Improving passive transfer of immunoglobulins in calves. II: Interaction between feeding method and volume of colostrum fed

S. M. Godden,* D. M. Haines,†† K. Konkol,* and J. Peterson*

*Department of Veterinary Population Medicine, University of Minnesota, St. Paul 55108

†Department of Veterinary Microbiology, Western College of Veterinary Medicine, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

††The Saskatoon Colostrum Co. Ltd., Saskatoon, Canada

ABSTRACT

The objective of this study was to investigate the effect of method of feeding (nipple bottle vs. esophageal tube feeder) on passive transfer of immunoglobulin (Ig) G when either a large or small volume of colostrum was fed. Newborn bull calves were removed from the dam before suckling and randomly assigned to 1 of 4 colostrum replacer (CR) treatment groups: 1.5 L (100 g of IgG) of CR fed using a nipple bottle (group 1; $n = 24$); 1.5 L (100 g of IgG) of CR fed using an esophageal tube feeder (group 2; $n = 24$); 3.0 L (200 g of IgG) of CR fed using a nipple bottle (group 3; $n = 24$), or 3.0 L (200 g of IgG) of CR fed using an esophageal tube feeder (group 4; $n = 25$). Blood samples collected at 24 h of age showed that serum IgG levels were significantly greater in calves fed large (3 L) volumes of CR compared with calves fed small (1.5 L) volumes of CR, regardless of feeding method. These differences were attributed to the larger mass of IgG ingested by calves fed 3 L of CR (200 g of IgG) compared with calves fed 1.5 L of CR (100 g of IgG). For calves fed small (1.5 L) volumes of colostrum, serum total protein (TP, g/dL), serum IgG (IgG, mg/mL), acceptable passive transfer rates (APT, %), and apparent efficiency of absorption of IgG (AEA, %) were significantly greater for calves fed with a bottle (TP = 5.3 g/dL; IgG = 12.5 mg/mL; APT = 100%; AEA = 51.1%) compared with calves fed with an esophageal tube feeder (TP = 5.0 g/dL; IgG = 9.8 mg/mL; APT = 41.7%; AEA = 40.5%). However, for calves fed large (3 L) volumes of colostrum, there was no difference in passive transfer indices for calves fed with a bottle (TP = 5.8 g/dL; IgG = 19.7 mg/mL; APT = 100%; AEA = 41.1%) compared with calves fed with an esophageal tube feeder (TP = 5.9 g/dL; IgG = 18.7 mg/mL; APT = 100%; AEA = 39.0%).

Key words: colostrum, nipple bottle, esophageal tube feeder, passive transfer

INTRODUCTION

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 (FPT) of immunoglobulins (Ig) from colostrum, contributing to excessively high preweaning mortality rates as well as other short- and long-term losses associated with animal health, welfare, and productivity. A successful colostrum management program will require producers to consistently provide calves with a sufficient volume of clean, high-quality colostrum within the first few hours of life (McGuirk and Collins, 2004).

The method of feeding colostrum can influence the time to first feeding, the volume consumed, and possibly pathogen exposure, all of which can affect passive transfer of IgG and calf health. Because high rates of FPT (serum IgG <10.0 mg/mL) have been reported in calves left to suckle the dam (Edwards and Broom, 1979; Brignole and Stott, 1980; Besser et al., 1991), it is currently recommended that the calf be removed from the dam within 1 to 2 h of birth and fed a known volume of clean colostrum using either a nipple bottle or esophageal feeder (McGuirk and Collins, 2004). In national surveys 68.1, 70.5, 76.2, and 64.4% of calves were reportedly fed using a nipple bottle or esophageal tube in 1992, 1996, 2002, and 2007, respectively (NAHMS, 1993, 1996, 2002, 2008). In 2007, 52 or 12.4% of producers reported feeding calves colostrum with either a bucket or bottle, or an esophageal tube feeder, respectively (NAHMS, 2008).

Although using an esophageal tube feeder is convenient and quick, it is known that the esophageal groove reflex is not triggered when colostrum is administered by this method, resulting in colostrum deposition in the forestomachs (Lateur-Rowet and Breukink, 1983; Chapman et al., 1986). In contrast, when a nipple bottle or bucket is used, suckling triggers the esophageal groove reflex, depositing colostrum directly into the omasum and abomasum, where it can quickly empty into the

Received October 28, 2008.

