis of serum bone metabolism markers. The metabolism markers used were pyridinoline (**PYD**), Metra Serum PYD (a marker of bone resorption), and Metra Osteocalcin (**OC**, a marker for bone degradation). Fecal samples were collected for three consecutive days when cows in each block averaged 20 ± 4 DIM. The weight was recorded, and samples were taken four times a day at six, 12, 18 and 24 hours after the morning TMR feeding. Apparent digestibility was determined based on the average dry matter intake collected during the seven days ending with the fecal collection. Apparent nutrient absorption was calculated to be the difference between the nutrient ingested and the nutrient fecal extraction. The total absorbable requirement for each cow was calculated based on the NRC (2001) model adjusted for body weight and milk yield.

What the research found:

The basal diet was determined lower in both Ca and P than originally designed. The nutrient content of the corn silage was 0.15% calcium and 0.25% phosphorus on a dry matter basis. In the high calcium and phosphorus diets the nutrient concentrations of calcium and phosphorus were 7 & 21% above the NRC (2001) estimated requirements. The low calcium and phosphorus diets were 35 and 9% below the NRC (2001) estimated requirements. The calcium-to-phosphorus ratio in the treatment rations were between 1:1 and 1.7:1, within the recommended range (NRC, 2001).

In terms of production, pregnant cows averaged 30.6 pounds of dry matter intake during the last three weeks of gestation. The lowest intakes were during the day before calving and on the calving date at 17 pounds. Production levels were highest during the first month of lactation with an average of more than 96.8 pounds per cow per day in multiparous cows. Calcium and phosphorus did not significantly affect feed consumption, milk yield, and yield of milk components. Milk fat yield tended to be lower in cows on the LCa diets compared to those on HCa diets.

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Cows ingested 32 grams more calcium on the HCa diets than those fed the LCa diets and fecal excretion of calcium was only 22 grams higher on the HCa diets over LCa. This implies that cows fed both the LCa and HCa diets absorbed the calcium similarly.

It is believed that calcium and phosphorus are able to independently influence the breakdown of vitamin-D_3 metabolites. It was suggested that high phosphorus levels may suppress breakdown of nutrients by α-hydroxylase in the kidneys (Horst et al., 1994). In this study, cows fed the LCaHP diets appeared to absorb calcium more efficiently than LCaLP diets. The researchers' positions were that this was due to priority being given to calcium absorption compared to the active absorption of calcium on HCa diets. This active absorption of calcium may be limited by the diminished kidney α-hydroxylase function on the HCaHP diets because of the high phosphorus levels creating negative feedback.

Phosphorus intake, fecal output (grams/day and the percent of fecal dry matter) were significantly affected by the phosphorus content of the diets. This may be the result of the cows fed LCa diets taking in 4.12 grams more phosphorus than those fed the HCa diets.

In this study, the treatment diets appeared to supply insufficient apparently absorbed calcium and phosphorus. The total absorbable requirements averaged about 76 grams of absorbed calcium and 64 grams of absorbed phosphorus per day (NRC, 2001). The treatment diets supplied 27-58% of the calcium total absorbable requirements and 57-65% or the phosphorus total absorbable requirements. By assuming that the measured apparent absorption in this study was the average for the experimental period, the researchers estimated that nutrient bone resorption was between 990 and 1,620 grams of calcium and 660 to 810 grams of phosphorus.

Protein output in feces was increased because of phosphorus intake. On the HP diets, 124 grams more crude protein was excreted by cows fed the HP diets compared to those fed LP diets. Researchers determined that the higher crude protein fecal excretion was not because of higher crude protein intake or lower milk protein yield.

Osteocalcin (bone building) is a metabolite of protein synthesis by osteoblasts (bone builders) and was used as a marker for bone formation in this study. Pyridinoline is biomarker of bone resorption that can be found in collagen type I from skin and be detected in serum (Allen, 2003). Since mature cows were used in this study and not growing cows, the presence of the pyridinoline concentration in the serum was attributed to bone resorption.

