Colostrum Management for Dairy Calves

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The placenta of the cow separates the maternal and fetal blood supplies, preventing in utero transmission of protective immunoglobulins (Ig) [1]. Consequently, the calf is born agammaglobulinemic and so depends almost entirely on the absorption of maternal Ig from colostrum after birth. The absorption of maternal Ig across the small intestine during the first 24 hours after birth, termed passive transfer, helps to protect the calf against common disease organisms until its own immature immune system becomes functional. Calves are defined as having failure of passive transfer (FPT) if the calf serum IgG concentration is less than 10 mg/mL when sampled between 24 and 48 hours of age [2,3]. Achieving early and adequate intake of high-quality colostrum is widely recognized as the single most important management factor in determining health and survival of the neonatal calf (Fig. 1) [3–6]. In addition to reduced risk for preweaning morbidity and mortality, additional long-term benefits associated with successful passive transfer include reduced mortality in the postweaning period, improved rate of gain and feed efficiency, reduced age at first calving, improved first and second lactation milk production, and reduced tendency for culling during the first lactation [7–10].

Unfortunately, many producers continue to incur significant loss associated with FPT. In the United States mortality rates in preweaned dairy heifers are estimated to range between 8% and 11% [2,4,11]. Poor colostrum management is one of the key factors contributing to these excessive losses. In one study 41% of 2177 calves sampled between 24 and 48 hours of age had FPT (serum IgG < 10 mg/mL) [2]. It was estimated that approximately 31% of preweaning mortality events occurring in the first 3 weeks of life were attributed to FPT [9]. These studies point to the need for producers to adopt practices to improve colostrum management. This article reviews
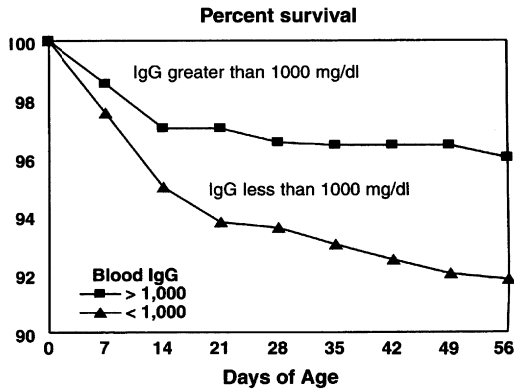
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Fig. 1. Calf survival by serum IgG concentration. (*From* National animal health monitoring system. National dairy heifer evaluation project. Dairy herd management practices focusing on preweaned heifers. Ft. Collins, (CO): USDA-APHIS Veterinary Services; 1993.)

the process of colostrogenesis and discusses important components of colostrum. The key components of developing a successful colostrum management program are discussed.

Colostrogenesis and colostrum composition

Bovine colostrum consists of a mixture of lacteal secretions and constituents of blood serum, most notably Ig and other serum proteins, which accumulate in the mammary gland during the prepartum dry period [12]. This process begins several weeks before calving, under the influence of lactogenic hormones, including prolactin, and ceases abruptly at parturition. Important constituents of colostrum include Ig, maternal leukocytes, growth factors, hormones, cytokines, nonspecific antimicrobial factors, and nutrients. Concentrations of many of these components are greatest in the first secretions harvested after calving (first milking colostrum), then decline steadily over the next six milkings (transition milk) to reach the lower concentrations routinely measured in saleable whole milk (Table 1) [12].

Immunoglobulins

IgG, IgA, and IgM account for approximately 85% to 90%, 5%, and 7%, respectively, of the total Ig in colostrum, with IgG_1 accounting for 80% to 90% of the total IgG [13]. Although levels are highly variable among cows and studies, one study reported that mean colostral concentrations of IgG, IgA, and IgM were 75 mg/mL, 4.4 mg/mL, and 4.9 mg/mL, respectively [14]. IgG, and IgG_1 in particular, are transferred from the bloodstream across the mammary barrier into colostrum by a specific transport mechanism: Receptors on the mammary alveolar epithelial cells capture

Table 1
Composition of colostrum, transition milk and whole milk of Holstein cows

Parameter	Colostrum	Transition milk (milking postpartum)		Milk
	1	2	3	6
Specific gravity	1.056	1.040	1.035	1.032
Total solids (%)	23.9	17.9	14.1	12.9
Fat (%)	6.7	5.4	3.9	4.0
Total protein (%)	14.0	8.4	5.1	3.1
Casein (%)	4.8	4.3	3.8	2.5
Albumin (%)	6.0	4.2	2.4	0.5
Immunoglobulins (%)	6.0	4.2	2.4	0.09
IgG (g/100 mL)	3.2	2.5	1.5	0.06
Lactose (%)	2.7	3.9	4.4	5.0
IGF-I (µg/L)	341	242	144	15
Insulin (µg/L)	65.9	34.8	15.8	1.1
Ash (%)	1.11	0.95	0.87	0.74
Calcium (%)	0.26	0.15	0.15	0.13
Magnesium (%)	0.04	0.01	0.01	0.01
Zinc (mg/100 mL)	1.22	—	0.62	0.3
Manganese (mg/100 mL)	0.02	—	0.01	0.004
Iron (mg/100 g)	0.20	—	—	0.05
Cobalt (µg/100 g)	0.5	—	—	0.10
Vitamin A (µg/100 mL)	295	190	113	34
Vitamin E (µg/g fat)	84	76	56	15
Riboflavin (µg/mL)	4.83	2.71	1.85	1.47
Vitamin B_{12} (µg/100 mL)	4.9	—	2.5	0.6
Folic acid (µg/100 mL)	0.8	—	0.2	0.2
Choline (mg/mL)	0.7	0.34	0.23	0.13