Accepted December 12, 2008.

¹Corresponding author: godde002@umn.edu

small intestine to be absorbed. Thus, there is a potential disadvantage for tube feeding, because the delay in emptying of colostrum from the forestomachs into the small intestine could result in poorer absorption of IgG, because of the progressive decline in the efficiency of Ig absorption over time (termed gut closure; Besser et al., 1985; Michanek et al., 1989). However, the significance of this limitation is unclear because outflow of colostrum from the forestomachs to the abomasum and small intestine begins rapidly and occurs for the most part within 3 h after feeding (Lateur-Rowet and Breukink, 1983). Adams et al. (1985) reported that calves fed colostrum using a bottle had higher serum IgG concentrations compared with calves fed with an esophageal tube feeder, but the authors concluded that these differences were numerically small and not of practical importance. It has generally been accepted that either method of feeding, bottle or esophageal tube feeder, will achieve acceptable rates of passive transfer provided that a sufficient volume of colostrum is consumed soon after birth (Adams et al., 1985; Besser et al., 1991; Kaske et al., 2005).

Despite this conventional thinking, some uncertainties remain. First, many early studies were observational in nature and did not include control groups. Also, studies conducted 20 or more years ago fed relatively small volumes of colostrum at first feeding, compared with the present day when it is frequently recommended that 4 L of maternal colostrum (10% of BW) be fed at first feeding. However, there is still wide variation across the industry as to the volume of colostrum fed at first feeding. The NAHMS 2007 dairy study reported that 16.8, 43.1, and 40.1% of calves were fed either 2 quarts or less, more than 2 quarts but less than 4 quarts, or 4 quarts or more at first feeding, respectively (NAHMS, 2008). As an additional consideration, the dairy industry has recently seen the introduction of commercial colostrum replacers (**CR**). These products typically contain 100 to 125 g of IgG per dose and are designed to be mixed in warm water to create a relatively small final feeding volume, typically between 1.5 and 2 L.

Should the volume of colostrum or CR fed affect the choice of feeding method? Examination of a single full-term stillborn Holstein calf weighing approximately 50 kg revealed the capacity of the reticulorumen to be approximately 1 L (S. M. Godden, unpublished observation). If this, albeit very small, sample is representative, then the authors hypothesize that for Holstein calves fed small volumes of colostrum (e.g., 1.5 to 2 L) using an esophageal tube feeder, a relatively large proportion of the total volume fed would be retained in the reticulorumen, with delayed outflow into the abomasum. Conversely, if a large volume (e.g., 3 or 4 L) was fed using an esophageal tube feeder, we hypothesize that

proportionately more of the total volume of colostrum fed would overflow out of the reticulorumen, passing quickly into the abomasum. This hypothesis is supported by Chapman et al. (1986) who reported that when fluids were administered to calves using an esophageal tube feeder, overflow into the abomasum occurred after approximately 400 mL had been given. If this hypothesis is correct, and if the delay in emptying from the forestomachs associated with tube feeding truly does cause a significant reduction in efficiency of absorption of colostrum IgG, then this effect on passive transfer would be expected to be more pronounced in calves fed a relatively small volume of colostrum compared with calves fed larger volumes of colostrum using an esophageal tube feeder. The objective of this study was to investigate the effect of method of feeding (bottle vs. tube) on passive transfer of IgG when either a large or small volume of colostrum was fed.

MATERIALS AND METHODS

Calf Enrollment and Sampling

Protocols used for enrolling and treating calves within this study were approved by the University of Minnesota Institutional Animal Care and Use Committee (University of Minnesota, Minneapolis). The study was conducted between June and August 2007 on a commercially owned dairy facility that housed 400 dry and transition cows (Emerald Dairy II, Emerald, WI). When calving was imminent, cows were moved from a freestall pen into individual maternity pens. Bull calves from observed calvings were removed from the dam within 20 to 30 min of birth and before suckling could occur. To be eligible for enrollment, bull calves had to be single birthed, weigh ≥ 31.7 kg, and have a calving ease score ≤ 3 (on a scale of 1 to 5).

