Replacement Heifers From Birth To Weaning

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The replacement enterprise is a pivotal component of most modern dairy farms. By providing a consistent and economical supply of high quality replacements to the lactating herd (or for sale to other herds), the replacement enterprise can be viewed as a profit (or loss) center for the dairy. This enterprise approach to calf rearing, which requires sound business and management decisions, can allow producers to evaluate the replacement enterprise and identify areas where the enterprise may be improved.

Calves are born with a predetermined genetic potential, which may be permanently affected by management decisions implemented throughout the rearing period and by environmental factors. A calf's genetic potential may be viewed as an upper limit that is expressed only if proper decisions are implemented at the appropriate time. Studies have shown that the level of management has a profound effect on calf morbidity and mortality (James et al., 1984; Curtis et al., 1985; Waltner-Toews et al., 1986a, 1986b; Jenny et al., 1981). Proper management of young stock, particularly during the neonatal period, can markedly reduce morbidity and mortality,

whereas improper management will lead to economic losses from increased cost of veterinary intervention, death losses, reduced growth, and suboptimal reproductive performance. In addition, poor management of young stock can reduce the lifetime productivity of the individual cow and the herd as a whole.

The most critical time in the life of the dairy replacement is during the first few days, when morbidity and mortality are greatest. A recent USDA study of farms throughout the U.S. with more than 30 cows (NAHMS, 1992) indicated that preweaning mortality of calves born alive was 8.4%, whereas mortality after weaning was only 2.2%. Clearly, the loss of calves prior to weaning is a major concern for all dairy producers.

Colostrum feeding

Regardless of the method of feeding colostrum, a key component to a successful calf management program is an adequate concentration of serum IgG. Because serum IgG concentration is so closely related to the calf's overall resistance to infectious agents (e.g., viruses, bacteria, parasites), it has been used as a measure of overall protection provided by the dam. Although the level of IgG that provides adequate protection will vary with the particular situation (pathogen load in the environment, stress, housing, feeding, etc.), a level of 10 g/L has been suggested as a reasonable goal for IgG in the serum of calves by about 24 hours of age. The condition of serum IgG 10 g/L is termed failure of passive transfer (FPT) and is associated with increased morbidity and mortality.

In the NAHMS study of U.S. dairy herds (NAHMS, 1992), 2,177 heifer calves (from 593 farms) were used to assess serum immunoglobulin (Ig) concentrations. Blood from these calves was sampled between 24 and 48 hours of age and serum was measured for immunoglobulin G (IgG), which comprises most of the Ig in blood. Serum IgG is responsible for most of the calf's resistance to disease and is obtained by consumption of colostrum
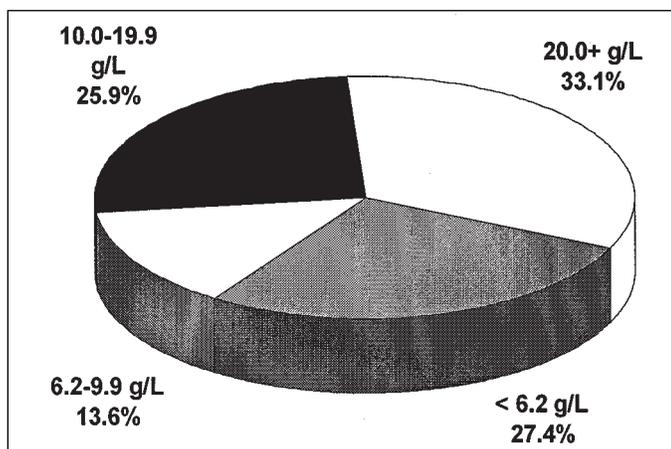
Figure 1

during the first 24 hours after birth.

Over 40% of all calves sampled had IgG concentrations below the recommended level of 10 g/L (Figure 1). Worse still, over 25% of calves were below 6.2 g/L, which put them at a much greater risk of disease than calves with higher IgG levels. Mortality rates of calves with serum IgG less than 10 g/L was over twice that of calves with higher IgG levels (Figure 2). Of course, many other factors contribute to calfhood mortality, but this study indicated that over half of the death loss of calves with serum IgG levels less than 10 g/L (about 40% of dairy heifer calves) can be attributed to lack of IgG intake.

For many years, researchers, extension specialists and dairy professionals have recommended early feeding of a large amount of colostrum to provide Ig prior to closure of the small intestine. Recent research has indicated the continued importance of feeding colostrum and has further refined our understanding of the importance of colostrum to the young calf. Not only does colostrum provide vital Ig, but it also provides significant amounts of immune proteins and nutrients that support the calf during the first few days of life.

Allowing the calf to nurse the dam for one or more days has been shown to be an inadequate method of supplying colostrum in many research studies. Although many producers (>30%; NAHMS, 1992) allow their calves to suckle the dam, a considerable body of research indicates that many calves - up to 40% - may obtain insufficient Ig with this method of feeding. When calves suckle the dam, it is very difficult to know when the calf begins to nurse and how much colostrum it consumes. Calves having difficult births, and calves from heifers are at particular risk of FPT due to insufficient colostral consumption. Further, calves often have a difficult time finding the teats of cows with large, pendulous udders, and may consume inadequate colostrum. Because of the high degree of FPT when calves are left to suckle the dam, most dairy professionals recommend separating calves from the dam and feeding colostrum by a nipple-bottle or esophageal feeder (if the calf will not consume enough colostrum by bottle).

