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# Colostrum Management for Dairy Calves



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## KEYWORDS

• Calf • Colostrum management • Passive immunity • Monitoring

## KEY POINTS

- Colostrum management is the single most important management factor in determining calf health and survival.
- Although good progress has been made in the past 20 years, there remains a considerable opportunity for many dairy producers to improve their colostrum management practices, resulting in improved short-term and long-term health and performance of the animals.
- Producers should provide calves with a sufficient volume of clean, high-quality colostrum within the first few hours of life.

## INTRODUCTION

The syndesmochorial placenta of the cow separates the maternal and fetal blood supplies, preventing in utero transmission of protective immunoglobulins (Ig) (Fig. 1).<sup>1</sup> Consequently, the calf is born agammaglobulinemic and so is almost entirely dependent on the absorption of maternal Ig from colostrum after birth. Achieving early and adequate intake of high-quality colostrum is widely recognized as the single most important management factor in determining the health and survival of neonatal calves.<sup>2-4</sup> 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. 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, reduced age at first calving,

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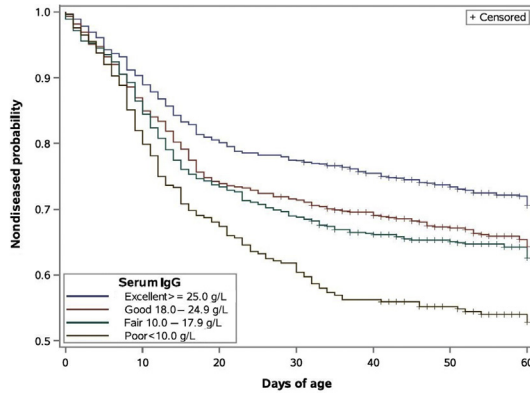
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**Fig. 1.** Nondiseased probability for preweaned heifer calves by days of age and serum IgG concentration categories. Corresponding with serum IgG levels of greater than or equal to 25.0 g/L, 18.0 to 24.9 g/L, 10 to 17.9 g/L, and less than 10.0 g/L were serum total protein categories of greater than or equal to 6.2 g/dL, 5.8 to 6.1 g/dL, 5.1 to 5.7 g/dL, and less than 5.1 g/dL, and Brix score categories of greater than or equal to 9.4%, 8.9% to 9.3%, 8.1% to 8.8%, and less than 8.1%, respectively.<sup>131</sup>

improved first and second lactation milk production, and reduced tendency for culling during the first lactation.<sup>5–8</sup> Benefits from colostrum may be attributed to protective Ig as well as high levels of nutrients and bioactive compounds that stimulate postnatal growth and development.<sup>9</sup>

Calves have historically been defined as having failure of passive transfer (FPT) if the serum IgG concentration is less than 10 g/L when sampled between 24 and 48 hours of age, based on increased mortality risk below this threshold.<sup>10–12</sup> However, this definition of FPT needs to be reevaluated, given that recent studies have described reduced morbidity in calves to be associated with incrementally higher serum IgG levels (Fig. 1).<sup>4,12,13</sup> Although the US dairy industry has shown steady improvement in colostrum and calf management over the past few decades, a recent national dairy study reported FPT to affect 15.6% of calves tested,<sup>14</sup> indicating a need for continued efforts to improve colostrum management. This article reviews the process of colostrum genesis and colostrum composition, and discusses the key components of developing a successful colostrum management program. In addition, it discusses methods for monitoring and presents new goals for passive immunity in dairy herds.

## 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.<sup>15</sup> 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, leukocytes, growth factors, hormones, 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 6 milkings (transition milk) to reach the lower concentrations routinely measured in saleable whole milk (Table 1).<sup>15</sup>

Parameter	Colostrum		Transition Milk (Milking Postpartum)	
	1	2	3	Milk
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
IgGF-I ( $\mu\text{g/L}$ ) <sup>9</sup>	341	242	144	15
Insulin ( $\mu\text{g/L}$ ) <sup>9</sup>	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
Potassium (%)	0.14	0.13	0.14	0.15
Sodium (%)	0.07	0.05	0.05	0.04
Chloride (%)	0.12	0.1	0.1	0.07
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
Copper (mg/100 g)	0.06	—	—	0.01
Cobalt ( $\mu\text{g}/100\text{ g}$ )	0.5	—	—	0.10
Vitamin A ( $\mu\text{g}/100\text{ mL}$ )	295	190	113	34
Vitamin D (IU/g fat)	0.89–1.81	—	—	0.41
Vitamin E ( $\mu\text{g}/\text{g fat}$ )	84	76	56	15
Thiamine ( $\mu\text{g}/\text{mL}$ )	0.58	—	0.59	0.38
Riboflavin ( $\mu\text{g}/\text{mL}$ )	4.83	2.71	1.85	1.47
Biotin ( $\mu\text{g}/100\text{ mL}$ )	1.0–2.7	—	—	2.0
Vitamin B <sub>12</sub> ( $\mu\text{g}/100\text{ mL}$ )	4.9	—	2.5	0.6
Folic acid ( $\mu\text{g}/100\text{ mL}$ )	0.8	—	0.2	0.2
Choline (mg/mL)	0.7	0.34	0.23	0.13
Ascorbic acid (mg/100 mL)	2.5	—	2.3	2.2

Adapted from Foley, J.A. and D.E. Otterby. Availability, storage, treatment, composition, and feeding value of surplus colostrum: A review. *J. Dairy Sci.* 1978; 61:1033-1060; with permission and data from Hammon, H.M., I.A. Zanker, and J.W. Blum. Delayed colostrum feeding affects IGF-1 and insulin plasma concentrations in neonatal calves. *J. Dairy Sci.* 2000; 83:85-92.

