The goals of raising calves to weaning age are optimizing growth and minimizing health problems. We do this by understanding the digestive system, immune system, nutrient needs, and feed options.

The Digestive System

At birth, the dairy calf's digestive system is underdeveloped. From birth to about 2 weeks of age, the calf is a monogastric, or simple-stomached, animal. The abomasum is the only stomach compartment actively involved in digestion, and milk or milk replacer provides nutrients. As the calf begins to eat dry feeds, particularly grains containing readily fermentable carbohydrates, the rumen takes on a more important role. The stomach compartments grow and change as the calf develops into a ruminant animal. The fascinating differences between calves and mature ruminants create unique nutritional needs for preweaned calves.

Anatomy

At birth, the calf's stomach contains the same four compartments found in adult ruminants. However, the calf's reticulum, rumen, and omasum are inactive and undeveloped. The newborn's functional stomach, the abomasum, is similar to a human's stomach. As the calf grows and begins to consume a variety of feeds, its stomach compartments grow and change accordingly (Figure 1 and Table 1).

The abomasum constitutes 60 percent of the young calf’s stomach capacity. In contrast, it makes up only 8 percent of the stomach capacity in a mature cow. At birth, the reticulum and rumen make up 30 percent of the stomach capacity, and the omasum makes up approximately 10 percent. By 4 weeks of age, the reticulum and rumen comprise roughly 58 percent of the stomach, the omasum remains the same at 12 percent, and the abomasum falls to about 30 percent.

The stomach compartments grow in proportion to the calf’s body size. By 12 weeks of age, the reticulum and rumen will make up more than two-thirds of the total stomach capacity. The omasum still makes up about the same proportion at 10 percent. In contrast, the abomasum comprises only 20 percent.

The abomasum continues to function as it did at birth, and it actually grows in size. However, the reticulum and rumen grow in size and in function; they become the most important parts of the stomach system. As the stomach develops more fully, the calf begins functioning as a mature ruminant. The objective of calf nutrition is to promote rumen development early in life.

Figure 1. Development of bovine stomach compartments from birth to maturity.
Table 1. Relative size of bovine stomach compartments from birth to maturity.

<table>
<thead>
<tr>
<th>Age</th>
<th>% of Total stomach capacity</th>
<th>% of Total stomach capacity</th>
<th>% of Total stomach capacity</th>
<th>% of Total stomach capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newborn</td>
<td>25</td>
<td>5</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>3 to 4 months</td>
<td>65</td>
<td>5</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Mature</td>
<td>80</td>
<td>5</td>
<td>7 to 8</td>
<td>7 to 8</td>
</tr>
</tbody>
</table>

**Preruminant Digestion**

At birth, the rumen is nonfunctional; it has little tissue development and lacks a population of microorganisms. In the absence of a functional reticulorumen, the calf depends on its digestive enzymes. These are released primarily from the abomasum and small intestine and break down fats, carbohydrates, and protein.

In the young calf, some liquids can bypass the rumen and flow directly to the abomasum through the esophageal groove (Figure 2). The esophageal groove is formed when muscular folds from the reticulorumen come together, stimulated by sights and sounds calves associate with feeding and a reflexive response to swallowing. Any liquid (milk or water) consumed while the calf is excited by the anticipation of feeding bypasses the rumen and enters the abomasum. On the other hand, when the calf drinks in response to thirst, liquid enters the rumen instead of the abomasum. The esophageal groove forms whether calves are fed from a nipple bottle or an open pail.

Within 10 minutes after milk or colostrum feeding, the liquid forms a clot in the abomasum due to enzymes (chymosin and pepsin) and hydrochloric acid acting on casein (milk protein) and fat in the milk. Chymosin, also known as rennin, binds specifically with casein. Clotting binds much of the casein and fat into a clump, or curd, to be digested slowly by stomach enzymes over a period of 12 to 18 hours. Many of the enzymes required for normal, rapid digestion of feeds are produced in limited amounts in the first 48 hours of life. Low enzyme activity and curd formation following first colostrum feeding allow the calf to digest and assimilate nutrients slowly, yet efficiently, preventing scours caused by undigested nutrients reaching the large intestine. When a second feeding of colostrum or transition milk occurs, it simply adds to the already formed curd in the calf’s stomach. This system allows the calf to receive a steady supply of nutrients over the first 24 to 48 hours of life, as long as it is fed casein-containing liquids.

The fraction of milk that does not form a curd is called whey. Whey is composed of water, minerals, lactose, and other proteins (including immunoglobulins). Whey passes directly into the small intestine for absorption and/or digestion within 10 minutes after feeding. From the small intestine, immunoglobulins can be absorbed into the calf’s blood stream. Again, the newborn’s limited digestive capacity aids the calf by enabling rapid absorption of the immunoglobulins that it needs.

With the exception of lactose (milk sugar), the newborn calf cannot effectively digest sugars or starches. By three weeks of age, there is a marked improvement in the calf’s ability to digest carbohydrates, although the digestion of starch varies according to its origin and processing methods. As the calf’s digestive enzymes become more active, there is also an increased ability to digest vegetable proteins in feeds.

**Figure 2. Muscular folds of the reticulorumen form the esophageal groove and direct milk to the abomasum.**
Rumen Development

The functional rumen acts as a fermentation vat, where microorganisms digest complex carbohydrates and high-fiber feedstuffs. The lining of the rumen wall in an adult cow has a very pronounced covering of papillae. These papillae are finger-like projections that greatly increase rumen surface area, the area through which nutrients can be absorbed. Papillae development is stimulated by the end products of microbial fermentation, specifically butyric acid and, to a lesser extent, propionic acid.

Developing the rumen of newborn calves is one of the most important and interesting areas of calf nutrition. From the standpoint of efficiently and economically feeding dairy replacements, developing the rumen so that it can serve as a fermentation chamber for forages and grains is fundamental.

Within a few days of birth, the calf's rumen begins to develop a population of microbes. The number and types of bacteria are a function of the types of feeds the calf eats. The esophageal groove does not function when the calf eats dry feeds; they enter the rumen, where they must be digested by microbes or chewed further by ruminant. In addition to feeds, the environment, bedding, and hair provide microorganisms that inoculate the calf's rumen. The types of rumen microbes that proliferate are those that best digest and utilize the feeds eaten by the calf. In addition to feed particles, rumen microbes require water to grow properly and ferment feedstuffs. If water is not provided to the calf early in life, rumen microbial growth is limited. Water consumed as plain water enters the rumen and becomes available for the microbes' use. However, water consumed in other feeds, including milk or milk replacer, is not readily available to rumen microbes because it enters the abomasum.

There are two separate components to rumen development. The first is the physical size of the organ. At birth, the rumen is small and undeveloped. The diet has long been known to affect this aspect of rumen development. By 4 weeks of age, if the calf is fed only milk or milk replacer, the rumen will be quite small. As milk or milk replacer is fed in increasing amounts, the abomasum grows in size, but the rumen remains proportionately small and grows only moderately. This difference is great, especially when calves of the same age that are fed different diets are compared.

The rumen will be small relative to the abomasum if the calf receives a diet of only milk or milk replacer for 6 or more weeks. The longer a calf is fed large amounts of liquid feed, the greater the restriction on rumen growth relative to the size of the calf. Interestingly, while the calf appears normal or grows at rapid rates, her rumen is underdeveloped. Lack of rumen development causes a slump in growth rates after weaning.

The second aspect of rumen development is the elongation of rumen papillae and thickening of rumen walls. Feeding management can drastically affect their development.

Compare the rumen papillae development of a 6-week-old calf fed only milk replacer with one fed milk and moderate amounts of free-choice grain from 3 days of age. The calf fed grain in addition to milk shows a great deal more papillae development and a much thicker, darker, and more vascularized rumen wall (Figure 3, A and B).
Now compare a third calf fed milk and good quality hay from 3 days of age (Figure 3, C). Despite eating moderate amounts of hay, the papillae are not developed at all, and the rumen wall is quite thin. This is because the digestion end products of hay include more acetic acid, which rumen walls do not use for papillae growth and development. Calves with access to large amounts of roughage will have a considerable increase in rumen size. However, this is due largely to stretching, not real growth, of the rumen tissue.

In calves fed milk and grain papillae grow larger and the rumen walls thicken as calves get older. In comparison, calves fed milk and hay until 8 or 12 weeks have very limited papillae development, and the rumen walls remain thin, despite the consumption of appreciable amounts of hay. In fact, the rumen development of a 4-week-old calf on milk and grain is greater than that of a 12-week-old calf fed milk and hay. Rumen development of calves fed milk, grain, and hay will vary from calf to calf depending on individual preferences for dry feedstuffs.

The bottom line is that a small amount of grain, along with water, will create fermentation and, therefore, butyric acid production in the rumen. This, in turn, enhances the development of a more functional rumen that can better digest grains and, later in life, forages.

The process of rumen papillae growth is self-generating and allows grain-fed calves to have a tremendous amount of rumen development at an early age — 3 to 4 weeks. Early rumen development and therefore earlier weaning are the reasons to feed grain early. Calves started on grain late or those that consume too little grain at a young age are at a definite disadvantage.

