Mineral Problems Facing the Fresh Cow

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Introduction

Efficient milk production continues to require the dairy cow to experience gestation and parturition each yr. The transition from pregnant, nonlactating to non-pregnant, lactating is too often a disastrous experience for the cow. Most of the metabolic diseases of dairy cows—milk fever, ketosis, retained placenta, and displacement of the abomasum—occur within the first 2 wk of lactation. The etiology of many of those metabolic diseases that are not clinically apparent during the first 2 wk of lactation, such as laminitis, can be traced back to insults that occurred in early lactation. In addition to metabolic disease, the overwhelming majority of infectious diseases, especially mastitis, but also diseases such as Johne's disease and Salmonellosis, become clinically apparent during the first 2 wk of lactation. The well-being of the cow and her profitability could be greatly enhanced by understanding those factors that account for the high disease incidence in periparturient cows.

The bovine feto-placental mass and its demand for energy, protein, and minerals increases dramatically with increasing gestational age. By the end of gestation, daily development of the fetus requires about 0.82 of Mcal NeL, 117 g of protein, 10.3 g of calcium, 5.4 g of phosphorus, and 0.2 g of magnesium (NRC, 2001). However, the metabolic demands imposed on the cow by the formation of colostrum far exceed the demands of the fetus. The production of just 10 kg of colostrum the d of calving will require that 11 Mcal NeL, 140 g of protein, 23 g of calcium, 9 g of phosphorus, and 1 g magnesium be supplied from the diet or brought in to the mammary gland from body stores. The high demand for nutrients imposed on the body by the increased activity of the mammary gland cannot always be met, resulting in development of such metabolic diseases as milk fever and the ketosis-fatty liver complex.

The act of parturition and the onset of lactation impose tremendous physiologic challenges to the homeostatic mechanisms of the cow. This review will attempt to describe what is known and, maybe more importantly, what is unknown about the physiologic changes occurring in the periparturient dairy cow and their relationship to development of disease.

Hypocalcemia and Milk Fever

Hypocalcemia, especially if it is severe enough to cause milk fever, will begin a cascade of secondary problems in the fresh cow. Hypocalcemia (low blood calcium, not just milk fever) impairs abomasal contractions increasing the chance for displacement of the abomasums. It can also prevent the teat sphincter from closing after milking allowing bacteria access to the mammary gland resulting in more mastitis. The stress of hypocalcemia causes secretion of cortisol which further impairs the immune system of the fresh cow. Milk fever and low blood calcium reduce feed intake, increasing the risk of ketosis in the cow as well.

We now believe that hypocalcemia occurs because the dairy cow is in an alkaline blood condition, largely because of the high potassium content of the forages utilized in close-up cow rations. A second major cause of hypocalcemia is inadequate magnesium absorption from the close-up and fresh cow rations leading to low

blood magnesium concentration. We believe that when blood magnesium is marginally low it interferes with the body's ability to regulate blood calcium concentration.

Dietary Cation-Anion Difference and Acid-Base Status

The difference between the total number of non-metabolizable cations and anions in the blood is referred to as the Strong Ion Difference. Strong Ions enter the blood from the digestive tract making the cation-anion difference of the diet the ultimate determinant of blood Strong Ion Difference. Once absorbed the concentration of Strong Ions in the blood is regulated by the kidneys. Adjustment of the Strong Ion Difference of the blood is slower than respiratory control of blood pH but is capable of inducing much greater changes in blood pH.

In theory all the cations and anions in the diet are capable of exerting an influence on the Strong Ion Difference of the blood. The major cations present in feeds and the charge they carry are sodium (+1), potassium (+1), Ca (+2), and Mg (+2). The major anions and their charges found in feeds are chloride (-1), sulfate (-2), and phosphate (assumed to be -3). Cations or anions present in the diet will only alter the Strong Ion Difference of the blood if they are absorbed into the blood. The trace elements present are absorbed in such small amounts that they are of negligible consequence to acid-base status. Organic acids such as the volatile fatty acids are generally absorbed in the undissociated form so that they carry both a positive and negative charge into the blood. They also are rapidly metabolized within the liver so they have only a small effect on blood pH under most circumstances. However in the case of lactic acidosis the lactate anion can build-up in the blood of the affected animal and cause severe metabolic acidosis.

