Short communication: Apparent efficiency of colostral immunoglobulin G absorption in Holstein heifers

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ABSTRACT

Adequate absorption of bovine colostrum correlates with improved neonatal health. The apparent efficiency of absorption (AEA) of immunoglobulins can be measured using a mathematical equation based on serum and colostral IgG concentration levels, as well as calf body weight and the volume of colostrum being fed. Although commonly measured in research projects, little information is available on the normal AEA across a large group of healthy calves on multiple farms. The purpose of this study was to observe how contributing factors (volume of feeding, birth weight, and time of feeding) can alter AEA and establish a reference range for AEA in healthy calves. Study subjects were 100 Holstein heifer calves from 5 different dairies in North Carolina and Colorado. After a normal calving, the heifer received either 4 or 5.6 L of colostrum within 4 h of birth, an aliquot of the fed colostrum was saved, and a blood sample was collected between 24 and 36 h after birth. Birth weights were measured using the same weight tape on each farm. Radial immunodiffusion assay was performed to obtain IgG concentrations in the colostrum and serum samples. From this data, the AEA was calculated. The AEA ranged from 7.7 to 59.9% with mean of $28.1 \pm 9.5\%$ and median of 27.5%. The AEA of 69% of the calves fell between 21 and 40%. The AEA varied widely between calves, even when feeding was standardized. Results suggest that serum IgG concentration may potentially be increased by feeding increased volumes of colostrum or genetic selection, given the wide range of AEA values obtained. **Key words:** colostrum, apparent efficiency of absorption, transfer of passive immunity

Short Communication

Adequate absorption of bovine colostrum correlates with improved neonatal health (Robison et al., 1988). With a cotyledonary placenta, calves are born agammaglobulinemic, relying completely on the ingestion of high-quality colostrum for adequate transfer of immunoglobulins. Inadequate colostrum intake and absorption can lead to failure of passive transfer (**FPT**), which is responsible for a preweaning mortality of 8% in dairy heifers (Tyler et al., 1998; USDA, 2007) in addition to negatively affected calf growth rates and future milk production (Donovan et al., 1998a,b; DeNise et al., 1989). Unfortunately, the rate of FPT ranges between 13 and 19.2% on dairies, even with the best colostrum feeding-management practices (USDA, 2007).

Absorption of colostral IgG is driven by both colostrum quality and the efficiency of absorption. Most efforts in colostrum management are focused on the colostrum quality. Dam characteristics, such as cow age, parity, and breed, have all been shown to affect colostrum quality (Muller and Ellinger, 1981; Pritchett et al., 1991; Guy et al., 1994; Morin et al., 2001). Certain management factors have also been shown to correlate with colostrum quality, including pooling of colostrum and timing of first milking (Weaver et al., 2000; Moore et al., 2005).

The efficiency of IgG absorption in calves is affected by several other factors, with the timing of feeding being the most critical (Edwards and Broom, 1979; Besser et al., 1985; Michanek et al., 1989; Besser et al., 1991; Davis and Drackley, 1998). It has been documented that optimal enterocyte absorption in calves occurs before 4 and 6 h of life (Besser et al., 1985; Michanek et al., 1989). This is now a key part of colostrum-management recommendations.

The individual variation in efficiency of absorption across calves fed in similar manners is unclear. The apparent efficiency of absorption (**AEA**) of IgG can be calculated based on the calf's weight, the volume of colostrum fed, and the IgG concentrations of both the colostrum and the calf's blood serum. Other research where AEA has been measured has been predominantly

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focused on comparisons between experimental and control groups, without comparison to an established reference; in such studies, mean AEA values of control calves have ranged from 16.3 to 45% (Bush et al., 1971; Baumwart et al., 1977; Arthington et al., 2000a,b; Quigley et al., 2000; Jones et al., 2004; Elizondo-Salazar and Heinrichs, 2009; Ghoreishi et al., 2015). In addition to the variability in reported AEA ranges, limited calf numbers and varying feeding procedures limit the ability to compare these values across studies. In future research, it would be useful to be able to compare treatments to an established AEA range for healthy calves of a given age, breed, and sex. In the present study, it was hypothesized that a normal reference range for AEA would be determined, given the sample size. An additional hypothesis was that increased time to feeding would negatively affect AEA. The purpose of our study was to address this deficit by determining the range of AEA found over a large population of calves across multiple farms, and also to determine how contributing factors (volume of feeding, birth weight, and time of feeding) can alter AEA.

