Newborn lambs (n = 45) at the Agricultural Research Institute of Northern Ireland were fed either 50 grams of commercial lamb milk replacer or 50 grams of commercial colostrum replacer (bovine origin) in 200 ml of water four times during the first 24 hours of life or were given ad libitum access to the ewe. Total plasma protein at 24 hours of age was highest in lambs allowed to suckle the ewe (76.9 g/L). However, by 14 days of age, there were no differences in plasma protein levels among the three treatments. Bovine IgG was measured in lambs fed colostrum replacer and ovine IgG was measured in other lambs. Mean plasma IgG concentrations at 24 hours of age were 0.7 (milk replacer), 18.0 (colostrum replacer), and 26.6 (dam’s milk) g/L. Bovine IgG administered orally to newborn lambs was adequately absorbed, and circulating IgG concentrations were sufficiently maintained throughout this study.

**ABSTRACT**

Newborn lambs (n = 45) at the Agricultural Research Institute of Northern Ireland were fed either 50 grams of commercial lamb milk replacer or 50 grams of commercial colostrum replacer (bovine origin) in 200 ml of water four times during the first 24 hours of life or were given ad libitum access to the ewe. Total plasma protein at 24 hours of age was highest in lambs allowed to suckle the ewe (76.9 g/L). However, by 14 days of age, there were no differences in plasma protein levels among the three treatments. Bovine IgG was measured in lambs fed colostrum replacer and ovine IgG was measured in other lambs. Mean plasma IgG concentrations at 24 hours of age were 0.7 (milk replacer), 18.0 (colostrum replacer), and 26.6 (dam’s milk) g/L. Bovine IgG administered orally to newborn lambs was adequately absorbed, and circulating IgG concentrations were sufficiently maintained throughout this study.

**INTRODUCTION**

Provision of an adequate mass of immunoglobulins to neonatal lambs is critical to minimize the risk of failure of passive transfer (FPT). Because immunoglobulins do not cross the placenta in sheep, lambs are born without circulating immunoglobulin. Newborn lambs, calves, and piglets may suffer from FPT, particularly in cases of multiple births, maternal agalactia, weak animals not strong enough to nurse sufficient colostrum,1 or animals with poor IgG absorption.2 Conversely, McGuire and coworkers3 reported that only 3.3% of lambs developed FPT when management practices were designed to ensure suckling and selection of ewes for postweaning lamb production. Bovine colostrum may be provided to newborn lambs when ovine colostrum from the dam is not available.4 However, availability of bovine colostrum may be limited, and administration of this supplement may be impractical under some management conditions.

Commercial colostrum supplement products have been developed to provide exogenous
IgG to calves when IgG concentrations are low or when colostrum is unavailable due to maternal agalactia, acute mastitis, or other causes. However, few alternatives to maternal colostrum have been developed for lambs.

Sources of exogenous IgG include lacteal secretions (milk or colostrum), bovine plasma extracts, or eggs. Poor absorption of IgG from commercial colostrum products derived from lacteal secretions has been reported in calves, possibly due to a low mass of IgG. Garry and coworkers also reported poor IgG absorption from commercial colostrum supplements when fed to provide IgG concentrations typical of colostrum. Conversely, absorption of IgG from commercial colostrum supplements derived from plasma protein has been reported to be similar to that of fresh maternal colostrum in calves. Plasma and serum proteins have long been recognized as potential replacements for colostrum, with Igs composed mainly of IgG₁ and IgG₂. Most IgG in colostrum is derived from serum IgG from the dam and is actively transported into the mammary gland during the last few weeks of gestation. In addition to IgG, serum contains protease inhibitors that may contribute to acceptable absorption of IgG. Recently, Quigley and coworkers reported plasma IgG concentrations greater than 10 g/L in newborn calves fed a colostrum replacer providing more than 100 g of IgG/dose. Immunoglobulins fed in that study were derived from bovine plasma. These data suggest that a colostrum replacer containing a greater mass of IgG could be more effective in providing satisfactory transfer of passive immunity to neonates.

Immunoglobulins derived from bovine plasma are available in large quantities from the meat-processing industry. These immunoglobulins can be collected, processed, and manufactured to human edible standards and may be an excellent source of IgG for neonates. Although bovine IgG fed via cow colostrum is well absorbed by the newborn lamb, no available data indicate whether bovine IgG derived from plasma can be absorbed by the lamb and will confer passive immunity. Therefore, the objective of this study was to determine if colostrum containing an IgG concentrate derived from bovine plasma would provide circulating bovine IgG for newborn lambs and provide passive immunity to common ovine pathogens.