Feeding calves by nipple bottles has two inherent advantages – it allows the producer to control the time at which calves are fed and allows the producer to control (at least partially) the amount fed to the calf. Feeding by nipple is the preferred method of feeding colostrum to calves. Most producers (64%) use nipple bottles to feed colostrum to calves

in the first 24 hours after birth.

The amount of colostrum to be fed by nipple bottle should depend on size of the calf, age at first feeding, quality of colostrum, and other factors. However, the mass of IgG in colostrum is the most important factor affecting successful transfer of immunity in calves (Bush and Staley, 1980). Traditionally, feeding of 2 liters (quarts) of colostrum at two feedings has been recommended. However, due to concerns about poor colostrum quality (low IgG concentration), many researchers and veterinarians now recommend 4 liters (quarts) at the first feeding (Besser et al., 1991). A recent producer guide (BAMN, 1994) suggested that if colostrum quality is estimated with a colostrometer, 2 quarts of good quality colostrum can be fed in each of two feedings; if quality is not determined, then 3 quarts of colostrum should be fed in the first feeding. Calves will generally consume 3 or more liters by nipple bottle when they are healthy and stand within about an hour of birth. However, if the producer desires to provide 4 liters (1 gallon) of colostrum to calves at the first feeding, an esophageal feeder may be necessary.

Use of an esophageal feeder is becoming an increasingly popular method of providing colostrum to calves. The esophageal feeder has several inherent advantages, including control of the time of colostrum feeding; control of the amount of colostrum fed; and the ability to force the calf to consume a known (usually large) amount of colostrum at the first feeding. Disadvantages of using the esophageal feeder include delivering the colostrum to the rumen and possibility of delivering colostrum into the lungs. About 2% of producers were regularly feeding colostrum by esophageal feeder in the U.S. in 1992 (NAHMS, 1992). However, many veteri-
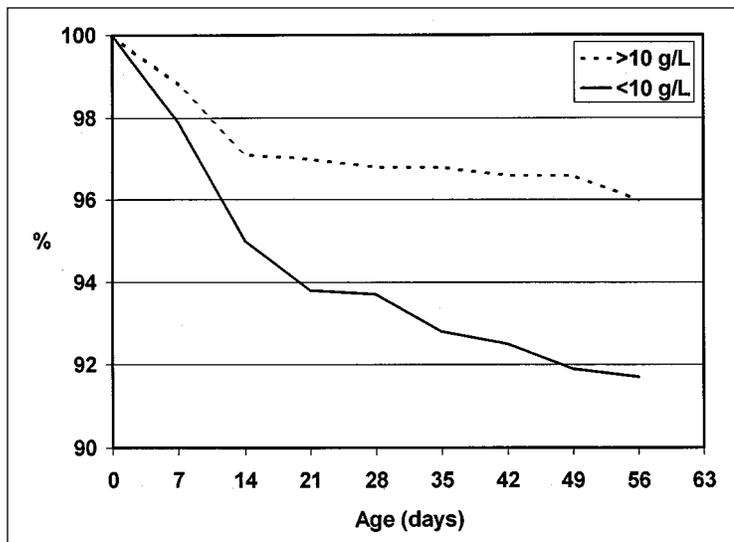
Figure 2

narians are recommending this practice, so the application is likely to become more prevalent.

Use of the esophageal feeder to feed large quantities of colostrum has been associated with lower apparent efficiency of IgG absorption (AEA) and slightly lower serum IgG concentration compared to feeding colostrum by nipple bottle (Lee et al., 1983). When colostrum is administered by esophageal feeder, the colostrum enters the rumen before moving into the abomasum and intestine (Lateur-Rowet and Breukink, 1983). It takes 2 to 4 hours for the colostrum to leave the rumen. This may actually be the reason for lower AEA, as the intestine matures during this time, reducing the number of actively absorbing cells in the intestine. However, many veterinarians recommend feeding four quarts of colostrum as soon as possible after birth, to ensure that all four quarts are consumed. Others (Adams et al., 1985; Molla, 1978) support the use of esophageal feeders to provide large amounts of colostrum without significant effect on serum IgG concentrations.

Use of the esophageal feeder is most useful when colostrum quality cannot be determined. Because it is not possible to determine with great precision the quality of colostrum, there is a risk that an insufficient mass of Ig will be provided to the calf in the first feeding. Additionally, the efficiency with which Ig are absorbed declines as the calf ages, so the first feeding may be the most important. Thus, the recommendation has been made to use a large first feeding (1 gallon) and not be concerned about significant consumption at a second feeding 12 hours later.

Colostrum Quality

The amount of IgG absorbed depends on the calf's ability to absorb IgG (efficiency of absorption) and the mass of IgG consumed. The mass of IgG consumed is a function of the quantity of IgG x the IgG concentration of the colostrum. The concentration of Ig in colostrum varies according to the cow's disease history, volume of colostrum produced, season of the year, breed, and other factors. Research from Washington (Pritchett et al., 1991) indicated the average concentration of IgG1 (a sub-fraction of IgG) in colostrum from 919 Holstein cows was 48.2 g/L with a range of 20 to >100 g/L. A Tennessee study (Quigley et al. 1994b) measured colostrum from 96 Jersey cows and found that samples averaged 66 g/L of IgG, with a range of 28 to 115 g/L. The difference between 20 and 100 g/L of IgG in colostrum can mean the difference between FPT and successful passive transfer.