### **Immunoglobulins**

IgG, IgA, and IgM account for approximately 85% to 90%, 5%, and 7%, respectively, of the total Ig in colostrum, with IgG<sub>1</sub> accounting for 80% to 90% of the total IgG.<sup>16</sup>

Although levels are highly variable among cows, one study reported that mean colostrum concentrations of IgG, IgA, and IgM were 75 g/L, 4.4 g/L, and 4.9 g/L, respectively.<sup>17</sup> IgG, and IgG<sub>1</sub> in particular, is transferred from the blood stream across the mammary barrier into colostrum by a specific transport mechanism; receptors on the mammary alveolar epithelial cells capture IgG<sub>1</sub> from the extracellular fluid, and the molecule undergoes endocytosis, transport, and eventually release into the luminal secretions.<sup>16</sup> The alveolar epithelial cells cease expressing this receptor, most likely in response to increasing prolactin concentrations, at the onset of lactation.<sup>18</sup> Smaller amounts of IgA and IgM are largely derived from local synthesis by plasmacytes in the mammary gland.<sup>16</sup> Although not well understood, colostrum transfer of IgE also occurs and may be important in providing early protection against intestinal parasites.<sup>19</sup> After absorption into the calf's circulation, the duration of passive immunity from maternal Ig is highly variable and depends to a great extent on the total mass of Ig consumed and absorbed within the first 24 hours of life. The rate of decay of colostrum antibodies can be influenced by multiple factors, including active viral infections or vaccination.<sup>20–22</sup>

### **Maternal Leukocytes**

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Fresh colostrum contains leukocytes of maternal origin; in cattle, macrophages and lymphocytes (mononuclear cells) make up the largest proportion of maternal colostrum leukocytes.<sup>23</sup> Maternal colostrum leukocytes enter the tissues of neonates following ingestion or enteral delivery in a variety of species, including rats, sheep, swine, and cattle,<sup>24–26</sup> and feeding colostrum containing maternal leukocytes has been associated with modified neonatal immune responses.<sup>27–31</sup> Blood mononuclear cells from calves fed colostrum containing maternal leukocytes developed the ability to activate cell-mediated immune responses by the time calves were 1 week of age, compared with 3 weeks of age for calves fed leukocyte-free colostrum.<sup>27</sup> Significant differences in percentage and degree of blood mononuclear cell activation were measured in calves receiving colostrum containing maternal leukocytes, compared with calves fed leukocyte-free maternal colostrum or frozen colostrum.<sup>29–31</sup> Both freezing<sup>28</sup> and heat treatment (Godden, unpublished, 2010) of colostrum kill most if not all colostrum leukocytes. Blood mononuclear cells from 1-day-old calves fed colostrum containing maternal leukocytes were significantly more responsive to bovine viral diarrhea virus, compared with day-old calves that received frozen colostrum or leukocyte-free colostrum.<sup>28</sup> In contrast, there was no difference between treatment groups in the response to a mycobacterial antigen that the calves' dams had not encountered, suggesting that antigen-specific responses measured in a calf following ingestion of maternal colostrum leukocytes are related to specific immune memory in the dam. In support of this, cell-mediated immune responses in piglets that nursed maternal colostrum containing leukocytes were significantly higher if their dams had been vaccinated against the tested antigen than if their dams had not been vaccinated.<sup>32</sup> Although research has not evaluated the degree of difference in responses induced by colostrum leukocytes from a calf's own dam versus colostrum leukocytes from another cow, cross-fostering experiments in piglets suggest that effects of colostrum leukocytes on neonatal cell-mediated immunity are greatest when the colostrum contains leukocytes from the neonate's dam.<sup>33</sup>

Although multiple studies have confirmed that colostrum leukocytes modify immune responses in calves in ways that seem relevant to protective immunity, to date research has not clearly shown an unequivocally beneficial effect of colostrum leukocytes on practical outcomes such as calf respiratory or enteric morbidity, or induction of specific and measurable protective immunity following vaccination. Colostrum