Data from Hammon HM, Zanker IA, Blum JW. Delayed colostrum feeding affects IGF-1 and insulin plasma concentrations in neonatal calves. J Dairy Sci 2000;83:85–92; and Foley JA, Otterby DE. Availability, storage, treatment, composition, and feeding value of surplus colostrum: a review. J Dairy Sci 1978;61:1033–60.

IgG_1 from the extracellular fluid, and the molecule undergoes endocytosis, transport, and finally release into the luminal secretions [13]. The alveolar epithelial cells cease expressing this receptor, most likely in response to increasing prolactin concentrations, at the onset of lactation [15]. Smaller amounts of IgA and IgM are largely derived from local synthesis by plasmacytes in the mammary gland [13]. Although not well understood, colostral transfer of IgE also occurs and may be important in providing early protection against intestinal parasites [16].

Maternal leukocytes

Normal bovine colostrum contains greater than 1×10^6 cells/mL of immunologically active maternal leukocytes, including macrophages, T and B lymphocytes, and neutrophils [13,17]. At least a portion of colostral leukocytes are absorbed intact across the intestinal barrier [18]. Liebler-Tenorio

and colleagues [19] reported that the preferential route of uptake of colostral leukocytes through the intestinal barrier is through the follicle-associated epithelium of Peyer patches in the jejunum and ileum. Reber and colleagues [20] proposed that, after entering the neonatal circulation, maternal leukocytes traffic to neonatal nonlymphoid tissues and secondary lymphoid tissues, disappearing from the neonatal circulation by 24 to 36 hours after feeding colostrum. Although their functional importance in calves is not routinely measured, early evidence suggests that colostral leukocytes enhance lymphocyte response to nonspecific mitogens, increase phagocytosis and bacterial killing ability, and stimulate humoral immune responses (IgG formation) in the calf [17,21–23]. Presumably these cells would not be viable in pasteurized colostrum or colostrum replacer products. The role and functional significance of colostral leukocytes remains areas of active research.

Cytokines and growth factors

Other important components of colostrum include growth factors, hormones, cytokines, and nonspecific antimicrobial factors. Bioactive components of colostrum with antimicrobial activity include lactoferrin, lysozyme, and lactoperoxidase [24–26]. Oligosaccharides in colostrum may provide protection against pathogens by acting as competitive inhibitors for the binding sites on the epithelial surfaces of the intestine [27]. Growth factors in bovine colostrum include transforming growth factor beta-2 (TGF-β2), growth hormone (GH), and insulin, but their function in colostrum is not fully understood (see Table 1) [24]. Colostral insulinlike growth factor-I (IGF-I) may be a key regulator in the development of gastrointestinal tracts of bovine neonates, including stimulation of mucosal growth, brush-border enzymes, intestinal DNA synthesis, increased villus size, and glucose uptake increased [28–30]. Trypsin inhibitor, a compound found in colostrum in concentrations nearly 100 times greater than in milk, serves to protect IgG and other proteins from proteolytic degradation in the intestine of the neonatal calf.

Nutrients

Although the immunologic importance of colostrum is frequently discussed, the nutritional significance of the first colostrum meal should not be overlooked. The total solids content (%) in first milking colostrum and whole milk in Holstein cows has been reported to average 23.9% and 12.9%, respectively (see Table 1) [12]. Much of this increase in colostrum solids content is attributed to a more than fourfold increase in protein content of colostrum versus milk, this being because of significant increases in Ig and casein content [5]. The crude fat content of first milking Holstein colostrum (6.7%) is also significantly higher than for milk (3.6%) [12]. Energy from fat and lactose in colostrum is critical for thermogenesis and body temperature regulation. Certain vitamins and minerals, including calcium, magnesium, zinc, manganese, iron, cobalt, vitamin A, vitamin E,

carotene, riboflavin, vitamin B12, folic acid, choline, and selenium are also found in increased concentrations in bovine colostrum versus milk (see Table 1) [12,27].