**Figure 3. Comparison of rumen papillae development at 6 weeks in calves fed milk only (A), milk and grain (B), or milk and hay (C). Note the marked differences in papillae length and color.**

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**Colostrum**

**Introduction**

Colostrum is the first milk produced after a normal dry period and mammary involution, or the first milk secreted by a heifer, and it is an essential part of a newborn calf’s survival. As the newborn's first food source, colostrum provides essential nutrients to increase metabolism and stimulate digestive activity. Colostrum is also the source of passive immune protection that is essential for keeping the calf healthy. The quality, quantity, and timing of colostrum feeding are major factors affecting calf morbidity and mortality.

True colostrum contains twice as much dry matter and minerals and five times as much protein as whole milk (Table 2). It is also higher in energy and vitamins. The high content of fat and vitamins A, D, and E in colostrum are especially important because the newborn calf has low reserves of these nutrients. In addition, the relatively low lactose content of true colostrum reduces the incidence of diarrhea.

**Table 2. Typical composition of colostrum and transitional milk.**

<table>
<thead>
<tr>
<th>Item</th>
<th>Milking number</th>
<th>Milking number</th>
<th>Milking number</th>
<th>Milking number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids (%)</td>
<td>23.9</td>
<td>17.9</td>
<td>14.1</td>
<td>12.9</td>
</tr>
<tr>
<td>Protein (%)</td>
<td>14.0</td>
<td>8.4</td>
<td>5.1</td>
<td>3.1</td>
</tr>
<tr>
<td>IgG (mg/ml)</td>
<td>32.0</td>
<td>25.0</td>
<td>15.0</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Colostrum also contains immunoglobulins (antibodies), which are critical in providing the calf with immunity from infectious diseases. In the bovine, antibodies cannot cross the placental wall and pass directly from the dam to the fetus. Instead, the calf receives immunity by consuming adequate amounts of colostrum within the first few hours after birth. During the first 24 hours after birth, the calf can absorb antibodies directly from the gut into the bloodstream without digesting them. This type of protection, from the dam to the calf via colostrum, is called “passive immunity.” Passive immunity helps to protect the calf until its own immune system becomes fully functional. The gap between passive immunity provided by colostrum and the calf's own immunity creates a period where the calf is at greater risk of illness (Figure 4).

**Figure 4. Antibodies from colostrum protect calves until their own immune systems are fully functional.**

The immunoglobulin content of colostrum ranges from 2 to 23 percent, compared to only about 0.1 percent in whole milk. Immunoglobulin content is directly related to the percentage of solids in the colostrum, which ranges from 17 to 36 percent. The percentage of antibodies in colostrum decreases rapidly with each milking. Usually, the second milking contains 60 to 70 percent as many immunoglobulins as the first milking (Table 2).

The primary colostrum antibodies are immunoglobulin G (IgG), immunoglobulin A (IgA), and immunoglobulin M (IgM). IgG constitutes 80 to 85 percent of all immunoglobulins in colostrum and provides immunity against a wide variety of systemic infections and disease. IgA comprises 8 to 10 percent of the immunoglobulins, and IgM makes up 5 to 12 percent. Research data shows that the half-life of IgG is 21 days, IgM is 4 days, and IgA is 2 days. IgG is not only the most prevalent type, it also lasts the longest in the calf's bloodstream.

**Quality**

Two factors dictate colostrum quality: immunoglobulin concentration (specifically IgG) and the presence or absence of bacteria. In terms of IgG, good quality colostrum contains at least 50 grams of IgG per liter (g/L). Management practices have limited control over IgG concentration, but it can be measured easily, and feeding practices can be managed around it. On the other hand, proper management can ensure low bacterial loads and high quality, clean colostrum.

IgG concentration in colostrum varies tremendously due to a variety of factors, including the disease history and exposure of each cow, the volume of colostrum produced, the season of the year, dry cow nutrition, and breed. Values for IgG in colostrum can easily range from 20 to 100 g/L, which can mean the difference between adequate immunity and failure of passive transfer (inadequate immunity).
Cows produce antibodies in response to pathogens to which they have been exposed. Cows exposed to a greater number of pathogens tend to produce colostrum with more immunoglobulins than cows exposed to fewer pathogens. This explains why older cows often produce colostrum with a greater number and variety of immunoglobulins than younger cows. However, if older cows are not exposed to many pathogens, their colostrum may not have high levels of antibodies. Heifers raised on other farms, where they are not exposed to the same pathogens as lactating cows, also produce inferior colostrum. An older cow on your farm produces the best quality colostrum, and a first-calf heifer raised at another location and moved to the farm a few days before freshening produces the poorest.

Although it is true that older cows often produce colostrum with higher IgG concentration than first- or second-lactation animals, research has shown that in some herds heifers produce colostrum with adequate IgG. It has also been found that in some cases the second milking colostrum exceeds 50 g/L of IgG. Discarding colostrum based on the first milking volume or by lactation number of the cow can unnecessarily restrict colostrum supply. Instead, test all colostrum and feed or discard based on the estimated IgG content.

A good dry cow and heifer vaccination program can improve colostrum quality. Vaccines stimulate increased maternal antibody production and aid in passively immunizing the calf. The dam can be vaccinated against rotavirus, coronavirus, clostridium, and *E. coli* during the dry period.

Here’s a summary of some major factors affecting the IgG concentration in colostrum:

- **First milking volume**—cows that produce a large quantity of colostrum (greater than 18 pounds, or about 2 gallons) often produce lower concentrations of immunoglobulins, likely due to dilution.
- **Immune status of the dam**—as it relates to her pathogen exposure and vaccination level.
- **Time between calving and first milking**—IgG levels in colostrum decline rapidly after calving, so calves should be milked as soon as possible.
- **Leaking milk prepartum or milking before calving**—both reduce antibody levels by colostrum removal or by dilution.
- **Length of the dry period**—a 3- to 4-week dry period is needed to allow antibodies from the blood to be concentrated in colostrum. Continuous milking (no dry period) has been found to reduce colostrum volume and IgG concentration.
- **Age of the cow**, especially as it relates to increased exposure to pathogens—most 2-year-old cows have antibodies to fewer pathogens relative to older cows. Cows in third or greater lactation generally produce colostrum with more Ig than younger cows.
- **Dry cow nutrition**—There is some debate, but not much research, about effects of nutrition during the dry period on colostrum quality and volume. Feeding a balanced diet that meets current NRC recommendations for protein, energy, minerals, and vitamins is a good preventive strategy.
- **Breed**—Jerseys tend to have the highest levels of antibodies, Holsteins have the lowest, and other breeds fall in the middle.
- **Season of the year**—may be related to environmental stress and forage quality.

The large amount of variation in colostrum quality can make feeding and managing this critical feed challenging. Colostral IgG can be measured in a lab with great accuracy, but the tests are expensive and time-consuming. While high quality colostrum containing a large percentage of immunoglobulins is typically very thick and creamy, appearance alone is not a good indicator of quality. Volume of first-milking colostrum also can be misleading and is not a recommended method for estimating colostrum immunoglobulin content. Fortunately, there are simple devices that can be used to quickly estimate colostrum IgG content.

The colostrometer estimates IgG content by measuring the specific gravity or density of colostrum, which is correlated with antibody concentration. The colostrometer is a hydrometer with a scale calibrated in milligrams per milliliter (mg/mL) of immunoglobulins. When it is placed in a container of colostrum, colored areas on the scale indicate whether the colostrum is acceptable or unacceptable for feeding newborn calves. Colostrum that tests in the green range contains 50 to 140 mg/mL of IgG, which is acceptable for feeding to calves. Colostrum that falls in the yellow or red range (less than 50 mg/mL) should not be used for the first feeding. Note that the units mg/mL and g/L are equivalent.

For greatest accuracy with the colostrometer, measure colostrum IgG concentration using colostrum cooled to room temperature (72°F). At lower temperatures, the colostrometer overestimates the IgG concentration, and temperatures above 72°F will underestimate immunoglobulin concentrations.

Another method of testing colostrum is a Brix refractometer, which measures the bending of light as it passes through the sample. The scale in a Brix refractometer was originally designed to measure the amount of sucrose in a solution, but Brix values can be correlated to IgG. A Brix value of 22 percent corresponds to 50 mg/mL, meaning colostrum with a Brix value above this cutoff point can be considered high-quality colostrum.

To use a Brix refractometer, a few drops of colostrum are placed on the prism and the sample cover is lowered. Brix refractometers are available in both digital and optical models. Optical refractometers are held up perpendicular to a light source. The Brix value is
read at the line between the light and dark areas that appear on the scale. For colostrum samples, digital models may be easier to use, because high fat content of colostrum often causes a blurred band, rather than a distinct line, on the optical refractometer scale. This band can make it difficult to determine the exact Brix value and reduces the repeatability of measurements. Digital refractometers seem to be able to read these high-fat samples accurately. Brix refractometers are available for solutions with a wide range of sugar content. A scale that starts at zero and goes to approximately 35 provides a good range for testing colostrum.