The osteocalcin concentrations in the serum were not affected by dietary calcium or phosphorus levels, but did change over the duration of the study. The concentrations were lowest immediately after calving. At 15 days postpartum, the levels returned to precalving levels (~30 ng/mL) and increased through the end of the study at 30 DIM. Around parturition, the osteocalcin concentrations in the serum may be decreased as a result of the increased parathyroid hormone in the bloodstream. The researchers expected that bone accretion (bone building) rates and the serum osteocalcin change with the dietary calcium and phosphorus contents. The demands for calcium and phosphorus in early lactation cows may be able to override their ability to absorb these nutrients from the intestines or mobilize them from bones. This study may not have been long enough to adequately detect the serum changes induced by dietary calcium or phosphorus since they would be most noticeable after milk yield peaks and dry matter intake reaches its maximum later in the lactation cycle. This is when bone stores of calcium and phosphorus are depleted or the demand for milk production over intestinal absorption supply decreases.

The pyridinoline (bone resorption) concentrations were significantly (1 n*M*) lower in cows fed HCa than those fed LCa. Overall the pyridinoline levels were lowest in cows on the HCaHP treatment diets amongst all diets. Serum pyridinoline levels were highest in cows on the LCaHP diets. At 15 DIM, the serum pyridinoline levels were similar between HP and LP levels. The concentrations of pyridinoline decreased slower on the HP treatments compared to the LP treatments from 15-30 DIM. Pyridinoline levels were lowest on calving day and reached their highest levels at 15 DIM. At 30 DIM, the concentrations returned to levels like those in cows at 10 days before calving.

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Analysis showed that the interaction between calcium and phosphorus tended to be significant and this suggests that phosphorus levels will affect bone nutrient mobilization and is dependent on the calcium levels. However, there was no significant interaction over time for calcium levels. Based on this, the researchers believe that high phosphorus levels may delay the return of the bone mobilization to basal levels when low calcium levels are fed to multiparous cows. The results of this study suggest that bone resorption was probably stimulated soon after late-gestation cows were offered the standard nonlactating cows' TMR in this study and that larger pyridinoline concentrations were released in the bloodstream.

The metabolism of calcium and phosphorus is an integral process in lactating cows. It is assumed that high calcium levels in the diet should increase the supply of calcium available for milk production. The increased availability decreases needs of the cows' bodies to mobilize bone nutrients in early lactation phases. Hypocalcemia and low phosphatemia both independently stimulate the kidneys' production of vitamin-D_3 metabolites or to enhance the capability of intestinal receptors to bind those metabolites. Conversely, the absorption of calcium through the intestines may be limited when levels of excess phosphorus suppress the activity of the α-hydroxylase of the enzymes most responsible for the production of the metabolites. Dietary phosphorus may influence the intestinal absorption of calcium by influencing the breakdown of vitamin-D_3 metabolites in the kidneys or the by changing the capability of intestinal receptors to bind those metabolites.

What this means on a practical level:

In this study, the apparent absorption of calcium was higher and the serum concentrations of pyridinoline (resorption) were lower in cows fed high calcium diets. Specifically, on HCaLP diets, higher absorption of calcium was observed, but the pyridinoline levels were similar between the high and low phosphorus levels of the high calcium diets. This research suggests that cows deficient in calcium can override a negative phosphorus feedback, but that calcium absorption in LCaHP diets was ineffective in reducing bone resorption. These nutrient levels (calcium and phosphorus) independently influence bone resorption in early lactation dairy cows.

Dietary calcium and phosphorus did not significantly influence feed intake, milk yield or milk components yield during the first month of lactation. However, calcium intake did negatively affect the concentrations of serum of pyridinoline (for bone resorption). Bone resorption was higher in cows fed 100 g of phosphorus/day. This was evident through a calcium and phosphorus interaction over time as an extended period of high serum pyridinoline levels. Dietary calcium did not influence phosphorus digestion. These results suggest that phosphorus can be and should be reduced in early lactation, high producing cows to allow for the more efficient utilization of dietary calcium.

Information for this article was taken from:

Moreira, V.R., L.K. Zeringue, C.C.Williams, C. Leonardi, and M.E. McCormick. 2009. *Influence of calcium and phosphorus feeding on Markers of bone metabolism in transition cows.* Journal of Dairy Science. 92:5189-5198. doi: 10.3168/jds.2009-2289.

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