Components of a successful colostrum management program

To achieve successful passive transfer of IgG, the calf must first consume a sufficient mass of Ig in colostrum and then be able to successfully absorb a sufficient quantity of these molecules into its circulation. Major factors affecting the mass of Ig consumed by the calf include the quality and volume of colostrum fed. The major factor affecting the absorption of Ig molecules into circulation is the quickness, after birth, with which the first colostrum feeding is provided. The remainder of this article reviews these and other important factors affecting passive transfer, management strategies for preventing bacterial contamination of colostrum, and the use of colostrum supplements and replacers, and provides recommendations for monitoring the colostrum management program.

Colostrum quality

Although it is recognized that colostrum contains a wide spectrum of important immune and nutritional components, because the relationship between Ig concentrations and calf health is best understood, and because IgG composes more than 85% of total Ig in colostrum, the concentration of IgG in colostrum has traditionally been considered the hallmark for evaluating colostrum quality. High-quality colostrum has an IgG concentration greater than 50 g/L [6]. The IgG concentration in colostrum can vary dramatically among cows. In one recent study, colostrum IgG averaged 76 g/L, but ranged from 9 to 186 g/L for individual Holstein cows [31]. Some factors affecting colostrum quality, such as breed or age of the dam, may be out of the producer's ability to manipulate. Several other important factors affecting colostrum quality, however, including preparturient vaccination, dry period length, and time to colostrum collection, can be managed by producers. This section reviews factors affecting colostrum quality and discusses cow-side testing of colostrum quality.

Breed

Comparative studies have reported that there can be a breed effect on colostrum quality [32,33]. In one study, IgG_1 concentration was greater in secretions from beef cows (113.4 g/L) than from dairy cows (42.7 g/L) [32]. In another study, Holstein cows produced colostrum with total Ig content (5.6%) that was numerically lower than for Guernsey (6.3%) and Brown Swiss (6.6%) cows, and statistically lower than for Ayrshire (8.1%) and Jersey (9.0%) cows [33]. Breed differences could be attributed to genetic differences and/or dilutional effects.

Age of dam

Most, but not all, studies report a tendency for older cows to produce higher quality colostrum, presumably because of older animals have had a greater period of exposure to farm-specific pathogens [33–36]. As one example, Tyler and colleagues [36] reported that the mean colostral IgG concentration for Holstein cows in their first, second, or third and greater lactations was 66, 75, and 97 g/L, respectively. In the same study, however, there was reportedly no difference in IgG concentration for Guernsey cows in their first (119 g/L), second (113 g/L), and third and greater lactations (115 g/L). Producers should be discouraged from automatically discarding colostrum from first-calf heifers, because it may be of very good quality.

Nutrition in the preparturient period

Studies generally have shown that Ig content of colostrum is not affected by prepartum maternal nutrition [37]. In a study feeding beef cows either 100% (CO) or 57% (RS) of National Research Council (NRC) (1984) [38] protein and energy requirements, maternal nutrition did not affect either colostrum IgG concentration (43.0 versus 39.5 g/L for RS and CO, respectively) or the calves' serum IgG concentration at 24 hours (19.1 versus 20.2 mg/mL for RS and CO, respectively) [39]. Lacetera and colleagues [40] reported that cows supplemented with injections of selenium and vitamin E in late pregnancy produced a greater volume of colostrum than unsupplemented cows, when all cows were fed a prepartum diet that was deficient in Vitamin E and selenium. Treatment had no impact on colostrum IgG concentration, however. Producers should feed dry cows and heifers nonlactating rations balanced according to NRC (2001) guidelines [41].

Season of calving

Some, but not all, studies have reported that exposure to high ambient temperatures during late pregnancy is associated with poorer colostrum composition, including lower mean concentrations of colostral IgG and IgA, and lower mean percentages of total protein, casein, lactalbumin, fat, and lactose [34,42]. These effects may be attributed to the negative effects of heat stress on dry matter intake resulting in nutritional restriction, reduced mammary blood flow resulting in impaired transfer of IgG and nutrients from the blood stream to the udder, or impaired immune reactivity of mammary gland plasmacytes that produce IgA [42]. Producers should adopt the similar heat-abatement strategies for prepartum cows and heifers as are routinely used for lactating animals.

Volume of colostrum produced

Pritchett and colleagues [35] observed that cows producing less than 8.5 kg of colostrum at first milking were more likely to produce high-quality (> 50 g/L) colostrum than cows producing higher quantities of first milking colostrum (≥8.5 kg). This finding was presumed to be attributable to

dilutional effects. However, more recent studies report that there is no predictable relationship between colostrum IgG concentration and weight of colostrum produced at first milking [43,44].

Mastitis

Persistent intramammary infection (IMI) during the nonlactating period has not been associated with altered IgG1 concentration. IMI is associated with lower colostral volume produced, however [45]. Producers should not feed colostrum from cows with clinical mastitis.

Pooling

Pooling of colostrum from multiple dams is generally discouraged because larger volumes of low-quality colostrum may dilute smaller volumes of higher-quality colostrum [3]. Furthermore, pooling raw colostrum may increase the number of calves potentially exposed to colostrum-borne pathogens.