leukocytes fed alone are not sufficient to protect calves from fatal disease in the neonatal period,<sup>34</sup> and recent studies comparing proportions of calves affected by naturally occurring diarrhea or respiratory disease after calves consume fresh maternal colostrum containing leukocytes, or frozen colostrum from their own dam<sup>31</sup> or other cows,<sup>35</sup> have shown small or variable differences in disease between the groups. Regarding the effect of colostrum leukocytes on vaccine responses, Meg-anck and colleagues<sup>36</sup> evaluated humoral and cell-mediated responses to tetanus toxoid vaccination at 2, 5, or 10 days of age in calves fed pooled colostrum whey with maternal leukocytes added, or calves fed only pooled colostrum whey; this work suggested that colostrum leukocytes influenced both tetanus toxoid-specific cell-mediated and humoral responses in calves, but the number of calves tested was small, and the effects measured varied substantially for calves vaccinated at 2, 5, or 10 days of age. Langel and colleagues<sup>37</sup> evaluated total (ie, not antigen-specific) monocyte and lymphocyte responses by measuring relative numbers and activation state of calf blood mononuclear cell subsets after routine calthood vaccination; these investigators found significant differences between groups at certain time points over the months following vaccination. However, the clinical relevance of these differences for immunity against specific pathogens, or resistance to disease, was not defined. In summary, colostrum leukocytes modify calf immune responses, and these effects may affect cow health and immunity months or years later. However, to date, effects of colostrum leukocytes on practically important health outcomes have not been unequivocally identified, which may in part be because it is logistically challenging and expensive to conduct research to measure effects of colostrum leukocytes on calf immunity and health, so trials to date may not have included enough calves to provide adequate statistical power to identify small but important health differences.

### **Nutrients and Nonnutritive Factors**

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In addition to Ig for passive immunity, colostrum also contains high amounts of nutrients and nonnutritive biologically active factors that stimulate maturation and function of the neonatal gastrointestinal tract (GIT).<sup>9</sup> The total solids content (percentage) in first milking colostrum and whole milk in Holstein cows was reported to average 23.9% and 12.9%, respectively (see [Table 1](#)). Much of the increase in colostrum solids content is attributed to a more than 4-fold increase in protein content of colostrum versus milk, this being caused by significant increases in both Ig and casein content.<sup>2</sup> The crude fat content of first milking Holstein colostrum (6.7%) is also significantly higher than for milk (3.6%).<sup>15</sup> Energy from fat and lactose in colostrum is critical for thermogenesis and body temperature regulation. Certain vitamins and minerals, including calcium, magnesium, zinc, vitamin A, vitamin E, carotene, riboflavin, vitamin B12, folic acid, choline, and selenium, are also found in increased concentrations in bovine colostrum.<sup>15,38</sup>

Nonnutritive factors found in increased levels in colostrum include, but are not limited to, growth factors, hormones, cytokines, and nonspecific antimicrobial factors. Trypsin inhibitor, a compound found in colostrum in concentrations nearly 100 times greater than in milk, serves to protect Ig and other proteins from proteolytic degradation in the intestine of the neonatal calf. Bioactive components with antimicrobial activity include lactoferrin, lysozyme, and lactoperoxidase.<sup>39–41</sup> Oligosaccharides may provide protection against pathogens by acting as competitive inhibitors for the binding sites on the epithelial surfaces of the intestine.<sup>38</sup> It has also been suggested that certain oligosaccharides in colostrum may contribute to gut microbiome development by serving as a substrate to beneficial microorganisms such as *Bifidobacterium*, although this hypothesis requires further study.<sup>42</sup>

Growth factors in bovine colostrum include transforming growth factor beta-2, growth hormone, and insulin. Colostral insulinlike growth factor I and II may be key to regulating development of the GIT of bovine neonates, including stimulation of mucosal growth, brush-border enzymes, intestinal DNA synthesis, and increased villus size, resulting in enhanced absorptive capacity and glucose uptake.<sup>9,43</sup>

Another intriguing and potentially beneficial factor found in high levels in colostrum may be microRNAs (miRNAs). MiRNAs are short, noncoding RNA molecules that can regulate gene expression at the posttranscriptional level, and could represent one possible method of postnatal signaling from the mother to the neonate. Although studies are needed to describe their functional significance in calves, early research in other species suggests that, once absorbed by the neonate, MiRNAs from colostrum may be important in the differentiation and functional development of the intestinal epithelium,<sup>44</sup> and could also play an important role in the maturation of the neonate's immune system.<sup>45</sup>

These nutrients and nonnutritive factors, combined with benefits of disease protection from Ig, may contribute to the short-term and long-term benefits from improved colostrum intake, including improved rate of gain, reduced age at first calving, improved first and second lactation milk production, and reduced tendency for culling during the first lactation.<sup>5-8</sup> Further research is needed to investigate the concept of epigenetic programming or imprinting effects of colostrum on both short-term and long-term health and performance.<sup>9</sup>

## COMPONENTS OF A SUCCESSFUL COLOSTRUM MANAGEMENT PROGRAM

To achieve successful passive transfer, calves must consume a sufficient mass of IgG in colostrum, and then successfully absorb a sufficient portion of IgG into their circulation. In order to achieve acceptable passive transfer (APT) in greater than or equal to 90% of calves fed, using the traditional definition of APT (serum IgG >10 g/L), it has been estimated that a minimum of 150 to 200 g of IgG needs to be delivered to the calf shortly after birth. In order to achieve the more ambitious goals for excellent passive transfer, presented later in this article, the authors estimate that producers need to deliver greater than or equal to 300 g of IgG shortly after birth. The 2 major factors affecting the mass of Ig consumed are the quality and volume of colostrum fed. Factors affecting the absorption of Ig molecules into circulation include the quickness with which the first colostrum feeding is provided after birth, bacterial contamination of colostrum, and metabolic status of the calf. This article next discusses these key factors, strategies for minimizing bacterial contamination of colostrum, the use of colostrum supplements (CSs) and replacers, benefits of multiple feedings, and benefits of extended colostrum or transition milk feeding after intestinal closure.

