Effect of feeding maternal colostrum or plasma-derived or colostrum-derived colostrum replacer on passive transfer of immunity, health, and performance of preweaning heifer calves

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ABSTRACT

The objective of this study was to evaluate the effect of feeding maternal colostrum (MC), a plasma-derived (PDCR) or colostrum-derived colostrum replacer (CDCR) on passive transfer of immunity, health, and performance of preweaning heifer calves. Preplanned contrasts were performed for MC versus CR (PDCR combined with CDCR) and PDCR versus CDCR. At birth, calves were randomly assigned to 1 of 3 treatment groups: MC ($n = 49$), 3.8 L of maternal colostrum; PDCR ($n = 49$), 550 g (1 dose; 150 g of IgG) of a PDCR; or CDCR ($n = 49$), 470 g (1 dose; 100 g IgG) of a CDCR. The best total protein cutoff for determining passive transfer was >5.2 , 5.6 , and 5.1 g/dL for MC, PDCR, and CDCR, respectively. Serum total protein was greater for calves fed MC (mean $\pm$ SE; 6.14 ± 0.11 g/dL) than for calves fed PDCR (5.29 ± 0.11 g/dL) and CDCR (5.27 ± 0.11 g/dL). Serum IgG concentrations were greater for calves fed MC ($2,098 \pm 108$ g/dL) than for calves fed PDCR (927 ± 107 g/dL) or CDCR ($1,139 \pm 108$ g/dL). Apparent efficiency of absorption was greater for CDCR than PDCR (38.8 ± 3.0 vs. $21.6 \pm 3.0\%$). Adequate passive transfer was greatest for MC (91.8%), followed by CDCR (49%) and PDCR (28.6%). Calves fed MC had greater weaning weights and body weight gain than calves fed CR. Morbidity was lower for calves fed MC (46.9%) than for calves fed PDCR (71.4%) or CDCR (67.3%). Calves fed MC tended to have lower mortality than calves fed CR. Given the conditions of this trial, feeding 3.8 L of MC was superior to feeding one dose of CR. Further research is needed to evaluate calf performance when a higher dose of CR is fed.

Key words: maternal colostrum, colostrum replacer, performance, dairy calf

INTRODUCTION

Colostrum management and feeding is critical for calf health, their future productive life, and farm profitability (Robison et al., 1988; Faber et al., 2005). It is currently recommended that a calf needs to ingest at least 150 to 200 g of IgG within 2 h of birth to achieve successful passive transfer (Chigerwe et al., 2008b). It is understood that this can be reached by feeding 3 to 4 L of good quality maternal colostrum (MC); namely, an MC with IgG concentration greater than 50 g/L, bacterial count less than 100,000 cfu/mL, and coliform count less than 10,000 cfu/mL (McGuirk and Collins, 2004; Chigerwe et al., 2008b). A hydrometer (colostrometer) can be used as an on-farm test for guidance on colostrum quality; colostrum contains at least 50 g/L of IgG when the colostrometer reads 70 g/L or more (Chigerwe et al., 2008a).

However, when colostrum quality is poor or unavailable, colostrum replacer (CR) may be a suitable alternative to MC because it is easier to store and process. Advantages over MC may also exist when considering bacterial contamination, and recent studies have found that feeding a CR can reduce the transmission of Johne's disease by 44% (Pithua et al., 2009). Varying reports have been published on the success of passive transfer when CR is used. Poulsen et al. (2010) found no significant difference in rates of passive transfer between a bovine serum-based CR and maternal colostrums. Conversely, Swan et al. (2007) found higher rates of failure of passive transfer when a CR was fed, which could impair health and survival. Fidler et al. (2011) and Godden et al. (2009a) found similar results when calves were fed a commercial CR at the recommended dose. Despite higher rates of failure of passive transfer, a recent report found no difference in mortality rates from birth to first calving (Pithua et al., 2010). Nonetheless, others have observed that mortality was twice as high for heifers with failure of passive transfer compared with heifers with successful transfer (Robison et al., 1988; Wells et al., 1996). More information on morbidity and mortality of calves fed

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CR would improve the body of knowledge and help the producer make an informed decision about colostrum feeding management.

It is widely accepted that a serum total protein (TP) of at least 5.2 to 5.5 g/dL correlates well with calves achieving successful passive transfer (Weaver et al., 2000); that is, reaching serum IgG concentrations of 1,000 mg/dL (the gold standard test). However, some commercial products (e.g., Acquire Colostrum Replacer; APC Inc., Ankeny, IA) indicate that when feeding their product, (plasma-derived CR), a serum TP cutoff of 4.7 g/dL would be more appropriate. A cutoff of 4.2 g/dL (Quigley et al., 2002) or 4.85 g/dL (Mowrey, 2001) has been suggested as appropriate cutoffs for determining passive transfer when using a plasma-derived CR (PDCR). It has been suggested that a bovine PDCR may allow superior absorption compared with a lacteal-derived CR (Quigley et al., 2001); however, this has not been substantiated by recent preliminary reports (Place et al., 2010).