When using a refractometer, the prism and sample cover must be thoroughly cleaned after every sample to avoid residue that could affect the next measurement. It is a good practice to check the calibration of the refractometer occasionally. The manufacturer should provide instructions on checking and adjusting the calibration, but distilled water should produce a reading of zero when the instrument is properly calibrated.

Colostrum quality is typically expressed in terms of IgG, but contaminants also influence quality. Obviously, fewer contaminants mean higher quality. Common contaminants include bacteria, blood, and remnants of mastitis infections (white blood cells, infectious organisms, endotoxins, and antibiotic residues). Good, clean colostrum can be compromised if a cow's udder and teats are not well-cleaned, sanitized, and dried before the initial milking or nursing. Do not feed excessively bloody or mastitic colostrum. Regularly maintain and clean milking equipment, especially waste milk cans and their lids. These containers should be cleaned and sanitized just like other milking equipment to minimize bacterial contamination of colostrum.

Another key to keeping bacteria levels in check is feeding or cooling colostrum as soon as possible (within 30 minutes of milking). The warm, nutrient-rich liquid is an excellent environment for bacteria to grow. Bacteria counts of less than 100,000 colony-forming units per milliliter (cfu/mL) are considered acceptable, but research studies have shown that 36 to 82 percent of colostrum samples tested exceeded this level of bacterial contamination.

**Quantity**

Large breed calves should receive 4 quarts of undiluted colostrum within one hour of birth, or 2 quarts within an hour and an additional 2 quarts within 6 to 8 hours. Small breed calves can be fed 3 quarts within the first hour. Since many calves will not or cannot drink this large amount at one time, an esophageal feeder may be used to feed all or part of the colostrum.

Research shows calves can absorb IgG with similar efficiency whether fed from a bottle or an esophageal feeder. However, rough handling when using a tube feeder can injure calves. Procedures for using an esophageal feeder are described later in this article. Nursing is an unreliable method for feeding colostrum, and 40 percent of calves allowed to nurse on their own do not drink enough colostrum. Only 25 percent will get adequate colostrum within the first hour after birth. Quality, quantity, and timing all may be compromised by nursing.

The level of IgG necessary to provide adequate protection to the calf will vary depending on the pathogen load in colostrum and the environment, stress, housing, and feeding practices. Other factors include the calf's size and the efficiency of IgG absorption.

It is important to understand that feeding a large volume of colostrum cannot overcome low antibody concentration or high bacterial contamination. Volume is not the only factor determining the successful transfer of immunity from cow to calf.

**Timing**

Timing of colostrum feeding is critically important for two reasons: the short-lived ability to absorb large molecules and the potential for pathogenic bacterial colonization of the intestine.

The cells lining the intestine begin to mature shortly after birth. This maturation process makes cells unable to absorb intact macromolecules by about 24 hours of age. In addition, for a limited time after birth, the secretion of digestive enzymes remains low, allowing antibodies to escape digestion and enabling maximum absorption. By about 12 hours after birth, enzyme secretion increases, thereby reducing the antibodies' ability to reach the blood. Stressed calves typically have even less time to absorb antibodies than normal calves. Calves born to dams that experienced heat stress before calving have also been found to absorb less IgG.

At best, only 50 percent of the antibodies a calf consumes ever reach the bloodstream. This is measured by apparent efficiency of absorption, which is rarely over 50 percent and frequently less than 35 percent. Within 6 hours, the average ability of the gut walls to absorb immunoglobulins decreases by one-third. By 24 hours, the walls absorb less than 10 percent of what could originally be absorbed (Figure 5).

**Figure 5. The calf's ability to absorb antibodies declines rapidly over the first 24 hours.**
However, antibodies in colostrum may help fight infectious organisms in the calf’s digestive tract beyond 24 hours. The unabsorbed antibodies line the calf’s intestinal tract, providing a protective coating that prevents micro-organisms from attaching to the wall. This defense mechanism is inhibited if bacteria such as *E. coli* (found in manure) enter the digestive tract first. *E. coli* organisms can attach to the gut walls and inhibit the attachment and absorption of colostrum antibodies (Table 3).

Early bacterial inoculation of the gut creates another problem: immature intestinal cells can absorb infectious organisms as well as antibodies. If bacteria enter the bloodstream before antibodies, the calf has an extremely high risk of death. Bacteria in colostrum also can interfere with IgG absorption. Therefore, the colostrum and the calf must be kept as clean as possible.

Table 3. Effects of early colostrum feeding on intestinal *E. coli* attachment in colostrum-deprived calves.

<table>
<thead>
<tr>
<th>Feeding</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>E. coli</em> fed alone</td>
<td>Bacterial attachment to intestine and level of <em>E. coli</em> in circulation high.</td>
</tr>
<tr>
<td>Colostrum and <em>E. coli</em> fed together</td>
<td>No bacterial attachment to intestine.</td>
</tr>
<tr>
<td>Colostrum fed alone, <em>E. coli</em> fed one hour later</td>
<td>No bacteria attached to intestine and no <em>E. coli</em> in circulation. High level of circulating antibodies.</td>
</tr>
</tbody>
</table>


**Heat Treatment**

In many cases, colostrum quality can be improved by heat treatment (pasteurization), which reduces bacterial contamination. When pasteurizing colostrum, heat at 140°F for 30 to 60 minutes to reduce bacteria counts without affecting colostrum IgG levels or viscosity. Pasteurization may provide an added benefit of higher serum total protein concentrations in calves. In most research trials, calves fed heat-treated colostrum had higher IgG concentrations in their blood and improved apparent efficiency compared to calves fed unheated colostrum.

Colostrum can be successfully pasteurized in batch systems or in individual bags within a water bath. Heat treatment at 140°F for 60 minutes has been shown to effectively eliminate *Mycoplasma bovis*, *Listeria monocytogenes*, *E. coli* O157:H7, *Salmonella enteritidis*, and possibly *Mycobacterium avium* ssp. *paratuberculosis*. However, the success of on-farm pasteurization is strongly related to management of the system.

It is important to start with high-quality colostrum (greater than 50 mg/mL of IgG) and maintain strict sanitation of colostrum and pasteurization equipment. Chill colostrum pre- and postpasteurization if it is not used immediately. Monitor the time and temperature of pasteurization and cleaning processes, and test bacteria levels (before and after pasteurization) periodically.
Keep in mind that the temperature of pasteurizing colostrum is important. Temperatures used to pasteurize milk (145°F; 63°C) are too high for colostrum and will denature the IgG molecules. There are many commercial systems for pasteurizing colostrum and thawing it.

Storage and Handling
Storage and handling influence colostrum quality. Colostrum must be fed as soon as possible (within 1 hour) after collection or cooled to lower than 40°F to prevent bacterial growth during storage. Do not let colostrum sit at room temperature; even half an hour at room temperature during the summer may allow bacterial populations to double. The same problem with bacterial growth can occur after frozen colostrum is thawed. Pouring off the liquid portion periodically as colostrum thaws (and putting it in the refrigerator) will limit bacterial growth.

Storing high quality colostrum is a good management practice. Surplus colostrum can then be used when good quality, fresh colostrum is not available for a newborn calf. Refrigeration (at 33 to 35°F) can preserve colostrum quality for only about 24 hours before bacterial growth reaches unacceptable levels. For long-term colostrum storage, freezing is the best alternative. Colostrum may be frozen (at -5°F) for up to a year without significant decomposition of antibodies. One report indicated that colostrum was stored for up to 15 years without serious deterioration. Frost-free freezers are not optimal for long-term colostrum storage, as they go through freeze-thaw cycles that can allow the colostrum to thaw. Repeated freeze-thaw cycles markedly shorten colostrum storage life.

Freezing colostrum in 2-quart bottles or 1-gallon plastic bags (with zipper-closure) is an excellent method of storage. When needed, these containers can be placed in warm (less than 120°F) water and allowed to thaw. Alternately, colostrum can be thawed in a microwave oven with little damage to the antibodies. It is important to microwave colostrum for short periods on low power and pour off liquid periodically to minimize heating. Also avoid “hot spots” inside frozen colostrum. Use of a turntable can help to minimize antibody damage.

Research has indicated that white blood cells (leukocytes) present in colostrum also contribute to the health of calves. Leukocytes in colostrum reduce the effects of bacterial disease in young calves. Leukocytes are killed by frozen storage and are found only in fresh colostrum. Although additional research is needed, it appears that using fresh colostrum from the dam may be the best way to get these disease-fighting cells into calves.

It is ideal to keep enough frozen colostrum on hand to feed several calves. A package of frozen colostrum should be used when colostrum is of questionable quality or when it is not available.

In some herds, the supply of disease-free, high-quality colostrum is very limited, and replacer or supplement products can provide viable options for ensuring adequate immunity in calves. In other cases, the consistency and convenience of colostrum products is preferred over testing, sorting, and storing maternal colostrum.

Colostrum supplements are intended to be added to marginal colostrum when no other source of colostrum is available. Supplements cannot replace high quality colostrum because they do not contain sufficient quantities of antibodies to raise the blood level of IgG in calves above 10 mg/mL.