Preparturient vaccination of the dam

Although not all studies have shown positive results, a body of research has established that vaccinating the pregnant cow or heifer during the final 3- to 6-week period preceding calving results in increased concentrations of protective colostral antibodies, and increased passive antibody titers in calves of vaccinated dams, for some common pathogens including *Pasteurella haemolytica*, *Salmonella typhimurium*, *Escherichia coli*, rotavirus, and coronavirus [46–50].

Dry period length

Secretion of Ig from the dam's circulation into the mammary gland begins approximately 5 weeks before calving. In one observational study, dry period length (mean = 57.5 ± 11 days) was not associated with colostrum IgG concentration [35]. In a controlled study, Rastani and colleagues [51] also reported that colostrum quality was not different for cows with a 28- or 56-day dry period, respectively. Cows with excessively short dry periods (<21 days) or no dry period produce colostrum with significantly lower IgG concentrations [51,52]. Furthermore, dry period length can affect the volume of colostrum produced: In a recent controlled field study cows with a short (40-day) dry period produced 2.2 kg less colostrum than did cows with a conventional (60-day) dry period [44].

Delayed colostrum collection

The concentration of Ig in colostrum is highest immediately after calving, but begins to decrease over time if milking is delayed. In one study, delaying harvest of colostrum for 6 hours, 10 hours, or 14 hours after calving resulted in a 17%, 27%, and 33% decrease in colostral IgG concentration, respectively [53]. To collect the highest quality colostrum, producers should aim

to milk the cow within 1 to 2 hours after calving if possible, with a maximum delay of 6 hours.

Cow-side testing of colostrum quality

Empiric recommendations suggest rejecting colostrum that is visibly watery, bloody, or is from cows that leaked before calving [54]. It is difficult to predict, based on such factors as dam parity, weight of colostrum produced at first milking, or visual consistency, which colostrum collected will be of high (>50 g/L IgG) versus low quality [43]. The colostrometer, a hydrometer instrument that estimates IgG concentration by measuring colostrum specific gravity, is one rapid and inexpensive cow-side test that may be useful to differentiate high- from low-quality colostrum (specific gravity >1.050 approximates IgG concentration >50 g/L IgG). Factors such as content of fat and other solids, plus colostrum temperature, affect the hydrometer reading, however. Pritchett and colleagues [55] reported that the sensitivity and specificity of the instrument for detecting low-quality colostrum were 0.32 and 0.97, respectively, meaning that the instrument would incorrectly classify two of every three low-quality colostrum samples as acceptable. Pritchett and colleagues [55] suggested that to avoid misclassification error, producers should alter the hydrometer cutoff points to 45, 60, or 110 g/L if feeding either 3.78, 2.84, or 1.89 L of colostrum at first feeding, respectively. Test specificity would be severely compromised by using higher cutpoints, however, resulting in an excessive portion of colostrums being misclassified as deficient [3]. Others have suggested that if a large enough volume (eg, 3.78 L) is fed at first feeding, then there may be limited value to using a hydrometer. Despite its limitations, the hydrometer may still be useful to differentiate high- from low-quality colostrum used for first versus later feedings, respectively.

An alternate tool for differentiating high- from low-quality colostrum may be a commercially available cow-side immunoassay kit (Colostrum Bovine IgG Quick Test Kit, Midland Bio-Products, Boone, Iowa). Chigerwe and colleagues [56] recently reported that the sensitivity and specificity of this test kit to identify poor-quality colostrum (IgG<50 g/L) were 0.93 and 0.76, respectively. With this relatively low specificity, the immunoassay test would incorrectly classify one in every four high-quality colostrum samples as unacceptable. One additional limitation of the immunoassay is that it yields only a positive or negative result, but does not provide an estimate of the actual IgG concentration. The immunoassay costs approximately $4 (United States dollars [USD]) per sample and takes approximately 20 minutes to run.

Volume of colostrum consumed at first feeding

To achieve successful passive transfer in an average 43-kg (90 lb) Holstein calf, experts calculate that producers should feed at least a minimum mass of