Therefore, the objective of this study was to evaluate the effect of feeding MC, 1 dose of PDCR, or 1 dose of colostrum-derived CR (CDCR) on serum TP, IgG concentration, calf morbidity (disease incidence), calf mortality, and weight gain from birth to weaning. Preplanned contrasts were performed for MC versus CR (PDCR combined with CDCR) and PDCR versus CDCR. A secondary objective was to determine the cutoff value for TP for prediction of passive immunity and the apparent efficiency of absorption (AEA) of IgG when feeding PDCR or CDCR.

MATERIALS AND METHODS

Animals, Housing, Feeding, and Vaccination Program

One hundred and fifty Holstein heifer calves were enrolled into the study at birth, between October and December 2011, from a commercial dairy farm milking 3,000 cows, located in Bell County, Florida. The observation period was completed at the end of January 2012. A sample size of 150 calves (50 per treatment group) was calculated (Minitab Inc., State College, PA) for $\alpha = 0.05$ and $\beta = 0.2$, to detect differences in weaning weight of 5 kg (SD of 8 kg) and death losses of 10%. Bull calves, twins, and crossbred animals were excluded from enrollment. Prepartum cows were monitored hourly, and calves were removed from their dam immediately after calving to prevent suckling.

Calves were housed from birth to weaning in individual, covered hutches placed on top of sand 1.5 m apart from each other. Aside from treatment at birth (MC or CR), calves were fed 3.0 L of milk twice daily

from d 1 to 49 ± 3 , then received 3.0 L of milk in the morning from d 50 ± 3 to 56 ± 3 , and were weaned from milk at d 56 ± 3 d. All milk was derived from the farm's hospital herd and pasteurized before being fed to the calves. Calves were offered starter grain and water ad libitum from d 1 to 56 ± 3 d.

Treatments

At birth calves were randomly assigned, following an excel-generated random list, to one of 3 treatment groups: MC = 3.8 L of maternal colostrum; PDCR = 550 g of Acquire CR containing 150 g (1 dose) of IgG (APC Inc.) dissolved in warm water to make 3.8 L of solution; CDCR = 470 g of Calf's Choice Total Silver (Balanced) CR containing 100 g (1 dose) of IgG (Alta Genetics USA Inc., Watertown, WI) dissolved in warm water to make 3.8 L of solution. The recommendation for PDCR and CDCR is to dissolve one dose in 1.4 and 1.25 L of water, respectively; however, a decision was made to standardize the volume of solution fed to all calves to eliminate volume fed as a confounder (Jones et al., 2004) and because mass of IgG fed is more important than concentration (Stott and Fellah, 1983). These CR products are licensed as an aid in the prevention of failure of passive transfer and are regulated by the USDA. Testing by the National Veterinary Services Laboratory (Ames, IA) ensures that products meet the requirements for sale, including microbiologic safety and concentration of IgG per dose advertised. All calves were fed via an esophageal tube within 2 h of birth.

Colostrum was harvested aseptically after predipping, wiping, and drying the teats, using a vacuum milking system in a herringbone milking parlor. All maternal colostrum was tested by a colostrometer and only colostrum measuring at least 70 g/L of IgG was fed to the calves; therefore, we estimate that a minimum of 190 g of IgG ($3.8 \text{ L} \times 50 \text{ g of IgG/L}$) was fed to MC calves (Chigerwe et al., 2008a). Fresh harvested colostrum was immediately fed to newborn calves, and excess was stored in 3.8 L bags and frozen at -20°C . Calves were usually fed fresh colostrum; however, if sufficient good quality fresh colostrum was not available, a 3.8-L bag was thawed and fed. Samples of MC were collected before feeding for aerobic culture at a commercial laboratory (All Florida Veterinary Laboratory Inc., Archer, FL). All samples had counts below 20,000 cfu/mL, with the exception of one that was 500,000 cfu/mL.

BW Measurement and Blood Sample Collection and Analyses

All calves had their BW recoded at birth and at weaning or 1 d before weaning (55 ± 4 d) using an

electronic scale (model 701 and MP600 multi-purpose load bars, Tru-Test Ltd., Pakuranga Manukau, New Zealand).

A blood sample (8 mL) was collected from every calf at d 1 to 7 of age (mean = 4.3 d), 30 min before the morning feeding by puncture of the jugular vein into evacuated tubes with no anti-coagulant (Vacutainer; Becton Dickinson, Franklin Lakes, NJ). Samples were allowed to clot and then placed on ice and tubes were centrifuged at $3000 \times g$ for 10 min at room temperature for serum separation. After calibration, a refractometer was then used to read serum TP. Remaining serum was then frozen at -25°C and later analyzed for IgG concentration using a radial immunodiffusion test kit (Triple J Farms, Bellingham, WA) according to the manufacturer's protocol. Briefly, 5 μL of serum sample was added to the wells in the gel containing anti-bovine IgG antibody and incubated for 27 h at room temperature in the absence of light exposure. After incubation, the diameter of the precipitation rings was measured and total IgG concentration was calculated based on the linear relationship between diameters squared and total IgG concentration. The interassay CV of the radial immunodiffusion assay was 4.3%. This test was considered the gold standard for identifying calves with failure of passive transfer; calves with a serum IgG concentration less than 1,000 mg/dL were considered to have failure of passive transfer (Dawes et al., 2002). The AEA of IgG was calculated for the PDCR and CDCR groups using the following formula as previously reported (Quigley and Drewry, 1998; Godden et al., 2009a):

$$\text{AEA} = \{(\text{Serum [IgG], g/L} \times \text{Birth weight, kg} \times 0.09) / \text{IgG intake, g}\} \times 100.$$

Serum volume was considered as 9% of the birth weight as previously reported (Tao et al., 2012).

