Evaluation of Quality, Quantity, and Timing of Colostrum Feeding on Immunoglobulin G₁ Absorption in Jersey Calves*

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ABSTRACT

Twenty-four Jersey calves were randomly assigned to 1 of 4 treatment groups (6 calves per group). Pooled colostrum from first milkings (colostrum high in IgG₁, 84 mg/mL) of multiparous cows was fed to treatment groups 1 and 2. Pooled colostrums from second and third milkings (colostrum low in IgG₁, 31.2 mg/mL) of multiparous Jersey cows were fed to calves in treatment groups 3 and 4. The quality and timing of colostrum feeding was as follows: group 1 were fed (high IgG₁ colostrum) 4 L at 0 h (birth); group 2 calves were fed (high IgG₁ colostrum) 2 L at 0 h (birth) and 2 L at 12 h; group 3 calves were fed (low IgG₁ colostrum) 4 L at 0 h (birth); and group 4 calves were fed (low IgG₁ colostrum) 2 L at 0 h (birth) and 2 L at 12 h. Mean serum IgG₁ was 38.66, 45.66, 13.81 and 9.95 mg/mL in groups 1 to 4, respectively. At 48 h of age, calves fed colostrum with higher concentrations of total ingested IgG₁ (groups 1 and 2) had significantly higher serum protein and IgG₁ concentrations than calves fed low IgG₁ colostrum at 48 h of age (groups 3 and 4). Mean apparent efficiency of IgG₁ absorption was measured at 48 h; calves (group 2) receiving 2 L at birth and 2 L at 12 h of high IgG₁ colostrum had higher mean apparent efficiency of IgG₁ absorption than calves (group 4) fed 2 L of colostrum that was low in IgG₁ at birth and 12 h (31.2 and 18.2% in groups 2 and 4, respectively). Results suggest that Jersey calves should receive 2 separate feedings of high quality colostrum to maximize the colostral IgG₁ absorption.

(**Key words:** colostrum, immunoglobulin IgG₁, Jersey calves)

Abbreviation key: AEA = apparent efficiency of absorption.

INTRODUCTION

Inadequate or improper colostrum feeding and management cause a significant portion of the calf morbidity and mortality on United States dairy farms. The importance of adequate colostrum of suitable quality in the critical first 24 h of life is well documented (McGuire et al., 1976; Bush and Staley, 1980; Matte et al., 1982). Colostrum is the secretion from the mammary gland in the first 24 h after calving. Total solids composition of colostrum is 21 to 27%, compared with that of whole milk (12 to 13%). Colostrum contains high levels of immunoglobulins, which play an important role in establishing passive immunity in the young calf, and play an important role at the localized intestinal level. Immunoglobulin intake depends on colostrum intake and its Ig concentration. Lactation number, breed of cow, and length of the nonlactating period influence volume and Ig concentration of colostrum (Muller and Ellinger, 1981; Pritchett et al., 1991; Tomkins and Jaster, 1991). There are 3 types of Ig in colostrum of dairy cattle: IgG, IgM, and IgA, which typically account for about 85 to 90, 5, and 7%, respectively, of total Ig in colostrum (Larson et al., 1980; Roy, 1980). There are 2 isotypes of IgG: IgG₁ and IgG₂. These Ig work together to provide the calf with passive immunity (immunity provided by the cow and not synthesized by the calf) until the calf's own active immunity develops. Immunoglobulin ingested by the calf is taken up by the epithelial cells of the small intestine and passes into the lymph spaces and then into the blood circulation through the thoracic duct. This transfer mechanism (passive transfer) starts to decline approximately 12 to 23 h after birth and ceases on average at 24 h (McCoy et al., 1970; Stott et al., 1979a). Although the level of Ig that provides adequate protection will vary with exposure to infectious organisms, stress, environment, and temperature, a management target of 10 mg/mL has been suggested as a minimum level of IgG in the serum of calves by approximately 24 h of age to prevent failure of passive transfer (Bovine Alliance on Management and Nutrition, 1995). Discouragingly, statistics gathered by the National Animal Health Monitoring System (2002) indicate dairy producers do an inadequate job of providing

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colostrum to dairy calves. Over 40% of dairy heifer calves sampled by the National Dairy Heifer Evaluation Project had serum IgG concentrations below 10 mg/mL, and more than 25% of calves had levels below 6.2 mg/mL, which put calves at a much greater risk.