## FACTORS ASSOCIATED WITH COLOSTRUM QUALITY AND YIELD

Although it is recognized that colostrum contains a wide spectrum of important immune and nutritional components, the concentration of IgG in colostrum has traditionally been considered the hallmark for evaluating colostrum quality, with high quality defined as IgG levels greater than 50 g/L. Colostrum IgG levels can vary dramatically among cows; in an observational study that tested 2253 colostrum samples from 104 farms in 13 states, mean colostrum IgG level was 74.2 g/L, with the 5th and 95th percentiles ranging from 24.9 to 130.2 g/L. A total of 77.4% of samples had colostrum IgG level greater than 50 g/L.<sup>46</sup> Factors affecting colostrum quality and yield are reviewed next and methods for testing colostrum quality are discussed.

### ***Breed***

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Comparative studies have reported that there can be a breed effect on colostrum quality.<sup>47,48</sup> In one study, Holstein cows produced colostrum with total Ig content (5.6%) that was lower than for Guernsey (6.3%), Brown Swiss (6.6%), Ayrshire (8.1%), or Jersey (9.0%) breed cows.<sup>48</sup> Breed differences could be caused by genetics and/or dilutional effects.

### ***Age of Dam***

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Most, but not all, studies report a tendency for older cows to produce higher-quality colostrum, presumably /because of older animals having had a longer period of exposure to farm-specific pathogens.<sup>46,49,50</sup> In a study by Shivley and colleagues,<sup>46</sup> colostrum from first and second lactation cows had similar colostrum quality (73.2 and 71.7 g/L of IgG), whereas colostrum from third lactation and older cows was of higher quality (83.3 g/L IgG). Producers should test and record the quality of all colostrum fed. Producers should not automatically discard colostrum from first calf heifers without first testing, because it may be of very good quality.

### ***Nutrition in the Preparturient Period***

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Studies have generally reported that Ig content of colostrum is not greatly affected by restricting prepartum maternal nutrition.<sup>51–53</sup> Mann and colleagues<sup>54</sup> reported that feeding a controlled energy diet that met, but did not exceed, energy requirements during the dry period increased colostral IgG but did not affect colostrum yield, compared with diets that offered increased energy. Lacetera and colleagues<sup>55</sup> 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. Aragona and colleagues<sup>56</sup> reported that supplementation with nicotinic acid for 4 weeks prepartum increased IgG concentration in colostrum from 73.8 to 86.8 g/L. More research is needed to investigate whether and how nutrition of the dam during the preparturient period may affect colostrum yield and quality. Producers should feed rations balanced according to National Research Council 2001 guidelines.<sup>57</sup>

### ***Season of Calving***

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The relationship between season and colostrum quality or volume remains unclear. Although some 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,<sup>49,58</sup> others have reported the opposite.<sup>46</sup> It has been suggested that any negative effects of heat stress on colostrum quality might be associated with reduced dry matter intake or reduced mammary blood flow resulting in impaired transfer of IgG and nutrients to the udder.<sup>58</sup> Season may also have an impact on colostrum yield, although this is less well described. In a year-long study of a 2500-cow Jersey dairy in Texas, colostrum yield was highest in June but declined during the fall and winter months.<sup>59</sup> A low-temperature humidity index and a shortened photoperiod 1 month before and at calving were both highly correlated with reduced colostrum yield. The investigators hypothesized that shortened photoperiod may reduce colostrum production because of its impact on melatonin and prolactin, hormones known to be involved with colostrogenesis. However, a study that experimentally manipulated photoperiod reported no effect of photoperiod during the dry period on colostrum



quality or yield.<sup>60</sup> Producers should adopt heat-abatement strategies for prepartum cows and heifers and are advised to bank frozen colostrum to meet needs during low colostrum production months.<sup>59</sup>

### ***Preparturient Vaccination of the Dam***

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Although vaccination is not likely to increase total IgG in colostrum, a large body of research has established that vaccinating pregnant cows and heifers during the final 3 to 6 weeks preceding calving results in increased concentrations of antigen-specific protective colostral antibodies, and increased passive antibody titers in calves of vaccinated dams, specific for some common pathogens including *Pasteurella haemolytica*, *Salmonella typhimurium*, *Escherichia coli*, rotavirus, and coronavirus.<sup>61–64</sup>

### ***Dry Period Length***

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Cows with excessively short dry periods (<21 days) produce colostrum with lower IgG concentration.<sup>65</sup> Furthermore, cows with shorter dry periods produce lower yields of colostrum.<sup>59,66</sup> One controlled field study reported cows with a short (40-day) dry period produced 2.2 kg less colostrum than did cows with a conventional (60-day) dry period.<sup>67</sup>