100 g of IgG in the first colostrum feeding [5]. So what volume of colostrum should producers feed to meet or exceed this minimum dose? Obviously the answer to this question depends on the IgG concentration in the colostrum being fed. For example, if colostrum was known to contain 50 g/L IgG, then the producer would only need to feed 1.89 L (2 qt) to achieve the minimum goal of ingesting more than 100 g IgG. If the colostrum contained only 25 g/L of IgG, however, then the producer would need to feed 3.78 L (4 qt) to achieve the same ingested mass of IgG. Besser and colleagues [57] noted that only 36% of colostrum samples tested would be of high enough quality to provide greater than 100 g IgG if calves were only fed 1.89 L. Some 85% of colostrum samples tested would be of high enough quality to provide greater than 100 g IgG if calves were fed 3.78 L, however. Because producers frequently do not know the concentration of IgG in the colostrum being fed, it is currently recommended that calves be fed 10% to 12% of their body weight of colostrum at first feeding (3.78 L for a 43-kg calf). In one study mean serum IgG at 24 hours was significantly higher for calves fed 4 L of high-quality colostrum at 0 hours and a further 2 L at 12 hours (31.1 mg/mL IgG) as compared with calves fed only 2 L of high-quality colostrum at 0 hours and a further 2 L at 12 hours (23.5 mg/mL) (Fig. 2) [58]. Another study reported that Brown Swiss calves fed 3.78 L (versus 1.89 L) of colostrum at first feeding experienced significantly higher rates of average daily gain and greater levels of milk production in both the first and second lactation [10]. In national surveys, 26.1%, 35.9%, and 38.2% of producers reported feeding 4 or more quarts of colostrum within the first 24 hours in 1992, 1996, and 2002, respectively [2,4,11], indicating that increasing the volume of colostrum fed is still an area of opportunity for most dairy producers.

Efficiency of absorption of immunoglobulins

The term "open gut" refers to the unique ability of the neonatal enterocyte to nonselectively absorb intact large molecules, such as Ig, by pinocytosis [59]. From there, Ig molecules are transported across the cell and released into the lymphatics by exocytosis, after which they enter the circulatory system through the thoracic duct [60]. In a process referred to as "closure," the efficiency of colostral Ig absorption through the intestinal epithelium of the calf decreases linearly with time from birth to completely close at approximately 24 hours [3]. Feeding colostrum after the gut has closed still offers the benefit of local immunity in the gut lumen, but Ig absorption into the circulation no longer occurs. The following section discusses factors affecting the efficiency of Ig absorption, many of which are under management's control.

Time to first colostrum feeding

The major factor affecting efficiency of Ig absorption is age of the calf at feeding. The efficiency of Ig transfer across the gut epithelium is optimal in the first 4 hours postpartum, but after 6 hours there is a progressive decline
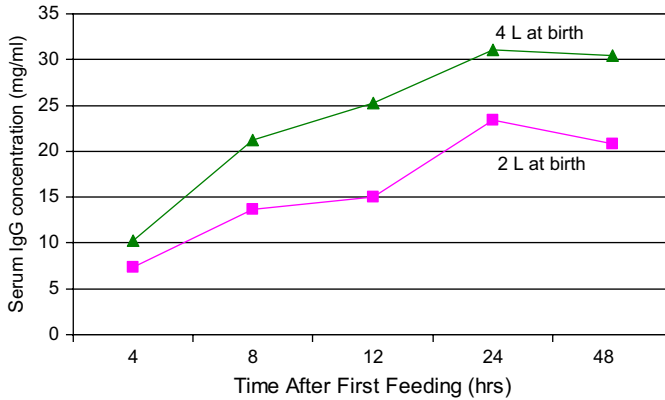
Fig. 2. Serum IgG concentrations in calves fed either 4 L or 2 L of colostrum at birth (all calves were fed an additional 2 L of colostrum at 12 hours of age). (*Data from* Morin DE, McCoy GC, Hurley WL. Effects of quality, quantity, and timing of colostrum feeding and addition of a dried colostrum supplement on immunoglobulin G1 absorption in Holstein bull calves. J Dairy Sci 1997;80:747–53.)

in the efficiency of Ig absorption over time [61,62]. Delaying the first colostrum feeding can only slightly postpone gut closure (36 hours) [63]. Producers should aim to feed all calves within 1 to 2 hours after birth and by 6 hours at a maximum.

Method of feeding

The method of feeding colostrum is worth considering because this can influence the time to first feeding, the volume consumed, and the efficiency of Ig absorption. High rates of FPT have been reported in calves left to suckle the dam [57,64]. This finding may be attributable to failure of the calf to voluntarily consume a sufficient volume of colostrum and delays in suckling. Edwards and Broom [65] reported that 46% of calves born to second parity and older cows had failed to suckle within 6 hours after birth. By comparison, 11% of calves born to first-calf heifers had failed to suckle within 6 hours after birth. These delays could be caused by numerous factors, including weak or injured cow or calf, mastitis or other illness in the cow, low pendulous udders or large teats, or poor mothering ability. It is for this reason that it is currently recommended that the calf be removed from the dam within 1 to 2 hours of birth, and that the calf then be hand-fed a known volume of colostrum using either a nipple bottle or esophageal feeder [6]. In national surveys, 68.1%, 70.5%, and 76.2% of calves were reportedly fed using a nipple bottle or esophageal tube in 1992, 1996, and 2002, respectively [2,4,11], indicating that progressively fewer producers are relying on suckling the dam for colostrum delivery.