To have a 95% confidence level $\pm 10\%$ confidence, it was calculated that 96 animals were needed; therefore, a total of 100 Holstein heifer calves from 5 different dairies were used in this study. Two of the dairies were privately owned (1,000 and 1,200 lactating cows, located in Colorado) and the remaining 3 were operated either by the North Carolina Department of Agriculture or North Carolina State University (30, 150, and 250 lactating cows). Any heifer born as twin, part of an abnormal delivery, or improperly administered colostrum was excluded. Following normal parturition, heifers were weighed and separated from the dam. Colostrum was fed, by bottle or esophageal tube, within 4 h of birth. For the 3 North Carolina dairies, 4 L of colostrum was administered, and for the 2 Colorado dairies, 3.7 L of colostrum was administered within 4 h of birth and an additional 1.9 L were administered before 12 h of birth. For each calf, a 50-mL aliquot of fed colostrum was retained and stored at -20°C for later IgG measurement. At 24 to 36 h after the birth, serum was collected from each calf, aliquoted, and frozen at -20°C for later IgG measurement.

Colostrum and serum samples were submitted to Prairie Diagnostic Services Inc. (Saskatoon, SK, Canada), where IgG levels were determined by radial immunodiffusion assay (Chelack et al., 1993) using the following reagents: rabbit anti-bovine IgG H^+L (Jackson ImmunoResearch Laboratories Inc., West Grove, PA) as the antiserum incorporated into the gel, bovine reference serum for standard curve (Bethyl Laboratories Inc., Montgomery, TX), and secondary reference

serum (USDA, Animal and Plant Health Inspection Service, Ames, IA) as assay control. Colostrum samples were tested in duplicate at 1:30 with detection range of 22.5 to 180 g/L. Significant hemolysis was noted in some samples. In those samples with duplicates in which one sample was hemolyzed and one was not, IgG was measured in both ($n = 44$). The mean percent reduction in serum IgG (56%) was used to estimate the IgG concentration in those samples in which both samples contained significant hemolysis.

Colostrum and serum IgG concentrations, calf weight, and the volume of colostrum fed were used to determine the AEA of each calf using the following equation:

$$\text{AEA} = \left[\frac{\text{serum IgG concentration (g/L)} \times \text{BW (kg)} \times [0.7 (\text{estimated \% blood volume})]}{\text{colostral IgG concentration (g/L)} \times \text{volume colostrum administered (L)}} \right] \times 100.$$

Statistical analyses were completed using SAS/STAT (ver. 14.1; SAS Institute Inc., Cary, NC). To compare the differences between each group of farms (4 vs. 5.6 L), a Mann-Whitney rank sum test was performed due to the lack of normal distribution. To analyze the correlations between birth weight, time to first feeding, colostrum volume, colostrum IgG concentration, and total IgG, and AEA, a multiple linear regression was used. Visual assessment of the plots were assessed to determine any relationship between the measured variables and AEA.

Calf birth weights were 38.8 ± 0.55 kg (mean $\pm$ SE), and time to first feeding was 70.4 ± 6.0 min (mean $\pm$ standard error). The FPT rate was 2% (both calves fed 4 L), where FPT corresponded to a serum IgG of less than 10 g/L (Besser et al., 1991; Table 1). The AEA was $28.1 \pm 0.96\%$ and AEA values ranged from 7.7% to 59.9% with a median of 27.5%. An AEA of 70% occurred when calves fell between 21 and 40% (Figure 1). Comparisons between calves fed 4 and 5.6 L showed that the mean colostrum IgG concentration was higher in the group receiving 5.6 L ($P = 0.005$), leading to a higher serum IgG concentration ($P = 0.001$). This group also had a higher AEA ($P = 0.043$; Figure 2).

The full multiple linear regression model demonstrated that time to feeding ($P = 0.967$) and colostrum IgG concentration ($P = 0.118$) were not significant and were removed from the model. The reduced model showed calf weight, colostrum volume fed, and total colostrum IgG were significantly correlated with AEA ($r = 0.19$, $P = 0.0002$) with no interactions between the variables. Yet, in spite of this significant result, visual assessment of the plots of AEA versus each of these variables showed no linear relationship.