### ***Volume of Colostrum Produced at First Milking***

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Pritchett and colleagues<sup>68</sup> 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 higher-producing cows, presumably because of dilutional effects. However, more recent studies report that there is no strong predictable relationship between colostrum IgG concentration and weight of colostrum produced at first milking.<sup>67,69,70</sup>

### ***Delayed Colostrum Collection***

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Most studies report that the concentration of Ig in colostrum is highest immediately after calving but begins to gradually decrease over time if harvest is delayed.<sup>60,71</sup> In an experimental study, Morin and colleagues<sup>60</sup> reported that colostral IgG concentration decreased by 3.7% during each subsequent hour that milking was delayed after calving, because of postparturient secretion (dilution) by the mammary glands. In another study, delaying harvest of colostrum for 6, 10, or 14 hours after calving resulted in a 17%, 27%, and 33% decrease in colostral IgG concentration, respectively.<sup>72</sup>

### ***Cow-Side Testing of Colostrum Quality***

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It is difficult to predict, based on such factors such as visual consistency, which colostrum collected will be of high (>50 g/L IgG) versus low quality.<sup>69</sup> The colostrometer, a hydrometer instrument that estimates IgG concentration by measuring specific gravity, can be useful to differentiate high-quality from low-quality colostrum (specific gravity >1.050 approximates IgG >50 g/L). However, factors such as content of fat and colostrum temperature affect the hydrometer reading.<sup>73</sup> More recently, several studies have validated use of the Brix refractometer, an instrument that measures percentage solids in a solution, to indirectly estimate IgG level in colostrum. The Brix refractometer is less affected by temperature and more durable than the glass colostrometer. Studies have reported that a value between 18% and 23% Brix is an appropriate cut point for determining good-quality colostrum (IgG >50 g/L).<sup>74–77</sup> An achievable herd-level goal is to harvest high-quality colostrum (IgG ≥50 g/L or Brix ≥22%) in greater than or equal to 90% of samples tested.

## VOLUME OF COLOSTRUM CONSUMED AT FIRST FEEDING

It is recommended that calves be fed 10% to 12% of their body weight (BW) of colostrum at first feeding (3–4 L for a Holstein calf). In one study, mean serum IgG level at 24 hours was significantly higher for calves fed 4 L of colostrum at 0 hours and a further 2 L at 12 hours (serum IgG = 31.1 g/L) compared with calves fed only 2 L of high-quality colostrum at 0 hours and a further 2 L at 12 hours (serum IgG = 23.5 g/L).<sup>78</sup> Another study reported that Brown Swiss calves fed 3.8 L (vs 1.9 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 lactations.<sup>8</sup> The method of delivering colostrum deserves consideration. Suckling the dam is the least preferred approach, because delays in suckling and failure to control quality and volume ingested can result in higher rates of FPT.<sup>79</sup> When colostrum is delivered with an esophageal tube feeder, the esophageal groove reflex is not triggered, resulting in fluid being deposited into the forestomachs. However, this is not a significant limitation because outflow of colostrum from the forestomachs to the abomasum and small intestine occurs for the most part within 3 hours.<sup>80</sup> As such, equal and acceptable levels of passive transfer are achieved when colostrum is delivered by nipple bottle or esophageal tube feeder, provided that a sufficient volume of colostrum is delivered.<sup>81,82</sup> One study reported that calves drinking from a nipple bottle consumed an average of only 2.2 L (range, 1–4 L).<sup>83</sup> As such, producers feeding colostrum by nipple bottle should be prepared to deliver any remaining colostrum using a tube feeder, or provide a second bottle feeding within 6 hours, for those calves that do not voluntarily consume their whole allotment. Veterinarians should train staff on how to safely administer colostrum using tube feeders. Equipment sanitation and maintenance are important for both bottles and tube feeders.

## 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.<sup>84</sup> 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.<sup>85</sup> In a process referred to as closure, the absorption of Ig across the intestinal epithelium decreases linearly with time from birth to completely close at approximately 24 hours.<sup>11</sup> Factors affecting the apparent efficiency of absorption (AEA) of Ig for the first colostrum feeding are discussed here, as well as the value of extended colostrum feeding and feeding colostrum or transition milk after gut closure.

### *Time to First Colostrum Feeding*

The efficiency of Ig transfer across the gut epithelium is optimal soon after birth, with a progressive decline in Ig absorption over time until gut closure.<sup>86,87</sup> Delaying the first colostrum feeding can only slightly postpone gut closure (36 hours).<sup>88</sup> In a study that randomized newborn calves to provide the first feeding of colostrum (7.5% BW; approximately 200 g of IgG) at different times, higher efficiency of absorption and maximum serum IgG levels were achieved for calves fed at 45 minutes of age (AEA = 51.8%; IgG = 25.5 g/L), compared with calves fed at 6 hours (AEA = 35.6%; IgG = 18.2 g/L) or 12 hours (AEA = 35.1%; IgG = 18.5 g/L).<sup>87</sup> Earlier feeding also resulted in more rapid bacterial colonization of the intestine with organisms such as *Bifidobacterium* spp. Producers should aim to feed all calves within 1 to 2 hours after birth.