Producers may have a personal preference for using either a nipple bottle or esophageal feeder for the first colostrum feeding. Although the esophageal

feeder method is quicker, it is known that when fluid is given with an esophageal feeder, the esophageal groove reflex is not triggered, resulting in fluid being deposited into the forestomachs. This limitation is not significant, however, because outflow of colostrum from the forestomachs to the abomasum and small intestine occurs for the most part within 3 hours [66]. Adams and colleagues [67] reported that calves fed colostrum using a bottle had only slightly higher serum IgG concentrations versus calves fed with an esophageal feeder, but that these differences were numerically small and statistically insignificant. It is generally accepted that either method of feeding achieves acceptable rates of passive transfer provided a sufficient volume of colostrum is consumed [67,68]. Veterinarians should train interested producers on how to properly use and clean esophageal feeders.

Presence of the dam

It has been reported that efficiency of Ig absorption was improved when calves were housed with the dam [69]. Considering that acceptable levels of serum IgG can be achieved without housing the calf with the dam, however, and given that the latter practice may increase the calf's risk for exposure to pathogens from the dam or her environment, it is currently recommended that the calf be removed from the dam within 1 to 2 hours of birth and then hand-fed a known volume of colostrum [6].

Metabolic disturbances

Decreased colostral Ig absorption in the first 12 hours has been reported in calves with postnatal respiratory acidosis, associated with prolonged parturition [70]. Although hypoxic calves may have delayed IgG absorption initially, studies have reported that there is no difference in overall absorptive capacity between hypoxic and normoxic calves and that there is no difference in serum IgG concentrations by the time of gut closure [71,72]. Weaver and colleagues [3] suggested that an increased rate of FPT seen in calves with metabolic or respiratory acidosis may be caused by a delay in the animal getting up to nurse, not by reduced absorptive capacity.

Cold stress

Absorption of Ig may be impaired when newborn calves are exposed to extreme cold, possibly because of direct effects on intestinal absorption and transport and indirect effects on the calf's ability to stand and nurse [73].

Bacterial contamination of colostrum

Bacteria in colostrum may bind free Ig in the gut lumen or directly block uptake and transport of Ig molecules across intestinal epithelial cells, thus interfering with passive absorption of colostral Ig [74–76]. This effect was demonstrated in a recent controlled study wherein newborn calves were

fed either 3.8 L of pasteurized (60°C × 60 min) colostrum or 3.8 L of raw colostrum, with the geometric mean total bacteria counts in the two colostrum treatment groups being 813 cfu/mL or 40,738 cfu/mL, respectively [77]. Although the volume, timing, and quality of colostrum fed to the two feeding groups was not different, calves fed pasteurized colostrum had significantly higher mean serum IgG levels at 24 hours of age (22.3 mg/mL) versus calves fed raw colostrum (18.1 mg/mL). This improvement was attributed to reduced bacterial interference with IgG absorption across the gut, resulting in higher efficiency of IgG absorption in calves fed pasteurized colostrum (35%) versus calves fed raw colostrum (27%) [77]. Strategies for preventing or minimizing bacterial contamination of colostrum are discussed in the next section.

Strategies for preventing bacterial contamination of colostrum

Although colostrum is an important source of nutrients and immune factors, it can also represent one of the earliest potential exposures of dairy calves to infectious agents including *Mycoplasma* spp, *Mycobacterium avium* subsp *paratuberculosis*, fecal coliforms, and *Salmonella* spp [78–80]. This exposure is a concern because pathogenic bacteria in colostrum could cause diseases such as diarrhea or septicemia. It is also a concern because bacteria in colostrum may interfere with absorption of Ig [74–76]. Experts recommend that fresh colostrum fed to calves contain fewer than 100,000 cfu/mL total bacteria count (TPC) and fewer than 10,000 cfu/mL total coliform count [6]. Unfortunately, average bacteria counts in colostrum fed on commercial dairies frequently far exceeds this cutpoint [31,76]. In one study of Wisconsin dairy herds, 82% of samples tested exceeded the upper limit of 100,000 cfu/mL TPC [76]. The following section describes management techniques for minimizing bacterial contamination of colostrum.

Preventing contamination during colostrum harvest, storage, and feeding procedures

Methods for reducing the risk for pathogen exposure to calves include avoiding feeding colostrum from known infected cows and avoiding pooling of raw colostrum. Additionally, all producers should take steps to avoid contamination during colostrum harvest, storage, or feeding processes. In a study of colostrum harvesting and feeding practices on one dairy, total bacteria counts (TPC cfu/mL) were very low or nil in colostrum stripped directly from the gland (geometric mean$_{udder}$ TPC = 27.5 cfu/mL). Significant bacterial contamination occurred, however, during the process of milking the colostrum into the bucket (geometric mean$_{bucket}$ TPC = 97,724 cfu/mL) [81]. These results emphasize the importance of minimizing colostrum contamination by properly prepping udders before harvesting colostrum, milking into a clean, sanitized bucket, and handling colostrum using clean, sanitized storage or feeding equipment.