Health Scoring, Health Events, and Death Events

Disease incidence and death loss, along with cause of death, was recorded weekly by the same investigator, who was blind to treatments. Health events were evaluated using a chart (Table 1) adapted from the School of Veterinary Medicine, University of Wisconsin-Madison calf health scoring chart (found at: http://www.vet-med.wisc.edu/dms/fapm/fapmtools/8calf/calf_health_scoring_chart.pdf). Calves were diagnosed with either pneumonia or diarrhea when they had a total respiratory score (combined cough, highest ear or eye score, and nasal discharge score) of at least 4 or a fecal score of at least 2, respectively. Besides weekly scoring, calves

were also monitored daily by trained farm personnel that used the same chart to record symptoms of any calf receiving treatment. Those records were combined with the weekly evaluations and used in the statistical analysis pertaining to disease events. Dairy personnel diagnosing disease and performing treatments were also blind to colostrum treatment. Once diagnosed, calves were treated using normal farm protocols. For pneumonia, this included florfenicol (Nuflor; Merck Animal Health Inc., Summit, NJ) and flunixin meglumine (Banamine; Merck Animal Health) if the calf's temperature was above 104°C . Diarrhea was initially treated with oral fluids and gut protectant (Kaolin-Pectin 4; Vet One; <http://www.vetone.net/default.html>), followed by sulfamethiazine (Albon; Pfizer Animal Health Inc. New York, NY) if no improvement was observed after 2 d. Other than diarrhea and pneumonia, calves were also treated for septic arthritis and omphalitis using ceftiofur hydrochloride (Excenel; Pfizer Animal Health).

At 3 and 5 wk calves received a modified live vaccine containing bovine rhinotracheitis virus, bovine viral diarrhea virus types 1 and 2, bovine parainfluenza-3 virus, and bovine respiratory syncytial virus (Bovishield Gold 5; Pfizer Animal Health). At 5 and 7 wk, calves received an 8-way Clostridium vaccine (Ultrabac 8; Pfizer Animal Health).

Statistical Analyses

Of the 150 calves enrolled, only 147 (49 in each treatment) were used for statistical analysis. One calf was enrolled but died the same day, and one calf received 2 types of colostrum on the same day (i.e., enrolled twice), therefore 3 records were removed. Only 123 calves were used in the weight gain analysis because 24 calves died during the trial, leaving 37, 41, and 45 calves in the CDCR, PDCR, and MC groups, respectively.

The best serum TP cutoff for predicting an IgG concentration, $>1,000$ mg/dL, was performed by receiver operating characteristic (ROC) curve analysis using MedCalc version 9.2 (MedCalc Software, Mariakerke, Belgium). The ROC curve analysis plots the sensitivity (Se) against the false-positive fraction ($1 - \text{specificity}$; Sp) to detect the best combination of Se and Sp for all TP values (Zweig and Campbell, 1993; Bicalho et al., 2008).

Continuous data, such as birth weight, serum TP concentration, IgG concentration, AEA, weight gain, and weaning weight, were analyzed by the GLM procedure of SAS (SAS Institute Inc., Cary, NC), and least squares means $\pm$ standard error of the mean are presented. The models included the main effects of treatment, birth weight, and interaction between treatment

Table 1. Calf health scoring chart¹

Clinical sign	Score			
	0	1	2	3
Cough	None	Induce single cough	Induced repeated coughs or occasional spontaneous cough	Repeated spontaneous coughs
Nasal discharge	Normal serous discharge	Small amount of unilateral cloudy discharge	Bilateral, cloudy, or excessive mucus discharge	Copious bilateral mucopurulent discharge
Eye scores ²	Normal	Small amount of ocular discharge	Moderate amount of bilateral discharge	Heavy ocular discharge
Ear scores ²	Normal	Ear flick or head shake	Slight unilateral droop	Head tilt or bilateral droop
Fecal scores	Normal	Semi-formed, pasty	Loose, but stays on top of bedding	Watery, sifts through bedding

¹Adapted from the University of Wisconsin–Madison calf health scoring chart that can be found at http://www.vetmed.wisc.edu/dms/fapm/fapmtools/8calf/calf_health_scoring_chart.pdf.

²Highest score of either parameter recorded, but not both. This was then added to the cough and nasal discharge scores to make the total respiratory score.

and birth weight. Effect of morbidity on weaning weight and weight gain was analyzed univariately using the GLM procedure of SAS. Morbidity was not included as an independent variable in the models for weaning weight and weight gain because treatment had an effect on morbidity; therefore, morbidity would become an intermediate variable (Hull, 1980). Multiple comparisons were performed when an effect of treatment was observed using the Dunnett adjustment option.