### ***Bacterial Contamination of Colostrum***

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High levels of bacteria in colostrum, and particularly coliform bacteria, may bind free Ig in the gut lumen and/or directly block uptake and transport of Ig molecules across intestinal epithelial cells, thus interfering with passive transfer.<sup>89</sup> Strategies to minimize bacterial contamination of colostrum are discussed next.

### ***Metabolic Disturbances***

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Decreased colostrum Ig absorption in the first 12 hours has been reported in calves with postnatal respiratory acidosis, associated with prolonged parturition.<sup>90,91</sup> Hypothermia may also be responsible for a delay in Ig absorption.<sup>92</sup> 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.<sup>93,94</sup> Producers should provide adequate supportive care to newborns, including warming and drying calves born during cold weather, and providing supplemental heat, blankets, and deep straw bedding. Pain management, through the provision of a nonsteroidal antiinflammatory, has been shown to improve calf vigor and enhance IgG absorption for low-vigor calves following difficult calvings.<sup>95–97</sup>

### ***Presence of the Dam***

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Ig absorption was improved when calves were housed with the dam.<sup>98</sup> However, considering that acceptable levels of serum IgG can be achieved without housing the calf with the dam, and given that the latter practice may increase the calf's risk of exposure to pathogens in the dam's environment, it is currently recommended that the calf be removed from the dam within 1 to 2 hours of birth and hand-fed colostrum.<sup>3</sup>

### ***Value of Extended Colostrum Feeding***

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Although it is well recognized that maximal efficiency of absorption of IgG is achieved when the first colostrum feeding is provided within 2 hours after birth, the neonatal intestine is still permeable to IgG past 12 hours. Providing a second feeding sometime after the first postnatal meal can further increase passive transfer of IgG. In a recent study in which calves were randomly assigned to be fed a second feeding (5% BW) of either colostrum, a 1:1 colostrum/milk mixture, or milk at 12 hours of age, calves achieved a higher maximum serum IgG concentration if they were fed either colostrum (30 g/L) or mixture (25.0 g/L) at the second feeding, compared with milk (22.4 g/L).<sup>99</sup>

### ***Value of Feeding Colostrum or Transition Milk After Gut Closure***

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Feeding colostrum after the gut has closed still offers benefits, even though Ig absorption no longer occurs. One benefit may be that bioactive compounds, such as hormones or oligosaccharides, may stimulate development of the GIT.<sup>42,100</sup> In one recent study, calves that were transitioned directly onto milk after the first colostrum meal had less overall gastrointestinal mass and less development of villi in the small intestine compared with calves fed either colostrum or transition milk for the first 3 days of life.<sup>100</sup> This improved GIT development could be beneficial for nutrient absorption and gut health. Another benefit may be local protection of the GIT by colostral antibodies. Challenge studies and field trials have reported health and growth benefits from supplementing the milk diet with colostrum for the first 14 days of life. One controlled field trial that added 70 g of colostrum powder containing 10 g of IgG into milk replacer twice daily for 14 days reported improved growth, reduced diarrhea

days, and reduced antimicrobial use in treated calves.<sup>101</sup> In another field trial, supplementation of milk replacer with 150 g of bovine colostrum powder containing 32 g of IgG, for the first 14 days, resulted in reductions in diarrhea, respiratory disease, umbilical enlargement, and antibiotic therapy in treated dairy calves.<sup>102</sup> Producers feeding pasteurized whole milk are encouraged to include transition milk in the pool.

## STRATEGIES FOR REDUCING BACTERIAL CONTAMINATION OF COLOSTRUM

Although it is an important source of nutrients and immune factors, colostrum can also represent one of the earliest potential exposures of dairy calves to infectious agents, including *Mycoplasma* spp, *Mycobacterium avium* subsp *paratuberculosis*, and *Salmonella* spp.<sup>103,104</sup> Furthermore, high levels of bacteria in colostrum may interfere with Ig absorption.<sup>89</sup> A negative association between colostrum bacteria levels and Ig absorption has been described in several studies.<sup>105–107</sup> Fresh/raw colostrum fed to calves should contain less than 100,000 colony-forming units (cfu)/mL total plate count (TPC) and less than 10,000 cfu/mL total coliform count.<sup>3</sup> However, bacteria levels in colostrum frequently exceed these goals in dairies. In an observational study that tested 827 colostrum samples from 67 farms in 12 states, almost 43% of samples had TPC greater than 100,000 cfu/mL and 17% of samples had greater than 1 million cfu/mL.<sup>104</sup> Strategies for minimizing bacterial contamination of colostrum are discussed next.