Before colostrum was fed, a 10-mL blood sample was collected from the jugular vein using a serum vacutainer tube. Eligible calves were then randomly assigned to 1 of 4 CR treatment groups:

1. Small volume, bottle (**SmB**): Feed one dose of CR product in a 1.5-L final volume using a nipple bottle (100 g of IgG fed; IgG concentration = 66.7 g/L).
2. Small volume, tube (**SmT**): Feed one dose of CR product in a 1.5-L final volume using an esophageal tube feeder (100 g of IgG fed; IgG concentration = 66.7 g/L).
3. Large volume, bottle (**LgB**): Feed 2 doses of CR product in a 3.0-L final volume using a nipple bottle (200 g of IgG fed; IgG concentration = 66.7 g/L).

4. Large volume, tube (**LgT**): Feed 2 doses of CR product in a 3.0-L final volume using an esophageal tube feeder (200 g of IgG fed; IgG concentration = 66.7 g/L).

The CR fed in this study was the Land O'Lakes Colostrum Replacer (Land O'Lakes Inc., St. Paul, MN). This is a lacteal-derived USDA regulated product licensed as a veterinary biologic as an aid in the prevention of FPT. Testing of serial samples by the National Veterinary Services Laboratory (Ames, IA) ensures that the product meets the requirements for sale, including microbiologic safety plus having equal to or in excess of 100 g of IgG in 470 g of powder (1 dose). The CR was mixed according to manufacturer label directions and fed within 2 h after birth. Enrollment data recorded for each calf included calf ID, dam ID, birth date, birth time, sex, calving ease score, colostrum treatment group assigned, and time of colostrum feeding. For bottle-fed calves, it was also recorded how much the calf voluntarily consumed (L) from the bottle. Because many bottle-fed calves in the LgB group did not voluntarily consume the entire 3 L of colostrum after 10 min of bottle feeding, the remaining volume was recorded and then fed using an esophageal tube feeder, as this would mimic the colostrum management strategy adopted by many farms. After the single colostrum feeding, all calves were moved into a 4 m × 4 m group pen and provided twice daily feedings of 1.8 L of a commercial milk replacer containing 22% CP (milk protein based) and 20% crude fat. At 24 h of age (± 1 h), a 10-mL postcolostral blood sample was collected from the jugular vein using a serum vacutainer tube.

Sample Analysis

Precolostral (0 to 1 h) and postcolostral (24 h) blood samples were refrigerated and allowed to clot overnight, then centrifuged and the serum separated within 24 h of collection. Zero- and 24-h serum total protein concentration (**TP**, g/dL) was determined using a commercially available hand-held refractometer (VET 360, Reichert Inc., Depew, NY). Sera were then frozen at -20°C until submission, on ice, to the Prairie Diagnostic Services Laboratory (University of Saskatchewan, Saskatoon, Canada) for IgG testing. Zero- and 24-h serum IgG samples from all calves were tested for total IgG concentration (mg/mL) by means of radial immunodiffusion as described by Chelack et al. (1993). The apparent efficiency of absorption of IgG (**AEA**, %), a calculated measure that estimates the proportion of the total IgG mass fed absorbed into the calf's circulation, was calculated using a formula described previously by Quigley et al. (2002), assuming a plasma volume of

9.9% of birth weight. A calf was defined as having acceptable passive transfer (**APT**) if serum IgG at 24 h was ≥ 10.0 mg/mL.

Statistical Analysis

Descriptive statistics were generated to describe calf characteristics and measures of passive transfer in calves including 0 and 24 h serum IgG (mg/mL) and TP (g/dL) concentrations, APT rate (%), and AEA of IgG (%). Linear regression (PROC MIXED in SAS, version 9.1. SAS Institute, Cary, NC) was used to describe the relationship between colostrum treatment group (explanatory variable: SmB; SmT, LgB, LgT) and each of the continuous dependent variables of interest (serum TP and serum IgG at 0 and 24 h and AEA (%)) of IgG at 24 h). Logistic regression (PROC GENMOD in SAS, version 9.1) was used to describe the relationship between treatment group and APT (24-h serum IgG ≥ 10.0 mg/mL). Contrast analysis was first used to compare the effect of treatment on passive transfer indices among the 4 treatment groups. Then, because an interaction was detected between the volume of colostrum fed (1.5 vs. 3.0 L) and the method of feeding (bottle vs. tube), data were subsequently stratified by volume of colostrum fed and analyzed separately for effect of feeding method (bottle vs. tube). Finally, because more than one-third of the bottle-fed calves in the LgB group did not voluntarily consume the entire 3 L of colostrum offered, a variable describing whether or not some colostrum had to be tube-fed in the LgB group was also offered into final models comparing results for the LgB versus LgT groups. Final significance was declared at $P < 0.05$.