**MATERIALS AND METHODS**

**Experimental Animals and Treatments**

Newborn lambs (n = 45) at the Agricultural Research Institute of Northern Ireland, Hillsborough, were used in the study. Ewes were Greyface (Border Leicester × Scottish Blackface) and were bred to Texel sires. Lambs were from single births that occurred within the flock between April 1 and April 21, 2000. Lambs were enrolled in the study if their birth had been observed, if they appeared clinically normal, and if they were fed within 4 hours of birth. Animals selected for the study were randomly assigned to be fed either 200 ml of reconstituted commercial lamb milk replacer (Volac Lamlac, Volac International, Ltd.) or 200 ml of reconstituted colostrum replacer of bovine origin in warm (approximately 40°C) water at each of four feedings in the first 24 hours or to have unrestricted access to the ewe for the first 24 hours to suckle maternal colostrum.

A commercially available immunoglobulin concentrate powder (approximately 50% IgG and 35% non-Ig protein) obtained by fractionation of bovine plasma (Nutragammmax 40™, Proliant, Inc., Ames, IA) was used in the study. The Ig concentrate was mixed with lactose, dextrose, salt, titanium dioxide, potassium chloride, magnesium sulfate, a dry fat blend (7% protein, 60% fat), a vitamin/mineral premix, glycine, and flavors. The experimental colostrum replacer was weighed into 1-kg containers and stored
at room temperature until fed.

Chemical composition of the colostrum replacer was 97.1% dry matter, 41.5% crude protein, 5.4% ash, and 21.4% IgG (air dry basis). Guaranteed analysis of the lamb milk replacer was 24% crude protein, 24% ether extract, and 7% ash. The lamb milk replacer contained no IgG. Both feeds contained low bacterial counts (less than $6 \times 10^4$ CFU/g), and both were negative for the presence of *Salmonella*.

After an observed birth, each lamb was placed behind a metal grill partition within the lambing pen to permit contact between the ewe and lamb but to prevent suckling. Pen partitions were subsequently removed for lambs assigned to have free access to their dams for suckling. Lambs receiving either lamb milk replacer or colostrum replacer remained behind the partition for 24 hours and were fed by esophageal feeder to eliminate variability due to voluntary intake. Dams of lambs fed milk or colostrum replacer were milked at least twice during the first 24 hours.

Lambs were weighed at birth and every 14 days thereafter through Day 56. After 24 hours, lambs were managed according to the normal practices of the farm for the next 56 days. Records of lamb deaths and required antibiotic treatments were maintained for all lambs in the study.

**Blood Sampling**

At birth and at 24 hours, whole blood (approximately 3 ml) was collected from each lamb by jugular venipuncture into evacuated tubes containing EDTA. Immediately following blood sampling at 24 hours, lambs on milk or colostrum replacer were given free access to suckle their dams. A third blood sample was taken from all lambs at 14 days of age.

Blood samples were centrifuged and plasma was withdrawn, frozen (−20°C), and shipped to the laboratory for determination of total protein by the biuret method. IgG was determined by a method described by Mancini and coworkers as modified by Fahey and McKelvey.

**Statistical Analysis**

Data were analyzed by one-way analysis of variance using a completely randomized experimental design. Dependent variables included plasma total protein and IgG at birth, 24 hours, and 14 days; body weight at birth; and ages at feeding and at blood samplings. Means were compared by Tukey's test. Morbidity and mortality in the treatment groups were compared by chi-square analysis. Significance was declared at $P < .05$ unless otherwise noted.

**RESULTS**

The mean body weight of all lambs at birth was 5.1 kg; group mean weights ranged from 4.7 (lambs fed colostrum replacer) to 5.4 kg (lambs fed milk replacer). Mean body weights and gains were not significantly different among treatments at any time (Table 1).

Lambs that suckled the ewes did so for the first time an average of 1 hour after birth; lambs receiving milk replacer received their first feeding an average of 1.6 hours after birth; and those receiving colostrum replacer were first fed an average of 2.1 hours after birth. Ages at subsequent feedings were similar between lambs fed milk replacer and those fed colostrum replacer. Subsequent feeding times were not observed for lambs that suckled their dam.