### Preventing Contamination During Colostrum Harvest, Storage, and Feeding

Producers should avoid feeding colostrum from known infected cows (eg, Johne disease) and should avoid pooling raw colostrum. Contamination during colostrum harvest, storage, or feeding processes can be reduced by properly cleaning and sanitizing udders before harvesting colostrum; milking into a clean, sanitized bucket; and transferring colostrum into 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. Unless colostrum is to be fed right away, it should be frozen or refrigerated within 1 hour after collection. Colostrum may be frozen for up to 1 year, provided repeated multiple freeze-thaw cycles do not occur. When thawing frozen colostrum, producers should avoid overheating colostrum (avoid temperatures >60°C) or some denaturation of Ig can occur.<sup>108</sup> Options for storing fresh colostrum include refrigeration with or without the use of US Food and Drug Administration–approved preservatives such as potassium sorbate (0.5% final solution in colostrum). In one study, average bacterial counts in raw refrigerated colostrum reached unacceptably high levels (TPC >100,000 cfu/mL) after 2 days of refrigeration. By comparison, average colostrum TPC remained less than 100,000 cfu/mL for 6 days of refrigeration when colostrum was preserved with potassium sorbate.<sup>109</sup>

### Heat-Treated Colostrum

Although pasteurization at higher temperatures can damage Ig, colostrum may be safely heat treated (HT) using a lower-temperature, longer-time approach (60°C [140 F] for 60 minutes), maintaining IgG levels and fluid characteristics while eliminating important pathogens, including *E coli*, *Salmonella enteritidis*, and *Mycoplasma bovis*, and significantly reducing risk of exposure to *M avium* subsp. *paratuberculosis*.<sup>108,110,111</sup> Calves fed HT colostrum have improved efficiency of IgG absorption, presumably caused by reduced bacterial interference with IgG

absorption.<sup>105,112</sup> In a field study of 1071 newborn calves in 6 Midwest dairy herds, calves fed HT colostrum had higher serum IgG level (18.0 g/L) and reduced risk for diarrhea (30.9%) compared with calves fed fresh colostrum (15.4 g/L; 36.5%).<sup>106</sup> Possibly contributing to these health benefits, Malmuthuge and colleagues<sup>113</sup> reported that feeding HT colostrum enhanced GIT colonization with *Bifidobacterium* but reduced colonization with *E coli* within the first 12 hours. If refrigerated in a clean covered container, the shelf life of HT colostrum is at least 8 days.<sup>114</sup> Goals for bacteria levels in HT colostrum are TPC less than 20,000 cfu/mL and coliform count less than 100 cfu/mL, respectively.

## USE OF COLOSTRUM SUPPLEMENTS OR REPLACEMENT PRODUCTS

Although feeding high-quality, clean maternal colostrum is considered the gold standard, the use of high-quality CSs or colostrum replacements (CRs) may be attractive to producers for a variety of reasons, including availability, consistency, convenience, and as a means of breaking the transmission cycle of pathogens such as *M avium* ssp. *paratuberculosis*.<sup>115</sup> Supplements typically contain less than or equal to 60 g of IgG per dose and are intended to supplement (not replace) existing colostrum. There is no added benefit of feeding CS if already feeding 3 to 4 L of high-quality maternal colostrum.<sup>116</sup> By comparison, CR products are designed to completely replace maternal colostrum. They should provide a minimum of 100 g of IgG per pack and should also provide sufficient levels of nutrients to the calf to support metabolic needs in the first day of life. In Canada and the United States, CS and CR products may be licensed through the Canadian Food Inspection Agency, Canadian Center for Veterinary Biologics (Ottawa, ON), or through the US Department of Agriculture (USDA) Center for Veterinary Biologics (CVB; Ames, IA), respectively. In addition to other requirements, licensed products must originate from bovine colostrum; must be processed using accepted protocols to guarantee efficacy, safety, purity, and potency (minimum IgG content); and every serial made for sale and distribution must be tested for purity and potency.<sup>117,118</sup> Many products that are not CVB-licensed are produced in the United States, using a variety of manufacturing techniques, and with Ig sources including spray-dried bovine colostrum, milk, whey, bovine serum, or plasma. Nonlicensed products are not legally able to claim to supply IgG or to purport to be used for the prevention of FPT, although their use for this purpose is widespread in the United States.

A major consideration when feeding CR products is delivering an adequate dose of IgG to the calf. Many products provide only 100 to 150 g of IgG per pack, although some products provide label directions that suggest feeding increased masses of IgG, at the discretion of the producer. Although not true of all products, studies have shown that several commercially available CR products, when administered at a high enough IgG mass (150–200 g of IgG) within a few hours after birth, can provide acceptable serum IgG concentrations when using a conventional goal for APT (eg,  $\geq 90\%$  of calves with serum IgG  $\geq 10$  g/L).<sup>119–122</sup> However, if producers hope to achieve the more ambitious goals for passive transfer that are proposed in relation to monitoring, the authors suggest that they may need to deliver at least 300 g of IgG in a CR product. Research is required to investigate this hypothesis. Apart from dose, there can also be differences among CR products in Ig absorption, with studies generally reporting greater AEA percentage for lacteal-derived CR compared with serum-derived or plasma-derived CR.<sup>123,124</sup> Because of variable performance among products, veterinarians should review results of peer-reviewed controlled trials when recommending CR products to producers.