Products designed to replace colostrum contain more immunoglobulin than supplement products and provide more antibodies than poor or moderate quality colostrum. To be labeled as a colostrum replacer, the product must have been found to raise IgG levels in calves to 10 mg/mL or more. In addition to IgG, these products typically also provide fat, protein, vitamins, and minerals needed by the newborn. Multiple trials have reported acceptable levels of serum IgG and total protein in calves fed various replacer products. However, it is important to select products that are proven to be effective because not all products that have been tested in public research have provided adequate immunity. Generally speaking, the quality and effectiveness of colostrum replacer products have improved in recent years.

To consistently meet the passive transfer goal of greater than 10 mg/mL of IgG, calves typically need to receive 150 to 200 grams of IgG in the first 12 hours of life regardless of the source of that IgG.

Evaluating Colostrum Management
Success in providing adequate immune protection to calves can be monitored by taking blood samples from calves at 24 to 48 hours of age and measuring serum total protein using a refractometer with either a total protein or Brix scale. Total protein in serum is highly correlated to IgG levels. If calves have received enough high quality colostrum, serum total protein will be 5.5 grams per deciliter (g/dL) or greater. When total protein falls between 5.0 and 5.5 g/dL, there is a marginal risk for mortality and morbidity. Total serum protein levels less than 5.0 g/dL put the calf at high risk for health problems. On average, 90 percent of calves should achieve at least 5.2 g/dL. When using a Brix refractometer, 8.4 percent Brix indicates calves received enough high-quality colostrum.
We cannot prevent exposure to intestinal and respiratory pathogens. However, colostrum-derived immunity can significantly diminish the severity of these infections. While the exposure dose of a given pathogen strongly influences disease severity, the calf’s immunity can mitigate these effects. In a colostrum-fed calf, a low dose of a given pathogen results in subclinical disease (no visible sickness) and an immune response to the pathogen. The calf’s own immune system thus protects it from future infections by that pathogen.

The “clinical threshold dose” (the level of exposure that results in disease) is considerably lower for colostrum-deprived calves than for colostrum-fed calves (Figure 6). The number of organisms needed to cause disease is much lower in calves that have not acquired immunity from colostrum antibodies. Beyond the clinical threshold dose, the greater the pathogen exposure is, the more severe the illness. Calves with colostrum-acquired immunity can be exposed to larger pathogen doses yet suffer less severe illnesses than colostrum-deprived calves.

Figure 6. Relationship between exposure dose of pathogen and severity of disease.

![Graph showing the relationship between exposure dose and severity of disease.]

Source: Adapted from D. Hancock, Dairy Herd Management, Feb. 1984.

Colostrum affects both morbidity (illness) and mortality (death). Results of a national survey of heifer management practices showed that mortality rates for calves with low antibody levels (less than 10 g/L) were more than twice that of calves with higher levels (Figure 7). Consistently feeding colostrum with high antibody levels and low bacteria counts is the foundation for raising healthy calves.

Figure 7. Calf survival rates by level of serum IgG.
Nutrient Requirements

The newborn calf must be fed highly digestible feedstuffs containing adequate levels of high-quality protein, energy, vitamins, and minerals.

Protein

Protein provides amino acids used to build body tissues. A newborn calf has few digestive enzymes, and it cannot utilize most vegetable proteins as well as it utilizes milk proteins. Follow the newborn calf's colostrum diet with whole milk or milk replacer containing milk protein or specially processed alternative proteins (see Table 8). By the time a calf is weaned, at 4 to 6 weeks of age, it can utilize most vegetable proteins very efficiently. After 4 months of age, when the calf has a fully developed rumen, larger rumen volume that reduces rate of passage, and an established microbial population, non-protein nitrogen compounds (such as urea) may be fed.

Energy

Energy is used to support body functions and allow dietary protein to be used in building body tissue. Young calves lack certain digestive enzymes and are therefore unable to completely digest starch, some sugars (e.g., sucrose or table sugar), and some types of fat. While calves can digest saturated fats, including milk fat, coconut oil, palm oil, and lard, they have limited ability to digest unsaturated fats such as corn and soybean oils. The major sources of energy for the newborn should be derived primarily from lactose (milk sugar) and highly digestible fat. It is very important to provide adequate energy, since the calf’s metabolic rate, or rate at which energy is used, is greatest during the first two weeks of life. Cold weather and other environmental stresses increase the calf’s energy requirements.

The rate of rumen development and microbial growth determines how soon the young calf can digest complex starches and carbohydrates, since microbes convert these energy sources into microbial protein. Within two weeks of age, the calf can digest starch. Shortly thereafter, it can digest complex carbohydrates.

Table 4 shows the daily protein and energy requirements of dairy calves fed milk or milk replacer and calf starter.

Table 4. Daily energy and protein requirements of dairy calves fed milk or milk replacer and starter.

<table>
<thead>
<tr>
<th>Body Weight lb</th>
<th>Calves gaining 1.0 lb/day NE</th>
<th>Calves gaining 1.0 lb/day g</th>
<th>Calves gaining 1.0 lb/day</th>
<th>Calves gaining 1.5 lbs/day NE</th>
<th>Calves gaining 1.5 lbs/day g</th>
<th>Calves gaining 1.5 lbs/day</th>
<th>Calves gaining 1.5 lbs/day</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NE 1 Mcal</td>
<td>NE 2 Mcal</td>
<td>ME 3 Mcal</td>
<td>CP lb</td>
<td>NE 1 Mcal</td>
<td>NE 2 Mcal</td>
<td>ME 3 Mcal</td>
</tr>
</tbody>
</table>
The amounts of protein and energy required by a calf are divided into two categories based on their use for maintenance and growth. Maintenance describes the amount of energy and protein needed to support normal bodily functions, including maintaining body temperature. Maintenance requirements are related to body size; bigger animals have higher maintenance needs. Environmental conditions also affect maintenance requirements. Calves housed in drafty, wet conditions have more maintenance energy needs than those housed in draft-free, dry environments. Extremely cold or hot weather also increases energy needs. Growth requirements account for the nutrients required to build body tissues. It is important to understand that nutrients the calf consumes are used to support maintenance first. Most nutrients fed in excess of maintenance needs can be used for growth. Notice in Table 4 that calves with the same body weight have the same energy requirements for maintenance, regardless of growth rate. Nutrients needed to support growth logically increase as growth rate increases.

Calf growth is affected by many factors, but daily intake of protein and energy are the most important. Most often, energy intake is the first limiting factor to growth. If a calf consumes more energy than she needs for maintenance, the “extra” energy can be used to convert dietary protein into body tissue. However, if a calf consumes less energy than required for maintenance, there is no energy available for growth. Diets must provide enough energy to support growth and enough protein to be used for that growth. Feeding too little of either nutrient, or feeding the wrong ratio of energy to protein, will limit growth. Nutrients are provided by liquid feeds and starter grain, and intake and composition of both these feeds affect growth potential. In addition, it is important to pay close attention to the day-to-day variability in liquid feeds as nutrient fluctuations can contribute to scours and poor growth in young calves.

Figure 8 demonstrates the difference in energy needs between calves. If calves are fed the same daily amount of metabolizable energy (ME), for example, 1.25 pounds per day of milk replacer containing 20 percent protein and 20 percent fat (2.15 Mcal ME/lb), one might think all calves will gain weight at the same rate. This is not the case, because calves with different body weights have different maintenance energy requirements. A constant feeding level will meet the needs of an average calf, but exceed the needs of smaller calves and fall short of the needs of larger calves, resulting in different rates of gain. Notice that all four of the example calves in Figure 8 have their maintenance energy needs satisfied when fed 1.25 pounds of milk replacer per day, but 3 of the 4 calves will need more milk replacer to achieve 1.0 pound of gain per day. Energy consumed in excess of maintenance needs can be applied to growth. Therefore, calves with greater excess energy can be expected to grow more. However, there is another factor to consider—increased growth requires increased dietary protein.

Figure 8. Dry matter intake required to meet net energy needs for maintenance (solid bars) plus one pound of gain per day (open bars) in calves fed milk replacer containing 20% protein and 20% fat (2.15 Mcal/lb ME). A line drawn at milk replacer intake of 1.25 pounds per day shows that only the 70-pound calf will be able to gain one pound per day when fed only milk replacer at this rate.
Figure 9 shows the increase in protein requirements as rate of gain increases. The graph also shows that calves fed high levels of protein must be fed more dry matter to realize improved rates of gain. If dry matter is not increased, the extra protein essentially is wasted because energy becomes the first limiting factor. The nitrogen in this excess protein ends up in manure, increasing the amount of nitrogen that must be removed from the farm. In addition, when calves are fed only milk or milk replacer the amount fed to each calf must be adjusted as the calf grows to ensure both energy and protein needs continue to be met. Based on the requirements shown in Figure 9, a standard 20 percent crude protein milk replacer fed at 1.23 pounds per calf per day will support daily gains of nearly 0.75 pound in calves weighing 100 pounds. However, the milk replacer would need to contain 21% crude protein to realize the full 0.75-pound rate of gain. A better understanding of this relationship has led most milk replacer companies to offer milk replacers with higher protein levels and a protein to energy ratio that more closely match calves' requirements.