Plasma protein levels at birth were similar among all treatments (Table 1); however, by 24 hours, lambs allowed to suckle the ewe achieved a significantly higher mean concentration of total protein compared with lambs fed milk replacer ($P < .05$). Change in plasma total protein from 0 to 24 hours was significantly greater in lambs allowed to nurse the ewe than in lambs fed milk replacer or those
TABLE 1. Variables Measured for Lambs Fed Lamb Milk Replacer,* Colostrum Replacer†, or Given Free Access to Dam’s Milk During First 24 Hours after Birth

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lamb Milk Replacer</th>
<th>Bovine Colostrum Replacer</th>
<th>Dam’s Milk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (kg)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birth</td>
<td>5.3 ± 0.2</td>
<td>4.7 ± 0.2</td>
<td>5.4 ± 0.2</td>
</tr>
<tr>
<td>28 days</td>
<td>15.3 ± 0.5</td>
<td>15.4 ± 0.5</td>
<td>16.4 ± 0.5</td>
</tr>
<tr>
<td>56 days</td>
<td>24.6 ± 0.9</td>
<td>23.6 ± 0.9</td>
<td>23.6 ± 0.9</td>
</tr>
<tr>
<td>Age at feeding (hr)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; feeding</td>
<td>1.6 ± 0.3&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>2.1 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.0 ± 0.3&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; feeding</td>
<td>7.6 ± 0.3</td>
<td>8.0 ± 0.3</td>
<td>Not determined</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; feeding</td>
<td>13.7 ± 0.3</td>
<td>14.2 ± 0.3</td>
<td>Not determined</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; feeding</td>
<td>19.7 ± 0.3</td>
<td>20.2 ± 0.3</td>
<td>Not determined</td>
</tr>
<tr>
<td>Age at blood sampling (hr)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; sampling</td>
<td>1.0 ± 0.2</td>
<td>1.8 ± 0.2</td>
<td>0.7 ± 0.2</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; sampling</td>
<td>25.2 ± 0.3</td>
<td>25.9 ± 0.3</td>
<td>25.3 ± 0.3</td>
</tr>
<tr>
<td>Total protein (g/L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 hr</td>
<td>53.43 ± 3.45</td>
<td>57.73 ± 3.45</td>
<td>54.91 ± 3.71</td>
</tr>
<tr>
<td>24 hr</td>
<td>52.93 ± 4.60&lt;sup&gt;b&lt;/sup&gt;</td>
<td>66.31 ± 4.60&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>76.93 ± 4.76&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>14 days</td>
<td>65.41 ± 5.32</td>
<td>72.76 ± 5.53</td>
<td>76.88 ± 5.33</td>
</tr>
<tr>
<td>Change, 0 – 24 hr</td>
<td>−0.51 ± 2.66&lt;sup&gt;b&lt;/sup&gt;</td>
<td>8.57 ± 2.66&lt;sup&gt;b&lt;/sup&gt;</td>
<td>23.55 ± 2.85&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Change, 1 – 14 days</td>
<td>13.12 ± 4.24</td>
<td>6.43 ± 4.40</td>
<td>−0.05 ± 4.24</td>
</tr>
<tr>
<td>Plasma IgG (g/L)&lt;sup&gt;‡&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 hr</td>
<td>0.05 ± 0.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.16 ± 0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.07 ± 0.03&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>24 hr</td>
<td>0.72 ± 2.07&lt;sup&gt;c&lt;/sup&gt;</td>
<td>17.98 ± 2.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>26.64 ± 2.14&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>14 days</td>
<td>1.35 ± 1.17&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.29 ± 1.22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.87 ± 1.17&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Change, 0 – 24 hr</td>
<td>0.67 ± 2.06&lt;sup&gt;c&lt;/sup&gt;</td>
<td>17.83 ± 2.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>26.57 ± 2.14&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Change, 1 – 14 days</td>
<td>0.61 ± 1.10&lt;sup&gt;c&lt;/sup&gt;</td>
<td>−7.67 ± 1.14&lt;sup&gt;b&lt;/sup&gt;</td>
<td>−16.30 ± 1.14&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Morbidity and mortality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of lambs at birth</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>No. of lambs at 56 days</td>
<td>14</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>6.7</td>
<td>13.3</td>
<td>6.7</td>
</tr>
<tr>
<td>Lambs treated for illness (%)</td>
<td>13.3</td>
<td>6.7</td>
<td>0.0</td>
</tr>
</tbody>
</table>

*200 ml of reconstituted lamb milk replacer fed four times in 24 hours.
†50 g bovine colostrum replacer in 200 ml fed four times in 24 hours.
‡Bovine IgG in lambs fed colostrum replacer, ovine IgG in other lambs.