Binary data, such as adequate passive transfer (yes or no), morbidity (any disease = yes; no disease = no), and mortality (died = yes; alive = no), were analyzed using the LOGISTIC procedure of SAS using a model similar to GLM. Effect of passive transfer of immunity on morbidity and mortality was analyzed univariately using the LOGISTIC procedure of SAS. Passive transfer was not included as an independent variable in the models for morbidity and mortality because treatment had an effect on passive transfer; therefore, passive transfer would become an intermediate variable (Hull, 1980).

Time to the first disease event or death was analyzed using the LIFETEST procedure of SAS, and survival curves were built using MedCalc version 9.2; *P*-values for the log-rank test were presented. For both the GLM and LOGISTIC models, treatment was forced in the final models but other variables were removed if *P* > 0.10 based on Wald statistics criterion. In a multivariable model, the LSM (GLM) or odds ratio (LOGISTIC) are adjusted for all variables left in the model. Preplanned contrasts were performed for MC versus CR (PDCR combined with CDCR) and PDCR versus CDCR. Differences with *P* ≤ 0.05 were considered significant, and 0.05 < *P* ≤ 0.10 was considered a tendency toward statistical difference.

RESULTS

TP, IgG Concentration, AEA, and Passive Transfer

The ROC curve analysis showed that the best serum TP cutoff for predicting an IgG concentration of 1,000 mg/dL was >5.2 g/dL [Se = 84.4, Sp = 100, area under the curve (AUC) = 0.94; *P* < 0.001] for MC, >5.6 g/dL (Se = 63.2, Sp = 94.3, AUC = 0.78; *P* = 0.002) for PDCR, and >5.1 g/dL (Se = 79.2, Sp = 72.0, AUC = 0.83; *P* < 0.001) for CDCR.

Treatment significantly (*P* < 0.001) affected serum TP (Table 2). Multiple comparisons showed that serum TP were greater (*P* < 0.001) for calves fed MC (6.1 ± 0.11 g/dL) than for calves fed PDCR (5.3 ± 0.11 g/dL) or CDCR (5.3 ± 0.11 g/dL). No difference (*P* = 0.89) was observed between the PDCR and CDCR groups. Treatment significantly (*P* < 0.001) affected serum IgG concentration (Table 2). Serum IgG concentrations were greater (*P* < 0.0001) for calves fed MC (2,098 ± 108 g/dL) than for calves fed PDCR (927 ± 107 g/dL) or CDCR (1139 ± 108 g/dL). No difference (*P* = 0.16) was observed between the PDCR and CDCR groups.

Treatment affected (*P* < 0.001) AEA, and CDCR had greater AEA than PDCR (38.8 ± 3.0 vs. 21.6 ± 3.0%). Apparent efficiency of absorption could not be calculated or reported for the MC group because the dose of IgG fed to these calves was not quantified. Birth weight also affected (*P* = 0.01) AEA, and the relationship was positive (AEA = −13.19 + 1.15 × Birth weight). No interaction was observed between treatment and birth weight (*P* = 0.51) on AEA.

Treatment also affected (*P* < 0.001) the proportion of calves with adequate passive transfer, with all treatment groups being significantly (*P* < 0.05) different (MC = 91.8, PDCR = 28.6, and CDCR = 49.0%).

Table 2. Effect of treatment with different types of colostrum on preweaning calf health and growth

Item	Treatment ¹			SEM	CR ² n = 98	P-value ³		
	MC n = 49	PDCR n = 49	CDCR n = 49			TRT	C1	C2
Birth weight, kg	35.9 ^{ab}	37.0 ^b	38.4 ^{bc}	0.8	37.7 ± 0.6	0.07	0.05	0.21
Serum total protein, g/dL	6.1 ^a	5.3 ^b	5.3 ^b	0.11	5.3 ± 0.08	<0.001	<0.001	0.89
Serum Ig, mg/dL	2,098 ^a	926 ^b	1,139 ^b	108	1,033 ± 76	<0.001	<0.001	0.16
AEA Ig, %	—	21.6	38.8	3.0	30.2 ± 2.4	—	—	<0.001
Passive transfer, %	91.8 ^a	28.6 ^b	49.0 ^c	—	38.8	<0.001	<0.001	0.04
Weaning weight, kg	61.2 ^{a,B}	57.2 ^{b,A}	59.5 ^B	0.9	58.4 ± 0.7	0.008	0.01	0.08
BW gain, kg	24.6 ^{a,B}	20.7 ^{b,A}	22.9 ^B	0.9	21.8 ± 0.6	0.007	0.009	0.09

^{a-c}Values within a row are significantly different, $P < 0.05$.

^{A,B}Values within a row tend to differ, $P \leq 0.10$.

¹MC = calves that within 2 h of birth were fed 3.8 L of maternal colostrum; PDCR = calves that within 2 h of birth were fed 550 g of plasma-derived colostrum replacer (Acquire Colostrum Replacer, Ankeny, IA) containing 150 g of Ig dissolved in warm water to make 3.8 L of solution; CDCR = calves that within 2 h of birth were fed 470 g of colostrum-derived colostrum replacer (Alta Calf's Choice Total Balanced; Alta Genetics USA Inc., Watertown, WI) containing 100 g of Ig dissolved in warm water to make 3.8 L of solution.

