Effects of milk replacer feeding rate and long-term antibiotic inclusion in milk replacer on performance and nutrient digestibility of Holstein dairy calves up to 4 months of age

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ABSTRACT

The objectives of this study were to evaluate calf performance and diet digestibility when feeding a milk replacer (MR; 25% crude protein, 18% fat, dry matter basis) at a moderate (MOD) and high (HI) rate, along with MOD with neomycin-oxytetracycline inclusion (1.43 each g/kg; NTMOD). Male Holstein calves ($n = 48$; 45 ± 1.0 kg of body weight; 3 to 4 d of age) were housed in individual pens for 56 d. All calves were initially fed 0.66 kg of dry matter from MR for the first p.m. and following a.m. feeding, then randomly assigned to 1 of 2 feeding programs: (1) 0.66 kg of dry matter/d for first 39 d divided into 2 equal a.m. and p.m. meals and 0.33 kg for 3 d fed once daily in the a.m. feeding only (MOD, NTMOD); (2) 0.85 kg of dry matter/d for the first 4 d divided into 2 equal a.m. and p.m. meals, 1.07 kg of dry matter/d for the next 31 d divided into 2 equal a.m. and p.m. meals, and 0.48 kg for 7 d fed once daily in the a.m. feeding only (HI). Calves were fed a textured starter containing whole grains (20% crude protein, 43% starch, dry matter basis). Fecal samples were collected for 5 individual calves per treatment between d 47 to 51 to estimate digestibility. Calves were moved into groups by treatment (4 calves/pen) at 56 d and fed the same starter blended with 5% hay until d 112. Data were analyzed as a completely randomized design with repeated measures when applicable using mixed models. Milk replacer dry matter intake averaged 27.4 kg for MOD and NTMOD and 40.3 kg for HI per calf. Prewaning starter intake was less for calves fed HI versus MOD. Prewaning calf BCS change was greater for calves fed HI versus MOD. Prewaning medical treatment days were fewer for calves fed NTMOD versus MOD. Postweaning starter intake was less for calves fed HI versus MOD. Postweaning average daily gain was less for calves fed NTMOD versus

MOD. Over the 56-d nursery trial, calves fed HI had less starter intake than calves fed MOD. Digestibility of dry matter, organic matter, acid detergent fiber, and neutral detergent fiber were greater for calves fed MOD versus NTMOD or HI during d 47 to 51 postweaning. Additionally, digestibility of fat was greater for calves fed MOD versus HI. During d 56 to 112, hip width change was greater for calves fed MOD versus NTMOD or HI. Over 0 to 112 d, body weight gain was 100, 98, and 102 kg, whereas hip width change was 10.2, 9.0, and 9.2 cm for calves fed MOD, NTMOD, and HI, respectively. Any preweaning improvements from feeding NTMOD or HI over MOD were lost during the postweaning period, which could be partially explained by reductions in diet digestibility.

Key words: calf, digestibility, antibiotics

INTRODUCTION

The dairy industry has continually moved toward feeding more milk or milk replacer (MR) to young calves for benefits in improved growth rates (Diaz et al., 2001), health outcomes (Ballou et al., 2015), welfare (von Keyserlingk et al., 2009), and potential for improved milk production in the first and subsequent lactations (Gelsinger et al., 2016). However, some studies have illustrated that dry feed intake is equally influential on increasing early growth rates and later performance in lactation in replacement heifers (Gelsinger et al., 2016; Chester-Jones et al., 2017). When more milk or MR is fed to a calf, starter intake is less. The substitution of starter intake for milk or MR is a relatively small amount of total DMI (<15 kg) over the first 4 mo of a calf's life. However, the delay in starter intake can slow rumen development and reduce starter digestibility pre- and postweaning (Terré et al., 2007a,b; Hill et al., 2010, 2016b). Reduced postweaning digestion can also last 4 wk or more (Hill et al., 2016b; Dennis et al., 2018). Growth advantages are frequently lost by 4 mo of age when comparing milk or MR programs that deliver a moderate amount of DM (0.66 kg of DM/d) to programs that feed more than 0.66 kg of

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DM (Hill et al., 2007, 2016a,b). A few studies have suggested gradual weaning from high milk or MR feeding rates is needed to initiate earlier starter consumption and transition the calf to dry feed to avoid slumps in growth during and after weaning (Eckert et al., 2015; Meale et al., 2015). However, several recent studies have not been able to identify successful milk feeding and weaning programs to ameliorate disruptions in digestibility and maintain growth rates after feeding high rates of milk or MR (Hill et al., 2016a,b; Dennis et al., 2018).