Parameters describing calf birth weight (kg), calf age at first feeding (min), and calving ease score (1 to 3) were initially offered as additional covariates into all models. However, as none of these terms were significantly associated with the outcomes of interest and none interacted with the variable describing colostrum treatment group, they were subsequently removed from all models.

RESULTS AND DISCUSSION

Early studies have described a numerically small increase in passive transfer of IgG when feeding small volumes of colostrum using a nipple bottle instead of an esophageal tube feeder (Adams et al., 1985). However, other researchers have reported high and acceptable rates of passive transfer using either feeding method, provided that a sufficient volume of high-quality colostrum is fed soon after birth (Besser et al., 1991; Kaske et al., 2005). This is the first study to examine, in a

controlled trial, the effect of method of feeding (bottle vs. tube) on passive transfer of IgG when either large or small volumes of colostrum were fed. A commercial CR was fed, instead of maternal colostrum, to standardize the total mass of IgG (g) fed within both the large and the small volume treatment groups, and 1 dose versus 2 doses of the CR were fed to standardize the concentration of IgG (mg/mL) in the colostrum administered across all 4 treatment groups.

A total of 24, 24, 24, and 25 calves were enrolled into the colostrum treatment groups SmB, SmT, LgB, and LgT, respectively. Birth weights (kg) and dystocia scores were not different among treatment groups (Table 1). There was some variation in mean age at first feeding (min) among the treatment groups (Table 1). However, because time to first feeding was not associated with passive transfer outcome measures, this variable was omitted from the final models. Precolostral serum TP (g/dL) and IgG (mg/mL) concentrations at 0 h were not different among the 4 treatment groups (Table 2).

Not surprisingly, calves fed 200 g of IgG in 2 doses of CR had significantly higher serum TP (g/dL) and IgG (mg/mL) concentrations at 24 h compared with calves fed 100 g of IgG in 1 dose of CR. These results are consistent with previous studies that have reported that calves fed higher total masses of IgG achieve significantly higher serum IgG concentrations (Foster et al., 2006; Chigerwe et al., 2008; Godden et al., 2009).

Effect of Feeding Method on Passive Transfer in Calves Fed a Small Volume of CR

Among calves fed 100 g of IgG in a small (1.5 L) volume, there were significantly higher 24-h serum TP and IgG concentrations in calves fed using a nipple bottle compared with calves fed using an esophageal tube feeder (Table 2). Although 100% of calves fed 100 g of IgG in a 1.5-L volume using a bottle experienced APT (serum IgG ≥ 10.0 mg/mL), only 41.7% of calves fed using an esophageal tube feeder attained this target (Table 2). As birth weight, age at first feeding, and dystocia score were not different among the 2 treatment groups, the likely explanation is that the disparity is due to differences in AEA (% of IgG absorbed), which was significantly greater in calves fed using a bottle compared with a tube (Table 2). These results are in agreement with those of an earlier study that reported improvement in passive transfer of IgG when using a nipple bottle (instead of an esophageal tube feeder) when small volumes of colostrum were fed (Adams et al., 1985). These results are also consistent with the authors' hypothesis that differences in passive transfer of IgG will be apparent when a small volume of colostrum is fed using an esophageal tube feeder (vs.

bottle), because a relatively large proportion of the total volume fed is deposited in the reticulorumen and will experience some delay, even if only up to 3 h, in emptying into the abomasum.

Effect of Feeding Method on Passive Transfer in Calves Fed a Large Volume of CR

Method of feeding (bottle vs. tube) had no effect on 24-h serum IgG (mg/mL), serum TP (g/dL), and APT rates (%) when calves were fed 200 g of IgG in a large volume (3 L) of CR (Table 2). Apparent efficiency of absorption of IgG did not differ between these 2 treatment groups (Table 2). These results support previous studies that concluded that, when large volumes of colostrum are fed, similar levels of passive transfer are achieved, regardless of the method of feeding used (bottle vs. tube; Adams et al., 1985; Besser et al., 1991; Kaske et al., 2005). These results also support the authors' hypothesis that differences in feeding method may become less important and nonsignificant when a large volume of colostrum is fed, because a relatively smaller proportion of the total volume is deposited into the reticulorumen, whereas the majority will overflow into the abomasum and small intestine where IgG absorption can immediately begin.