Much research has been directed toward colostrum feeding programs with large breed dairy cattle, but information is limited on serum immunoglobulin G₁ concentrations when colostrum with high and low concentrations of Ig is fed during the first 12 h after birth in Jersey calves. Although the relationship between specific gravity of colostrum and Ig is similar to that in Holstein cows, colostrum from Jersey cows appear to contain a greater concentration of Ig (Quigley et al., 1994). Limited information is currently available, especially for Jersey calves, concerning the interaction of quantity, quality, and timing of colostrum feeding. Results of this experiment will help to provide recommendations on feeding colostrum to Jersey calves with respect to reducing morbidity and mortality and increasing performance and management. Such information will be of benefit to veterinarians, nutritionists, and Jersey producers. The objective of this study was to compare serum immunoglobulin G₁ levels when colostrum with high or low concentrations of IgG₁ is fed during the first 12 h after birth in Jersey dairy calves.

MATERIALS AND METHODS

The California Polytechnic State University–San Luis Obispo Animal Care and Use Committee approved all procedures using animals before the start of the experiment. The experiment was conducted at California Polytechnic State University Dairy Farm (San Luis Obispo, CA). Student herdsmen monitored calvings, and Jersey calves were removed from their dams before colostrum ingestion. Navels were treated with 7% iodine solution, and calves were weighed, identified with an ear tag, and placed in a maternity pen. After the initial colostrum feedings, calves were moved to a hutch for the remainder of the study. The general health of the calves was monitored daily, and any health problems or treatments were recorded.

Fresh colostrum from first milkings (high IgG₁ colostrum) and colostrum from second and third milkings (low IgG₁ colostrum) were collected from multiparous donor Jersey cows as they calved. An aliquot was tested for IgG₁ concentration, and the bulk stored at –20°C. When enough colostrum of desired quality (IgG₁ content) was collected for the experiment, the colostrum was thawed, pooled, and refrozen in 2-L portions in plastic bottles. The IgG₁ concentration was determined (IgG₁ single radial immunodiffusion kit; VRMD, Inc., Pullman, WA) for the pooled colostrum, and the pooled

colostrum was used for the entire experiment. The pooled colostrum was thawed rapidly in warm water as needed and fed to calves within 2 h of birth. Table 1 presents the quality and quantity of colostrum administered and timing of subsequent colostrum feedings in the experiment. The time of first colostrum feeding was designated as 0 h (groups 1, 2, 3, and 4), and subsequent feedings (group 2 and 4) were fed 12 h later. Calves were fed via nipple bottle, and any colostrum not consumed was administered using an esophageal feeder.

Twenty-four Jersey calves were randomly assigned to 1 of 4 treatment groups (6 calves per group). Pooled colostrum from first milkings (high IgG₁ colostrum) of multiparous cows was fed to treatment groups 1 and 2. Pooled colostrums from second and third milkings (low IgG₁ colostrum) of multiparous Jersey cows were fed to calves in treatment groups 3 and 4. The quality and timing of colostrum feeding was as follows: group 1 calves were fed 4 L of high IgG₁ colostrum at 0 h (birth); group 2 calves were fed 2 L of high IgG₁ colostrum at 0 h (birth), and 2 L at 12 h; group 3 calves were fed 4 L of low IgG₁ colostrum at 0 h (birth); and group 4 calves were fed 2 L of low IgG₁ colostrum at 0 h (birth) and 2 L at 12 h (Table 1).

Calves in groups 1 and 3 were fed whole milk at 10% of BW at 12 h, with all groups fed whole milk for the remainder of study. Blood samples were drawn from the jugular vein of calves just before the first colostrum feeding (0 h) at birth, 12, 24, and 48 h of life. In groups 2 and 4, the blood was drawn before feeding colostrum at 12 h. Serum was separated and frozen at –20°C. Concentrations of IgG₁ in colostrum and serum were determined by radial immunodiffusion (VMRD, Inc.). Serum protein concentrations were measured by handheld refractometer (American Optical AO refractometer, El Paso, TX). Efficiency of IgG₁ absorption was determined by multiplying the estimated plasma volume of the calf by its 48-h serum IgG₁ concentration and dividing this product by the mass of colostrum IgG₁ that was fed. Plasma volume at 48 h was estimated to be $0.08 \times \text{BW}$ (Quigley and Drewry, 1998), and birth BW was used to estimate BW at 48 h.