The difference between the number of cation and anion particles absorbed from the diet determines the pH of the blood. The cation-anion difference of a diet is commonly described in terms of mEq/kg of just sodium, potassium, chloride, and sulfate as follows:

Dietary Cation – Anion Difference (DCAD) = $(Na^+ + K^+) - (Cl^- + S^{--})$.

This equation is useful, although it must be kept in mind that Ca, Mg, and P absorbed from the diet will also influence blood pH. We have evaluated the relative acidifying activity of various anionic salts by feeding them to dry cows and evaluating their ability to reduce urine pH (which reflects the changes in blood pH). These data lead us to believe the DCAD of a diet and its acidifying activity is more accurately described by the following equation:

$$(0.2\ Ca^{++} + 0.16\ Mg^{++} + Na^+ + K^+) - (Cl^- + 0.6\ S^{--} + 0.64\ P^{---})$$

This equation suggests that the major dietary factors determining blood and urine pH are Na, K and Cl. It also suggests that sulfate is less acidifying than chloride, in general agreement with the findings of Oetzel et al. (49). Tucker et al (64) felt that sulfate was about 60% as acidifying as chloride. The particular coefficient is less important than the concept that chloride may be the better choice of acidifying agent. A complete equation should probably also include ammonium as this cation seems to contribute to the cation content of the blood as well , especially when certain high nitrogen grass silages are included in the diet of the cow (11).

Most nutritionists using the equation $((Na^+ + K^+) - (Cl^- + S^{--})$ have a target DCAD for milk fever prevention of about -50 mEq/kg. Using the more physiologically relevant equation, $(0.2\ Ca^{++} + 0.16\ Mg^{++} + Na^+ + K^+) - (Cl^- + 0.60\ S^{--} + 0.64\ P^{---})$, the target DCAD should still be about -50 mEq/kg. The true usefulness of the equation is that it helps you predict how certain minerals will affect the acid-base balance. For example if sodium chloride (NaCl) is fed to the cow both the sodium cation and the chloride anion are nearly 100% absorbed from the diet into the blood. The blood gains salt but since the number of positively and negatively charged particles entering the blood is the same there is no net change in electrical charge of the blood and the pH is not altered. However if calcium chloride ($CaCl_2$) is fed, approximately 15% of the calcium cation equivalents (remember calcium carries a charge of +2) will enter the blood while nearly 100% of the negatively charged chloride will enter the blood. There are more negatively charged particles entering the blood than positively charged particles and the H^+ of the blood

must increase to offset the electrical imbalance. When H+ increases, the pH decreases, meaning the blood has been acidified.

Several of the variables in the above DCAD equations are fixed reducing the usefulness of the equations when formulating rations. A strategy this author uses is to set dietary Ca at 0.8-1.0%. Then I set dietary P and Mg at 0.35-0.4 %. I keep dietary sulfur above 0.25% (to ensure adequate substrate for rumen microbial amino acid synthesis) but below 0.4% (to avoid possible neurological problems associated with sulfur toxicity (27)). The key to clinical milk fever prevention is to keep sodium and potassium as close to the requirement of the cow as you can (0.10-.15% for Na and 1.0% for potassium). The key to reduction of subclinical hypocalcemia is to then add chloride to the ration to counteract the effects of even low levels of potassium on blood alkalinity. In practice we find that the level of chloride needed will be about 0.5% less than the level of potassium. So if the lowest ration potassium that can be achieved is 1.4% K then the amount of chloride needed to acidify the cow properly will be approximately 0.9%. There is a limit to the amount of chloride a cow will ingest so it is important to reduce diet potassium and important to choose a palatable source of chloride when manipulating DCAD. Traditionally this was done by adding anionic salts such as ammonium chloride, calcium chloride, or magnesium sulfate to the ration. Unfortunately these salts often reduced feed intake in cows causing more problems than it was curing. We believe that chloride is a more effective acidifier than sulfate anions. We also have demonstrated that hydrochloric acid is a more effective acidifying agent than the traditional anionic salts and also appears to be more palatable. Several commercial firms are now producing anion supplements that are based on hydrochloric acid that has been dried down onto a suitable carrier to make a safe supplement. Beware that liquid hydrochloric acid creates fumes that are toxic and corrosive, making it very unsafe to use on dairies.