Table 1. Mean $\pm$ SE IgG concentrations and failure of passive transfer (FPT) of calves fed 4 or 5.6 L of colostrum

Item	Mean serum IgG (g/L)	Mean colostrum IgG (g/L)	FPT calves (%)
Heifers fed 4 L	23.5 $\pm$ 1.3 ^a	58.4 $\pm$ 2.8 ^a	2 ^a
Heifers fed 5.6 L	39.5 $\pm$ 1.7 ^b	69.6 $\pm$ 2.9 ^b	0 ^a
All heifers	31.1 $\pm$ 1.3	63.8 $\pm$ 2.1	2

^{a,b}Significant differences ($P < 0.05$) are denoted by differing superscripts in columns.

The AEA was shown to have a rather broad range in our study, following implementation of generally accepted calf feeding recommendations. In spite of this variability, the rate of failure of transfer of passive immunity was quite low (2%), suggesting that even at the lowest AEA, adequate serum IgG concentrations can be achieved if calves are fed at least 4 L of colostrum within 4 h of birth. As no relationship between AEA and total IgG fed could be identified, IgG absorption does not appear to be a saturable process. This is in contrast to a study by Conneely et al. (2014), which showed an apparent physiological limitation to the amount of IgG absorbed. In that study, calves were fed either 7, 8.5, or 10% of their BW in colostrum; the AEA and mean serum concentrations of IgG were highest for calves fed 8.5% of their BW in colostrum, suggesting a saturation for IgG absorption (Conneely et al., 2014). In our study, separating the larger volume feedings into 2 feedings likely allowed for greater absorption, and affected this assessment. Also, unmeasured colostral components that are being absorbed alongside IgG possibly affect this saturation process (Besser and Gay, 1985).

Time of feeding did not appear to affect AEA in our study, but it must be considered that first feeding oc-

curred within the first 4 h of life for all calves. The AEA has been shown to consistently decrease as age of first feeding increases from 1 to 12 h after birth, when AEA begins to drop off more sharply (Osaka et al., 2014). Such trends are a consequence of permanent physiological changes that occur in the calf's gastrointestinal system by 24 to 30 h of age, which reduce the permeability of the small intestine to large macromolecules (Deutsch and Smith, 1957). Had the time of first feeding in our study been more variable between calves, or had increased past 4 h, lower AEA values would have been expected and perhaps a significant correlation with time of first feeding would have been observed. An example of this is seen in a study by Kruse (1970), in which increases in time of first feeding from 2 to 6, 10, 14, and 20 h was correlated significant decline in absorption of available IgG. Results of the present study, however, suggest that no significant benefit in the form of increased AEA occurs with a change in first feeding time between 0 and 4 h. This is supported by the conclusion of Stott et al. (1979), who demonstrated that the highest rates of absorption occurred during the first 4 h following feeding.

Our study had several limitations, most notably the fact that 2 different volumes of colostrum were admin-

Figure 1. The number of heifers from all the dairies per grouping of percentage of apparent efficiency of absorption (AEA). **Figure 2.** The distribution of calves based on the volume of feeding (either 4 or 5.6 L of colostrum) to the percentage of apparent efficiency of absorption (AEA).

istered to calves. The inclusion of only Holstein heifers in our study, although intentional to identify a reference range for this group, is somewhat limiting when trying to compare this data set to other breeds or to bull calves. Breed (Norman et al., 1981; Muggli et al., 1984) and sex (Odde, 1988; Perino et al., 1995) of the calf may affect AEA, but these findings are difficult to assess due to differences in rates of dystocia in bulls versus heifers and varying maternal colostrum quality across breeds. It is expected that similar studies would need to be conducted for other breeds and bull calves while controlling for dystocia and colostrum quality to appropriately compare individual calves to an established reference range.

In conclusion, our study identifies the range of AEA in Holstein heifers fed at least 4 L of colostrum within 4 h of birth. Given the low rate of FPT in this study, despite the wide range of AEA values, it can be concluded that the colostrum feeding protocols used for this project result in adequate AEA. The timing of feeding does not appear to affect AEA if the calves are fed at least 4 L within 4 h of birth. Feeding a larger volume of colostrum over 2 feedings as done here may improve AEA, but a limit may exist to the total amount of IgG that can be absorbed in a single feeding. For future studies, it would be beneficial to increase the sample size, include bull calves and other breeds, and to include additional variations in colostrum feeding practices into the analyses.

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