Increasing milk or MR feeding rates has been suggested to reduce morbidity and mortality in calves, possibly through enhanced immunity (Griebel et al., 1987; Ballou, 2012; Ballou et al., 2015). Griebel et al. (1987) found that feeding 50% below maintenance protein and energy requirements reduced immune function in calves under 4 wk of age, whereas Ballou (2012) and Ballou et al. (2015) suggested that feeding high planes of nutrition improved immune function in Holstein and Jersey calves. Ollivett et al. (2012) reported quicker recovery from *Cryptosporidium parvum* infection and greater ADG if calves were fed a high plane of nutrition (0.30 Mcal of ME/kg of BW^{0.75} using a 28% protein, 20% fat MR) compared with a low plane of nutrition (0.13 Mcal of ME/kg of BW^{0.75} using a 20% protein, 20% fat MR). However, some studies have reported similar or greater morbidity rates from feeding more milk or MR (Quigley et al., 2006; Hengst et al., 2012; Bach et al., 2013a).

Morbidity and mortality rates are major concerns on calf-raising operations. A recent survey of 104 commercial operations in the United States (n = 2,545 calves) reported 38% of calves had at least one morbidity event, with 56% of those calves diagnosed with enteric disease and 33% of calves displaying respiratory disease (Urie et al., 2018). On the operations surveyed, nearly 14% of all calves enrolled were given antibiotics in milk or MR (Urie et al., 2018). In a survey of farms in California, 56% of calves were fed a medicated MR and 54% of farms added a medication to prevent diarrhea and respiratory sickness (Walker et al., 2012). While antibiotic usage in calf feeds has declined over the last 25 yr, some farms continue to prophylactically administer antibiotics in liquid feeds to reduce morbidity. Additionally, many farms (62% of operations surveyed in Urie et al., 2018) feed a combination of MR with waste milk or waste milk alone, which may contain low levels of antibiotic residues. One university study reported feeding neomycin sulfate and oxytetracycline in MR for 14, 26, or 42 d increased starter intake, improved feed efficiency, and reduced days with diarrhea compared with no antibiotic use (Litherland et al., 2010). However, Berge et al. (2009) reported in-

cluding neomycin sulfate and tetracycline HCl in waste milk fed to calves without clinical signs of disease and with adequate passive transfer reduced starter intake, BW gain, and increased diarrhea on a large commercial farm. Several studies have illustrated continual feeding of antibiotics in waste milk can result in shedding of antimicrobial-resistant pathogenic bacteria (Berge et al., 2006; Maynou et al., 2017) and may also modify rumen bacterial populations in calves (Li et al., 2017).

As there are mixed responses to MR feeding rates and prophylactic treatment with antibiotics in the literature, one objective of this trial was to identify effects of moderate and high MR feeding rates on DMI, digestibility estimates, and health outcomes, including postweaning data to 4 mo of age. The second objective was to investigate the use of neomycin sulfate and oxytetracycline on health, performance, and digestibility estimates of calves pre- and postweaning. We hypothesized feeding more than 0.66 kg of DM from MR would improve early growth but reduce postweaning digestion and growth and feeding antibiotics in MR would improve calf performance.

MATERIALS AND METHODS

All animals were cared for as described in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 2010). Male Holstein calves (48 head initially; 3 to 4 d of age) were received at the Nurture Research Center located in southwest Ohio from a commercial dairy farm after a 3.5 h transit. The calves were housed in individual pens (1.2 m × 2.4 m) with a coarse rock, tile-drained base bedded with wheat straw in a barn with curtain sides, natural ventilation, and no added heat. The day after arrival at approximately noon, the calves were weighed (d 0; 45 ± 1.4 kg of initial BW). At this time, blood was sampled intravenously, serum was separated by centrifugation at 3,000 × g (VWR, Batavia, IL) at 20°C for 15 min, and serum protein concentration was estimated using an optical refractometer (ATAGO U.S.A., Inc., Bellevue, WA). Calves were fed 1 of 3 MR treatments: (1) MR (25% CP, 18% fat, DM basis; Table 1) fed at a moderate rate (**MOD**); (2) MOD with addition of neomycin-oxytetracycline (1.43 g/kg each; Phibro Animal Health Corp., Teaneck, NJ; **NTMOD**); or (3) MR fed at a high rate (**HI**). All calves were initially fed 0.66 kg of DM from MR without medication for the first p.m. feeding after arrival and the following a.m. feeding. Calves were then randomly assigned to 1 of 2 feeding programs: (1) 0.66 kg of DM/d for first 39 d divided into 2 equal a.m. and p.m. meals and 0.33 kg for 3 d fed once daily in the a.m. feeding only (MOD and NTMOD); or (2) 0.85 kg of DM/d for the first 4