**Figure 9. Effect of rate of gain on protein and dry matter intake requirements of a 100-pound calf fed 20% protein, 20% fat milk replacer containing 2.15 Mcal/lb ME.**

These examples not only demonstrate the relationship between energy and protein, they also reinforce the importance of knowing each calf's actual body weight. Guessing a calf's birth weight and feeding her less than she requires in the first few weeks of life may limit her growth. On the other hand, overfeeding of young or small calves could result in more digestive upsets and scours as well as lower starter intake, which restricts rumen development. Weight tapes designed specifically for calves can be used if scales are not available. To feed calves accurately, the weight of both calves and feeds must be known.
Vitamins
Calves require many of the same vitamins as monogastrics, including vitamin K and the water-soluble B vitamins: thiamine, riboflavin, niacin, choline, biotin, pyridoxine, folic acid, B12, and pantothenic acid. Vitamin K and water-soluble B vitamins are found in colostrum, fermented colostrum, whole milk, and good milk replacers. Rumen microorganisms can produce these vitamins once the calf's rumen begins to function. The young calf also requires the fat-soluble vitamins A, D, and E, which are in short supply at birth, but which are present in colostrum. Whole milk or milk replacers and supplemented grain mixtures normally supply all of these vitamins. Vitamin C is synthesized in the calf's tissue and is not required in the diet.

Minerals
Dairy calves require the same minerals for growth as other animals. Milk and milk replacers generally supply adequate amounts of many minerals needed during the first few weeks of life. The mineral content of colostrum and milk may be low or deficient, especially in mineral-deficient dams. Calf starters usually contain adequate levels of the major and trace minerals required by the young calf.

Liquid Feeds
After a few days of colostrum feeding, there are several liquid feed options available. One or several different liquid feeds may be fed throughout the year. These include milk replacers, waste milk, excess colostrum/transition milk, or whole milk. Any of these choices can provide excellent feed, although each option has advantages and disadvantages.

When comparing different options consider differences in the amount of nutrients provided as well as the cost. Cost per pound of gain may be helpful in comparing feeds that differ in composition or amount fed. Cost comparisons for alternative feeding systems also may include expected differences in the rates of sickness and death and the associated costs of treatment or loss.

The value of feeds is best compared on a dry matter or “solids” basis to allow an accurate comparison of feeds with different solids content. To determine the cost of a pound of milk replacer, simply divide the price per bag by the weight in the bag. Then divide this price by the dry matter concentration of the powder. If no dry matter value is provided on the bag, an estimate of 95 percent may be used. Whole milk is valued at the price received for milk sold. Divide the price per hundredweight by 100 to calculate the price per pound of liquid. Then divide this price by the solids content of the milk, typically about 12.5 percent. The result is the value of one pound of milk solids. Transition milk and colostrum can be considered free, as they cannot be sold.

Putting a dollar value on waste milk is a little more complicated, and there are several methods used. At a minimum, the value of waste milk is equal to the cost of production. This may be a valid cost for a portion of the milk because most farms will have some waste milk. However, if the number of cows being treated is greater than 3 percent of the milking herd, then the true value of waste milk must include an opportunity cost. If cows were not being treated, this milk would have the same value as all other milk sold. Therefore, the value of waste milk may be as high as the price received for whole milk. To find the value of solids in waste milk an estimate of 12.5 percent can again be used. In addition to the milk value, if milk is pasteurized these costs must be considered as well. The pasteurizer and associated equipment for hauling or storing milk should be assigned an annual cost that includes purchase price, depreciation, installation, operation (including cleaning), and labor for the pasteurization process. This annual cost can then be spread out over the total pounds of milk pasteurized in a year. The pasteurization cost is then added to the value of milk to determine the true cost of the feed.

Milk Replacer
Calves may be started on a milk replacer when 2 to 4 days old, but the switch from whole milk to milk replacer should be gradual. Abrupt changes will increase the likelihood of nutritional scours and stress. Table 5 shows the recommended nutrient composition of milk replacer. Milk replacers designed for calves more than 3 to 4 weeks of age should not be used for younger calves. The label directions on the replacer bag should be carefully followed.

Approximately half of the dairy calves in the United States are fed milk replacer for most or all of their liquid feeding period. Convenience and biosecurity are key factors that make using milk replacer appealing to dairy producers. There are many options available for calf milk replacer, and each is designed to meet different needs. To sort through them, first set goals for calf growth, health, and weaning age. Then select a product designed to meet those goals. When comparing products, the first step is to read the label. The most important items to identify are the crude protein and fat content, ingredients, and feeding instructions. Differences in the price of milk replacer are due to ingredient selection, manufacturing technology, and nutritional quality. Consider these factors when balancing cost and calf performance.

Table 5. Suggested nutrient content of milk replacer fed to replacement calves.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Amount</th>
</tr>
</thead>
</table>

Feeding the Newborn Dairy Calf
Minimum Crude Protein (%)  20 to 28
Minimum Fat (%)  10 to 22
Maximum Crude Fiber (%)  1 to 2

**Macro minerals (%)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>1.0</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.7</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.07</td>
</tr>
</tbody>
</table>

**Trace minerals (ppm)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>100</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Vitamins (IU/lb)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4,091</td>
</tr>
<tr>
<td>D</td>
<td>273</td>
</tr>
<tr>
<td>E</td>
<td>22.7</td>
</tr>
</tbody>
</table>

Source: Adapted from Nutrient Requirements of Dairy Cattle, 2001.

The composition and quality of a milk replacer influence the growth, health, and overall performance of calves. Ingredient and nutrient levels vary greatly between products. Protein sources are typically the most expensive milk replacer ingredients. The search for less expensive ingredients has produced many options for protein sources. These sources vary in amino acid composition, bioavailability or digestibility, and the presence of antinutritional factors. Milk proteins are typically more digestible and contain a more favorable profile of amino acids than non-milk proteins (Table 6). In a very young calf, milk proteins are highly digestible, at 92 to 98 percent, and plant proteins are somewhat less digestible, at 85 to 94 percent. Plant proteins with antinutritional factors may cause allergic reactions, poor digestion, or diarrhea. Milk replacers in the United States are typically based on whey and whey protein concentrate.

**Table 6. Amino acid content (% of total protein) of common milk replacer ingredients.**

<table>
<thead>
<tr>
<th>Amino acid*</th>
<th>Whey protein concentrate</th>
<th>Dried skim milk</th>
<th>Soy protein concentrate</th>
<th>Modified wheat protein</th>
<th>Bovine plasma</th>
<th>Porcine plasma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lysine</td>
<td>9.1</td>
<td>8.2</td>
<td>6.3</td>
<td>1.6</td>
<td>6.5</td>
<td>6.1</td>
</tr>
<tr>
<td>Methionine + cystine</td>
<td>4.4</td>
<td>4.2</td>
<td>2.8</td>
<td>4.3</td>
<td>3.2</td>
<td>2.8</td>
</tr>
<tr>
<td>Threonine</td>
<td>7.3</td>
<td>4.2</td>
<td>4.1</td>
<td>2.6</td>
<td>4.6</td>
<td>4.0</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>6.0</td>
<td>7.0</td>
<td>4.8</td>
<td>4.4</td>
<td>2.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Leucine</td>
<td>10.5</td>
<td>10.0</td>
<td>7.9</td>
<td>7.8</td>
<td>7.0</td>
<td>6.7</td>
</tr>
<tr>
<td>Arginine</td>
<td>2.5</td>
<td>3.6</td>
<td>6.1</td>
<td>4.0</td>
<td>4.2</td>
<td>4.2</td>
</tr>
<tr>
<td>Valine</td>
<td>5.8</td>
<td>6.7</td>
<td>5.2</td>
<td>4.4</td>
<td>5.0</td>
<td>4.7</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>2.2</td>
<td>1.4</td>
<td>1.3</td>
<td>1.0</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Histidine</td>
<td>1.9</td>
<td>2.7</td>
<td>2.6</td>
<td>2.2</td>
<td>2.3</td>
<td>2.4</td>
</tr>
<tr>
<td>Phenylalanine + tyrosine</td>
<td>6.2</td>
<td>9.7</td>
<td>8.8</td>
<td>9.9</td>
<td>7.6</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Source: Davis and Drackley, 1998. The Development, Nutrition, and Management of the Young Calf. *Value for each amino acid is grams of the amino acid per 100 grams of crude protein.
Compared to milk proteins, vegetable proteins often contain more crude protein. However, their protein quality, or amino acid content, is slightly inferior. Some soy-based milk replacers contain added lysine and methionine to improve their amino acid profile. Most soy isolates or concentrates used today are highly digestible to the young calf. Animal proteins often contain high levels of protein, and some have very high amino acid concentrations, similar to milk proteins.