These are simply guidelines and are based on the setting of certain parameters at constant values as outlined above. Urine pH of the cows is a better gauge of the appropriate diet DCAD than any formula (37). Urine pH on high cation diets is generally above 8.2. Limiting dietary cations (primarily potassium) will reduce urine pH only a small amount (down to 7.8). For optimal control of subclinical hypocalcemia and milk fever the average pH of the urine of Holstein cows should be between 6.2 and 6.8, which essentially requires addition of anions to the ration. In Jersey cows the average urine pH of the close-up cows has to be reduced to between 5.8 and 6.3 for effective control of hypocalcemia. If the average urine pH of any group of cows is between 5.0 and 5.5, excessive anions have induced an uncompensated metabolic acidosis and the cows will suffer a decline in dry matter intake. Urine pH can be accurately checked 48 or more hrs after a ration change. Urine samples should be free of feces and made on midstream collections to avoid alkalinity from vaginal secretions. In cows offered feed twice / day the timing of the urine collection does not seem critical. In cows fed fresh feed just once / day the diurnal variation in urine pH can be a full pH unit. The best estimate of acid-base status in cows fed one time / day appears to be from samples obtained 6-9 hrs after fresh feed was offered.

Mg status

As already discussed the integrity of the interaction between PTH and its receptor is vital to Ca homeostasis. Hypomagnesemia (blood magnesium below 1.8 mg/100 ml plasma) is also capable of interfering with the ability of PTH to act on its target tissues. When PTH binds to its receptor this normally initiates activation of adenylate cyclase, resulting in production of the second messenger cyclic AMP, or phospholipase C, resulting in production of the second messengers diacylglycerol and inositol 1,4,5-triphosphate. Both adenylate cyclase and phospholipase C require Mg for full activity. In man, it is well recognized that hypomagnesemia can cause hypocalcemia and that Mg therapy alone restores the serum Ca concentration to normal; Ca and/or vitamin D therapy are ineffective (55).

Ordinarily, PTH will cause increased renal tubular reabsorption of Mg, so the kidneys are excreting less of the excess dietary Mg absorbed. This causes blood Mg to be elevated in the typical milk fever cow (25). However if dietary Mg is insufficient or if rumen absorption of Mg is impaired, there is no excess Mg to conserve and the plasma Mg concentration will fall below 1.85 mg/dl as a result of the lactational drain of Mg.

Sampling the blood of several cows within 12 hrs after calving is an effective index of the Mg status of the periparturient cows. If serum Mg concentration is not at least 2.0 mg/dl it suggests inadequate dietary Mg absorption and that hypomagnesemia may be contributing to hypocalcemia in the herd. Mg content of the close-up dry cow ration should be at least 0.35 - 0.4% to ensure adequate Mg absorption during this critical period.

Heifers do not need anionic salts. They may perform more poorly as a result of reduced feed intake. Again this is more of a problem when the unpalatable anionic salts are used. Ideally heifers would be fed separately from older cows—they perform better on higher protein diets, without anions, and, when housed separately, do not have to compete with cows for bunkspace. Heifers do respond to the lower potassium diets with less udder edema. When chloride is utilized as an anion source it has a diuretic effect, which may decrease udder edema in some herds. However this may not be true when ammonium chloride salts are used.

Frequently asked questions on DCAD

Are some anions better than no anions?

In my opinion—yes. But the full benefit of anion supplementation is only seen when urine pH (and blood pH) are adequately acidified. Many nutritionists are reluctant to add anions as they do not feel the urine pH will be monitored properly. They prefer to control potassium in the diet and maybe use a small amount of calcium chloride and magnesium sulfate to get adequate levels of calcium and magnesium into the ration. This is probably better than no anion program but will not give total control of subclinical hypocalcemia.

What level of calcium do I feed if I am not going to add anions to the diet?