²CR = values for PDCR combined with CDCR.

³TRT = treatment; C1 = contrast between MC and CR (PDCR combined with CDCR); C2 = contrast between PDCR and CDCR.

⁴AEA = apparent efficiency of absorption.

⁵Passive transfer defined by serum Ig $\geq 1,000$ mg/dL.

Adequate passive transfer was greatest for MC (91.8%) followed by CDCR (49%) and PDCR (28.6%). Birth weight or interaction between treatment and birth weight did not affect any other variable besides AEA ($P > 0.15$).

Birth Weight, Weaning Weight, and Weight Gain

A tendency ($P = 0.07$) was observed for an association between treatment and birth weight (Table 2). Calves fed MC were lighter ($P = 0.02$) at birth than calves fed CDCR (35.9 ± 0.8 vs. 38.4 ± 0.8 kg), but no difference ($P > 0.20$) existed between MC and PDCR (37.0 ± 0.8 kg) calves or PDCR and CDCR calves. Contrast showed that calves fed MC were lighter ($P = 0.05$) at birth than calves receiving CR (37.7 ± 0.6 kg). Morbidity significantly ($P < 0.001$) affected weaning weight and BW gain from birth to weaning; calves that had at least one disease event ($n = 91$) had decreased weaning weight (57.5 ± 0.7 vs. 61.7 ± 0.8 kg) and BW gain from birth to weaning (20.5 ± 0.8 vs. 25.5 ± 0.8 kg) compared with calves that remained healthy ($n = 56$).

Treatment significantly ($P = 0.008$) affected weaning weight (Table 2). Weaning weights were greater ($P = 0.002$) for calves fed MC (61.2 ± 0.9 kg) than calves fed PDCR (57.2 ± 0.9 kg), but similar ($P = 0.19$) to calves fed CDCR (59.5 ± 0.9 kg). Weaning weights tended ($P = 0.08$) to be greater for calves fed CDCR than calves fed PDCR. Contrasts showed that calves fed MC had greater ($P = 0.01$) weaning weights than calves fed CR (58.4 ± 0.7 kg). Birth weight also affected ($P < 0.001$)

weaning weights, and the relationship was positive (weaning weight = $43.9 + 0.425 \times$ birth weight). No interaction was observed between treatment and birth weight ($P = 0.35$) on weaning weight.

Treatment significantly ($P = 0.007$) affected BW gain from birth to weaning (Table 2). Weight gains were greater ($P = 0.002$) for calves fed MC (24.6 ± 0.9 kg) than calves fed PDCR (20.7 ± 0.9 kg), but similar ($P = 0.17$) to calves fed CDCR (22.9 ± 0.9 kg). Weight gains tended ($P = 0.09$) to be greater for calves fed CDCR than calves fed PDCR. Contrasts showed that calves fed MC had greater ($P = 0.009$) BW gains than calves fed CR (21.8 ± 0.6 kg). Birth weight also affected ($P < 0.001$) weight gain, and the relationship was negative (weight gain = $43.9 - 0.5751 \times$ birth weight). No interaction was observed between treatment and birth weight ($P = 0.33$) on weaning weight.

Morbidity and Mortality

Calves with failure of passive transfer had increased ($P < 0.03$) morbidity [71.9 (46/64) vs. 54.2% (45/83)] and mortality [25.0 (16/64) vs. 9.6% (8/83)] as compared with calves without failure of passive transfer. Treatment significantly ($P = 0.03$) affected morbidity (Table 3). Morbidity was lower ($P \leq 0.04$) for calves fed MC (46.9%) than for calves fed PDCR (71.4%) or CDCR (67.3%). Morbidity was similar ($P = 0.66$) between calves fed PDCR and CDCR; contrasts showed that calves fed MC had lower ($P = 0.009$) morbidity than calves fed CR (69.4%). When looking at each disease separately, treatment tended ($P = 0.09$) to af-

fect the incidence of diarrhea. Calves fed PDCR had greater ($P = 0.04$) incidence of diarrhea (49.0%) than calves fed MC (28.6%), and calves fed CDCR tended ($P = 0.10$) to have greater incidence (44.9%) of diarrhea than calves fed MC. Contrast showed that incidence of diarrhea was greater ($P = 0.03$) in calves fed CR (46.9%) than in calves fed MC, but similar ($P = 0.69$) between PDCR and CDCR. Treatment had no effect ($P > 0.30$) on incidence or pneumonia or other diseases (arthritis plus omphalitis). Incidence of pneumonia for MC, PDCR, and CDCR was 24.5, 38.8, and 32.7.0%, respectively. Incidence of other diseases for MC, PDCR, and CDCR was 4.1, 2.0, and 6.1%, respectively.

Treatment tended ($P = 0.09$) to affect mortality (Table 3). Mortality was lower ($P = 0.03$) for calves fed MC (8.2%) than for calves fed CDCR (24.5%); however, mortality was similar ($P \geq 0.22$) between calves fed MC and PDCR (16.3%) and between PDCR and CDCR. Contrasts showed that calves fed MC tended ($P = 0.06$) to have lower mortality than calves fed CR (20.4%).