The amount of Ig in colostrum depends on a large number of factors, including the disease history of the cow. That is, cows tend to produce Ig in response to pathogens to which they have been exposed. Therefore, cows exposed to a greater number of pathogens tend to produce colostrum with greater Ig than cows exposed to fewer pathogens. This is often why older cows will produce colostrum containing more Ig than younger cows. However, if older cows are not exposed to many pathogens, the colostrum produced may not have high levels of Ig. This is also why a good dry cow vaccination program can improve the quality of colostrum. Moreover, cattle raised on a farm will produce colostrum with antibodies specific for the organisms on that farm which is an added benefit. Finally, prepartum milking or leaking of milk from the udder prior to calving can reduce the concentration of Ig in colostrum.

Research has also indicated that the volume of colostrum produced will influence colostral Ig concentration. In general, colostrum produced in large volumes will have lower Ig concentration than colostrum produced in smaller volumes. This is only a general rule, however, and the relationship between Ig concentration and volume is not constant.

Timing Of Colostrum Feeding

The time at which colostrum is first fed has a critical role in determining if the calf will acquire adequate passive immunity and whether it becomes ill. The timing of colostrum feeding is important for two reasons: loss of absorptive sites and bacterial colonization of the intestine.

As mentioned above, the maturation of the intestine begins shortly after birth. Current theories suggest that intestinal epithelial cells lose their ability to absorb macromolecules intact after about 24 hours due to maturation of the cells and development of the cellular digestive apparatus; however, this maturation begins shortly after birth. Rajala and Castrén (1995) reported a decline in serum IgG concentration of 2 g/L at 30 min after birth; regression of serum IgG concentration on age at first feeding in calves fed maternal colostrum (Abel and Quigley, 1993) also indicated a reduction of AEA within 1 hour of birth. Clearly, there is a compelling reason to feed calves as soon as possible after birth to maximize acquisition of passive immunity.

In addition to maturation of intestinal cells, the secretion of digestive enzymes in the abomasum and intes-

tine of the calf may also contribute to lower AEA by degrading IgG prior to absorption. At birth and for a limited period thereafter, the secretion of digestive enzymes remains limited to allow macromolecule such as IgG to escape digestion and allow absorption (Thivend et al., 1980). However, by about 12 hours, enzyme secretion becomes more marked, thereby reducing the ability of IgG molecules to reach the peripheral circulation.

The intestinal tract of the neonate is sterile at birth; however, within a few hours bacteria from the environment begin to colonize the intestine. This colonization can be hastened by an environment that promotes the growth of pathogens (ie., a dirty environment). If a calf is born into an environment containing large numbers of pathogenic bacteria, the chances of colonization by pathogenic bacteria is increased. This may lead to septicemia, leading to severe morbidity and, often, mortality. Further, James et al. (1981) reported that the presence of bacteria in the intestine may actually speed closure, thereby reducing the acquisition of passive immunity.

Logan et al. (1977) studied the effects of early colonization of pathogens on neonatal calves. Calves were fed colostrum and challenged with E. coli. The first group was fed colostrum, then challenged; group 2 were challenged, then fed colostrum. Nearly all calves in the second group became morbid, and about 75% of the group died. Conversely, calves fed colostrum prior to E. coli challenge did not become sick and none died. Quigley et al., (1994a) reported that calves removed from their dams at birth showed different temporal acquisition of enteric pathogens from birth to 35 days compared to those left with the dam for 24 hours. Clearly, the dam and the calving environment can contribute significantly to the amount and type of bacteria to which the calf is exposed shortly after birth.

Liquid Feeds For Preweaned Calves

Prior to rumen develop-ment, the functional compartment of the calf's stomach is the abomasum. Milk, colostrum, or milk replacer feeding will bypass the rumen by closure of the esophageal (reticular) groove, causing the liquid to travel from the esophagus to the omasum and abomasum. Closure of the reticular groove occurs by a neural stimulation in response to feeding. Note that closure will occur when calves are fed from buckets or bottles, and whether the liquid is warm or cold. Also, water will not cause closure of the reticular groove, and enters the rumen when consumed.

Milk or milk replacer consumed by-passes the rumen; therefore, digestion of these liquids will occur in the abomasum (true stomach) and intestine. The site of digestion depends somewhat on the type of liquid. Whole and waste milk and colostrum will form a clot caused by the production of rennin in the abomasum. This acts to hold fat and casein in the abomasum, thereby slowing flow into the intestine. Most modern milk replacers contain little casein, so a clot will not form in the abomasum when milk replacers are fed. In most cases, this does not markedly affect digestibility or metabolizability of energy or protein.

