J. Dairy Sci. 102:4190–4197
https://doi.org/10.3168/jds.2018-15555

Effect of butyrate on passive transfer of immunity in dairy calves

R. L. Hiltz and A. H. Laarman*
Department of Animal and Veterinary Science, University of Idaho, Moscow 83844-2330

ABSTRACT

The objectives of this study were to determine the effects of supplemental butyrate on (1) Ig production in dams and (2) Ig absorption in their calves. Twenty dry dams fed a close-up total mixed ration were assigned to either a control treatment (CTRL-D) or a butyrate treatment where the close-up total mixed ration was supplemented with butyrate at 1% of dry matter intake (wt/wt; BUT-D). At calving, calves were assigned to 1 of 2 treatments: a control group fed colostrum replacer only (CTRL-C) and a butyrate group fed colostrum replacer with supplemental butyrate at 2.5% (wt/vol; BUT-C). Serum IgG, glucose, and β-hydroxybutyrate were measured weekly in both dams and calves. Additionally, calves were weighed weekly to determine average daily gain. In dams, serum IgG concentration was not different between CTRL-D and BUT-D (1,785 ± 117 vs. 1,736 ± 137 mg/dL, respectively), nor was there a change in Ig levels in the colostrum between control and butyrate groups. Serum total protein did not differ between CTRL-D and BUT-D dams. Dam dry matter intake did not differ between CTRL-D and BUT-D but did decrease 1 wk before parturition. Compared with CTRL-C calves, BUT-C calves had significantly decreased serum IgG concentration at 24 h (2,110 ± 124 vs. 1,400 ± 115 mg/dL), wk 1 (1,397 ± 121 vs. 866 ± 115 mg/dL), and wk 2 (1,310 ± 121 vs. 797 ± 115 mg/dL). Additionally, apparent efficiency of absorption was lower for the BUT-C group compared with the CTRL-C group (35.3 ± 2.1 vs. 25.9 ± 2.0). Differences in serum Ig concentrations between the CTRL-C and BUT-C groups did not affect average daily gain (0.59 ± 0.05 vs. 0.48 ± 0.05 kg/d, respectively), serum glucose concentrations, or serum β-hydroxybutyrate concentrations. These data demonstrate that butyrate inclusion in colostrum negatively affects IgG absorption in newborn calves, whereas calf body weight gains were unaffected.

Received August 14, 2018.
Accepted January 25, 2019.
*Corresponding author: annelaarman@uidaho.edu

Key words: immunoglobulin, passive transfer, butyrate, calf

INTRODUCTION

Managing and improving passive transfer of Ig from dam to calf remains a key determinant in young animal health. Calves are born agammaglobulinemic (i.e., no circulating Ig) due to placental cotyledons that prevent in utero passage of maternal antibodies to the fetus (Borghesi et al., 2014). Consequently, calves' only opportunity for passive transfer of immunity occurs postnatally, through maternal colostrum. The Ig obtained via colostrum is the sole source of antibodies until calves start to produce their own Ig in sufficient quantities. Obtaining colostral Ig is therefore of utmost importance to calf health.

Without adequate absorption of colostral Ig into the bloodstream, calves experience failure of passive transfer of immunity. Between 32 and 41% of calves experience failure of passive transfer of immunity, and this incidence has changed little in the last 20 yr (Tyler et al., 1999; Beam et al., 2009; Windeyer et al., 2014). Currently, the threshold for failure of passive transfer of immunity is a blood IgG concentration below 10 mg/mL or a serum total protein concentration below 5.2 to 5.5 g/dL at 24 to 48 h of life (Moore, 2012; Windeyer et al., 2014). Promoting passive transfer of immunity, and thereby preventing failure of passive transfer of immunity, is the underlying drive for feeding colostrum.

Two main factors determine the success or failure of passive transfer of immunity: the dam's ability to produce sufficient Ig and transport them into the colostrum, and the calf's ability to uptake those Ig into circulation (Weaver et al., 2000). Little is known about the actual method of production and transport of Ig into colostrum (Porter, 1972; Jang et al., 2017), though some research points to FcRn receptors as a possible method of transport into the mammary gland (Mayer et al., 2005; Cervenak and Kacskovics, 2009). In calves, absorption of IgG is nonselective (Staley et al., 1972); therefore, FcRn receptors are unlikely to play a role in IgG absorption. Furthermore, Ig absorption is time dependent because absorption capacity declines rapidly

after 12 h of life and gut closure (the inability of the small intestine to absorb macromolecules) is complete around d 1 of life (Stott et al., 1979). Increasing maternal production of Ig and calf Ig absorption rates is key to improving passive transfer of immunity in calves.

Improving production and absorption of Ig may be possible through dietary butyrate supplementation. Supplemental butyrate has been shown to have positive effects on VFA absorption (Laarman et al., 2013b), epithelial energy availability (Bergman, 1990; Laarman et al., 2013a), and IgG concentration in porcine colostrum (Jang et al., 2017), highlighting butyrate's ability to increase transepithelial transport capacity. When pregnant sows are fed supplemental butyrate, piglets born from those sows have higher IgG concentrations (Fang et al., 2014). In young livestock, butyrate supplementation in liquid feed has been shown to have stimulatory effects on small intestine development in calves (Górka et al., 2018) and a tendency to increase circulating IgA concentrations in piglets (Jang et al., 2017).

Currently, little is known about the effect of butyrate on IgG production in cows and subsequent effects on IgG absorption in calves. Therefore, the objectives of this study were to determine the effect of supplemental butyrate on IgG production in pregnant cows and IgG absorption in calves. We hypothesized that butyrate supplementation would increase colostral IgG concentrations in cows and increase Ig absorption in calves.

MATERIALS AND METHODS

Animals, Feeding, and Treatments

All animal procedures were approved by the Institutional Animal Care and Use Committee of the University of Idaho, Moscow (AUP 2017-33).All cattle were housed in a tiestall facility and calves were individually housed in pens at the Palouse Research, Extension, and Education Center (University of Idaho, Moscow). All animals had unlimited access to water.