Table 1. Analyses of feeds used in the trials

Nutrient	Nursery		Grower	
	Milk replacer	Starter	Starter	Hay
DM	96.3	87.8	87.5	87.1
CP	24.8	20.5	20.3	10.2
ADF	—	6.9	6.5	43.9
NDF	—	14.5	13.7	64.6
Sugar	—	6.4	5.9	10.6
Starch	—	39.3	40.2	1.2
Fat	18.3	3.83	3.75	1.6
Ash	5.58	6.74	6.83	9.11

d divided into 2 equal a.m. and p.m. meals, 1.07 kg of DM/d for the next 31 d divided into 2 equal a.m. and p.m. meals, and 0.48 kg for 7 d fed once daily in the a.m. feeding only (HI). Milk replacer was reconstituted with warm water to 14% solids and fed twice daily at 0600 and 1530 h. The MR used was formulated with added synthetic AA (Hill et al., 2008) and fatty acids (Hill et al., 2011). Rejected MR was weighed back after each feeding. A whole-grain, textured calf starter (20% CP, 39% starch with specific fatty acids added as in Hill et al., 2011; Table 1) and water were fed for ad libitum intake during the nursery trial. Every other bag of MR and calf starter was sampled and composited for nutrient analysis.

Calves were weighed weekly during the nursery trial. Hip widths were measured using a caliper and BCS were assessed by palpating the transverse process by one experienced technician (1 being thin to 5 being obese; modified from Wildman et al., 1982) on d 0, 14, 28, 42, and 56. Feces were scored daily using a 1 to 5 scale with 1 being normal and 5 being watery (modified from Kertz and Chester-Jones, 2004). Antibiotic medical treatments were recorded daily and were based on the calf displaying lethargy, coughing, nasal discharges, or rectal temperatures $>39.4^{\circ}\text{C}$. Calves with fecal scores >2 received oral electrolytes, but these were not counted as medical treatments.

Five calves/treatment were randomly selected for use to estimate diet digestibility postweaning (d 47 to 51). Fecal grab samples were palpated rectally and composited by calf for use to estimate total-tract diet digestibility as described by Hill et al. (2016a). Acid-insoluble ash was used as an internal marker. The nursery pens were bedded with long wheat straw, and straw consumption by calves was possible (Hill et al., 2010, 2016a,b). This was accounted for by not adding new bedding 3 d before and during fecal collection periods to minimize the chance of straw intake during the week of digestibility measurements. Mathematically, unaccounted for consumption of straw could have reduced estimates of digestibility.

On d 56, calves from the nursery trial were grouped by preweaning treatment and moved to pens (4 calves/pen within treatment) for the grower trial until 112 d of age. The pens had 6.5 m² of outside pen space and 1.35 m² of inside pen space bedded with wheat straw per calf. Calf starter used in the nursery trial was blended with 5% chopped grass hay (approximately 2.5 cm long) on an as-fed basis and fed for ad libitum intake with free-choice access to water. Grower feed refusals were weighed daily to determine DMI. Every other bag of starter and every bale of hay was sampled and composited for nutrient analysis. Calf BW, hip width, and BCS were determined on d 56, 84, and 112.

Composites of feeds, refusals, and feces were analyzed (AOAC International, 2000) for DM (oven method 930.15), ash (oven method 942.05), CP (Kjeldahl method 988.05), fat (alkaline treatment with Roesse-Gottlieb method 932.06 for MR; diethyl ether extraction method 2003.05 for starters and hay), NDF with ash by the procedure of Van Soest et al. (1991) without sodium sulfite or α -amylase, ADF with ash (Robertson and Van Soest, 1981), starch (α -amylase method; Hall, 2009), sugar (colormetric method; Dubois et al., 1956), and acid insoluble ash (Van Keulen and Young, 1977). The trials were conducted from January through May 2016. The average temperature in the nursery trial was 0°C with a range from -18 to 21°C . The average relative humidity was 82% with a range from 28 to 100%. The average temperature in the grower trial was 10°C with a range from -4 to 28°C . The average relative humidity was 76% with a range from 20 to 100%.

In the nursery trial, data of daily intakes were reduced to weekly means for each calf. In the grower trial, data of daily intake were reduced to means in 28-d periods for each pen of calves. All data were analyzed as a completely randomized design, or when applicable a completely randomized design with repeated measures in wk, or in 14-, or 28-d periods, respectively, using MIXED procedures (version 8, SAS Institute Inc., Cary, NC). Calf in the nursery trial and pen (4 calves/pen) in the grower trial were the experimental units.

In the mixed models with repeated measurements, calf or pen was treated as a random variable and the first-order autoregressive structure type was selected as the appropriate covariance structure based on goodness-of-fit criteria (lowest Akaike information criterion; Littell et al., 1998). Significance was defined as $P \leq 0.05$, whereas $0.05 < P \leq 0.10$ was considered to indicate a trend toward a significant effect.