Nutrient digestibility increases with age to about 3 weeks of age due to maturation of tissues secreting digestive enzymes. Calves 3 weeks of age are especially

Table 2: Typical ingredient and nutrient composition of milk replacers[1].

ingredient, %	all-milk	soy isolate	soy protein concentrate	soy flour	animal plasma
whey protein concentrate	44.5	7.0	9.2		41.4
delactosed whey	10.0	10.0	10.0	8.5	
dried whey	25.2	50.8	19.8	46.5	28.2
soy isolate		11.2			
soy protein concentrate			15.0		
soy flour				33.8	
animal plasma					7.5
fat	19	19.5	14.5	9.7	20.0
mineral/vitamin/amino acids	1.3	1.5	1.5	1.5	2.8
Nutrient, %					
protein	20.0	20.0	21.0	24.0	20.0
fat	20.0	20.0	15.0	10.0	20.0
fiber	0.15	0.15	0.5	1.0	0.15

1: Composition of individual replacers may vary. Adapted from: Tomkins & Jaster, 1991; Quigley and Bernard, 1996.

susceptible to lower quality ingredients in milk replacer, although milk and milk ingredients in milk replacers are digested well.

Sources of liquids for calves prior to weaning include whole milk, waste milk, excess colostrum, and milk replacer. Most U.S. dairy producers use some combination of all of these sources. Whole milk is an excellent feed for calves prior to weaning, but is expensive compared to other sources of liquid feed. In most cases, whole milk is the most expensive source of liquid and, thus, is not the best liquid source for calves prior to weaning. However, whole milk contains more protein and energy than most milk replacers (Table 1), and is second only to excess colostrum in nutrient content. Anecdotal reports indicate that some producers have success in raising calves only when whole milk is used - this has been attributed to factor(s) inherent in the milk, such as Ig, protein, or other component. However, this may be more a function of level of management than some component of whole milk. The amount of whole milk to feed is approximately 10% of body weight, with consideration given to health of the calf and environmental conditions. Excessive milk feeding can lead to nutritional scours and delayed consumption of calf starter.

Milk replacers are an excellent option for feeding liquid calves prior to weaning. Milk replacers used in the U.S. are composed of whey and whey protein, fats and minerals and vitamins (Table 2). Some replacers utilize vegetable protein (soy, wheat, potato) or animal protein (fish, plasma, erythrocyte) to replace some or all of the milk protein from whey protein concentrate. Due to its high price, little skim milk is used in modern milk replacers. Milk replacers have been used successfully by many producers for many years – they are the feed of choice for most feeders of preweaned replacement as well as veal calves.

Composition of milk replacers will influence the performance of calves prior to weaning. Important factors include source and amount of protein and energy, vitamin and mineral supplementation, and inclusion of critical nutritional additives such as emulsifiers. Unfortunately, methods traditionally used to determine milk replacer quality are not useful with modern replacers used in the industry. For example, rennet coagulation was used as a method of determining the amount of casein in a milk replacer, and thus its "quality". However, few (if any) modern milk replacers contain casein (a component of skim milk), so none will form a rennet clot.

Table 1: Comparison of whole milk and selected milk replacers[1].

Item	Whole milk	20:20 All milk	22:15 SPC	22:20 All milk
DM, %	12.5	95.0	95.0	95.0
Protein, % of DM	26.4	21.1	23.2	23.2
Fat, % of DM	28.0	21.0	15.8	21.1
Crude fiber, % of DM	0.0	0.2	0.2	0.2
ME, Mcal/kg	4.9	4.5	4.2	4.5
Ca	0.95	0.8	0.8	0.8

1: Composition of individual milk replacers may vary from data contained herein due to differences in ingredients and processing.

This does not mean that all replacers are poor quality. Whey proteins can support growth as well as casein protein. Another method of determining protein quality is crude fiber content. The crude fiber content of a milk replacer will indicate the relative amount of vegetable protein added to a milk replacer; it will not indicate whether that protein is digestible. Milk replacers can contain soy proteins that have been chemically modified to increase their digestibility and reduce the antigenicity of proteins such as glycinin and B-conglycinin and denature trypsin inhibitors. These milk replacers perform quite acceptably, and are usually available at a less expensive price compared to all-milk replacers. Furthermore, some vegetable protein sources (e.g., soy isolate) contain no crude fiber, and thus, measuring crude fiber will not necessarily indicate the presence of vegetable protein.

Determining milk replacer quality is best determined by animal performance. However, some factors that are related to performance include: 1) a reputable manufacturer; 2) analysis of replacer (protein and fat); 3) ingredients used; level of medication; and 5) other characteristics (Morrill, 1992). Milk replacers should not contain off-color materials, should mix quickly and evenly, and stay in solution. Method of preparation and feeding can influence performance of calves fed commercial milk replacers. Proper emulsification requires sufficient temperature – use warm, not cold water!

Excess colostrum is an excellent feed for young calves. It is high in DM and protein, and low in lactose. It may be stored refrigerated in small bulk tanks or refrigerators for several weeks. Due to its higher DM content, surplus colostrum may cause calves' feces to become somewhat "loose". However, this is not usually a significant problem, and can be alleviated by diluting the colostrum (3:1

or 4:1) with water. Recent research suggests that antibodies in surplus colostrum may contribute somewhat to intestinal immunity (Drew, 1994; Fowler et al., 1995), however, large-scale studies using surplus colostrum have not been completed.