Twenty multiparous, late-pregnancy Holstein cows were fed a dry close-up cow TMR ad libitum. Dams were blocked by BW and assigned to either control (**CTRL-D**; n = 10) or butyrate (**BUT-D**; n = 10) treatments (672 ± 80 vs. 694 ± 71 kg, respectively; $P = 0.54$). Using 10 animals per treatment allows detection of 15% difference between treatments with 80% power when coefficient of variation within treatment is 10% (Berndtson, 1991). Three weeks before expected calving date, dams in BUT-D received supplemental butyrate at a manufacturer-recommended rate of 1% of their DMI as a rumen-protected butyrate supplement (Ultramix C, Nutriad, Hampshire, IL), whereas CTRL-D dams received no supplement. Treatments were top dressed to ensure that all treatment was consumed during morning feeding at 0700 h until calving. All cows were fed a close-up TMR twice daily (0700 and 1800 h) ad libitum with targeted orts of 5 to 10%. At calving, cows were removed from the study.

All calves received 200 g of IgG in 4 L of colostrum replacer (Sav-a-Calf, Milk Products LLC, Chilton, WI) between 30 min and 2 h after birth; all births were observed and normal. Calves were allowed to suckle and, if unwilling to finish the full 4 L, were given the rest via an esophageal feeder. Only 1 calf suckled the entire 4 L and did not need to be tubed via the esophageal feeder. Calves were assigned to 2 groups, balancing for BW at birth and dam treatment. In one group, calves received a non-rumen-protected butyrate supplement (Ultramix GF, Nutriad) in their colostrum at 2.5% (wt/vol; **BUT-C**), whereas control calves did not receive supplement (**CTRL-C**). Calves were not blocked by sex; distribution included 5 bulls and 4 heifers in BUT-C and 6 bulls and 3 heifers in CTRL-C. Treatments were assigned such that half of the CTRL-C calves came from BUT-D dams and half came from CTRL-D dams, and half of BUT-C calves came from BUT-D dams and half came from CTRL-D dams. Butyrate dosage was based on a previous study (Laarman et al., 2013a) in which butyrate dosed at 2.5% of DM was effective in increasing short-chain fatty acid uptake capacity in lactating cows. All calves received whole milk and ad libitum starter until weaning.

Sample Collection and Analysis

Samples of TMR were taken 3 times per week, composited, and dried in a convection oven at 60°C for 48 h to obtain DM values. Butyrate treatment calculations were then adjusted according to the adjusted DM of the TMR. Weekly, composite TMR samples were analyzed for nutrient composition (Cumberland Valley Analytical Services, Waynesboro, PA).

For the dams, blood serum was collected weekly until calving and within 30 min of parturition (Vacutainer, Becton Dickinson, Franklin Lakes, NJ). Samples were centrifuged at 1,693 × *g* for 20 min at 4°C and, when separated, serum was collected and stored at −20°C. Colostrum was collected at first milking (0700 or 2000 h) and was also frozen at −20°C. Both blood and colostrum samples were analyzed for IgG concentration (Bovine IgG Test Kit, Triple J Farms, Bellingham, WA) and for total protein via refractometer (Misco Refractometers, Solon, OH).

For calves, BW was measured at birth and then weekly until weaning. Calf serum was collected before colostrum feeding, then daily for the first 3 d of life, and then weekly until weaning. Samples were collected and

centrifuged at 1,693 × *g* for 20 min at 4°C and, when separated, serum was collected and stored at −20°C. Calf serum was examined for IgG content, glucose (Glucose Auto Kit, Fujifilm Wako Diagnostics, Mountain View, CA), and BHB concentrations at all time points (3-HB Auto Kit, Fujifilm Wako Diagnostics).

Calf apparent efficiency of absorption (**AEA**) was calculated based on the equation by Quigley et al. (1998):

$$\text{AEA} = \frac{\text{plasma IgG}\left(\text{g/L}\right) \times \text{BW}\left(\text{kg}\right) \times 0.089\left(\text{L/kg}\right)}{\text{IgG intake}\left(\text{g}\right)} \times 100\%.$$

Statistics

Statistical analysis was performed using the MIXED procedure of SAS version 9.4 (SAS Institute Inc., Cary, NC). For variables with repeated measures, the statistical model used was

$$Y = \mu + T_i + D_j + T \times D_{ij} + \varepsilon_{ijk},$$

where Y is the dependent variable, μ is the mean, T_i is the time, D_j is the diet term, $T \times D_{ij}$ is the interaction of time and diet, and ε_{ijk} is the residual error. Animal was used as the subject of repeated measures. Five variance–covariance structures were tested, and the variance–covariance structure with the lowest Akaike information criterion was selected for the analysis. A Tukey post hoc test was used to differentiate different time points. For variables without repeated measures, the statistical model used was

$$Y = \mu + D_j + \varepsilon_{ijk},$$

where Y is the dependent variable, μ is the mean, D_j is the diet term, and ε_{ijk} is the residual error. Correlation analysis was done using PROC CORR in SAS version 9.4.

RESULTS

Effect of Butyrate Supplementation on Dams

One dam was removed from the study due to being confirmed open. Another dam had stillborn calves, so no calves were allocated to the calf portion of the study. There was no difference in serum IgG concentrations for CTRL-D versus BUT-D (1,785 ± 117 vs. 1,736 ± 137 mg/dL, respectively; $P = 0.79$; Figure 1). Serum total protein values did not differ between CTRL-D and BUT-D (6.65 ± 0.13 vs. 6.39 ± 0.14 g/dL; $P = 0.26$). Colostrum IgG levels were also unchanged between CTRL-D and BUT-D, with a wide range of Ig concentrations obtained overall (160 ± 72.1 vs. 117 ± 35.1 g/L, respectively; $P = 0.46$). Similar results were obtained with colostral total protein values for CTRL-D and BUT-D (6.65 ± 0.13 vs. 6.39 ± 0.14 g/dL, respectively; $P = 0.20$; Figure 2) even though the correlation between Ig concentration and total protein level is not excellent (r = 0.17, $P = 0.05$). Additionally, dam DMI was unaffected by treatment for CTRL-D and BUT-D (14.1 ± 1.34 vs. 14.1 ± 0.93 kg/d, respectively; $P = 0.52$; Figure 3). Calving date deviation from expected date of birth did not change due to treatment (−1.7 ± 1.7 vs. −5.4 ± 1.6 d for CTRL-D and BUT-D, respectively; $P = 0.26$).