Of interest, 37.5% (9 of 24) of the calves fed 3 L of CR using a bottle did not voluntarily consume the full 3 L, whereas the remaining 62.5% of calves did voluntarily consume the full 3 L from the bottle. These results are consistent with a recent study that recorded the voluntary colostrum intake at first feeding when Holstein heifer calves were fed up to 3 L by nipple bottle (Urday et al., 2008). In that study, the median colostral intake was 2.34 L with a range of 0 to 3.0 L. Thirty-one percent of calves consumed less than 2 L and 44% of calves consumed the maximum 3 L offered. This is of practical importance to producers who prefer feeding with a bottle. If a significant proportion of calves will not voluntarily consume larger volumes of colostrum, then it is recommended for producers to tube-feed the remaining volume of colostrum (Urday et al., 2008). There were no significant differences in passive transfer parameters when comparing tube-fed calves, bottle-fed calves that did voluntarily consume the full 3 L of CR, and bottle-fed calves that did not voluntarily consume the full 3 L of CR (remainder was tube-fed; Table 3).

In summary, this study has practical implications for colostrum management programs. The first recommendation is that, regardless of the feeding method used, producers wishing to increase the passive transfer of Ig should feed larger volumes of colostrum or CR to deliver a greater total mass (g) of Ig to the small in-

Table 1. Description of newborn calves fed either small (1.5 L) or large (3 L) volumes of colostrum replacer using either a bottle or an esophageal tube feeder

Parameter	Treatment group			
	1.5 L by bottle	1.5 L by tube	3 L by bottle	3 L by tube
Calves, n	24	24	24	25
Birth weight, ¹ kg	41.9 ± 5.2 (34.0 to 52.2) ^a	42.3 ± 3.5 (34.5 to 51.3) ^a	42.5 ± 4.4 (33.1 to 49.0) ^a	42.5 ± 4.2 (34.9 to 51.3) ^a
Calving ease score ²	1 (1 to 2) ^a	1 (1 to 2) ^a	1 (1 to 2) ^a	1 (1 to 2) ^a
Age at feeding, ¹ min	45.2 ± 20.6 (15 to 110) ^a	43.8 ± 35.8 (15 to 120) ^a	33.8 ± 15.3 (15 to 80) ^{ab}	28.4 ± 9.5 (15 to 60) ^b
Total mass of IgG fed, g	100 ^a	100 ^a	200 ^b	200 ^b

^{a,b}Values within row are significantly different ($P < 0.05$).

¹Mean ± SD (range).

²Median (range).

Table 2. Passive transfer indices for newborn calves fed either small (1.5 L) or large (3 L) volumes of colostrum replacer using either a bottle or an esophageal tube feeder

Parameter ¹	Treatment group			
	1.5 L by bottle	1.5 L by tube	3 L by bottle	3 L by tube
Calves, n	24	24	24	25
Prefeeding serum sample				
Total protein, ² g/dL	4.58 ± 0.23 (4.2 to 5.1) ^a	4.48 ± 0.25 (3.8 to 4.9) ^a	4.55 ± 0.25 (4.1 to 5.0) ^a	4.65 ± 0.31 (4.2 to 5.4) ^a
IgG, ² mg/mL	0.23 ± 0.24 (0.1 to 1.0) ^a	0.25 ± 0.23 (0.1 to 1.0) ^a	0.20 ± 0.12 (0.1 to 0.5) ^a	0.19 ± 0.17 (0.1 to 0.9) ^a
24-h serum sample				
Total protein, ² g/dL	5.30 ± 0.24 (4.8 to 5.8) ^a	4.96 ± 0.46 (4.3 to 6.6) ^b	5.84 ± 0.38 (5.1 to 6.7) ^c	5.87 ± 0.32 (5.1 to 6.4) ^c
IgG, ² mg/mL	12.50 ± 2.28 (10.0 to 18.2) ^a	9.85 ± 3.51 (6.8 to 24.5) ^b	19.65 ± 3.35 (11.7 to 27.0) ^c	18.65 ± 3.15 (13.2 to 25.3) ^c
AEA IgG, ² %	51.07 ± 6.46 (39.2 to 62.9) ^a	40.47 ± 10.91 (28.3 to 83.6) ^b	41.07 ± 6.81 (23.9 to 52.9) ^b	39.04 ± 6.57 (25.8 to 50.6) ^b
Calves with APT, ² n (%)	24 (100) ^a	10 (41.7) ^b	24 (100) ^a	25 (100) ^a

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

¹AEA = apparent efficiency of absorption of IgG at 24 h; APT = adequate passive transfer (serum IgG at 24 h ≥ 10.0 mg/mL).