Recommendations for acceptability of protein sources are presented in Table 7. Milk proteins are the best choice, especially for calves less than 3 weeks of age. Many non-milk protein sources are manufactured or processed specifically for use in calf milk replacers, and they can be supplemented with amino acids to improve their nutritional value. However, these sources can vary in quality and labels can be carefully worded to disguise how much non-milk protein is included. All non-milk proteins should be used with some caution and an understanding that their use is primarily to reduce milk replacer cost.

Table 7. Protein sources used in calf milk replacer and recommendations concerning their acceptability.

<table>
<thead>
<tr>
<th>Milk Proteins</th>
<th>Non-Milk Proteins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended for calves of any age</td>
<td>Acceptable for calves over 3 weeks of age</td>
</tr>
<tr>
<td>Dried whey protein concentrate</td>
<td>Soy protein isolate</td>
</tr>
<tr>
<td>Dried skim milk</td>
<td>Protein modified soy flour</td>
</tr>
<tr>
<td>Casein</td>
<td>Soy protein concentrate</td>
</tr>
<tr>
<td>Dried whey</td>
<td>Modified wheat protein</td>
</tr>
<tr>
<td>Dried whey product</td>
<td>Animal plasma</td>
</tr>
<tr>
<td></td>
<td>Soy flour</td>
</tr>
<tr>
<td></td>
<td>Egg protein</td>
</tr>
<tr>
<td>Not recommended</td>
<td>Meat solubles</td>
</tr>
<tr>
<td></td>
<td>Fish protein concentrate</td>
</tr>
<tr>
<td></td>
<td>Wheat flour</td>
</tr>
</tbody>
</table>

Feed milk replacer at 10 to 12 percent of birth weight. Faster growth rates can be achieved at higher feeding rates as long as calves start slowly and the amount fed is built up gradually to help avoid scouring.

Milk replacer generally contains between 20 and 28 percent crude protein, with 20 to 22 percent crude protein being most common. Crude fat levels range from 10 to 28 percent, and 20 percent is the most common. It is important that major minerals (including calcium, phosphorus, and magnesium), trace elements, and vitamins A, D, and E are balanced as well.

Many companies also offer high protein, low fat milk replacers (protein greater than 24 percent and fat less than 20 percent) that provide a more optimum ratio of protein to energy for efficient growth. It is important to pay close attention to the feeding instructions for these milk replacers. Calves must be fed more than in conventional programs and the amount fed to each calf may need to be adjusted as the calf grows. Instructions for feeding are detailed on the milk replacer feed tag. Calves also must be managed more carefully when feeding for higher rates of gain as they may be more susceptible to nutritional scours, especially when milk replacer is fed at greater than 12.5 percent solids and water availability is limited. Grain intake often is reduced in early life, thereby limiting rumen development. Research and on-farm experience have shown that this can result in restricted growth after weaning and produce calves that are similar in size to conventionally fed calves by 4 to 6 months of age.

Follow the manufacturer's instructions for powder and water amounts, water temperature, and mix order; these instructions typically are printed on the label. Water temperatures of 110 to 120°F (43 to 49°C) are commonly recommended. Mixing is difficult at lower temperatures, and higher temperatures can cause the fat to separate. It is important to measure dried milk replacer and water accurately to be sure the amount of solids fed is correct. For the most consistent mixing, use a scale to weigh both the powder and the water and a thermometer to check water temperature. Alternatively, use the cup provided in the bag to measure powder and measure the water by volume.

Mix milk replacer using slow, circular motion. Whipping, mixing too fast, and mixing too long can cause foaming or separation of fat into a greasy surface layer. Good milk replacer will go into solution easily and leave no clumps of powder. In reality, milk replacer is not a true solution, but rather a suspension, so most milk replacer will settle if left standing more than 10 to 15 minutes. If milk replacer must stand before feeding, give it a quick stir before feeding each calf.
Whole Milk

Before the mid-1950s, whole milk was the primary liquid feed for calves. It is an excellent feed for calves, but its use was discouraged for over 50 years because milk replacer was usually a cheaper feed source. However, since the mid-2000s milk replacer prices have risen quite a bit due to the increasing use and value of whey protein. When evaluating your options for liquid feed, calculate the actual costs rather than making assumptions based on tradition. As market conditions change, there may be times when whole milk from the bulk tank is a very viable option. In addition to cost, disease transmission is a potential problem when feeding whole milk, so consider pasteurizing whole milk before feeding. Be sure to consider the storage and handling changes that would need to occur if switching from a milk replacer program to a whole milk system.

A calf should be fed whole milk at a rate of approximately 10 to 12 percent of its body weight per day. Feeding much below this amount causes poor growth due to lack of necessary nutrients. Feeding higher levels of whole milk can result in more rapid growth rates, but it is not recommended due to decreases in grain consumption and prolonged weaning time (and slowed rumen development).

Waste Milk

Waste milk can support weight gains similar to whole milk without increasing scouring or illness. However, feeding waste milk increases risks of pathogen exposure, antibiotic residues, and antibiotic resistance. In addition, day-to-day variability of waste milk may contribute to scouring and poor growth in young calves, especially on very small farms. Calves raised for bob or heavy veal should not be fed milk from cows treated with antibiotics. These compounds leave residues in the veal calf. Milk from treated cows should only be fed to calves kept as herd replacements or kept for at least eight weeks after the last feeding of treated milk.

Waste milk contains more microbial life than other liquid feeds. This dictates extra care in storing and handling this milk. Storage at room temperature for even a short period of time will allow rapid growth of bacteria. Mastitic milk should not be fed to group-housed calves that come into direct contact with other calves. Calves that suck each other immediately after drinking mastitic milk may actually inoculate the immature teats and eventually cause heifer mastitis. Mastitis-causing organisms can be passed only through direct contact; they cannot be passed from the gut to the udder.

Waste milk from cows with known infections of Johne's, E. coli, leukosis, salmonella, mycoplasma, or pasteurella should not be fed to calves unless it is pasteurized. Pooling milk from several cows is a common, but very risky, practice. The high number of bacteria in waste milk greatly increases the chance of spreading disease, and a single infected cow could pass disease to many calves. So while pooling waste milk may dilute microbial numbers, it is not recommended unless milk is pasteurized before feeding.

When waste milk is fed regularly, pasteurization should be considered. Both batch (vat) and continuous flow (high temperature, short time or HTST) methods can effectively reduce the bacteria in waste milk. Batch methods should include agitation to ensure even distribution of heat throughout the milk. Batch pasteurization requires heating milk to 145°F and holding it for 30 minutes. Using HTST pasteurization, milk must be heated to 161°F and held for 15 seconds. Regular monitoring of the time required to achieve the target temperature, the holding time, and temperatures throughout the pasteurization and cleaning cycles are recommended for best results. Keep in mind that some bacteria may survive pasteurization; it is not sterilization. In addition, proper cleaning and sanitation of equipment and proper handling of pasteurized milk are still required to prevent excessive bacterial growth. Feed milk soon after pasteurizing, and store any leftover milk at less than 40°F. Milk not fed within 24 hours should be pasteurized again before feeding.

Excess Colostrum or Transition Milk

Any excess high quality first colostrum (containing more than 50 g/L of IgG) should be frozen and saved for other newborns. Lower quality colostrum should not be fed to newborns, but can be fed after their initial colostrum feeding is complete. After the first milking, milk composition progressively becomes closer to normal milk. During this transition period, milk must be withheld from the bulk tank. Rather than pour it down the drain, many producers feed transition milk to calves.

Excess colostrum and transition milk provide a high quality, economical liquid diet; however, nutrient content may vary considerably from day to day and may contribute to scouring and poor growth. This is especially true when milk is collected from a small number of cows. Variability in nutrient content is reduced when milk from a larger number of cows is pooled; however the risk of disease transfer increases with pooled milk. To minimize disease risk, pooled milk can be pasteurized or calves can be fed milk from a single cow.
Feeding Amount

For many years, liquid feeding programs were designed to limit the amount of liquid feed and encourage early intake of dry feeds. While these programs do not support maximal weight gains before weaning, they do promote rumen development and early weaning. Early weaning systems encourage rumen development and continued growth after weaning. Interest in feeding larger amounts of liquid feeds has increased, and with higher feeding rates and proper care calves can grow faster without increased rates of nutritional scour.

In most cases, differences in calf growth due to preweaning feeding rate disappear by the time calves reach 4 to 6 months of age. A wide range of growth can be achieved by selecting a feeding program that matches your goals for calf growth. When evaluating different feeding programs, weigh the increased cost of feed against increased weight gain using cost per pound of gain. In addition, evaluate the long-term impact of higher rates of gain from an economic standpoint. Weight advantages at weaning must translate into reduced age at first calving, increased milk production, or improved health if they are to be cost effective for the majority of U.S. dairy operations. Since age at calving is more impacted by management and older heifer feeding programs and since growth rates prior to weaning have been shown to minimally influence milk production levels, improvements in calf health are required to justify increased costs of liquid feeds.

A general recommendation is to feed milk at 10 percent of birth weight or milk replacer at 12 percent of birth weight. As an example, feeding at 12 percent of birth weight, a 100-pound calf would need 12 pounds of milk replacer per day. This amount is typically divided into two feedings of 6 pounds. One pint of liquid milk or milk replacer weighs about 1 pound, so this would be 3 quarts at each feeding. At 10 percent of bodyweight, a calf weighing 80 pounds would receive 8 pounds, fed in two feedings of 2 quarts each.