Waste milk is that milk that is unsaleable due to mastitis or treatment with antibiotics. It is often considered a "free" source of liquid to feed to their calves. However, the opportunity cost of waste milk is significant – ie., the value of that milk if it weren't waste. In most cases, it is more economical to reduce the production through management and/or culling and feed an alternative source of liquid. Several precautions should be followed when using waste milk: 1) do not use milk from the first milking after antibiotic treatment - this milk contains too much antibiotic and may lead to residue problems; 2) do not use milk that is excessively bloody or unusual in appearance; 3) do not feed waste milk to group housed calves; 4) do not use milk from cows infected with Escherichia coli or Pasteurella. Finally, do not feed waste milk to calves held for short periods (e.g., bull calves for sale). Antibiotics in waste milk can carry over in the animal's tissues resulting in significant antibiotic residues.

The amount of liquid (milk, colostrum, milk replacer) has often been associated with the amount of growth attained by calves prior to weaning. A closer evaluation of the amounts of energy and protein provided by liquids under current feeding programs indicates that this assumption is incorrect. Under most situations, milk or milk replacer feeding provides sufficient energy to support only a limited amount of body weight gain. Although the amount of gain supported by liquids depends on many factors (body weight of calf, climatic conditions, health of the calf, etc.), it will generally support less than 400 grams of body weight gain per day, and usually significantly less than 400 grams/day. Most body weight gain will be obtained by consumption of calf starter, not liquid feeds.

Effects Of Environment On Liquid Feeding

Because calves are fed for limited body weight gain from liquid feeds, the importance of the calf's environment becomes especially important. An amount of milk replacer that will support 250 grams of body weight gain in thermoneutral conditions will not support the same gain when the temperature is -30 degrees centigrade. Generally, when the temperature is below freezing, additional energy should be supplied. When feeding milk replacer, this can be achieved by increasing the amount of fat (e.g., increasing from 10% fat to 20% fat) or by increasing the amount of powder added to each bottle or bucket. When milk or colostrum is fed, added amounts are necessary. In addition, commercial fat supplements may be added to milk or milk replacer to increase the energy density.

Feeding equipment usually consist of nipple bottles, buckets, and nipple pails. Calves readily adapt to nipple bottles, and training calves to drink is much easier. Training calves to drink from a bucket is initially more difficult, but buckets are easier to clean, and research indicates that they generally result in lower mortality. Nipple buckets are most difficult to clean, and thus are a choice only when good management is involved. Calves fed from buckets (or from a nipple with an enlarged opening) will experience some spillage of liquid into the rumen. Sanitation of all equipment is critical to the health and growth of calves. Hot water and disinfecting solution are important to inhibit the growth of bacteria (milk is an excellent growth medium for bacteria) and reduce the spread of disease.

Recent developments in feeding methods include use of computerized milk replacer feeding systems (Quigley, 1996) and group ("mob") feeders. Computer milk replacer feeding systems have been used in Europe for a number of years, and have been used on some farms in the U.S. over the past few years. Basically, the computer system is similar to the ones used to feed grain to lactating dairy cows. Each calf is fitted with a transponder that uniquely identifies it to the computer. When the calf enters the feeding station, it is identified by the computer that controls the system. Each calf is allotted a fixed amount of milk or milk replacer in a 24-hour period. This is usually divided into eight meals, each of which can occur every three hours. If a calf hasn't eaten in the past three hours, it is allowed to eat. When allowed to eat, the computer will measure a pre-

Table 3: Composition of the ruminant stomach at various ages.							
Compartment				(age in weeks)			
% of total	**0**	**4**	**8**	**12**	**16**	**20-26**	**34-38**
Reticulorumen	35	52	60	64	67	64	64
Omasum	13	12	13	14	18	22	25
Abomasum	49	36	27	22	15	14	11

Adapted from Church (1976).

determined amount of milk replacer powder into a mixing bowl. Warm water is added to the proper concentration (usually to make a 500 ml meal) and mixed thoroughly. The reconstituted milk replacer is then transferred to a feeding bowl, which is connected to the heavy duty nipple. Calves then drink the reconstituted milk replacer. If a calf enters the station before it is allowed another meal, the animal is allowed to nurse on the nipple, but no milk replacer is delivered. Usually calves are allotted eight 500 ml meals per day to make 4 liters. Evaluations of such systems indicate that they can be used successfully in many types of calf rearing programs; they are especially useful when labor is particularly expensive.

Mob feeders are a simpler approach to group feeding. A large barrel is fitted with several (5 or more) heavy duty nipples. Calves may be limit-fed milk or replacer from the mob feeder, or liquid may be available for ad libitum consumption. Calves fed ad libitum will consume markedly more milk replacer, thereby increasing costs. In some cases, milk replacer is acidified to reduce intake.

Weaning

When calves are weaned, the cost of rearing declines considerably. Whole milk or milk replacer is markedly more expensive than calf starter and hay, and labor associated with feeding liquids is reduced also. Thus, it makes economic sense to wean calves as soon as is reasonable. Traditionally, many researchers and extension professionals have recommended that calves be weaned at four weeks of age. It was argued that at this age, calves have sufficient ruminal development to allow them to obtain adequate nutrients from calf starter alone. However, according to the NAHMS (1992) study, only about 10% of producers wean calves at 4 weeks of age, indicating that producers have discounted this recommendation for their own reasons. An informal survey of veterinarians also raises question about early weaning – many veterinarians recommend weaning at 8 weeks or later.