<sup>a,b,c</sup>Values within a row with different superscripts are significantly different ($P < .05$).

Data (except percentages) are least squares means ± standard error of the mean.
fed colostrum replacer ($P < .05$). By 14 days of age, there were no significant differences among treatments and mean plasma total protein for all groups combined was 71.66 g/L (range = 65.41 to 76.88 g/L). The change in total plasma protein from Day 1 to Day 14 was similar among the treatments.

Some variation in plasma IgG levels at birth was observed among the groups of lambs (Table 1). By 24 hours, lambs allowed to nurse the ewe achieved significantly higher circulating ovine IgG concentrations (mean = 26.64 g/L) than did the group fed milk replacer ($P < .05$). However, two lambs in the group allowed to suckle their dam failed to achieve measurable ovine IgG at 24 hours. Minimal circulating IgG was detected in the lambs fed lamb milk replacer at 24 hours, demonstrating the lack of IgG in that supplement. Mean plasma bovine IgG in lambs fed colostrum replacer was significantly higher at 24 hours than mean ovine IgG in the group fed milk replacer ($P < .05$) but was lower than in lambs allowed to nurse the ewes. The level of bovine IgG in plasma of lambs fed colostrum replacer was less than 10 g/L in only one lamb (9.8 g/L) at 24 hours. Intake of IgG by lambs fed colostrum replacer was 43 g (data not shown). By 14 days of age, mean plasma IgG was similar between lambs fed colostrum replacer and those allowed to nurse the ewe; levels for both of these groups were higher than concentrations in lambs fed milk replacer.

The proportion of lambs requiring veterinary treatments was unaffected by treatment (zero in the group allowed to nurse their dam, 6.7% of lambs fed colostrum replacer, and 13.3% in lambs fed milk replacer).

Four of the 45 lambs enrolled in the study died before Day 56, giving an overall mortality rate of 8.9%. Deaths included one lamb fed milk replacer (6.7%), one lamb that suckled its dam (6.7%), and two lambs fed colostrum replacer (13.3%) (Table 1). Although necropsies were not performed to verify causes of death, clinical signs for these animals were consistent with enteric infection (elevated rectal temperature, diarrhea). Two of the four lambs that died had no measurable IgG at 24 hours of age.

### DISCUSSION

Lambs allowed to nurse the ewe were able to complete their first feeding an average of 0.6 to 1.1 hours before lambs receiving either milk replacer or colostrum replacer. An interval of 0.75 hours between the median time first to stand and suckling successfully has been reported in single crossbred lambs. In Scottish Blackface lambs of optimum weight, an average of 1.1 hours has been reported as the interval between the first attempt to suckle and suckling successfully. Thus, the first feeding times of lambs in each of the three treatments in the current study were expected to be at similar times after birth.

The relatively low rate of mortality and rapid rate of body weight gain suggested low exposure to pathogens throughout the study. Lambs were moved from the maternity barn to clean pastures within 14 days of birth, which reduced pathogen exposure. In addition, the lambing facility was thoroughly cleaned and disinfected to minimize pathogen transfer before the start of the study. Mortality in the present study was markedly lower than in other reports. The low exposure to pathogens due to excellent animal management and continued availability of transition milk from the ewe most likely contributed to low morbidity and mortality. Transition milk contains IgG and IgA that can provide local, intestinal immunity, thereby reducing the risk of disease.

Concentrations of ovine IgG in lambs left to nurse the ewe were variable, but averaged 26.64 g/L of plasma when lambs were 24 hours of age. Concentrations of IgG in three of
15 lambs allowed to nurse their dam failed to reach 10 g/L at 24 hours, indicating failure of passive transfer of immunity. Ovine IgG in plasma of remaining lambs in that group ranged from 13.4 to 56.2 g/L, indicating considerable variability in acquisition of passive transfer. Variability is inherent in such measurements, since factors such as volume and frequency of voluntary intake, colostrum quality and quantity, and ability of the lamb to absorb IgG markedly influence circulating IgG concentrations. Content of IgG in sheep colostrum is also quite variable. It has been reported that colostral IgG collected from ewes between 2 and 4 hours postpartum ranged from 20 to approximately 120 g/L. Significant breed effects on colostral IgG concentration have also been reported.