Data were analyzed using an ANOVA procedure with repeated measures on 2 factors — time of feeding and serum IgG₁ concentration measured over time (SAS Institute, 2001). Treatment effects were tested by IgG₁ concentration, time of feeding, calf within treatment, hour postbirth, and their interactions. When the appropriate *F*-test was significant ($P < 0.05$), multiple paired comparisons were made among groups. Between-groups comparisons were made at each sampling time. The ANOVA procedure was used to compare 48-h IgG₁ absorption efficiency within groups. Relationships between serum IgG₁ concentration and serum total pro-

Table 1. Design of experiment to study the effects of quality and timing of colostrum ingestion on IgG₁ absorption in Jersey calves.

Treatment group	Calves (no.)	IgG ₁ concentration in colostrum (mg/mL)	Volume of colostrum (L)		Total IgG ₁ ingested in 12 h (g)
			0 h	12 h	
1	6	84.0	4	0	336.0
2	6	84.0	2	2	336.0
3	6	31.2	4	0	124.8
4	6	31.2	2	2	124.8

tein were determined by Pearson correlation and regression analyses (SAS Institute, 2001).

RESULTS AND DISCUSSION

Body weights of Jersey calves were not different ($P > 0.10$) among treatments at birth (mean BW was 26.2, 28.4, 29.1, and 28.7 kg for groups 1, 2, 3, and 4, respectively). Concentration of total IgG₁ in pooled colostrum was 84.0 mg/mL (groups 1 and 2) and 31.2 mg/mL (groups 3 and 4) (Table 1). Amount of Ig in the colostrum varies according to the dam's disease history, volume of colostrum produced, season of year, breed, and time after calving. Concentrations of Ig in colostrum are highest in first milking after calving and decrease at subsequent milkings (Stott et al., 1981). Pritchett et al. (1991) indicated that the average concentration in colostrum of Holstein cows was 48.2 g/L, with a range of 20 to >100 g/L. The concentration of Ig in colostrum fed to the high quality groups (1 and 2) in Table 1 was similar to a study (Quigley et al., 1994) that measured colostrum from Jersey cows, and reported that samples averaged 65.8 g/L of IgG, with a range of 28.4 to 114.7 g/L.

Serum protein concentrations before colostrum feeding were relatively low, at 3.83, 4.20, 3.32, and 3.66 g/100 mL in groups 1, 2, 3, and 4, respectively, and were not different (Table 2). Calves in groups 1 and 2, which

were fed high quality colostrum (84 mg/mL), had higher ($P < 0.05$) concentrations of serum protein than calves fed lower quality colostrum (groups 3 and 4; 31.2 mg/mL) at 12, 24, and 48 h (Table 2). Calves fed 4 L of high quality colostrum (group 1) had approximately 44% greater serum protein concentration than calves fed 4 L of low quality colostrum (group 3) at 48 h. When calves were fed high quality colostrum (groups 1 and 2; 84 mg/mL IgG₁), no differences in time of colostrum feeding and concentrations of serum protein were detected at 12, 24, and 48 h (Table 2). Similarly, when calves were fed low quality colostrum (groups 3 and 4; 31.2 mg/mL IgG₁), no differences in time of colostrum feeding and concentrations of serum protein were detected at 12, 24, and 48 h, respectively (Table 2). Although calves in groups 3 and 4 received 124.8 g of total IgG₁ at 24 h of age, mean serum protein was <5.0 g/L, which has been reported as an indication of failure of passive transfer of immunity (Donovan et al., 1986).

A negligible amount of serum IgG₁ was found at birth in calves before colostrum feeding and was not different ($P > 0.10$) between groups. Feeding calves low quality colostrum resulted in marked differences in serum IgG₁ concentrations as related to the volume of colostrum fed and timing of feeding (Table 3). Calves (group 3) fed 4 L of low quality colostrum at birth had higher ($P < 0.05$) levels of IgG₁ at 12 and 24 h than calves fed 2 L of low quality colostrum at birth and 2 L at 24 h (group

Table 2. Serum protein concentrations ($\pm$ SE) in Jersey calves.