There are other economic benefits to promoting ruminal development in addition to reduced feed costs. After weaning, calves are less susceptible to disease and gain more body weight with lower labor and management costs. Therefore, it is usually most economical to manage calves to promote early rumen development and wean calves as early as is feasible.

According to the NAHMS (1992) study of dairy calf management practices, most dairy producers use age of the calf as the primary criterion for weaning. The most common age at weaning is 8 weeks (32.9% of producers), although a few (2.3%) wean at 3 weeks of age and others (21.4%) wean at 10 weeks of age or later. Some producers wean calves when calves starter intake reaches a predetermined level (usually 700-,000 grams /day) or when calves reach a preselected body weight.

Stress at weaning is often exacerbated by performing other management tasks at the same time. Some of these include dehorning, moving the calf into group housing, change in diet (offering different starter and/or hay), removing extra teats, etc. All of these stresses should be minimized at weaning, and should be performed at other times to minimize that stress.

Dry Feeds And Rumen Development

At weaning, the calf is forced to undergo several dramatic changes. Consider the following: 1. the primary source of nutrients changes from liquid to solid 2. the amount of dry matter the calf receives is cut dramatically at weaning 3. the calf must adapt from a monogastric type of digestion to a ruminant type of fermentation and digestion 4. changes in housing and management often occur around weaning which can add to stress.

At birth, the rumen and reticulum are under-developed, sterile and nonfunctional. Liquid feeds are shunted past the reticulorumen by the esophageal groove. However, by the time the calf is weaned, the rumen is the primary compartment of the stomach. It has increased in size, metabolic activity, and blood flow to the rumen has increased. Prior to weaning, the primary source of nutrients is liquid. During the transition period, both liquid and solid feeds provide nutrients to the calf. After weaning, only solid feeds (starter and hay) are available. Before solid feed is consumed, the abomasum is the primary compartment of the stomach and both energy (glucose and fat) and protein are derived from dietary sources. However, by weaning, the rumen has become an important compartment of the stomach, and all feed consumed is exposed to bacterial fermentation prior to reaching the abomasum. A net result of this fermentation is a change in the type of energy and protein available to the calf.

Not only does the activity of the stomach compartments change, but the size of each compartment changes as well. The percent of the stomach as reticulo-rumen increases from a low of about 38% to a high of 67% by 16 weeks of age (Table 3). Note, however, that by 4 weeks of age, the reticulo-rumen has increased to

52% of the total stomach capacity. In contrast, the proportion of the stomach as abomasum declines from a high of 49% at birth to a low of 11% after 32 weeks of age. The absolute size of the abomasum does not decline - the reticulo-rumen simply grows at a much faster rate than the abomasum during ruminal development.

Factors Required For Rumen Development

There are five requirements for ruminal development. They are:

1. Establishment of bacteria in the rumen.
2. Liquid in the rumen.
3. Outflow of material from the rumen (muscular action).
4. Absorptive ability of the tissue.
5. Substrate.

A number of other metabolic changes occur during ruminal development in the rumen and other tissues, but we will consider the above requirements for the rumen to begin to function.

When the calf is first born, the rumen is sterile - there are no bacteria present. However, by one day of age, a large concentration of bacteria can be found which are mostly aerobic (or oxygen-using) bacteria. Thereafter, the numbers and types of bacteria change as dry feed intake occurs and the substrate available for fermentation changes. The change in bacterial numbers and types is almost always a function of intake of substrate (Lengemann and Allen, 1959). Prior to consumption of dry feeds, bacteria in the rumen exist by fermenting ingested hair, bedding, and milk that flows from the abomasum into the rumen. The substrate ingested will also affect the types of ruminal bacteria that flourish in the young rumen. For example, calves fed mostly hay develop a different flora from those fed mostly grain.

To ferment substrate (grain and hay), rumen bacteria must live in a water environment. Without sufficient water, bacteria cannot grow and ruminal development is slowed. Most of the water that enters the rumen comes from free water intake. If water is offered to calves from an early age, this is not usually a problem; unfortunately, many producers in the U.S. do not provide free water to their calves until calves reach 4 or more weeks of age. Offering water in the winter can be a significant challenge in Canada and the northern U.S. However, calves still need water, even when it is cold. Sometimes, it may be necessary to bring warm water at an additional feeding to ensure that calves have enough liquid water available. Free water has been shown to increase rate of body weight gain and reduce scours (Kertz, 1984).

Milk or milk replacer does not constitute "free water". Milk or milk replacer will by-pass the rumen by closure of the esophageal (reticular) groove. Closure of the groove is a neural response to feeding. Free water does not stimulate closure of the groove, so water enters the rumen. Feeding water can increase body weight gain, starter intake, and reduce scours score.

Proper ruminal development requires that material entering the rumen must be able to leave it. Measures of ruminal activity include rumen contractions, rumen pressure, and regurgitation (cud chewing). At birth, the rumen has little muscular activity, and few rumen contractions can be measured. Similarly, no regurgitation occurs in the first week or so of life. With increasing intake of dry feed, rumen contractions begin. When calves are fed milk, hay, and grain from shortly after birth, rumen contractions can be measured as early as 3 weeks of age. However, when calves are fed only milk, rumen contractions may not be measurable for extended periods. Cud chewing has been observed as early as 7 days of age, and may not be related to ruminal development per se. However, calves will ruminate for increasing periods when dry feed (particularly hay) is fed.