A. If potassium can be controlled (get total ration K < 1.6% at least) then the diet calcium content does not seem critical. I like to get calcium to at least 0.8% and I will use a bit of calcium sulfate or calcium chloride to increase calcium if needed. I will not add calcium carbonate (limestone) just to reach the 0.8% Ca concentration. I would rather add no calcium than add calcium carbonate.

B. If you have no control over potassium in the diet (grazing systems are particularly hard to control) then I might consider trying to control hypocalcemia by instituting a "very low calcium" diet. For this to work the diet cannot supply more than 25 g calcium / day!! This only works when the forages are low in calcium (certain grass species that may be less than 0.35-0.4% Ca) and total feed intake is limited (grazing dry cows eat 6-8 kg / day, which is much less than confined dry cows consuming TMR, which eat 10-14 kg / day). Consuming 7 kg /d of a 0.35 % Ca grass will supply 24.5 g calcium / day. As can be seen this strategy can be difficult to implement.

Low potassium forages

The major culprit causing low blood calcium is high potassium coming into the ration from forages. Sodium is also very bad but generally is not very high in forages unless they are grown in soils that have been irrigated for a long time. FIND or GROW LOW POTASSIUM FORAGES FOR YOUR CLOSE-UP DRY COWS. Limit potash and manure applications. Rely on corn silage as a major feedstuff for close-up cows. It is palatable, and usually low in potassium. Some low potassium byproduct feeds should also be considered. I like to use beet pulp without molasses, brewers grains, and corn gluten feed. DO NOT TRUST POTASSIUM VALUES DETERMINED BY NEAR INFRARED ANALYSIS. Potassium and most minerals need to be determined by wet chemistry analyses.

It is also possible to grow forages with increased levels of chloride n them. We have been experimenting with calcium chloride fertilization for alfalfa and ammonium chloride fertilization with grasses to bring forage Cl levels to about 1%. However it is possible to find low potassium, high chloride forages that are ideal for use in the dry cow ration if you just insist on both a K and Cl test on forages for dry cows. Beware that chloride analysis are not done well by every laboratory. (NOTE: IN LACTATION HIGH DCAD FORAGES ACTUALLY INCREASE MILK PRODUCTION!)

Acute Hypophosphatemia

Beef cows fed a diet marginal in P will have a chronic hypophosphatemia of 0.6 - 1.1 mmol/L or 2-3.5 mg/dl. In late gestation plasma P can decline precipitously as the growth of the fetus

accelerates and removes substantial amounts of P from the maternal circulation. These animals often become recumbent and are unable to rise, though they appear fairly alert and will eat feed placed in front of them. Cows carrying twins are most often affected. Plasma P concentration in these recumbent animals is often less than 0.3 mmol/L or 1 mg/dl. The disease is usually complicated by concurrent hypocalcemia, hypomagnesemia, and in some cases hypoglycemia.

At the onset of lactation the production of colostrum and milk draws large amounts of P out of the extracellular P pools. This alone will often cause an acute decline in plasma P levels. In addition if the animal is also developing hypocalcemia, PTH will be secreted in large amounts which increases urinary and salivary loss of P. In dairy cows, plasma P concentrations routinely fall below the normal range at parturition and in cows with milk fever plasma P concentrations are often between 0.3 and 0.6 mmol/L or 1 and 2 mg/dl. Plasma P concentrations usually increase rapidly following treatment of the hypocalcemic cow with intravenous Ca solutions. This rapid recovery is due to a reduction in PTH secretion, reducing urinary and salivary loss of P. The calcium injection also stimulates resumption of gastrointestinal motility allowing absorption of dietary P and reabsorption of salivary P secretions (17).

Some animals developing acute hypophosphatemia do not recover normal plasma P concentration. This is sometimes the case in cows that are classified as "downer cows". This syndrome often begins as milk fever but unlike the typical milk fever cow, plasma P remains low (below 1 mg/dl) in some of these cows despite successful treatment of the hypocalcemia. Protracted hypophosphatemia in these cows appears to be an important factor in the inability of these animals to rise to their feet, but why plasma P remains low is unclear. In some cases the inability to absorb the salivary phosphate is secondary to poor rumen motility, but not in all cases. Excessive cortisol secretion could also be driving blood P concentration down (32). How this occurs is unknown. Treatment of cows with phosphate containing solutions (orally or intravenously) can effect a recovery in some animals (10) (18). The syndrome does not appear to be caused by low P diets as affected cows are often receiving diets containing 0.4% dietary P.