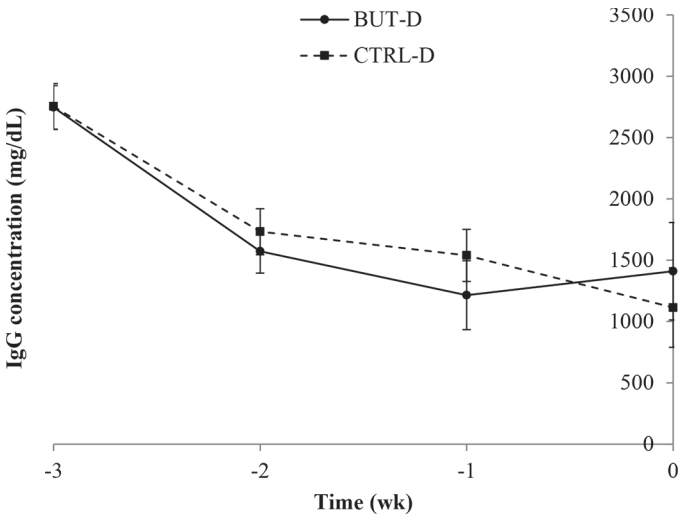

Figure 1. Serum IgG concentrations relative to calving of cows fed a close-up TMR (CTRL-D) or a close-up TMR with top-dressed butyrate included at 1% of DMI (BUT-D). Butyrate supplementation at 1% of DMI did not affect serum IgG concentration in dams ($P = 0.75$), but there was a decrease in serum IgG over time ($P < 0.01$). Error bars display SEM.

Effect of Butyrate Supplementation on Calves

Eighteen calves were born live and were separated into 2 treatment groups, balancing for dam treatment and BW (40.0 ± 0.8 vs. 39.6 ± 0.8 kg for CTRL-C and BUT-C, respectively; $P = 0.75$). Between bulls and heifers, BW at birth differed (43.1 ± 0.7 vs. 36.4 ± 0.8 kg; $P < 0.05$). At 24 h, serum IgG concentrations did not differ between bulls and heifers (1,906 ± 96 vs. 1,906 ± 113 mg/dL, respectively; $P = 0.99$), but serum IgG values were significantly higher for CTRL-C compared with BUT-C (2,110 ± 124 vs. 1,400 ± 115 mg/dL; $P < 0.01$). The difference in serum IgG concentrations between CTRL-C and BUT-C was sus-

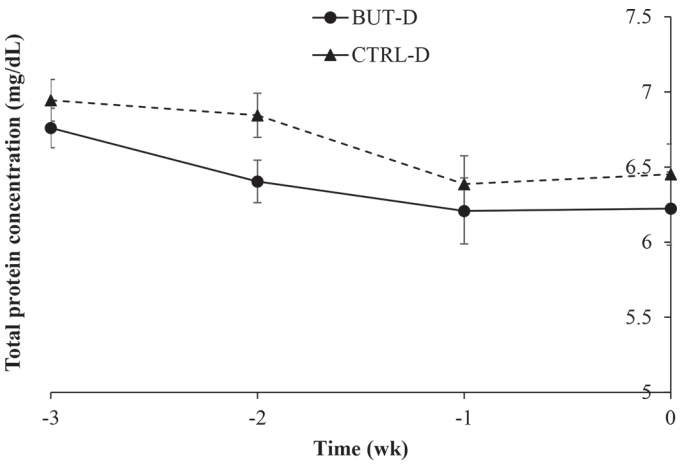

Figure 2. Dam serum total protein values relative to calving of cows fed a close-up TMR (CTRL-D) or a close-up TMR with top-dressed butyrate included at 1% of DMI (BUT-D). Butyrate supplementation at 1% did not affect serum total protein values in dams ($P = 0.26$), but there was a decrease in serum total protein over time ($P < 0.01$). Error bars display SEM.

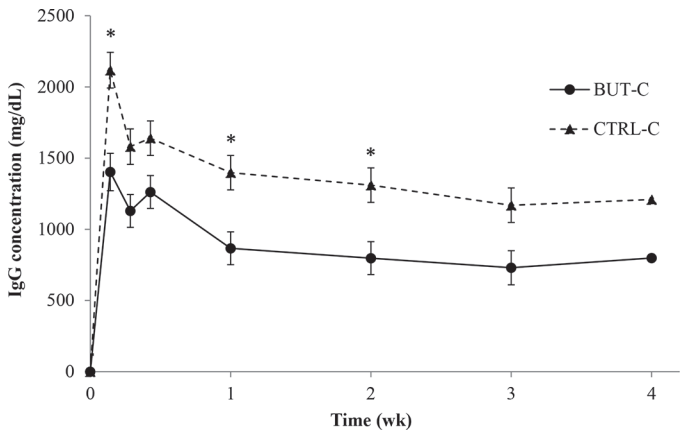

Figure 4. Calf serum IgG concentration by week of age for calves receiving colostrum replacer (CTRL-C) and calves receiving colostrum replacer supplemented with 2.5% butyrate (wt/vol; BUT-C). Butyrate supplementation decreased IgG values in BUT-C at 24 h of life ($P < 0.01$), wk 1 ($P = 0.03$), and wk 2 ($P = 0.05$). There was a diet × time interaction ($P = 0.04$). Additionally, serum IgG concentrations decreased over time ($P < 0.01$). Error bars display SEM; asterisks mark weeks in which BUT-C and CTRL-C are different ($P \leq 0.05$).

tained through wk 1 (1,397 ± 121 vs. 866 ± 115 mg/dL; $P = 0.03$) and wk 2 (1,310 ± 121 vs. 797 ± 115 mg/dL; $P < 0.05$; Figure 4). Additionally, serum total protein trended higher for CTRL-C versus BUT-C and was significantly higher at 4 wk of age (6.04 ± 0.17 vs. 5.21 ± 0.17 g/dL, respectively; $P = 0.03$; Figure 5). In calves, serum total protein tended to be weakly correlated with serum IgG (r = 0.17, $P = 0.06$; Figure 6).