Treatment group ¹	Time after first colostrum meal			
	0 h	12 h	24 h	48 h
	g/100 mL			
1	3.83 $\pm$ 0.21	6.08 $\pm$ 0.33 ^a	6.85 $\pm$ 0.50 ^a	6.58 $\pm$ 0.44 ^a
2	4.20 $\pm$ 0.27	6.10 $\pm$ 0.34 ^a	7.20 $\pm$ 0.25 ^a	6.86 $\pm$ 0.32 ^a
3	3.32 $\pm$ 0.26	4.65 $\pm$ 0.54 ^b	4.35 $\pm$ 0.60 ^b	4.58 $\pm$ 0.41 ^b
4	3.66 $\pm$ 0.29	4.00 $\pm$ 0.34 ^b	4.13 $\pm$ 0.36 ^b	4.30 $\pm$ 0.25 ^b

^{a,b}Means in the same column without a common superscript differ ($P < 0.05$).

¹Calves in group 1 were fed 4 L of colostrum that was high in Ig (84.0 mg of IgG₁/mL) at 0 h, calves in group 2 were fed 2 L of colostrum that was high in Ig, at 0 and 12 h, calves in group 3 were fed 4 L of colostrum that was low in Ig (31.2 mg of IgG₁/mL) at 0 h, and calves in group 4 were fed 2 L of colostrum that was low in Ig at 0 and 12 h.

Table 3. Serum IgG₁ concentrations ($\pm$ SE) in Jersey calves.

Treatment group ¹	Time after first colostrum meal		
	12 h	24 h	48 h
	(mg/ml)		
1	32.66 $\pm$ 3.30 ^a	39.66 $\pm$ 5.02 ^a	38.66 $\pm$ 5.01 ^a
2	34.33 $\pm$ 3.50 ^a	45.83 $\pm$ 3.96 ^b	45.66 $\pm$ 3.45 ^b
3	16.12 $\pm$ 1.82 ^b	15.83 $\pm$ 2.27 ^b	13.81 $\pm$ 1.93 ^c
4	7.75 $\pm$ 0.52 ^c	10.91 $\pm$ 1.06 ^c	9.95 $\pm$ 0.95 ^c

^{a,b,c}Means in the same column without a common superscript differ ($P < 0.05$).

¹Calves in group 1 were fed 4 L of colostrum that was high in Ig (84.0 mg/mL) at 0 h, calves in group 2 were fed 2 L of colostrum that was high in Ig at 0 and 12 h, calves in group 3 were fed 4 L of colostrum that was low in Ig (31.2 mg/mL) at 0 h, and calves in group 4 were fed 2 L of colostrum that was low in Ig at 0 and 12 h.

4). Differences were not present at 48 h, however. The lack of effect of 4 L of low quality colostrum on serum IgG₁ at birth vs. 2 L at birth and 2 L at 12 h suggests that offering calves a second feeding of low quality colostrum at 12 h will not provide adequate Ig protection. It is generally accepted that failure of passive transfer is indicated when a blood Ig concentration is less than 10 mg/mL at 48 h of age (Bovine Alliance on Management and Nutrition, 1995). A concentration of 15 mg/mL probably is more desirable as a management target to reduce calf morbidity and mortality (Davis and Drackley, 1998). As reported in Table 3, calves fed low quality colostrum (group 4) did not achieve the management target of 15 mg/mL. In contrast, calves fed colostrum relatively high in IgG₁ content resulted in higher ($P < 0.05$) serum IgG₁ concentrations at 12, 24, and 48 h (group 1 and 2) than calves receiving low quality IgG₁ colostrum (groups 3 and 4). Calves fed 4 L of high IgG₁ colostrum at birth (group 1) had similar serum IgG₁ concentrations at 12 h as those calves fed 2 L of high quality colostrum at birth (group 2). However, serum IgG₁ concentrations were higher ($P < 0.05$) at 24 and 48 h for those calves fed 2 L of high Ig colostrum at birth followed by 2 L at 24 h (group 2) compared with 4 L of high quality IgG₁ at birth (group 1). A standard recommendation with Holstein calves has been to feed 1.89 L of colostrum in the first few hours of life, followed by an additional 1.89 L within 12 h (Roy, 1980). Besser et al. (1985) and Gay (1994) recommended that 3.78 L of colostrum be fed by esophageal feeder immediately after birth. This initial feeding should be followed by second feeding of 1.89 L 12 h later. However, the Bovine Alliance on Management and Nutrition (1995) concluded that 2.84 L of colostrum fed soon after birth is adequate. Furthermore, if quality can be determined, this group recommends feeding only 1.89 L at birth (Bovine Alliance on Management and Nutrition, 1995). Calves receiving 1.89 L or less of colostrum, however,