Minimizing bacterial growth in stored colostrum

Bacteria can multiply rapidly if colostrum or milk is stored at warm ambient temperatures [81]. Unless colostrum is to be fed right away, it should be frozen or refrigerated within 1 hour after collection. It is generally accepted that colostrum may be frozen for up to 1 year, provided multiple freeze–thaw cycles do not occur. When thawing frozen colostrum, producers should avoid overheating colostrum (avoid temperatures $>60°C$ or $140°F$) or some denaturation of colostral Ig can occur [82]. Options for producers who wish to store fresh colostrum include refrigeration with or without the use of preservatives such as potassium sorbate [81]. IgG in raw refrigerated colostrum is stable for at least 1 week. Average bacteria counts in raw refrigerated colostrum may reach unacceptably high concentrations ($>100,000$ cfu/mL) after 2 days of refrigeration, however. By comparison, average colostrum bacteria counts remained less than 100,000 cfu/mL for 6 days of refrigeration when colostrum was preserved with potassium sorbate in a 0.5% final solution [81]. Information on potassium sorbate sources and mixing directions can be found at http://www.atticacows.com/orgMain.asp?orgid= 19&storyTypeID=&sid=&.

Pasteurizing colostrum

An additional tool that may be useful to reduce bacterial contamination of colostrum is pasteurization. Early studies tried to pasteurize colostrum using the same conventional methods and high temperatures as are typically used to pasteurize milk ($63°C$ [$145°F$] for 30 minutes or $72°C$ [$161°F$] for 15 seconds). This process yielded unacceptable results, however, including thickening or congealing of colostrum and denaturation of approximately one third of colostral IgG [83]. Despite these early setbacks, more recent research has determined that using a lower-temperature, longer-time approach ($60°C$ [$140°F$] for 60 minutes) to batch-pasteurize colostrum is sufficient to maintain IgG activity and colostrum fluid characteristics, while eliminating or significantly reducing important pathogens including *E. coli*, *Salmonella enteritidis*, *Mycoplasma bovis* and *Mycobacterium avium* subsp *paratuberculosis* [82,84]. In one recent on-farm controlled study, calves fed pasteurized colostrum ($60°C \times 60$ minutes) experienced a significant reduction in colostrum bacterial exposure and significantly higher serum IgG levels at 24 hours of age versus calves fed 3.8 L of raw colostrum [77]. If stored in a clean covered container, the shelf life of pasteurized refrigerated colostrum is at least 8 to 10 days [85]. The potential short- and long-term health and economic benefits of feeding pasteurized colostrum have not yet been described.

Use of colostrum supplements or replacement products

Farms can occasionally experience periods in which an adequate supply of clean, high-quality, fresh or stored colostrum is not available to feed to all

newborn calves. Contributing to this problem, some producers may discard colostrum from cows that test positive for *M avium* subsp *paratuberculosis*, bovine leukosis virus, or *M bovis* mastitis. Under such circumstances, using colostrum supplements (CS) or colostrum replacement (CR) products may offer producers a convenient way to improve levels of passive immunity in calves while reducing the risk for pathogen exposure through colostrum. Powdered commercial CS or CR products contain bovine Ig that is typically either lacteal- or plasma-derived. It is recommended that CS or CR products be mixed in water (according to label directions) and fed as a separate meal after any natural colostrum has been fed [6]. There are important differences between the less expensive CS products ($5–$7 per dose) and more expensive CR products ($25–$30 per dose). Colostrum supplement products typically contain less than 50 g IgG per dose, contain no nutrient pack, and are only intended to supplement (not replace) existing colostrum. If given alone, feeding CS products results in significantly lower serum Ig and greater risk for FPT in calves as compared with feeding fresh colostrum [86]. There is no added benefit of feeding CS products if already feeding 3 to 4 L of high-quality bovine colostrum [87,88]. By comparison, CR products contain a minimum of 100 g IgG per dose, provide a nutritional source of protein, energy, vitamins, and minerals, and are designed to completely replace (or feed in the absence of) maternal colostrum [89].

Results of CR studies have been mixed, with many products failing to routinely provide the necessary 10 mg/mL IgG in serum of calves fed CR [31,89–91]. In a controlled study of 12 dairy herds in Minnesota and Wisconsin, Swan and colleagues [31] reported that 239 commercial dairy calves fed a commercially available CR product (Acquire, American Protein Corporation, Inc., Ames, Iowa) had significantly lower serum IgG concentrations (5.8 mg/mL IgG) than 218 calves fed maternal colostrum (14.8 mg/mL IgG). Although a trend was present, the preweaning morbidity and mortality rates were not different for calves fed CR (morbidity = 59.6%; mortality = 12.4%) versus calves fed maternal colostrum (morbidity = 51.9%; mortality = 10%). Other studies have reported better rates of successful passive transfer (mean serum IgG >10.0 mg/mL), particularly when calves were fed two doses of CR product [89,92]. In one such study, the average 24-hour serum IgG level for calves fed either one dose (100 g IgG) or two doses (200 g IgG) of a lacteal-derived CR, or 3.78 L of maternal colostrum, were 11.6, 16.9, and 27.2 mg/mL IgG, respectively (Land O' Lakes Colostrum Replacement, Land O' Lakes Inc., St. Paul, Minnesota) [93]. Feeding higher doses of CR products may increase the rate of successful passive transfer, but the cost–benefit of this practice has yet to be described. Similarly, the effectiveness and cost–benefit of routinely using CR products in Johne's or other infectious disease control programs has yet to be described. Because of the highly variable performance among different products, veterinarians should review results of peer-reviewed controlled trials when selecting a CR product.