The absorption of end-products of fermentation is an important criterion of ruminal development. The end-products of fermentation, particularly the volatile fatty acids (VFA; acetate, propionate, and butyrate) are absorbed into the rumen epithelium, where propionate and butyrate are metabolized in mature ruminants. Then, the VFA or end-products of metabolism (lactate and ß-hydroxybutyrate) are transported to the blood for use as energy substrates. However, there is little or no absorption or metabolism of VFA in neonatal calves. Therefore, the rumen must develop this ability prior to weaning.

Many researchers have evaluated the effect of various compounds on the development of the epithelial tissue in relation to size and number of papillae and their ability to absorb and metabolize VFA. Results of these studies indicate that the primary stimulus to development of the epithelium are the VFA - particularly propionate and butyrate. Milk, hay, and grain added to the rumen are all fermented by the resident bacteria to these acids; therefore, they contribute VFA for epithelial development. Plastic sponges and inert particles - both added to the rumen to provide "scratch" - did not promote development of the epithelium. These objects could not

be fermented to VFA, and thus did not contribute any VFA to the rumen environment. Therefore, rumen development (defined as the development of the epithelium) is primarily controlled by chemical, not physical means. This is further support for the hypothesis that ruminal development is primarily driven by the availability of dry feed, but particularly starter, in the rumen.

Bacteria, liquid, rumen motility, and absorptive ability are established prior to rumen development, or develop rapidly when the calf begins to consume dry feed. Thus, the primary factor determining ruminal development is dry feed intake. To promote early rumen development and allow early weaning, the key factor is early consumption of a diet to promote growth of the ruminal epithelium and ruminal motility. Because grains provide fermentable carbohydrates that are fermented to propionate and butyrate, they are a good choice to ensure early rumen development. On the other hand, the structural carbohydrate of forages tend to be fermented to a greater extent to acetate, which is less stimulatory to ruminal development.

Effect Of Physical Form Of The Ration

For many years, producers have fed forage – primarily hay – to calves to promote ruminal development. The common reason was to give the calf the "scratch" needed to start development of the rumen. In fact, the development of rumen function is primarily chemical and is caused by VFA in the rumen. Providing forage has less of an effect on ruminal epithelial development, thus on activity and function. The concept of "scratch" to develop the rumen is a myth. However, forage is important to promote the growth of the muscular layer of the rumen and to maintain the health of the epithelium. Rumen papillae can grow too much in response to high levels of VFA – when this happens, they may clump together, reducing the surface area available for absorption. Also, some "scratch" is needed to keep the papillae free of layers of keratin, which can also inhibit VFA absorption. Therefore, hay should be part of the diet – after weaning. A good recommendation is to wean at 4 to 5 weeks of age and offer hay from 6 to 7 weeks of age. If calves are not weaned until 8 to 10 weeks of age, it may be a good idea to feed a limited amount of hay (500 grams/day) from about 6 weeks of age. However, the amount of hay should be limited to ensure that calves will consume sufficient starter.

There are other reasons to limit the hay offered to preweaned calves. The first is voluntary intake. Most calves do not eat significant amounts of hay if grain is also offered. Therefore, producers feed calves the best quality hay available on the farm, only to have it turned into bedding. Most of the intake of hay occurs only after 6 to 7 weeks of age. This is a good time to put hay in front of calves. Another reason not to feed hay to calves prior to weaning is the energy requirement of young calves. Calves have a high energy requirement relative to their ability to consume dry feed. Therefore, if calves consume significant amounts of hay, their intake of other feeds (ie., starter) will be limited. This has the effect of reducing intake of starter, which can slow growth. Finally, most hay has too little energy for calves. The energy requirement for calves can usually be met only when calves are fed milk or high quality milk replacer, and/or excess colostrum and calf starter. Even good quality legume hay generally has too little energy to support growth of preweaned calves.

Summary

Raising calves from birth to weaning must be directed toward the acquisition of passive immunity through proper colostrum feeding, feeding liquids and calf starter to ensure a smooth transition from preruminant to ruminant digestion, and housing to minimize stress and spread of pathogens. With proper management, it is possible to minimize death loss of young calves (< 5% of calves born alive) and thereby improve profitability of the replacement enterprise.

References:

1. Abel Francisco, S.F. and J.D. Quigley, III. 1993. Serum immunoglobulin concentration in response to maternal colostrum and colostral supplementation in dairy calves. Am. J. Vet. Res. 54:1051-1054.

2. Adams, G.D., L.J. Bush, J.L. Horner, and T.E. Staley. 1985. Two methods for administering colostrum to newborn calves. J. Dairy Sci. 68:773.

3. BAMN, 1994. A guide to colostrum feeding and management. Bovine Alliance on Management and Nutrition.

4. Besser, T.E., C.C. Gay, and L. Pritchett. 1991. Comparison of three methods of feeding colostrum to dairy calves. J. Amer. Vet. Med. Assoc. 198:419.

5. Bush, L.J., and T.E. Staley. 1980. Absorption of colostral immunoglobulins in newborn calves. J. Dairy Sci. 63:672.

6. Church, D.C. 1976. Digestive Physiology and Nutrition of Ruminants. Vol 1 - Digestive Physiology. O & B Books, Inc., Corvallis, OR.