## ON-FARM MONITORING AND GOALS FOR PASSIVE TRANSFER

A dairy's colostrum management program is one of very few processes in the animal health world that can be easily evaluated and should be routinely reviewed by veterinarians. Although serum IgG measured via radial immunodiffusion (RID) assay is considered the gold standard for evaluating passive transfer in calves,<sup>11</sup> it is expensive and generally requires that samples be tested at a laboratory. Other analytes, such as serum total protein (STP), have been extensively validated, are easily measured at the farm level, and are more economical than measuring IgG directly.<sup>125,126</sup> STP levels in healthy calves should be evaluated from blood samples collected from 24 hours after the first colostrum feeding to 10 days of age.<sup>127</sup> The earlier in this sampling window that samples are collected, the more accurately the results reflect true IgG absorption and the less likely it is for results to be influenced by IgG distribution/decay or dehydration. The use of a standard optical refractometer to measure STP or an optical or digital Brix refractometer, both of which are field friendly, is becoming more common. Optical refractometer values of 5.0 to 5.5 g/dL and Brix readings of 8.1% to 8.5% have been used as the cutoff for FPT.<sup>3,128–131</sup>

The individual calf standard for FPT (serum IgG <10 g/L) has been used for more than 35 years and is mainly based on a decreased risk of mortality when values are greater than or equal to 10 g/L.<sup>7,10,12</sup> Although strategies to evaluate colostrum management programs have traditionally been based on the individual calf standard, McGuirk and Collins<sup>3</sup> proposed sampling a minimum of 12 healthy calves and defined a successful program as one in which 80% of calves had an STP value of 5.5 g/dL or higher. From a study by Calloway and colleagues,<sup>128</sup> Tyler proposed (Personal Communication, 2002) that a successful passive transfer program was one in which 90% of sampled calves test 5.0 to 5.2 g/dL or higher.<sup>132</sup> However, one concern with this approach to setting goals includes the notion that "failure" should be used to describe calves with no measurable IgG, whereas "adequate" does not convey whether an optimal amount of IgG has been absorbed by the calf. In addition, a single cutoff that expresses failure versus adequate passive transfer is too simplistic, because it fails to recognize that increasing concentrations of IgG or STP are associated with reducing morbidity risk and improved calf performance. Studies by Furman-Fratczak and colleagues<sup>13</sup> and Windeyer and colleagues<sup>12</sup> showed that dairy calves with serum IgG levels greater than or equal to 15 g/L and STP greater than or equal to 5.7 g/dL, respectively, experienced lower rates of respiratory disease. In beef calves, Dewell and colleagues<sup>133</sup> reported lower morbidity rates when serum IgG level was greater than or equal to 24 g/L. Based on these and other studies, including the USDA National Animal Health Monitoring System's Dairy 2014 study,<sup>4,46</sup> a reevaluation of the FPT individual and herd-based cut points was conducted. A group of calf experts from the United States and Canada convened in 2018 to review and propose revised individual and herd-based evaluation standards. The proposed consensus standard is based on the association of lower morbidity and higher values of serum IgG, because mortality risk is associated with serum IgG values less than 10 g/L. The proposed standard includes 4 categories: excellent, good, fair, and poor. These categories can be applied to individual calves and to the operation for herd-based evaluation based on the percentage of calves that should be represented in each category (**Table 2**). Because serum IgG level is not commonly measured, equivalent STP and Brix levels are provided for the 4 categories. The proposed consensus standard is meant to set higher goals for calf health in the US dairy industry.

Producers feeding CR products should be aware that the relationship between STP and serum IgG can vary dramatically for calves fed different CR products, depending

Proposed Categories	Proposed IgG Levels (g/L)	Equivalent STP Levels (g/dL)	Equivalent Serum Brix Levels (%)	Proposed Calves in Each Category (%)
Excellent	≥25.0	≥6.2	≥9.4	>40
Good	18.0–24.9	5.8–6.1	8.9–9.3	~30
Fair	10.0–17.9	5.1–5.7	8.1–8.8	~20
Poor	<10.0	<5.1	<8.1	<10

on manufacturing techniques, the Ig source, level of inclusion, and level of absorption of Ig and non-Ig proteins. As such, the STP and Brix cut points suggested for monitoring passive transfer in calves fed maternal colostrum are frequently inaccurate for calves fed CR. Veterinarians are encouraged to use STP or serum Brix measures to monitor the effectiveness of a CR feeding program only if independently conducted studies are available describing the relationship between STP or serum Brix measures and serum IgG for the specific commercial CR product in use on the farm. If this information is not available for specific CR products, veterinarians are advised to periodically submit frozen serum samples for laboratory analysis of IgG using direct methods such as RID.

## SUMMARY

Colostrum management is the single most important management factor in determining calf health and survival. Although good progress has been made in the past 20 years, there remains a considerable opportunity for many dairy producers to improve their colostrum management practices, resulting in improved short-term and long-term health and performance of the animals. Producers should provide calves with a sufficient volume of clean, high-quality colostrum within the first few hours of life. Additional benefits may be captured by providing multiple feedings and by extended feeding of colostrum or transition milk after gut closure. Colostrum replacers are useful tools if 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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