Faster growth rates can be achieved at higher feeding rates, but be sure to gradually increase the amount you are feeding to allow calves to adjust and to limit scouring. Growth rates over 1.9 pounds per day are not recommended for young calves before puberty. Remember, if all calves are fed the same amount regardless of body weight, some will be underfed and some will be overfed. The amount fed must be adjusted during periods of stress, particularly for calves under 3 weeks of age.

Consistency in calf feeding is commonly recommended, but there is not much research on the effect of consistent or inconsistent feeding programs on calf performance. One study included two experiments using milk and milk replacer to investigate the effects of inconsistent nutrient intake. In the first trial all calves were fed about one pound of dry matter each day and received one gallon of liquid feed. Treatments were milk replacer (21% protein, 21% fat), raw, saleable milk, and a 50-50 mix of milk and milk replacer. Calves were weaned at 42 days. Milk-fed calves received more energy and protein, but preweaning average daily gain, starter intake, and feed efficiency were higher in calves fed milk replacer. In the second trial two milk replacers were fed at either a variable or fixed rate each day to provide 1.44 pounds of dry matter. Total amount fed per week was similar, and calves were weaned at 28 days. Milk replacer contained 27% protein and either 31 or 17% fat. Calves fed the fixed rate of milk replacer had greater average daily gain, starter intake, and feed efficiency before weaning than those fed a variable rate. In both experiments, calves fed a consistent diet grew faster and more efficiently than those fed an inconsistent diet. Effects of variation in nutrient intake were seen in these trials, even though the average or total nutrient intake was similar. In real world conditions, neither total nor average intake is controlled. This suggests that the actual impact of inconsistencies in mixing and feeding milk and milk replacer might be even greater on farms.

Weak or Sick Calves

Esophageal Feeder

Newborn calves are sometimes too weak to suckle or nurse from a pail or bottle. The esophageal feeder is an excellent device for force-feeding colostrum to these calves or for feeding electrolytes to sick calves. This inexpensive piece of equipment can save the life of a sick or weak calf.

The esophageal feeder consists of an esophageal probe, tube, clamp, and fluid container. The probe is a rigid or semiflexible tube made of plastic or stainless steel. It has a tear-shaped end designed to be easily inserted into the esophagus but not into the trachea (windpipe). The esophageal feeder should be thoroughly cleaned to prevent bacterial growth, especially after it has been used for colostrum.

The first step in using an esophageal feeder is to determine the length of tube to be inserted. Measure from the tip of the calf’s nose to the point of its elbow, which is the approximate location of the diaphragm. This distance is about 20 inches in most Holstein calves (Figure 10). The spot can be marked on the tube with a piece of tape. In young calves, only about 20 inches of the tube should be passed into the mouth and down the esophagus. If the weather is cold, the tube can be placed in warm water to make it more pliable.
The tube should first be lubricated by dipping it in the colostrum or milk. A calf will likely suck the end of the tube into its mouth, which makes the tube easier to pass.

Open the calf's mouth by applying pressure to the corner of the mouth or by grabbing over the bridge of the nose and applying pressure to the upper palate or gums. Once the mouth is open, pass the tube slowly along the tongue to the back of the mouth. When the tube is over the back of the tongue, the calf starts chewing and swallowing. The tube should then be passed down the esophagus. A correctly passed tube can be felt in the esophagus; the ball on the end of the tube can be felt quite easily.

If possible, the calf should be standing before feeding so fluids are less likely to back up and enter its lungs. Calves that are too weak to stand, however, may be fed lying down. The esophageal feeder is easier to use when calves are properly restrained. Young calves can be backed into a corner for better head control.

After the tube is passed and before any liquids are given, the tube should be checked for proper positioning in the esophagus (Figure 11). If it is properly positioned, the rings of the trachea and the rigid enlarged esophagus can be felt easily. Check the exposed end of the tube for spurts of air, which indicate that the tube is in the trachea.

Next, unclip the tube to allow the liquid to drain out of the bag. Hold the bag above the calf or hang it on a nail; it will take several minutes to drain. Liquids should be at body temperature to prevent temperature shock to an already weak calf.

When feeding is over, slowly remove the tube. Clean and sanitize the feeder, and then allow it to drain and dry.

**Figure 10. Hyperextension of a calf's neck and points for estimating length of esophageal tube.**

**Figure 11. Position of esophageal feeder in relationship to the trachea.**
Electrolyte Supplements

Electrolyte supplements are often needed for calves with moderate to severe scours. Treatment should be aimed at replacing lost fluids, restoring acid-base balance, and furnishing nutrients and energy to the calf. An electrolyte formula should be administered according to its label or a veterinarian's recommendation. The esophageal feeder is helpful in feeding these supplements.

A 100-pound calf can lose up to 10 percent of its body weight in one day. This calf needs an extra 3 to 5 quarts of fluid per day to correct dehydration; that is in addition to the 4 quarts the calf would normally consume. Electrolytes do not supply enough energy to be the sole source of nutrients. Therefore, milk should be given in addition to the electrolytes.

A 100-pound calf needs approximately 3,800 kilocalories to gain 1.5 pounds. An electrolyte with 70 grams of dextrose meets only 42 percent of the calf's energy requirements. Calves that do not receive enough energy when scouring will begin to break down muscle protein and will lose weight quickly. Continue to feed the normal amount of milk or milk replacer in addition to the electrolyte product.

An electrolyte supplement should contain sodium, alkalizing agents (bicarbonate, sodium citrate, sodium acetate, or a combination), potassium, chloride, glycine, and dextrose or glucose. Electrolytes containing bicarbonate or citrate should not be fed to calves until 15 to 20 minutes after they have consumed their milk. These two alkalizing agents prevent rennin and casein from clotting in the calf's stomach, causing rapid passage of nutrients through the small intestine. Most milk replacers do not contain casein, so alkalizing agents won't interfere with them. However, electrolyte solutions should not be mixed with milk replacer instead of water. This upsets the balance of electrolytes and ruins the product's ability to rehydrate the calf.
Dry Feed and Weaning

The preweaned calf requires both liquid and dry feeds and should be offered a dry grain mix by 3 days of age. During the first week of life, calves eat very little grain. By the second week, however, they should be eating noticeable amounts.

Adequate, early intake of dry feed is important because dry grain stimulates rumen development. Dry feed increases the number and variety of rumen bacteria and protozoa. These microorganisms grow rapidly on grain carbohydrates and produce the volatile fatty acids butyrate and propionate. These acids provide nutrients for the calf and stimulate rumen development.

In early weaning systems calves need to begin eating some grain by 2 weeks of age to allow enough rumen development to occur before weaning at 5 or 6 weeks of age. If we do a good job of managing grain intake, it is possible to wean calves at 6 weeks, even when milk feeding rates are high. It is important to remember that deciding to wean calves at a later age or bigger body weight does not remove the rumen development requirement. If calves are drinking a lot of milk, they usually will not eat much grain. Trying to wean calves that have not been eating grain is setting them up for a rough transition.

Ease weaning stress by ensuring calves eat at least half a pound of grain per day for 4 weeks or a pound per day for 2 weeks and that they reach 2 pounds per day for 3 consecutive days before weaning. Backing off milk feeding gradually before full weaning can be a helpful strategy for increasing grain intakes, but keep in mind the time required for rumen development (21 days from the time grain is first introduced). Assuming that calves are eating some grain when you start the weaning process, successful step down programs require a minimum of 12 to 14 days to prepare the rumen properly.

The crude protein recommendation for calf starter is 18% on a dry matter basis (Table 8). Research shows this level of protein is adequate to support growth in young calves, including calves on enhanced feeding programs. Fermentable starch in starter stimulates butyrate production and rumen development, and starter should contain at least 30% starch.

Table 8. Suggested calf starter nutrient content.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Amount (dry matter basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein (%)</td>
<td>18.0</td>
</tr>
<tr>
<td>Fat (%)</td>
<td>3.0</td>
</tr>
<tr>
<td>ADF (%)</td>
<td>11.6</td>
</tr>
<tr>
<td>NDF (%)</td>
<td>12.8</td>
</tr>
<tr>
<td>ME (Mcal/lb)</td>
<td>1.49</td>
</tr>
<tr>
<td>Macrominerals (%)</td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>0.7</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.45</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.1</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.2</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.65</td>
</tr>
<tr>
<td>Microminerals (ppm)</td>
<td></td>
</tr>
<tr>
<td>Manganese</td>
<td>40.0</td>
</tr>
<tr>
<td>Iron</td>
<td>50.0</td>
</tr>
<tr>
<td>Copper</td>
<td>10.0</td>
</tr>
<tr>
<td>Zinc</td>
<td>40.0</td>
</tr>
<tr>
<td>Cobalt</td>
<td>0.1</td>
</tr>
<tr>
<td>Iodine</td>
<td>0.25</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.3</td>
</tr>
<tr>
<td>Vitamins (IU/lb)</td>
<td></td>
</tr>
<tr>
<td>Vitamin A</td>
<td>1,818</td>
</tr>
<tr>
<td>Vitamin D</td>
<td>273</td>
</tr>
</tbody>
</table>
Calf starter must be palatable to encourage intake. A textured grain with coarsely processed corn, small grains, and pellets fortified with protein, minerals, and vitamins is recommended (Table 9). Starter commonly contains 5 to 6% molasses to improve palatability and reduce separation and waste. Whether textured or pelleted, calf starter should not be dry, dusty, moldy, or have an “off” flavor. Very fine-textured feed tends to cake together when wet, resulting in low intake. Including yeast culture in starter often improves grain intake and average daily gain.