Calf serum glucose values were unaffected by treatment (104 ± 2.33 vs. 108 ± 2.37 mg/dL; $P = 0.23$; Figure 7). Serum BHB concentrations also remained unchanged between CTRL-C and BUT-C (1.03 ± 0.051 vs. 0.872 ± 0.052 mg/dL, respectively; $P = 0.98$; Figure 8) but increased steadily by week ($P < 0.01$). Calf ADG was not significantly different between CTRL-C and BUT-C (0.59 ± 0.5 vs. 0.48 ± 0.5 kg/d; $P = 0.43$; Figure 9). Calf AEA at 24 h of life was significantly

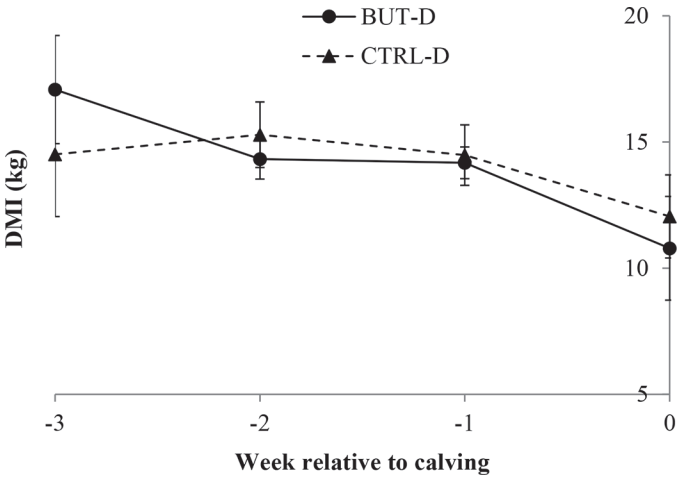

Figure 3. Dam DMI by week relative to calving of cows fed a close-up TMR (CTRL-D) or a close-up TMR with top-dressed butyrate included at 1% of DMI (BUT-D). Butyrate supplementation at 1% did not affect DMI in dams ($P = 0.52$), but there was a trend for decreasing DMI over time ($P = 0.06$). Error bars display SEM.

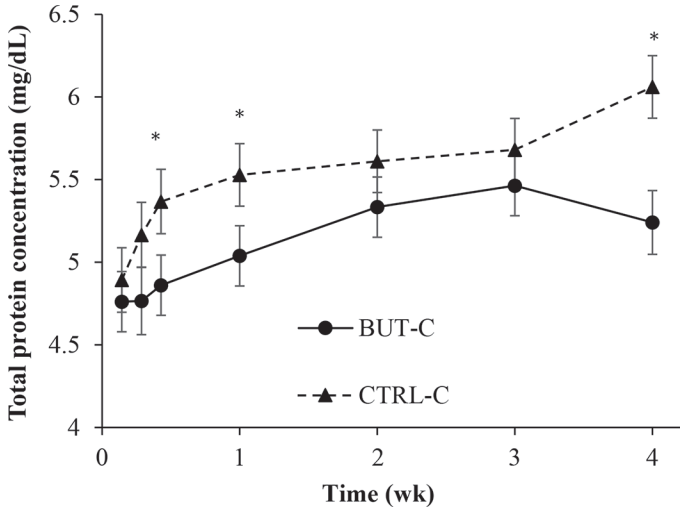

Figure 5. Calf serum total protein concentrations by week of life for calves receiving colostrum replacer (CTRL-C) and for calves receiving colostrum replacer supplemented with 2.5% butyrate (wt/vol; BUT-C). Butyrate supplementation decreased total protein values for BUT-C at wk 4 of life ($P = 0.03$). There was no diet × time interaction ($P = 0.39$). Error bars display SEM; asterisks mark weeks in which BUT-C and CTRL-C are different ($P \leq 0.05$).

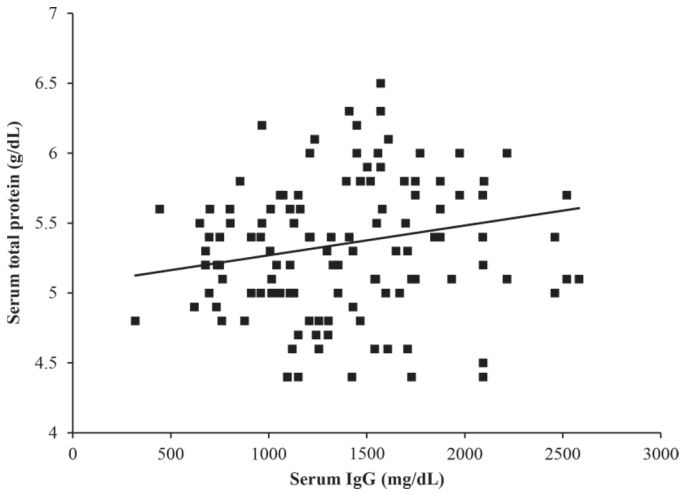

Figure 6. Correlation between serum IgG and total protein concentrations in calves fed a colostrum replacer (r = 0.17, $P = 0.06$).

higher for the CTRL-C group compared with the BUT-C group (35.3 ± 2.1 vs. 25.9 ± 2.0; $P < 0.01$; Table 1) and differed between bulls and heifers (33.8 ± 1.8 vs. 27.4 ± 2.2, respectively; $P = 0.05$). Apparent efficiency of absorption was strongly correlated with serum IgG concentration (r = 0.86; $P < 0.01$) but not with BW at birth.