"Pumping" or "Drenching" Cows

Abraham Lincoln said it was better to sit silently and let people think you were a fool than to open your mouth and prove it. At the risk of proving to be a fool I will give my 2 cents on drenching cows.

Because of the problems and cost and poor results associated with feeding energy precursors to cows that typically **go off feed the day of calving anyway** we got going on drenching cows. Ric Grummer's group had done some nice work showing that drenching cows for several days before and after calving (1 Liter propylene glycol/day) greatly decreased NEFA and liver fat deposition. We have tried propylene glycol, calcium propionate (a source of calcium and a glucose precursor) and glycerol (used years ago but too high priced - until biodiesel industry caused price drops recently) and the blood profiles we could produce in the animals here in our NADC lab herd looked good - reduce NEFA for at least several hrs immediately after drenching and for calcium propionate also get a boost in calcium. Sandy Stokes and I set out to see if there was anything to this in a commercial setting. First we looked at calcium propionate (1.5 lb / drench) vs. propylene glycol (300 mls/drench) in 2.5 gal water vs water alone giving it just at calving and at 24 hrs after calving. Cows getting propylene glycol averaged 3.1 kg more milk / day than water treated cows in early lactation($p<.05$). Cows getting the calcium propionate also made more milk (1.4 kg / day) but this was not statistically significant. Cows (removing the heifers from the data set) made 1.8 kg / day more but it still was not significant. One thing to keep in mind is that it is difficult to show a milk effect of less than 3-4 kg / day unless you have a large number of cows—sire effects alone make variation in milk production difficult to deal with. By the way this herd was a very well managed herd and the herd was averaging 40 kg milk / day (Stokes and Goff, 2001).

We have also tried using glycerol on farms. One less than ideally managed herd responded with 2.6 kg more milk / day in glycerol treated cows. Not statistically significant—only 50 cows per treatment. Blood profiles showed reduced NEFA etc. On another dairy (much better managed than the first) the same treatment had no effect and the cows actually lost nearly a kg of milk—again not statistically significant. That herd we did no blood work.

Several other studies have been done now (Pickett et al., 2003) and most show an acute drop in NEFA after drenching. None can show a significant milk benefit—usually because too few cows are used in the study. We are trying to see if electrolytes are needed or helpful. Is the water alone a key component to the drenches? How about magnesium, yeast, aspirin? We don't have enough cows or money to give you a full report on each yet. Then what about the combinations??

So is drenching worth it?? I don't have a good answer. I can say that it is not just a band-aid for poor nutrition as the first herd we worked with—where we did enough cows to get statistical significance—was an excellent herd where pre-fresh intakes were around 16 kg / day. If you can get 1 kg more milk / day the cost is certainly paid back many fold.

Now if you are brave enough or foolish enough to try this I suggest you try to keep some kind of records on it—drenching is too laborious to do if there is no measurable benefit.

What goes into a drench?

Energy precursors: choices are propylene glycol (about $$2.50/ kg), calcium propionate ($1.80 / kg) or sodium propionate ($2.10 / kg), or glycerol ($0.80/ kg). All can be toxic in high doses so you cannot just give a large dose. In the case of propylene glycol and glycerol it appears to cause osmotic changes in the brain and short term (and sometimes permanent) neuro problems. Ca propionate seems to be relatively safe until you get blood calcium too high. I haven't drenched sodium propionate very much so I don't have much on toxicity .

So how much?

ENERGY SOURCES

Propylene glycol: I limit to 300 mls / drench. I don't think the rumen smells very good at higher doses and I think (anecdotal evidence based on just a few cows) that 1 liter doses decrease rumen motility.

Calcium propionate: 1 lb / cow in smaller cows and Jerseys.1.5 lbs for bigger cows. 3 lbs will kill most cows from hypercalcemia.

Glycerol: 500 - 750 mls seems to work well. We look at glucose profiles following drenching and I don't think we see much benefit with the larger doses we used in some earlier field trials.