may not consume adequate IgG₁ to prevent disease if colostrum is not of high quality or if colostrum is not fed soon enough after birth (Davis and Drackley, 1998). A survey conducted by the National Animal Health Monitoring System (2002) showed that nearly half of US producers fed between 1.89 and 3.78 L of colostrum during the first 24 h of life, and more than one-fourth of producers fed more than 3.78 L. Another one-fourth of the producers, however, fed 1.89 L or less during the first 4 h. Many of the calves fed 1.89 L or less during the first 4 h are candidates for failure of passive transfer. Results of IgG measurements indicate that more than 40% of calves sampled had serum IgG concentrations below 10 mg/mL, and more than 25% had concentrations below 6.2 mg/mL, placing these calves at a great risk of disease.

Morin et al. (1997) investigated the interrelationship among colostrum quality, amount, and time of feeding and reported feeding 3 groups of Holstein calves as follows: 2 L of low-quality, pooled colostrum (32.9 mg/mL) at birth and 2 L at 12 h; 2 L of pooled high-quality colostrum (60.1 mg/mL) at birth and 2 L at 12 h; or 4 L of high-quality, pooled colostrum at birth and 2 L at 12 h of age. Colostrum high in Ig resulted in higher ($P < 0.05$) serum Ig concentrations at 48 h; the concentrations were highest when 4 L of colostrum high in Ig were fed to calves at birth (Morin et al., 1997). As reported in Table 3 of this study, the amount of IgG₁ absorbed by 48 h was 18% greater in calves fed 2 L of high-quality pooled colostrum at birth and 12 h vs. 4 L at birth. Besser et al. (1985) found a similar pattern of absorption for IgG₁ and reported a negative correlation between the efficiency of absorption and the mass of IgG₁ fed and suggested a physiologic limitation on the mass of immunoglobulin that can be absorbed from a given volume of colostrum.

It is critically important to feed colostrum immediately after birth. The intestine of the newborn is capable of absorbing large protein molecules (such as Ig) intact within the first 24 h of life, resulting in an increase in circulating IgG concentrations in the calf's blood. The transfer of Ig in the colostrum from the mother to calf is termed passive immunity. Insufficient serum IgG concentrations (less than 10 mg/mL by 48 h) are indicative of failure of passive transfer. Many factors influence failure of passive transfer. Providing calves with colostrum soon after the animal is born maximizes absorption potential of Ig. Stott et al. (1979a, b, c, d) demonstrated that the rate of absorption depends on the amount of colostrum fed and how soon after birth ingestion occurs. Stott et al. (1979c) indicated that delayed colostrum feeding might result in the probability of microorganism invasion of the intestinal epithelia; hence, the high rate of morbidity and mortality in calves with

Table 4. Apparent efficiency of absorption ($\pm$ SE) of IgG₁ in Jersey calves.

Treatment group ¹	48 h after first colostrum meal (%)
1	24.6 $\pm$ 1.6 ^{ab}
2	31.2 $\pm$ 3.4 ^a
3	25.6 $\pm$ 3.8 ^{ab}
4	18.2 $\pm$ 2.2 ^b

^{a,b}Means in the same column without a common superscript differ ($P < 0.05$).