DISCUSSION

In this experiment, we investigated the effects of supplemental butyrate on Ig production in dams and on Ig absorption in calves. We found that dams showed no response to butyrate in serum or in colostral IgG concentrations. The dose used for dams was based on the manufacturer's recommendation and was coated to ensure palatability. At the inclusion rate of 1%, the butyrate-supplemented TMR had 0.6% inclusion of palm oil; because the supplement was top dressed, the TMR was not separately analyzed. The butyrate dose for calves was based on a previous study in which ruminal dosing with butyrate at 2.5% of DMI increased

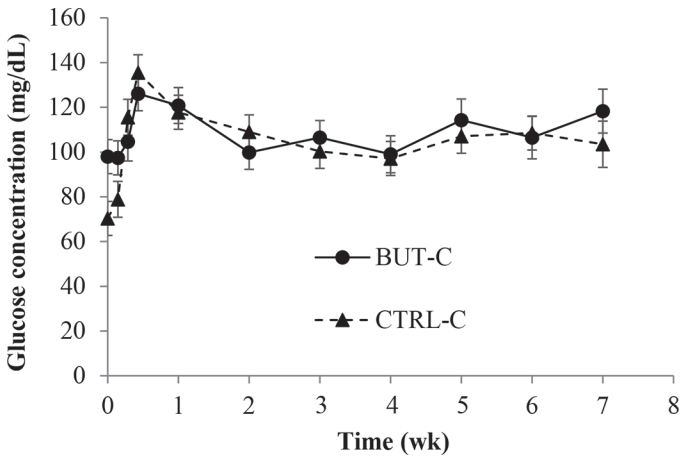

Figure 7. Calf serum glucose concentrations by week of life for calves receiving colostrum replacer (CTRL-C) and calves receiving colostrum replacer supplemented with 2.5% butyrate (wt/vol; BUT-C). Butyrate supplementation did not affect glucose concentration ($P = 0.23$). Error bars display SEM.

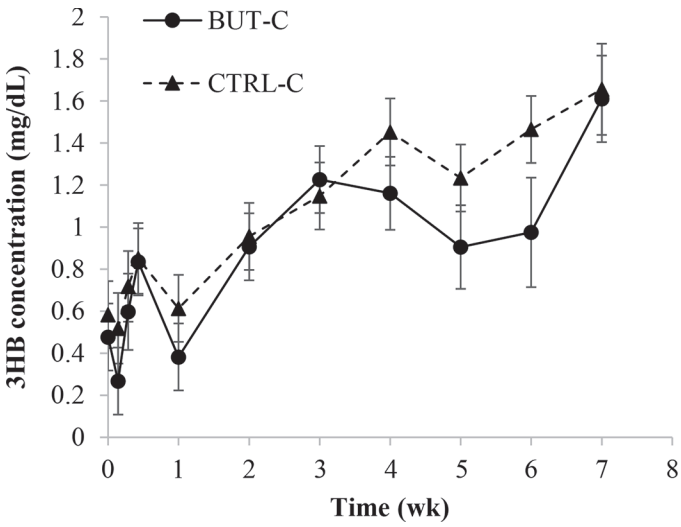

Figure 8. Calf serum 3-hydroxybutyrate (3HB) concentrations by week of life for calves receiving colostrum replacer (CTRL-C) and for calves receiving colostrum replacer supplemented with 2.5% butyrate (wt/vol; BUT-C). Butyrate supplementation did not have an effect on 3-hydroxybutyrate concentration ($P = 0.98$). Error bars display SEM.

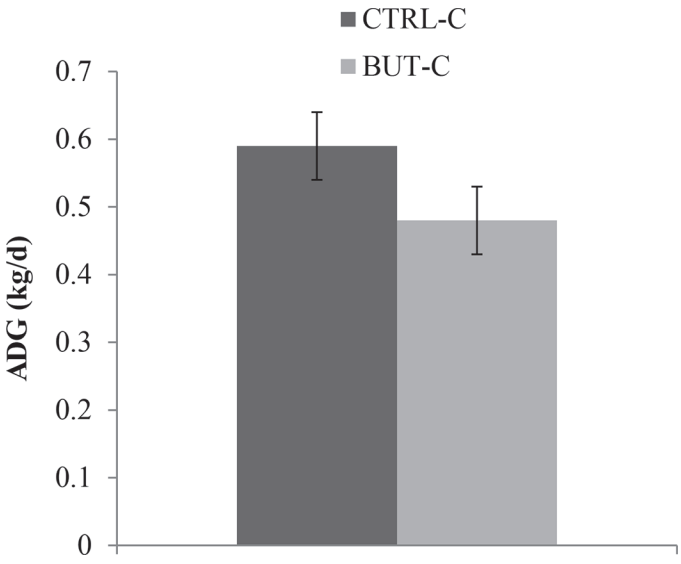

Figure 9. Calf ADG for calves receiving colostrum replacer (CTRL-C) and calves receiving colostrum replacer supplemented with 2.5% butyrate (wt/vol; BUT-C). Butyrate supplementation did not affect ADG ($P = 0.43$). Error bars display SEM.

absorption capacity of short-chain fatty acids (Laarman et al., 2013a).

Effect of Butyrate Supplementation on Dams

In the current study, no differences were seen between BUT-D and CTRL-D for IgG concentration in colostrum, which may be due to the variability in colostrum collection times. Colostrum was collected at the milking time immediately following calving; milking times were 0700, 1000, 2000, and 2300 h; thus, the range of time to first milking was between 1.5 and 10.5 h postpartum. Colostrum collected at 6, 10, and 14 h postpartum has been observed to have significantly lower IgG concentration compared with colostrum collected 2 h postpartum (Moore et al., 2005). The variability in time from calving to colostrum harvest likely explains much of the variation in colostrum quality and the lack of significant differences between treatments.