²Mean ± SD (range).

Table 3. Passive transfer indices for newborn calves fed a large (3 L) volume of colostrum replacer using either a bottle or an esophageal tube feeder, when stratified by whether or not bottle-fed calves voluntarily consumed all colostrum offered¹

Parameter ²	Treatment group		
	3 L by bottle	3 L by bottle	3 L by tube
	Voluntarily consumed total volume offered	Did not voluntarily consume total volume offered	
Calves, n	15	9	25
Volume consumed voluntarily, ³ L	3.0 (0)	2.13 ± 0.57 (1.1 to 2.8)	0 (0)
24-h serum total protein, ³ g/dL	5.90 ± 0.43 (5.4 to 6.7) ^a	5.73 ± 0.28 (5.1 to 6.0) ^a	5.87 ± 0.32 (5.1 to 6.4) ^a
24-h serum IgG, ³ mg/mL	20.22 ± 3.33 (14.1 to 27.0) ^a	18.70 ± 3.36 (11.7 to 21.9) ^a	18.65 ± 3.15 (13.2 to 25.3) ^a
AEA IgG, ³ %	42.47 ± 6.65 (29.8 to 52.9) ^a	38.7 ± 6.78 (23.9 to 46.8) ^a	39.04 ± 6.57 (25.8 to 50.6) ^a
Calves with APT, ³ n (%)	15 (100) ^a	9 (100) ^a	25 (100) ^a

^aValues within row are not significantly different ($P > 0.05$).

¹The volume (of 3 L total fed) not voluntarily consumed after 10 min of feeding by bottle was administered with tube feeder.

²AEA = apparent efficiency of absorption of IgG at 24 h; APT = adequate passive transfer (serum IgG at 24 h ≥ 10.0 mg/mL).

³Mean ± SD (range).

testine. Producers feeding larger volumes of colostrum or CR at first feeding can choose to use either feeding method and expect to achieve very high and equal levels of passive transfer. However, if producers choose to feed large volumes using a nipple bottle, a significant proportion of calves may not voluntarily consume the entire volume. In this instance, producers should tube-feed the remaining volume. Producers choosing to feed small volumes of colostrum or CR (because of limited availability of maternal colostrum or cost considerations for CR) should use a nipple bottle to ensure optimal passive transfer because, although all calves consuming 100 g of IgG in 1.5 L by nipple bottle achieved adequate passive transfer levels, many calves fed this amount by esophageal tube had levels lower than the minimal target of 10 mg/mL.

CONCLUSIONS

When feeding a small volume of CR, higher AEA (%) of IgG and serum IgG and TP concentrations were achieved when using a nipple bottle (vs. esophageal tube feeder). As such, if producers choose to feed a small volume of colostrum or CR, they should use a nipple bottle instead of an esophageal tube feeder. When feeding a large volume (3 L) of CR, equally high levels of passive transfer are achieved, regardless of the feeding method used (nipple bottle vs. esophageal tube feeder). However, because significantly greater serum IgG concentrations were achieved by feeding the larger volume and thus larger mass of IgG, because the concentration of maternal colostrum is unknown and for some dams may be less than that found in the CR used in this study, and because there still exists some uncertainty concerning the optimum (in contrast to the minimum) target levels for passive transfer, the authors

recommend that whenever possible producers should feed calves larger volumes of colostrum or CR.

ACKNOWLEDGMENTS

We thank the owners and staff at Emerald Dairy II (Emerald, WI) for their support of this study. This study was partially funded through a nonrestricted gift and in-kind support by the Saskatoon Colostrum Co. (Saskatoon, Saskatchewan, Canada).