Treatment significantly ($P = 0.009$) affected time to first disease event (Figure 1). Time to first disease event was increased ($P < 0.02$) for calves fed MC compared with PDCR and CDCR. Contrasts showed that MC had an increased time to first disease event ($P = 0.003$) compared with CR, but PDCR was not different than CDCR ($P = 0.54$). Median time to first disease event was 58, 18, and 20 d for MC, PDCR, and CDCR, respectively. Proportion of healthy calves at the end of the study were 53.1 (26/49), 28.6 (14/49), and 32.7% (16/49), for MC, PDCR, and CDCR, respectively.

Time to death is shown in Figure 2; a tendency ($P = 0.10$) for an effect of treatment was observed. Calves fed MC treatment had an increased ($P = 0.03$) time to death compared with CDCR, but similar ($P = 0.20$) to PDCR. Contrasts showed that calves fed MC had a tendency for decreased time to death ($P = 0.06$) compared with CR, but PDCR was not different than CDCR ($P = 0.39$). Median time to death was not calculated because more than 50% of the calves were alive at the end of the study. Proportion of live calves were 91.8 (45/49), 83.7 (41/49), and 75.5% (37/49), for MC, PDCR, and CDCR, respectively.

DISCUSSION

Given the importance of colostrum management and feeding to calf's health and profitability (Robison et al., 1988; Fowler, 1999; Faber et al., 2005), it is imperative that producers are well informed of the benefits or detriments of feeding MC or different types of CR. First, our results did not corroborate with earlier observations (Quigley et al., 2002) that a lower cutoff for serum TP (i.e., 4.2 or 4.85 g/dL) should be used to determine adequate passive transfer when feeding a PDCR. The cutoffs ranged from >5.1 to >5.6 , with PDCR having the highest cutoff at >5.6 mg/dL. These results support the long standing recommendation to use a cutoff between 5.2 and 5.5 g/dL to determine adequate passive transfer (Donovan et al., 1998; Tyler et al., 1998; Weaver et al., 2000) regardless of type of colostrum. A recent study (Swan et al., 2007) observed that cutoffs were very similar for MC (5.1 mg/dL) and PDCR (5.0

Table 3. Effect of treatment with different types of colostrum on mortality and morbidity from birth to weaning

Variable ¹	Level ²	Affected, % (no./no.) ¹	OR ³	95% CI	P-value ⁴		
					TRT	C1	C2
Morbidity Treatment	MC	46.9 (23/49)	—	—	0.03	0.009	0.66
	PDCR	71.4 (35/49)	2.8	1.2–6.5	0.01	—	—
	CDCR	67.3 (33/49)	2.3	1.0–5.3	0.04	—	—
	CR	69.4 (68/98)	2.6	1.3–5.2	—	—	—
Mortality Treatment	MC	8.2 (4/49)	—	—	0.09	0.06	0.32
	PDCR	16.3 (8/49)	2.2	0.6–7.8	0.22	—	—
	CDCR	24.5 (12/49)	3.7	1.1–12.3	0.03	—	—
	CR	20.4 (20/98)	2.9	0.9–9.0	—	—	—

¹Morbidity was defined by occurrence of any disease event (pneumonia, diarrhea, septic arthritis, or omphalitis) from birth to weaning. Mortality was defined by occurrence of death because of a disease event.

²MC = calves that were fed 3.8 L of maternal colostrum within 2 h of birth; PDCR = calves that were fed 550 g of plasma-derived colostrum replacer (Acquire Colostrum Replacer, Ankeny, IA) containing 150 g of Ig dissolved in warm water (~3.4 L) to make 3.8 L of solution within 2 h of birth; CDCR = calves that were fed 470 g of colostrum-derived colostrum replacer (Alta Calf's Choice Total Balanced; Alta Genetics USA Inc., Watertown, WI) containing 100 g of Ig dissolved in warm water (~3.45 L) to make 3.8 L of solution within 2 h of birth; CR = values for PDCR combined with CDCR.

³OR = odds ratio.

⁴TRT = treatment; C1 = contrast between MC and CR (PDCR combined with CDCR); C2 = contrast between PDCR and CDCR.

Figure 1. Time to first disease event for calves that within 2 h of birth were either fed 3.8 L of maternal colostrum (MC; $n = 49$; dotted line), 550 g of plasma-derived colostrum replacer (PDCR; Acquire Colostrum Replacer, Ankeny, IA) containing 150 g of Ig dissolved in warm water to make 3.8 L of solution ($n = 49$; dashed line), or 470 g of colostrum-derived colostrum replacer (CDCR; Alta Calf's Choice Total Balanced; Alta Genetics USA Inc., Watertown, WI) containing 100 g of Ig dissolved in warm water to make 3.8 L of solution ($n = 49$; solid line). An effect of treatment ($P = 0.009$) was observed, with MC having increased ($P < 0.02$) time to first disease event compared with PDCR and CDCR. Contrasts showed that MC had an increased time to first disease event ($P = 0.003$) compared with CR (PDCR combined with CDCR), but PDCR was not different than CDCR ($P = 0.54$). Median time to first disease event was 58, 18, and 20 d for MC, PDCR, and CDCR, respectively. Proportions of healthy calves were 53.1 (26/49), 28.6 (14/49), and 32.7% (16/49) for MC, PDCR, and CDCR, respectively.