In addition to colostrum harvest times, butyrate dosage may partly explain the lack of differences in colostral IgG. In sows, butyrate increased colostral IgG production at 500 mg/kg but not 1,000 mg/kg (Jang et al., 2017). The supplement fed in the current study was rumen protected, so the butyrate was absorbed in the small intestine, like in monogastric species. Butyrate might only affect IgG concentrations in colostrum at very low concentrations. More research is needed on the dose response of the bovine small intestine to dietary butyrate supplementation.

Limited information is available on the production and transport of Ig into colostrum for both monogastrics and ruminants (Baumrucker et al., 2010; Jang et al., 2017). Butyrate released into the small intestine is absorbed into the peripheral blood supply and passed through the liver. More than 80% of butyrate is metabolized in 1 pass through the liver (Hocquette and Bauchart, 1999), so there may be limited potential for dietary supplementation of butyrate to affect mammary transport of IgG into colostrum.

Effects of Butyrate on IgG Absorption in Calves

This study showed that butyrate supplementation of colostrum decreased serum IgG concentrations. Despite lower serum IgG concentrations, ADG was not affected by butyrate supplementation in colostrum. In calves, IgG absorption is nonselective in the small intestine (Staley et al., 1972), ruling out an effect of butyrate on FcRn receptors. Additionally, paracellular transport is unlikely to be a significant transport route because no degradation or morphological changes in tight junctions between cells are observed in the first 24 h of life (Jochims et al., 1994). In calves, therefore, pinocytosis is likely the principal IgG absorption route and the likeliest mechanism of action by butyrate.

Butyrate actively promotes cell differentiation and proliferation (Hamer et al., 2009; Górka et al., 2014) through inhibition of histone deacetylase complex 1 (Davie, 2003). In calves fed sodium butyrate, mid-jejunum epithelial cells had higher mitotis:apoptosis ratios, indicating faster maturation rate in those epithelial cells (Górka et al., 2014). Calf intestinal pinocytotic activity is lost in the first 24 h of life as epithelial cells mature (Jochims et al., 1994). Faster maturation rates would lead to a decreased window for IgG absorption. In this study, butyrate may be reducing IgG absorption by increasing cell differentiation rates, causing epithelial cells to mature earlier, thus reducing the amount of time during which the epithelial cells have the full pinocytic activity needed for IgG absorption.

It is possible, but unlikely, that AEA was reduced because of IgG–butyrate binding. Evidence exists of IgG binding to strains of *Streptococcus* spp. and *Staphylococcus* spp. (Björck and Kronvall, 1984; Moks et al., 1986); however, we are unaware of any evidence for IgG

Table 1. Calf sex distribution by treatment, calf birth weight by treatment and by sex, apparent efficiency of absorption (AEA) at 24 h by treatment and by sex, and ADG by treatment and by sex (LSM ± SD)[1]

	Treatment[2]			Calf sex		
Item	CTRL-C	BUT-C	*P*-value	Heifer	Bull	*P*-value
Calf sex (no.)						
Heifer	3	4				
Bull	6	5				
Birth weight (kg)	39.6 ± 0.84	39.9 ± 0.81	0.74	36.4 ± 0.90	43.1 ± 0.74	<0.01
AEA (%)	35.3 ± 2.08	25.9 ± 1.99	<0.01	27.3 ± 2.22	33.8 ± 1.83	0.04
ADG (kg/d)	0.59 ± 0.50	0.48 ± 0.50	0.43	0.52 ± 0.05	0.49 ± 0.04	0.64

[1]Butyrate supplementation and sex had an effect on AEA, but there was no interaction of treatment and sex ($P = 0.30$).

[2]At calving, calves were assigned to 1 of 2 treatments: a control group fed colostrum replacer only (CTRL-C) and a butyrate group fed colostrum replacer with supplemental butyrate at 2.5% (wt/vol; BUT-C).

binding to organic acids. Additionally, colostrum and whole milk naturally contain low concentrations of butyrate, and recent reviews of physiological effects and mechanisms of butyrate show no evidence of butyrate binding to organic acids (Górka et al., 2018).

Other factors affect AEA, including breed, age at first feeding, sex of the calf, and volume of colostrum administered (Quigley and Drewry, 1998), which were controlled by the experimental design of this study. Additionally, abomasal emptying rate should be considered because it explains 22% of AEA variation (Mokhber-Dezfooli et al., 2012) and may affect AEA if abomasal emptying occurs after 12 h of life. When colostrum is fed in the first 12 h of life, hourly declines in AEA range from 2.4 to 3.3% (Mokhber-Dezfooli et al., 2012; Osaka et al., 2014). Consequently, some exploration of variance in abomasal emptying rates is warranted.

Factors affecting abomasal clearance are the physicochemical properties of colostrum such as pH, osmolarity, volume administered, and caloric density. In our study, post hoc analysis showed that butyrate increased the pH of the colostrum replacer from 5.28 ± 0.02 to 5.90 ± 0.02. Between colostral pH 5.0 and 7.5, however, there is no difference in AEA in calves (Quigley et al., 2000), so it is unlikely that the pH change by butyrate supplementation would affect AEA. Additionally, the effect of osmolarity on abomasal emptying of colostrum is mixed. Osmolarity of 600 mOsm in milk replacer slows abomasal emptying (Sen et al., 2006), whereas addition of 300 m*M* sodium bicarbonate may cause AEA to increase (Morrill et al., 2010) or decrease (Cabral et al., 2014). Osmolarity increased from 276 ± 21 to 921 ± 3 mOsm when the supplement was added and therefore may affect abomasal emptying rates. Creating isotonic solutions between treatments was impractical because the supplemented colostrum would require an additional 2.5 L of water, which exceeds abomasal capacity. Therefore, it is possible that abomasal emptying rate was affected by butyrate supplementation but unclear in which direction, given previous results from bicarbonate supplementation.