I am beginning to think there is a limit to the amount of glucose precursor that can be sent thru the gluconeogenic pathway at one time. So combinations of these substances, each at its recommended dose, are more likely to hurt than help the cows.

CALCIUM SOURCES

Calcium propionate discussed above.

Calcium chloride is another possibility.

Very caustic and I don't like it especially in cows that were on anionic salts pre-calving. Too acidifying. But if you want to use it the proper dose would be around 120 g anhydrous calcium chloride / drench. (=50 g Calcium)

Do you need a calcium source in a drench? We thought it would be good—as studies we did in California (Goff et al., 19—) showed some benefits on reduction of hypocalcemia.

But if cows are fed anionic salts properly before calving there seems to be little benefit to an additional calcium drench as a fairly large study in Florida shows (Melendez et al., 2002).

MAGNESIUM

Whenever you give a calcium supplement you should also give a magnesium source as the calcium shuts off PTH secretion and blood magnesium falls precipitously. I like to give 220 g magnesium sulfate.7H2O (epsom salts) with these calcium drenches to help maintain normal blood magnesium. Other magnesium sources are not soluble enough.

ELECTROLYTES

Potassium chloride: I used to think this was only good in cows off feed but I am thinking now (again minimal data) that this might also be useful in these drenches. I give 110 g / drench. DON'T GO MUCH HIGHER THAN THIS—too much risk of heart blockage!!

OTHER

Yeast: I give 120 g / drench—no data—just seems like a good idea.

Aspirin: 2-3 boluses ground up. I use the 240 grain tablets and I give 3 of them so that comes out to about 45 g of aspirin / cow. *Does it do any good?* I don't know. May not even be legal to use aspirin in this way. But I figure we see many low grade fevers in fresh cows. I suspect there is also a certain amount of pain associated with the passage of a 100 lb object thru the pelvis that might inhibit appetite.

I like to think the aspirin might get her feeling well enough to go up to the bunk and eat.

Water: I usually use 3-5 gallons / drench. We are now looking at the blood work from cows given 5 vs 10 gallons in a drench. I can't really see much difference yet. I do think the greater volume increases work and problems from aspiration. Does it weigh down the rumen and prevent

LDA: ??? I have no data.

Alfalfa meal or expellers soymeal or even cornmeal: 1-1.5 kg fine ground so I can pump it through the tube into the rumen. Often more of a pain in the neck due to plugged pumps than it is worth. If I could easily get rumen fluid into each cow I would do that, Certainly I do it for sick cows—I have found that nearly every sick cow benefits from a rumen transfaunation with about 1-2 gal rumen juice.

You can pick and choose which of the above you want to use—sorry—no great data to back them up.

How to get it into the cow?

Our studies were all done with the Magrath esophageal tube and pump.

One man can operate it quite simply. However you can expect to drown 1 in 250 cows. I think the problem is mostly from impatience during pumping. The Cow should be chewing on the tube when you pump. Pump too fast and you get reflux back up esophagus and into throat. HOOK THIS SYSTEM UP TO A MOTORIZED PUMP AND KISS THE COW GOOD-BYE. You will exceed their ability to get it into the rumen and drown cows.

Because of the drowning issue I have switched over to the FLUX tube being sold by Thomas Geishauser up in Guelph. It is a longer tube that goes all the way into the rumen. I then use the magrath pump hooked up to the FLUX tube. If I was looking at a lot of cows I would probably mechanize the pumping with a sump pump since it would now be safe since it extends all the way into the rumen. Even with the flux tube—CHECK PLACEMENT OF TUBE BEFORE PUMPING—usually I can feel two hard objects in throat rather than one and I know I have succeeded in placing the tube into the esophagus. Feeling just one hard object means your tube is inside the trachea.

I don't drench more than once per 24 hrs. The doses of the ingredients listed above were done with that in mind. Giving every 12 hrs would likely prove toxic.

I hope this helps. Drenching remains poorly researched, but I suspect many of you may be thinking of giving it a try. At least I hope you don't repeat my mistakes. Just maybe you will get some of the responses we have gotten.

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