Concentrations of IgG in colostrum may be inadequate to predict the degree of acquisition of passive transfer of immunity. Absorption of IgG into the circulation depends on the mass of IgG consumed (colostrum intake × IgG concentration) × efficiency of IgG absorption. A close correlation between serum Ig concentration in lambs and mass of IgG consumed has been reported. Therefore, while colostral IgG concentration is one variable in the equation for calculating circulating IgG concentrations, other important variables also affect this response.

Concentrations of ovine IgG in plasma of lambs allowed to suckle the ewe in the present study were consistent with other published reports. Gilbert and coworkers reported 33 g of IgG/L of serum in lambs 36 hours of age. Daniels and coworkers reported a mean serum ovine IgG level of 17.5 g/L in lambs (mean body weight = 4.2 kg) 24 hours of age. Dawson and coworkers also reported high concentrations (21 to 28 g/L of serum) of IgG in lambs (mainly Texel × Greyface) at 24 hours. Results of one study reported that serum IgG concentrations in two-day-old lambs were correlated with litter size, date of lambing, age of dam, and duration of gestation.

In the present study, most lambs fed colostrum replacer achieved plasma IgG concentrations typical of acceptable passive transfer by 24 hours of age. The bovine IgG concentration at 24 hours was less than 10 g/L in one of 15 lambs fed the colostrum replacer, indicating failure of passive transfer in this animal. In the remaining lambs, plasma IgG concentrations ranged from 11.1 to 19.7 g/L. These data suggest that IgG derived from bovine plasma is generally well absorbed by newborn lambs during the first 24 hours of life.

Changes in concentration of IgG in plasma of lambs after 24 hours of age is an indication of the catabolism of maternally derived colostral IgG and production of the lamb's own IgG in response to antigenic stimulation. The low IgG concentration at 14 days of age in lambs fed lamb milk replacer indicates little active IgG production from birth to 14 days. It is also interesting to note that the concentration of bovine or ovine IgG in lambs fed colostrum replacer or dam's milk, respectively, did not differ from each other by 14 days. Concentrations of IgG in these lambs declined, but did so to a greater extent in lambs allowed to suckle their dams. Heterologous IgG may have a relatively short half-life in some animals. However, in the present study, bovine IgG provided in colostrum replacer resulted in IgG concentrations at 14 days of age similar to those in lambs allowed to suckle their dams. There are numerous differences in the origin and method of preparation of IgG in colostrum replacer and dam's colostrum that could have contributed to this differential loss of IgG from the circulation from 1 to 14 days of age; further research will be required to determine the nature of this observation.

Because of the low overall mortality in this study, it is not clear whether the bovine IgG would protect animals against endemic ovine
pathogens. Al-Jawad and Lees\(^1\) suggested that feeding blood or serum provided required Igs, but the lack of energy (carbohydrates and fat) may impair the lamb's ability to thermoregulate. The colostrum replacer used in this study contained dextrose, lactose, and animal fat to provide carbohydrates and energy for thermoregulation. It is unlikely, however, that the energy in colostrum replacer was similar to the energy intake by lambs left with the ewe. Furthermore, the lack of viable colostral leukocytes, growth factors, and hormones normally found in maternal colostrum may influence lamb vitality and disease resistance, although this study was not designed to evaluate these factors, nor is the impact of such factors sufficiently well documented to allow their inclusion in a colostrum replacer.

Provision of bovine IgG in a colostrum replacer resulted in bovine IgG concentrations in excess of 10 g of IgG/L of plasma in 14 of 15 lambs at 24 hours of age. By 14 days of age, mean bovine IgG concentration was 10.29 g/L, equivalent to 57% of the concentration at 24 hours. The half-life of bovine IgG appears to be at least 14 days. Most (87%) lambs allowed to nurse the ewe achieved excellent passive transfer of maternal IgG, although two lambs apparently failed to nurse the ewe. Lambs fed lamb milk replacer did not absorb measurable amounts of IgG. Further research is indicated to determine the value of bovine IgG as an alternative to ovine IgG in lambs when ovine colostrum is unavailable.

**ACKNOWLEDGMENTS**

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