¹Calves in group 1 were fed 4 L of colostrum that was high in Ig (84.0 mg/mL) at 0 h, calves in group 2 were fed 2 L of colostrum that was high in Ig at 0 and 12 h, calves in group 3 were fed 4 L of colostrum that was low in Ig (31.2 mg/mL) at 0 h, and calves in group 4 were fed 2 L of colostrum that was low in Ig at 0 and 12 h.

low IgG could be the result of transepithelial migration of pathogens before gut closure. With increasing age, there is a progressive decrease in absorption rate. Additionally, amount of colostrum fed and age at first feeding are the 2 major factors in determining maximum Ig concentration in serum. Maximum Ig concentration in serum for calves fed a given amount of colostrum decreases as the interval between birth and first feeding of colostrum increases (Stott et al., 1979c). Morin et al. (1997) reported similar results when fixed volumes of pooled colostrum were fed to calves; relatively higher serum IgG concentrations were achieved with high IgG colostrum than with low IgG colostrum.

Apparent efficiency of absorption (AEA) of serum IgG₁ was measured at 48 h to assess the success of the passive transfer of immunity (Table 4). Group 2 calves (receiving 2 L at birth and 2 L at 12 h of high IgG₁ colostrum) had higher ($P < 0.05$) mean AEA than group 1 calves (fed 4 L of colostrum high in IgG₁ at birth). Similar AEA rates were noted for group 1 and 3 calves. However, group 4 calves had a lower AEA compared with calves in groups 1, 2, and 3. Mean AEA from maternal colostrum typically averages 20 to 35% (Quigley and Drewry, 1998). The concentration of IgG in the colostrum may influence AEA. Stott and Fellah (1983) reported a linear response, where calves fed 1 L of colostrum were more efficient in absorbing IgG than were calves fed the same mass of IgG in 2 L. Stott et al. (1979c) suggested that there is a curvilinear relationship between AEA and IgG intake, and that an excessive amount of colostrum may cause inhibition in immunoglobulin absorption, particularly with increasing age. These authors propose that the problem of absorption inhibition of the specific Ig classes lends further evidence that 2 L of colostrum may be the maximum or optimum amount to be fed the average large-breed calf at birth up to 16 h (Stott et al., 1979c). A limited number

of surface receptors carry IgG from the intestinal wall to the blood stream. When all the receptors become saturated, there is no longer a means for IgG to be transported. Large amounts of colostrum containing a low concentration of IgG would not be absorbed adequately; instead, limited amounts of high quality IgG colostrum may be more important.

The relationship between serum IgG₁ and total protein in calves at 48 h is shown in Figure 1. Within treatment, calves were fed 2 different concentrations of IgG₁ and volumes of colostrum (Table 1). Absorption of IgG₁ and protein were highly correlated, as indicated by the significant linear regression of IgG₁ and protein (Figure 1). Total serum protein has been used as an estimate of circulating serum IgG concentration and as an indicator of susceptibility to neonatal disease (Naylor and Kronfeld, 1977; Naylor et al., 1977; Tyler et al., 1996; Quigley et al., 2002). Quigley et al. (2002) used the value of 5.2 g/dL of total protein as indicative of adequate passive transfer. When applying this criterion to our data, calves in groups 3 and 4 provided estimates of failure of passive transfer at 48 h. Serum IgG₁ concentrations at 48 h indicate successful passive transfer in groups 1 and 2, marginal passive transfer in group 3, and inadequate in group 4 (Table 3). These data suggest that the feeding of low quality colostrum (31.2 mg/mL) at 0 and 12 h (2 L) will lead to failure of passive transfer of colostral immunoglobulins.

CONCLUSIONS

The results from this study show the importance of colostral quality on IgG₁ intake and absorption. Jersey calves that received high quality colostrum (84.0 mg/mL IgG₁) had higher concentrations of IgG₁ and total serum protein than calves that received low quality colostrum (31.2 mg/mL IgG₁). Calves fed 2 L of high quality colostrum at 0 and 12 h had greater concentrations of IgG₁ after 24 h, and higher AEA at 48 h than calves fed similar IgG₁ concentrations one time at 0 h. Results suggest that dairy management practices support feeding Jersey calves 2 separate feedings of high quality colostrum to maximize the colostral IgG₁ intake.

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Figure 1. Regression of serum IgG₁ and serum total protein at 48 h of age in Jersey calves.

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