7. Curtis, C.R., H.N. Erb, and M.E. White. 1985. Risk factors for calfhood morbidity and mortality on New York dairy farms. Proceedings of Cornell Nutrition Conference, pp 90-99.

8. Drew, M.D. 1994. Effects of immunoglobulin fortification of milk replacers on the performance of calves challenged with Escherichia coli. J. Dairy Sci. 77 (Suppl. 1):298 (Abstr.).

9. Fowler, M.A., R.L. Sweat, T.E. Johnson, and L.K. Seiser. 1995. Prevention of rotavirus scours in neonatal calves with colostrum feeding. J. Dairy Sci. 78 (Suppl. 1):235 (Abstr.).

10. James, R. E., C. E. Polan, and K. A. Cummins. 1981. Influence of administered indigenous microoganisms on uptake of I125- -globulin in vivo by intestinal segments of neonatal calves. J. Dairy Sci. 64:52

11. James, R.E., M.L. McGilliard, and D.A. Hartman. 1984. Calf mortality in Virginia Dairy Herd Improvement herds. J. Dairy Sci. 67:908-911.

12. Jenny, B.F., G.E. Gramling, and T.M. Glaze. 1981. Management factors associated with calf mortality in South Carolina dairy herds. J. Dairy Sci. 64:2284-2289.

13. Kertz, A.F. 1984. Calves need water before they are weaned. Hoard's Dairyman. 129:826.

14. Lateur-Rowet, H.J.M. and H.J. Breuink. 1983. The failure of the oesophageal groove reflex, when fluids are given with an oesophageal feeder to newborn and young calves. Vet. Quart. 5:68.

15. Lee, R.B., T.E. Besser, C.C. Gay, and T.C. McGuire. 1983. The influence of method of feeding on IgG concentrations acquired by calves. Proceedings, 4th International Symposium on Neonatal Diarrhea. VIDO, Saskatoon, Saskatchewan, Canada. pp. 373-377.

16. Lengemann, F.W., and N.N. Allen. 1959. Development of rumen function in the dairy calf. II. Effect of diet upon characteristics of the rumen flora and fauna of young calves. J. Dairy Sci. 42:1171.

17. Logan, E.F., G.R. Pearson, and M.S. McNulty. 1977. Studies on the immunity of the calf to colibacillosis - VII: The experimental reproduction of enteric colibacillosis in colostrum-fed calves. Veterinary Record. 101:443-446.

18. Molla, A. 1978. Immunoglobulin levels in calves fed colostrum by stomach tube. Vet. Rec. 103:377.

19. Morrill, J.L. 1992. The Calf: birth to 12 weeks. Page 401 in Large Dairy Herd Mgmt., H.H. Van Horn and C.J. Wilcox, ed. Amer. Dairy Sci. Assoc, Savoy, IL.

20. National Animal Health Monitoring System. 1992. Dairy herd management practices focusing on preweaned heifers. USDA, Animal and Plant Health Inspection Service, Veterinary Services, Fort Collins, CO.

21. Pritchett, L.C., C.C. Gay, T.E. Besser, and D.D. Hancock. 1991. Management and production factors influencing immunoglobulin G1 concentration in colostrum from Holstein cows. J. Dairy Sci. 74:2336-2341.

22. Quigley, J.D., III, K.R. Martin, D. A. Bemis, L.N.D. Potgieter, C.R. Reinemeyer, B.W. Rohrbach, H.H. Dowlen, and K.C. Lamar. 1994a. Effects of housing and colostrum feeding on the prevalence of selected organisms in feces of Jersey calves. J. Dairy Sci. 77:3124.

23. Quigley, J.D., K.R. Martin, H.H. Dowlen, L.B. Wallis, and K. Lamar. 1994b. Immunoglobulin concentration, specific gravity, and nitrogen fractions of colostrum from Jersey cattle. J. Dairy Sci. 77:264-269.

24. Quigley, J.D., III. 1996. Growth, intake and behavior of calves fed milk replacer by nipple bottle or computer feeding system. Prof. Anim. Sci. 12:187.

25. Quigley, J.D., III and J.K. Bernard. 1996. Milk replacers with or without animal plasma for dairy calves. J. Dairy Sci. 79:1881-1884.

26. Rajala, P., and H. Castrén. 1995. Serum immunoglobulin concentrations and health of dairy calves in two management systems from birth to 12 weeks of age. J. Dairy Sci. 78:2737.

27. Thivend, P., R. Toulec, and P. Guilloteau. 1980. Digestive adaptation in the preruminant. Page 561 in Digestive Physiology and Metabolism in Ruminants. Y. Ruckebusch and P. Thivend, ed. AVI Publ. Co., Westport, CT.

28. Tomkins, T. And E.H. Jaster. 1991. Preruminant calf nutrition. Vet. Clin. of North America. 7:557-576.

29. Waltner-Toews, D., S.W. Martin, A.H. Meek, and I. McMillan.1986a. Dairy calf management, morbidity and mortality in Ontario Holstein herds. Prev. Vet. Med. 4:103-117.

30. Waltner-Toews, D., S.W. Martin, and A.H. Meek. 1986b. Dairy calf management, morbidity and mortality in Ontario Holstein herds. IV. Association of management with mortality. Prev. Vet. Med. 4:159-171.

Notes