Figure 2. Time to death for calves that within 2 h of birth were either fed 3.8 L of maternal colostrum (MC; $n = 49$; dotted line), 550 g of plasma-derived colostrum replacer (PDCR; Acquire Colostrum Replacer, Ankeny, IA) containing 150 g of Ig dissolved in warm water to make 3.8 L of solution ($n = 49$; dashed line), or 470 g of colostrum-derived colostrum replacer (CDCR; Alta Calf's Choice Total Balanced; Alta Genetics USA Inc., Watertown, WI) containing 100 g of Ig dissolved in warm water to make 3.8 L of solution ($n = 49$; solid line). A tendency ($P = 0.10$) for an effect of treatment was observed; MC treatment had an increased ($P = 0.03$) time to death compared with CDCR but was similar ($P = 0.20$) to PDCR. Contrasts showed that MC had a tendency for increased time to death ($P = 0.06$) compared with CR (PDCR combined with CDCR), but PDCR was not different than CDCR ($P = 0.39$). Median time to death was not calculated because more than 50% of the calves were alive at the end of the study. Proportions of live calves were 91.8 (45/49), 83.7 (41/49), and 75.5% (37/49) for MC, PDCR, and CDCR, respectively.

mg/dL). One important distinction from previous studies is that ROC curve analysis was used to determine the cutoffs instead of estimating them based on a linear regression equation. Although a linear regression equation will estimate what TP value would correspond to a certain concentration of IgG (e.g., 1,000 mg/dL), that value is not based on the optimal sensitivity and specificity for the test. Zweig and Campbell (1993) stated that ROC plots provide a pure index of accuracy by determining the limits of a test's ability to discriminate between alternative states of health (i.e., adequate passive transfer) over the complete spectrum of operating conditions (i.e., concentration of serum TP). Although it has been suggested that a bovine PDCR may allow superior absorption compared to a lacteal-derived CR (Quigley et al., 2001), that was not observed in this study. In fact, AEA of IgG was higher for the CDCR than for PDCR, which corroborates observations made by others (Place et al., 2010). The AEA for CDCR is similar to previous reports (Godden et al., 2009a) with a different brand of CDCR (Land O'Lakes Colostrum Replacer; Land O'Lakes Inc., St. Paul, MN),

where AEA ranged from 35.5 to 36.5%. The AEA for PDCR was lower than in some previous reports using a PDCR (Quigley et al., 2002) where AEA was 30%. However, results were within values reported in others (Quigley et al., 2001) where AEA of a PDCR (APC Inc.) containing 100 to 122 g of IgG ranged from 19 to 32%, or when the same PDCR used in this study was evaluated (Jones et al., 2004) where AEA was 20.3%. The authors speculated that low AEA observed by Quigley et al. (2001) was either caused by a method of fractionating bovine plasma to concentrate IgG that utilized polyethylene glycol (AEA = 19%) or feeding of CR twice, 8 h apart (AEA = 19–20%). In the study by Jones et al. (2004) calves were also fed twice, 12 h apart. It is not clear if polyethylene glycol is currently used for fractionation of bovine plasma to manufacture PDCR because APC Inc. could not disclose that information (Javier Polo, Vice President for Research and Development, APC Inc. personal communication). In the current study, both CR were fed once; therefore, twice feeding cannot explain the low AEA for PDCR. It is worth noting that the recommendations for feeding

PDCR and CDCR are to dissolve the product in warm water to make a solution of 1.5 or 1.9 L for CDCR or PDCR, respectively. Hence, both products were dissolved into a higher quantity of solution (3.8 L); however, it is unclear whether this could affect one product differently than the other. Feeding method (i.e., bottle vs. esophageal tube) does affect IgG concentration and AEA when smaller volumes (1.5 L) are fed but not when larger volumes (3.0 L) are fed (Godden et al., 2009b). In the current study both CR groups were fed using an esophageal tube.

As expected, calves fed 3.8 L of good quality MC within 2 h of birth had greater IgG concentrations and a greater proportion of adequate passive transfer than calves fed one dose of CR (Foster et al., 2006; Godden et al., 2009a). Greater IgG concentration in calves fed MC is likely the result of feeding a higher amount of IgG (≥ 190 g) compared with 1 dose of CR (100 or 150 g). However, CDCR having a greater proportion of adequate passive transfer than PDCR was somewhat unexpected because of the higher IgG content of 1 dose of PDCR compared with 1 dose of CR. This highlights the importance of both the amount of IgG fed and the AEA. Previous studies have observed that as few as 7 (Swan et al., 2007) to 10% (Foster et al., 2006) of calves have adequate passive transfer when fed 1 dose (125 g of IgG) of PDCR (Acquire, APC Inc.) or 1 dose (100 g of IgG) of CDCR (Immu-Start 50, Immu-Tek Animal Health Inc., Fort Collins, CO), respectively. On the other hand, as many as 81% of calves had adequate passive transfer when fed 1 dose (100 g of IgG) of a CDCR (Land O'Lakes Colostrum Replacer; Foster et al., 2006). Although the proportion of CDCR-fed calves achieving adequate passive transfer was lower than what was observed by Foster et al. (2006), the mean IgG concentration was very similar (1,160 mg/dL). Nonetheless, serum concentration of IgG and proportion of adequate passive transfer similar to what is achieved when feeding 3.8 L of MC has only been demonstrated when feeding 200 g of CDCR (Foster et al., 2006; Godden et al., 2009a). When amount of MC fed was restricted (1.42 L for Holsteins and 1.06 L for Jerseys) so that amount of IgG fed was similar to what was delivered with PDCR (250 g divided in 2 feedings 12 h apart), serum IgG concentration was also similar (Jones et al., 2004). Although IgG concentration was similar between MC and CR ($\sim 1,400$ mg/dL), this feeding scheme still resulted in 31% failure of passive transfer in Holstein calves because IgG concentration in female and male Holsteins averaged 990 and 1,235 mg/dL, respectively. Therefore, further investigation is needed to evaluate if feeding a higher dose of PDCR can achieve similar serum IgG concentration and pro-