There were several limitations to this study. One limitation was the use of colostrum replacer as opposed to maternal colostrum, which may include biological factors that affect absorption. Another limitation is that calf health may affect growth; due to low calf number and resulting statistical power, presence or absence of morbidity was not measured. Although all calves were raised in the same environment (individual housing, feeding, ambient temperature), examination of length of morbidity could give additional insight into the effect of decreased IgG levels on growth and health during early calfhood. Last, the relatively short length of the calf component of this study did not allow for a full examination of the effect on calf productivity and is a useful target for future studies.

CONCLUSIONS

In cows, butyrate supplementation in the dry period did not affect colostrum IgG concentrations or DMI. In calves, however, butyrate supplementation of colostrum decreased serum IgG concentrations. Future research should investigate mechanisms of IgG production in dams to understand why an increase in colostral IgG was seen in monogastrics but not in ruminants. Additionally, future research should examine the role of butyrate in enterocyte maturation in calves and its resulting effect on Ig absorption.

ACKNOWLEDGMENTS

Funding for this project was provided by the American Jersey Cattle Association (FY2017; Reynoldsburg, OH), Nutriad Inc. (Hampshire, IL), USDA Multi-State Hatch (NC-2040), the Department of Animal and Veterinary Science, University of Idaho, Moscow, and the Idaho Agricultural Experiment Station. The authors thank the University of Idaho dairy staff and Laarman laboratory members for technical assistance.

REFERENCES

Baumrucker, C. R., A. M. Burkett, A. L. Magliaro-Macrina, and C. D. Dechow. 2010. Colostrogenesis: Mass transfer of immunoglobulin G1 into colostrum. J. Dairy Sci. 93:3031–3038. https://doi.org/10.3168/jds.2009-2963.

Beam, A. L., J. E. Lombard, C. A. Kopral, L. P. Garber, A. L. Winter, J. A. Hicks, and J. L. Schlater. 2009. Prevalence of failure of passive transfer of immunity in newborn heifer calves and associated management practices on US dairy operations. J. Dairy Sci. 92:3973–3980. https://doi.org/10.3168/jds.2009-2225.

Bergman, E. N. 1990. Energy contributions of volatile fatty acids from the gastrointestinal tract in various species. Physiol. Rev. 70:567–590. https://doi.org/10.1152/physrev.1990.70.2.567.

Berndtson, W. E. 1991. A simple, rapid and reliable method for selecting or assessing the number of replicates for animal experiments. J. Anim. Sci. 69:67–76. https://doi.org/10.2527/1991.69167x.

Björck, L., and G. Kronvall. 1984. Purification and some properties of streptococcal protein G, a novel IgG-binding reagent. J. Immunol. 133:969–974.

Borghesi, J., L. C. Mario, M. N. Rodrigues, P. O. Favaron, and M. A. Miglino. 2014. Immunoglobulin transport during gestation in domestic animals and humans—A review. Open J. Anim. Sci. 4:323–336. https://doi.org/10.4236/ojas.2014.45041.

Cabral, R. G., M. A. Cabral, C. E. Chapman, E. J. Kent, D. M. Haines, and P. S. Erickson. 2014. Colostrum replacer feeding regimen, addition of sodium bicarbonate, and milk replacer: The combined effects on absorptive efficiency of immunoglobulin G in neonatal calves. J. Dairy Sci. 97:2291–2296. https://doi.org/10.3168/jds.2013-7007.

Cervenak, J., and I. Kacskovics. 2009. The neonatal Fc receptor plays a crucial role in the metabolism of IgG in livestock animals. Vet. Immunol. Immunopathol. 128:171–177. https://doi.org/10.1016/j.vetimm.2008.10.300.

Davie, J. R. 2003. Inhibition of histone deacetylase activity by butyrate. J. Nutr. 133:2485S–2493S. https://doi.org/10.1093/jn/133.7.2485S.

Fang, C. L., H. Sun, J. Wu, H. H. Niu, and J. Feng. 2014. Effects of sodium butyrate on growth performance, haematological and immunological characteristics of weanling piglets. J. Anim. Physiol. Anim. Nutr. (Berl.) 98:680–685. https://doi.org/10.1111/jpn.12122.

Górka, P., Z. M. Kowalski, R. Zabielski, and P. Guilloteau. 2018. Invited review: Use of butyrate to promote gastrointestinal tract development in calves. J. Dairy Sci. 101:4785–4800. https://doi.org/10.3168/jds.2017-14086.

Górka, P., P. Pietrzak, A. Kotunia, R. Zabielski, and Z. M. Kowalski. 2014. Effect of method of delivery of sodium butyrate on maturation of the small intestine in newborn calves. J. Dairy Sci. 97:1026–1035. https://doi.org/10.3168/jds.2013-7251.

Hamer, H. M., D. Jonkers, A. Bast, S. Vanhoutvin, M. Fischer, A. Kodde, F. J. Troost, K. Venema, and R.-J. Brummer. 2009. Butyrate modulates oxidative stress in the colonic mucosa of healthy humans. Clin. Nutr. 28:88–93. https://doi.org/10.1016/j.clnu.2008.11.002.

Hocquette, J.-F., and D. Bauchart. 1999. Intestinal absorption, blood transport and hepatic and muscle metabolism of fatty acids in preruminant and ruminant animals. Reprod. Nutr. Dev. 39:27–48.

Jang, Y. D., M. D. Lindemann, H. J. Monegue, and J. S. Monegue. 2017. The effect of coated sodium butyrate supplementation in sow and nursery diets on lactation performance and nursery pig growth performance. J. Livest. Sci. 195:13–20. https://doi.org/10.1016/j.livsci.2016.11.005.