### Table 9. Example of calf starter composition.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount (lb, as-fed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry shelled corn 1</td>
<td>35.025</td>
</tr>
<tr>
<td>Oats, barley 2</td>
<td>25.000</td>
</tr>
<tr>
<td>Soybean meal, 44%</td>
<td>32.000</td>
</tr>
<tr>
<td>Molasses 3</td>
<td>5.000</td>
</tr>
<tr>
<td>Trace mineral salt</td>
<td>1.000</td>
</tr>
<tr>
<td>Calcium sulfate (22% sulfur, 27% calcium)</td>
<td>0.100</td>
</tr>
<tr>
<td>Dicalcium phosphate (23% calcium, 18% phosphorus)</td>
<td>0.500</td>
</tr>
<tr>
<td>Limestone (38% calcium)</td>
<td>0.900</td>
</tr>
<tr>
<td>Magnesium oxide (54% magnesium)</td>
<td>0.200</td>
</tr>
<tr>
<td>Vitamin ADE premix 4</td>
<td>0.200</td>
</tr>
<tr>
<td>Selenium premix (0.02%) 5</td>
<td>0.075</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.000</strong></td>
</tr>
</tbody>
</table>

1 Cracked, flaked, or medium grind. 2 Crimped, rolled, or medium grind. 3 Level may be varied from 0 to 10 percent. 4 Potency (IU/lb): vitamin A, 2,500,000; vitamin D, 500,000; vitamin E, 2,500. 5 Use in selenium-deficient areas.

Whole corn, as well as whole oats and barley, can be completely digested by the young calf before weaning. Whole or lightly rolled corn is very palatable, with less dustiness than ground or steam-flaked corn. High-moisture grains are not recommended for young calves, since they heat quickly and mold in feed buckets or mangers. To use them successfully, grain buckets need to be emptied and refilled one or two times each day, especially during hot weather.

The growth rate of young calves depends heavily on grain intake. Unpalatable or poor-quality starter grains inhibit intake, thereby retarding rumen development and decreasing growth. Starter intake also is influenced by milk feeding and water availability. High rates of milk or milk replacer feeding and high levels of fat in milk replacer depress starter intake. On the other hand, availability of fresh, clean water promotes starter intake. Freshness of starter is important as well. Offer only small handfuls at each feeding until calves begin to eat starter. Remove uneaten starter and clean out wet or moldy feed daily to maintain freshness.

For many years, producers have fed hay to preweaned calves based on the theory that rumen development required physical stimulation, or “scratch.” Research has shown this is not the case. However, observations on farms and in recent research have shown that forage may be needed in calf diets when the consumption of starter puts calves at risk of rumen acidosis. The need for forage depends on the intake and fermentation rate of starch and the calf’s age.

Calves require fermentable carbohydrates for rumen development, and good quality starters contain a high concentration of starch. However, because calves tend to eat big meals all at once, high amounts of starch in starter can cause acidosis if the starch ferments rapidly in the rumen. In this situation, forage may be needed at earlier ages. When starter intake reaches 2 or more pounds per day it can be helpful to provide some material that will allow calves to ruminate and therefore modify rumen pH. Average quality (rather than high quality) forage is recommended to lessen the chance that some calves will eat primarily forage and very little grain, which would reduce their energy intake.

Both the type of grain and how it is processed affect starch fermentation rate. Grains need to be finely ground to form a good quality pellet, but this particle size reduction increases starch fermentability. Heat and moisture used in the pelleting process enhance the availability of starch. Many pelleted starters contain lower levels of starch to minimize the risk of acidosis. Feeding
texturized starter consisting of whole or minimally processed grains and a supplemental pellet does not prevent calves from eating large amounts of starch at once, but the starch in whole or partially processed grains will be available only after calves chew the grain and break it down. As a result, calves eating texturized starter will be at a lower risk for acidosis and can be on a non-forage diet for a longer period of time than calves fed a pelleted diet. When starter causes acidosis, forage intake will help buffer the rumen, which in some cases improves starter consumption. This effect is more commonly observed in older, weaned calves.

Although forage can help prevent acidosis, there are good reasons to not offer forage from day 1. At an early age forage consumption usually decreases energy intake, because forage is less energy dense per unit than grain and the complex, structural carbohydrates in forages are digested at a slower rate than starch in grain. Calves have limited space in their digestive tracts and bulky forages quickly fill this space, sending a signal to the brain that depresses appetite. Thus, gut-fill can easily become a limiting factor to obtaining enough nutrients in the young calf.

In addition, when rumen microbes digest forages they produce acetate, which will not impact rumen development. Grains are fermented to butyrate and propionate that do stimulate rumen development. Butyrate is the most important source of energy for rumen papillae growth. Moreover, starter intake variability between calves increases when forage is available; some calves prefer the forage, others the grain. This increases disparity in weaned groups. As a result, forage consumption prior to weaning should be limited to promote a smoother transition at weaning.

The physical form and quality of forage also affect starter and forage intake variability between calves. Long hay seems to increase variability when compared to chopped hay. In addition, when highly palatable forage is available some calves prefer it over starter; this is not common when feeding lower quality forage. The consumption of low quality, chopped forage is more consistent, and typically about 4% of total solid feed consumption. Bedding can, in some cases, supply this small amount of straw, so type and frequency of bedding may also influence the time at which calves need to be offered forage. Calf behavior at the time of adding bedding can serve as a useful indicator of when forage should be included in the ration. Calves normally nibble at new bedding, but if they gorge on it they may be indicating that they are missing forage in their ration.

Lack of forage in calves' diets has also been related to hyperkeratosis of rumen papillae. The outer layer of papillae is composed of keratin that is continually removed by the physical abrasiveness of large particles in the rumen. The lack of large particles staying in the rumen and rubbing against the rumen wall allows the keratin layer to build up, which likely reduces the absorptive capacity of papillae. The reduction in absorption capacity causes abnormal growth of papillae, and often, the reduced physical abrasion results in papillae clumping together. Texturized starters with whole or partially texturized grains, especially whole oats, barley, or similar grains, provide the rumen with the physical abrasiveness to prevent the buildup of keratin. Using texturized starters instead of forage to maintain a healthy rumen prior to weaning can be advantageous since texturized starters won't reduce energy intake and slow down rumen development like forage does.

Starter ingredient composition, physical form, and intake level are important factors to consider when making a recommendation as to when forage should be fed, and these change with different management practices. In the past we have recommended that forage be fed to calves when starter consumption reaches 5 to 6 pounds per day, at around 7 to 8 weeks of age. This recommendation is appropriate for texturized starter with coarsely processed or whole grains. However, when feeding a completely pelleted starter with high amounts of ruminally digestible starch, forage should be fed by 5 to 6 weeks of age to prevent acidosis. Lowering the starch concentration in the pellet could also prevent acidosis and the need to feed forage, but at the high cost of less rumen development by weaning time.

After weaning, starter consumption increases and good quality, high starch starters need to be supplemented with forage. The amount of forage to be added will depend on forage quality, starter composition, and the physical form of forage and starter. A good quality texturized starter or grower will need to be supplemented with only 5 to 10 percent forage up to 16 weeks of age. The need for forage when feeding pelleted starters will depend on the starch and fiber level in the pellets. High fiber pellets will not require forage in the diet as the pellets effectively contain that forage; however, pellets alone typically do not provide enough abrasiveness to prevent keratin buildup.

**Summary**

Proper feeding and care of young calves is the first step in raising healthy, productive replacement animals to enter your milking herd. Feed four quarts of high-quality colostrum within the first eight hours to provide calves with essential nutrients and antibodies. Match milk replacer to growth and weaning age goals to meet calves' needs and to balance feed costs and animal performance. Offer a palatable calf starter by three days of age to stimulate rumen development and allow weaning by four to six weeks of age. Remove uneaten starter daily to maintain freshness. Finally, remember that nutrition is not the only factor affecting calf health and growth. Provide calves with clean, dry, draft-free housing that protects them from harsh sun in the summer and cold winds in the winter. From three days of age, make fresh, clean, free-choice water available. Work with your veterinarian to ensure that calves receive adequate vaccination and to develop treatment protocols for sick calves.
Authors

Coleen M. Jones  
Research Associate, Dairy  
cjones@psu.edu  
540-997-5809

Jud Heinrichs  
Professor of Dairy Science  
ajh@psu.edu  
814-863-3916

extension.psu.edu

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