REFERENCES

- Adams, G. D., L. J. Bush, J. L. Horner, and T. E. Staley. 1985. Two methods for administering colostrum to newborn calves. *J. Dairy Sci.* 68:773–775.
- Besser, T. E., A. E. Garmedia, T. C. McGuire, and C. C. Gay. 1985. Effect of colostral immunoglobulin G1 and immunoglobulin M concentrations on immunoglobulin absorption in calves. *J. Dairy Sci.* 68:2033–2037.
- Besser, T. E., C. C. Gay, and L. Pritchett. 1991. Comparison of three methods of feeding colostrum to dairy calves. *J. Am. Vet. Med. Assoc.* 198:419–442.
- Brignole, T. J., and G. H. Stott. 1980. Effect of suckling followed by bottle feeding colostrum on immunoglobulin absorption and calf survival. *J. Dairy Sci.* 63:451–456.
- Chapman, H. W., D. G. Butler, and M. Newell. 1986. The route of liquids administered to calves by esophageal feeder. *Can. J. Vet. Res.* 50:84–87.
- Chelack, B. J., P. S. Morley, and D. M. Haines. 1993. Evaluation of methods for dehydration of bovine colostrum for total replacement of normal colostrums in calves. *Can. Vet. J.* 34:407–412.
- Chigerwe, M., J. W. Tyler, L. G. Schultz, J. R. Middleton, B. J. Steevens, and J. N. Spain. 2008. Effect of colostrum administration by use of oroesophageal intubation on serum IgG concentrations in Holstein bull calves. *Am J. Vet. Res.* 69:1158–1163.
- Edwards, S. A., and D. M. Broom. 1979. The period between birth and first suckling in dairy calves. *Res. Vet. Sci.* 26:255–256.
- Foster, D. M., G. W. Smith, T. R. Sanner, and G. V. Busso. 2006. Serum IgG and total protein concentrations in dairy calves fed two colostrum replacement products. *J. Am. Vet. Med. Assoc.* 229:1282–1285.
- Godden, S., D. Haines, and D. Hagman. 2009. Improving passive transfer of immunoglobulins in calves I: Dose effect of feeding a commercial colostrum replacer. *J. Dairy Sci.* 92:1750–1757.

- Kaske, M., A. Werner, H. J. Schuberth, J. Rehage, and W. Kehler. 2005. Colostrum management in calves: Effects of drenching vs. bottle feeding. *J. Anim. Physiol. Anim. Nutr. (Berl.)* 89:151–157.
- Lateur-Rowet, H. J. M., and H. J. Breukink. 1983. The failure of the oesophageal groove reflex, when fluids are given with an oesophageal feeder to newborn and young calves. *Vet. Q.* 5:68–74.
- McGuirk, S. M., and M. Collins. 2004. Managing the production, storage and delivery of colostrum. *Vet. Clin. North Am. Food Anim. Pract.* 20:593–603.
- Michanek, P., M. Venter, and B. Weström. 1989. Intestinal transmission of macromolecules in newborn dairy calves of different ages at first feeding. *Res. Vet. Sci.* 46:375–379.
- National Animal Health Monitoring System. 1993. National Dairy Heifer Evaluation Project. Dairy Herd Management Practices Focusing on Preweaned Heifers. USDA-APHIS Veterinary Services, Ft. Collins, CO.
- National Animal Health Monitoring System. 1996. Dairy 1996: National Dairy Health Evaluation Project. Dairy heifer morbidity, mortality, and health management focusing on preweaned heifers. USDA-APHIS Veterinary Services, Ft. Collins, CO.
- National Animal Health Monitoring System. 2002. Dairy 2002. Part 1: Reference of Dairy Health and Management in the United States. USDA-APHIS Veterinary Services, Ft. Collins, CO.
- National Animal Health Monitoring System. 2008. Colostrum Feeding and Management on U.S. Dairy Operations, 1991–2007. USDA-APHIS Veterinary Services, Ft. Collins, CO.
- Quigley, J. D. 3rd, C. J. Kost, and T. M. Wolfe. 2002. Absorption of protein and IgG in calves fed a colostrum supplement or replacer. *J. Dairy Sci.* 85:1243–1248.
- Urday, K., C. Munashe, and J. W. Tyler. 2008. Voluntary colostrum intake in Holstein heifer calves. *Bovine Pract.* 42:198–200.