Jochims, K., F. J. Kaup, W. Drommer, and M. Pickel. 1994. An immunoelectron microscopic investigation of colostral IgG absorption across the intestine of newborn calves. Res. Vet. Sci. 57:75–80.

Laarman, A. H., L. Dionissopoulos, O. AlZahal, S. L. Greenwood, M. A. Steele, and B. W. McBride. 2013a. Butyrate and subacute ruminal acidosis affect abundance of membrane proteins involved with proton and short chain fatty acid transport in the rumen epithelium of dairy cows. Am. J. Anim. Vet. Sci. 8:220–229. https://doi.org/10.3844/ajavssp.2013.220.229.

Laarman, A. H., L. Dionissopoulos, O. AlZahal, M. A. Steele, S. L. Greenwood, J. C. Matthews, and B. W. McBride. 2013b. Butyrate supplementation affects mRNA abundance of genes involved in glycolysis, oxidative phosphorylation and lipogenesis in the rumen epithelium of Holstein dairy cows. Am. J. Anim. Vet. Sci. 8:239–245. https://doi.org/10.3844/ajavssp.2013.239.245.

Mayer, B., M. Doleschall, B. Bender, J. Bartyik, Z. Bősze, L. V. Frenyó, and I. Kacskovics. 2005. Expression of the neonatal Fc receptor (FcRn) in the bovine mammary gland. J. Dairy Res. 72:107–112. https://doi.org/10.1017/S0022029905001135.

Mokhber-Dezfooli, M. R., M. Nouri, M. Rasekh, and P. D. Constable. 2012. Effect of abomasal emptying rate on the apparent efficiency of colostral immunoglobulin G absorption in neonatal Holstein-Friesian calves. J. Dairy Sci. 95:6740–6749. https://doi.org/10.3168/jds.2012-5926.

Moks, T., L. Abrahmsén, B. Nilsson, U. Hellman, J. Sjöquist, and M. Uhlén. 1986. Staphylococcal protein A consists of five IgG-binding domains. Eur. J. Biochem. 156. https://doi.org/10.1111/j.1432-1033.1986.tb09625.x.

Moore, M., J. Tyler, M. Chigerwe, M. E. Dawes, and J. R. Middleton. 2005. Effect of delayed colostrum collection on colostral IgG concentration in dairy cows. J. Am. Vet. Med. Assoc. 226:1375–1377. https://doi.org/10.2460/javma.2005.226.1375.

Moore, S. 2012. Monitoring failure of passive transfer in calves. Accessed Nov. 2, 2018. http://msue.anr.msu.edu/news/monitoring_failure_of_passive_transfer_in_calves.

Morrill, K. M., S. P. Marston, N. L. Whitehouse, M. E. Van Amburgh, C. G. Schwab, D. M. Haines, and P. S. Erickson. 2010. Anionic salts in the prepartum diet and addition of sodium bicarbonate to colostrum replacer, and their effects on immunoglobulin G absorption in the neonate. J. Dairy Sci. 93:2067–2075. https://doi.org/10.3168/jds.2009-2622.

Osaka, I., Y. Matsui, and F. Terada. 2014. Effect of the mass of immunoglobulin (Ig)G intake and age at first colostrum feeding on serum IgG concentration in Holstein calves. J. Dairy Sci. 97:6608–6612. https://doi.org/10.3168/jds.2013-7571.

Porter, P. 1972. Immunoglobulins in bovine mammary secretions. Immunology 23:225–238.

Quigley, J. D., III, and J. Drewry. 1998. Practical considerations in transition cow and calf management: Nutrient and immunity transfer from cow to calf pre- and postcalving. J. Dairy Sci. 81:2779–2790. https://doi.org/10.3168/jds.S0022-0302(98)75836-9.

Quigley, J. D., III, J. J. Drewry, and K. R. Martin. 1998. Estimation of plasma volume in Holstein and Jersey calves. J. Dairy Sci. 81:1308–1312. https://doi.org/10.3168/jds.S0022-0302(98)75693-0.

Quigley, J. D., III, P. French, and R. E. James. 2000. Short communication: Effect of pH on absorption of immunoglobulin G in neonatal calves. J. Dairy Sci. 83:1853–1855. https://doi.org/10.3168/jds.S0022-0302(00)75056-9.

Sen, I., P. D. Constable, and T. S. Marshall. 2006. Effect of suckling isotonic or hypertonic solutions of sodium bicarbonate or glucose on abomasal emptying rate in calves. Am. J. Vet. Res. 67:1377–1384. https://doi.org/10.2460/ajvr.67.8.1377.

Staley, T. E., L. D. Corley, L. J. Bush, and E. W. Jones. 1972. The ultrastructure of neonatal calf intestine and absorption of heterologous proteins. Anat. Rec. 172:559–579. https://doi.org/10.1002/ar.1091720310.

Stott, G. H., D. B. Marx, B. E. Menefee, and G. T. Nightengale. 1979. Colostral immunoglobulin transfer in calves I. Period of absorption. J. Dairy Sci. 62:1632–1638. https://doi.org/10.3168/jds.S0022-0302(79)83472-4.

Tyler, J. W., D. D. Hancock, J. G. Thorne, C. C. Gay, and J. M. Gay. 1999. Partitioning the mortality risk associated with inadequate passive transfer of colostral immunoglobulins in dairy calves. J. Vet. Intern. Med. 13:335–337.

Weaver, D. M., J. W. Tyler, D. C. VanMetre, D. E. Hostetler, and G. M. Barrington. 2000. Passive transfer of colostral immunoglobulins in calves. J. Vet. Intern. Med. 14:569–577.

Windeyer, M. C., K. E. Leslie, S. M. Godden, D. C. Hodgins, K. D. Lissemore, and S. J. LeBlanc. 2014. Factors associated with morbidity, mortality, and growth of dairy heifer calves up to 3 months of age. Prev. Vet. Med. 113:231–240. https://doi.org/10.1016/j.prevetmed.2013.10.019.