portion of adequate passive transfer as feeding 3.8 L of good quality MC.

Effect of feeding CR on weaning weight and BW gain has been evaluated in very few studies (Quigley et al., 2001; Jones et al., 2004). Quigley et al. (2001) observed a tendency for MC-fed calves to gain more BW from birth to weaning at 60 d of age, but no difference was observed in weaning weight. Jones et al. (2004) observed higher feed efficiency for calves fed MC, and a tendency for MC-fed calves to gain more BW in the first week of life but not during the first 29 d. Therefore, to our knowledge, this is the first time that lower weaning weight and BW gain has been reported when feeding 1 dose of CR compared with 3.8 L of MC. Failure to show a statistical difference might have arisen from lack of power or simply because of different experimental design. In the study by Quigley et al. (2001) the MC group only had 14 calves, and in the study by Jones et al., (2004) feeding of MC was restricted (1.42 L for Holsteins and 1.06 L for Jerseys) to match the IgG concentration in PDCR. Decreased weaning weight and BW gain from birth to weaning was likely a consequence of having inadequate IgG intake leading to increased morbidity in calves fed 1 dose of CR, as calves that had at least 1 disease event had decreased BW at weaning and gained less BW from birth to weaning.

As with weaning weight and BW gain, only 2 reports from 1 experiment evaluated the effect of feeding 1 dose of CR on morbidity (Swan et al., 2007) and mortality (Swan et al., 2007; Pithua et al., 2010) of dairy calves. In those studies, 11 of the 12 farms fed 3.8 L of MC, one farm fed 1.9 L of MC at first feeding, and 7 farms provided a second feeding of 1.9 L of MC 8 to 12 h after first feeding. Despite the fact that 93% of CR-fed calves had failure of passive transfer, and the known negative effect of failure of passive transfer on morbidity and mortality (Robison et al., 1988; Wells et al., 1996; Donovan et al., 1998), neither the study by Swan et al. (2007) or that of Pithua et al. (2010) found statistical differences in morbidity or mortality from birth to weaning (Swan et al., 2007) or mortality from birth to first calving (Pithua et al., 2010). Swan et al. (2007) alluded to poor MC quality or acceptable protection from 1 dose of CR as possible reasons for a lack of significant differences. Indeed, MC total plate count and total coliform count were 16.1×10^6 and 2.7×10^6 cfu/mL, respectively. Furthermore, although most herds were fed 3.8 L of MC, IgG concentration was lower (1,480 mg/dL) than what was observed in the current study, and 28% of calves had failure of passive transfer compared with only 8.2%. In the current study, higher morbidity and mortality for calves fed 1 dose of CR is likely a result of greater failure of passive transfer

given the observed higher morbidity and mortality for calves with failure of passive transfer. Nonetheless, the notion of acceptable protection from CR may only apply when comparing both CR, because although CDCR had greater proportion of calves with adequate passive transfer than PDCR, no difference was observed in morbidity or mortality. Calves fed CDCR did have a tendency to have higher weaning weight and higher BW gain from birth to weaning, but this may have been confounded by the fact that 4 more calves died in the CDCR group; therefore, further research is needed to evaluate weaning weight, weight gain, morbidity, and mortality between PDCR and CDCR. A need also exists to compare calf performance when amount of IgG from CR matches the amount in 3.8 L of MC (i.e., ≥ 190 g).

CONCLUSIONS

Cutoffs for determining adequate passive transfer should be maintained between 5.2 and 5.5 g/dL regardless of type of colostrum. The approach we take in our veterinary ambulatory clinic is to classify calves between 5.2 and 5.5 g/dL as having partial passive transfer and calves above 5.5 g/dL as having adequate passive transfer of immunity. Calves fed 3.8 L of good quality MC had increased IgG concentration, adequate passive transfer of immunity, weaning weights and BW gain, and decreased morbidity and mortality compared with calves fed 1 dose (100 or 150 g of IgG) of 2 commercially available CR. Calves fed CDCR had increased passive transfer of immunity and AEA compared with calves fed PDCR. Given the conditions of this trial, MC was superior to CR. Further research is needed to evaluate calf performance when a higher dose of CR is fed.

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