Monitoring the colostrum management program

Veterinarians can help producers develop programs to routinely monitor colostrum management. Possible laboratory-based test methods for directly measuring or estimating serum IgG concentrations in calves include radial immunodiffusion (RID), turbidimetric immunoassay (TIA), enzyme-linked immunosorbent assay (ELISA), sodium sulfite turbidity test, zinc sulfate turbidity test, serum gamma glutamyltransferase (GGT) activity, and whole-blood glutaraldehyde coagulation test [94–96]. In a recent review of these tests, Weaver and colleagues [3] raised concerns about unacceptably high levels of inaccurate results for the sodium sulfite turbidity test when using the 14% and 16% sodium sulfite test solutions, the zinc sulfate turbidity test if samples are exposed to CO_2 or are hemolyzed, GGT test results, and whole-blood glutaraldehyde coagulation test results. Although RID, TIA, or ELISA would be acceptable tests for use in periodic outbreak investigations, the expense and inconvenience of routinely submitting serum samples to a veterinary diagnostic laboratory would generally discourage their adoption for ongoing monitoring programs.

A lateral-flow immunoassay is one tool that could be used for on-farm testing (Midland Quick Test Kit – Calf IgG, Midland BioProducts Corp., Boone, Iowa). The manufacturer has reported the sensitivity, specificity, and overall accuracy of this assay to identify calves with serum IgG less than 10.0 mg/mL as being 0.99, 0.89, and 0.94, respectively [97]. Independent validation of this test is still required. One limitation of the immunoassay is that it yields only a positive or negative result, but does not provide an estimate of the actual serum IgG concentration. The assay requires approximately 20 minutes to complete and costs approximately $4.50 (USD) per sample.

Measurement of serum total solids (STS) by hand-held refractometer offers a convenient, simple, rapid, and inexpensive on-farm tool by which producers can monitor the colostrum feeding program. The refractometer instrument costs approximately $250 (USD). In an early study of 185 calves, STS had a good correlation with serum IgG concentration as measured using RID ($R^2 = 0.72$) [98]. Calloway and colleagues [99], reported that STS concentration test endpoints of 5.0 and 5.2 g/dL yielded the most accurate results in estimating the adequacy of passive transfer as defined by serum IgG 10.0 mg/mL or greater (sensitivity >0.80; specificity >0.80; proportion classified correctly >0.85). In that study lower or higher test endpoints misclassified larger numbers of calves. Because STS results do result in periodic misclassification of individual calves, the use of STS results as an individual animal diagnostic tool is discouraged. When results are interpreted at the group or herd level, however, STS results accurately reflect the proportion of calves that have FPT, thereby making it a useful on-farm tool for monitoring whether the colostrum management program is succeeding. It is recommended that serum samples be collected from a minimum of 12 clinically normal (not scouring) calves between 24 hours and 7 days of

age [6]. Wallace and colleagues [100] reported that the results of STS refractometry from centrifuge- and noncentrifuge-harvested sources of serum were highly correlated ($R^2 = 0.95$), so producers can conduct this test on-farm without need of a centrifuge. McGuirk and Collins [6] suggest that a goal is for 80% or more of calves tested to meet or exceed a STS cutpoint of 5.5 g/dL. Tyler suggests that 90% or more of calves tested should meet or exceed the more accurate STS cutpoint of 5.0 g/dL (J Tyler, personal communication, 2002). If it is determined that a disproportionate number of calves have FPT, then the veterinarian and producer must investigate to identify and then correct the root causes of FPT within the colostrum management program. In addition to periodically sampling groups of calves to assess FPT, producers can also periodically submit frozen colostrum samples to a microbiology laboratory for culture. A goal is for a majority of samples submitted to have at total bacteria count of less than 100,000 cfu/mL and a total coliform count less than 10,000 cfu/mL [6].

Summary

Colostrum management is the single most important management factor in determining calf health and survival. Unfortunately, a significant proportion of North American dairy calves suffer from failure of passive transfer, contributing to excessively high preweaning mortality. There is considerable opportunity for most dairy producers to improve their colostrum management practices, resulting in improved short- and long-term health and performance of the animal. A successful colostrum management program requires producers to consistently provide calves with a sufficient volume of clean, high-quality colostrum within the first few hours of life. Colostrum replacers are useful tools if a sufficient quantity of clean, high-quality maternal colostrum is not available. Ongoing monitoring helps producers to more quickly identify and correct problems within the colostrum management program.

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