RESULTS

Feed Intake and Growth Performance

Initial hip widths were less for calves fed MOD than calves fed NTMOD and HI and initial BW tended to be less for MOD compared with NTMOD (Table 2). Calves fed MOD and NTMOD consumed all of their MR offered, whereas calves fed HI consumed 97% of their MR offered throughout the nursery phase. Milk replacer DMI/calf averaged 27.4 kg for MOD and NTMOD and 40.3 kg for HI. Prewaning starter intake was less for calves fed HI versus MOD ($P = 0.01$). Prewaning calf ADG tended to be greater ($P = 0.06$) and BCS change was greater ($P < 0.01$) for calves fed HI versus MOD. Prewaning medical treatment days (antibiotic treatment based on lethargy and high rectal temperatures) were fewer for calves fed NTMOD versus MOD ($P = 0.01$), but abnormal fecal days and fecal scores were similar among treatments. Postweaning (d 42 to 56), starter intake was less for calves fed HI versus MOD ($P = 0.01$) and tended to be less for calves fed NTMOD versus MOD ($P = 0.07$). Postweaning ADG was less for calves fed NTMOD versus MOD, but similar between MOD and HI. Hip width change tended to be less for HI versus MOD. Over the 56-d nursery trial, calves fed HI had less starter intake than calves fed MOD and calves fed NTMOD had fewer medical days than calves fed MOD.

During the grower phase, initial BCS score was greater ($P = 0.05$) but BCS change tended to be less for calves fed HI versus MOD ($P = 0.08$; Table 3). Hip width change was greater for calves fed MOD versus calves fed NTMOD and HI ($P < 0.01$). Final BW, ADG, DMI, and feed efficiency were similar among treatments in the grower phase.

Over the nursery and grower phases (d 0 to 112), total DMI were 233 kg for MOD, 241 kg for NTMOD, and 223 kg for HI. Total BW gain was 100 kg for MOD, 98 kg for NTMOD, and 102 kg for HI. Overall feed efficiency (BW gain/total DMI) was 0.384 for MOD, 0.366 for NTMOD, and 0.387 for HI. Total hip width change was 10.2 cm for MOD, 9.0 cm for NTMOD, and 9.2 cm for HI. Total BCS change was 0.8 units for all treatments. These data were not evaluated statistically

because the experimental units differed between the nursery (1 calf) and grower (pen of 4 calves) trials.

Apparent Diet Digestibility Estimates

Digestibility was evaluated 5 to 10 d after weaning in the nursery trial (d 47 to 51; Table 4). Apparent digestibility of DM (74.4 vs. 71.3%; $P = 0.01$), OM (76.2 vs. 72.8%; $P = 0.005$), ADF (20.6 vs. 8.2%; $P = 0.004$), and NDF (27.9 vs. 16.9; $P = 0.01$) was greater for calves fed MOD versus NTMOD. Also, the apparent digestibility of DM (74.4 vs. 70.8%; $P = 0.006$), OM (76.2 vs. 73.1%; $P = 0.008$), ADF (20.6 vs. 8.9%; $P = 0.006$), NDF (27.9 vs. 17.8; $P = 0.02$), and fat (81.4 vs. 74.3%; $P = 0.01$) was greater, and that of CP (68.5 vs. 62.6%; $P = 0.10$) tended to be greater for calves fed MOD versus HI. Starch digestibility was similar regardless of preweaning treatments.

DISCUSSION

Effects of Feeding Rate on Performance and Digestibility

Growth and digestibility estimates observed in this study were similar to results previously reported by our group (Hill et al., 2013, 2016a,b) and Bach et al. (2013a) when calves were fed moderate and high rates of MR and observed until at least 4 mo of age. Reduced digestibility in the early postweaning period was also similar to other reports where digestion was estimated and was a contributing factor to reduced growth postweaning (Terré et al., 2007a; Hill et al., 2010, 2016a,b). In Hill et al. (2010), 2 trials estimated digestibility at d 53 to 56. In the first trial, MR was fed at similar rates and calves were weaned at similar ages as the current study. In the second trial, MR was fed at similar rates but programs differed in weaning ages compared with the current study. Both trials illustrated OM digestibility was 4 to 5 percentage points lower when calves were fed up to 1.09 kg of DM from MR compared with calves fed 0.66 kg of DM from MR (Hill et al., 2010). More recently, Dennis et al. (2018) estimated digestibility at d 45 to 49 and d 56 to 60 when calves were fed 0.66 kg/d or up to 1.09 kg/d of MR DM and found no differences in OM digestibility. However, NDF digestibility was less when 1.09 kg/d compared with 0.66 kg of MR DM/d was fed to calves (Dennis et al., 2018). Quigley et al. (2018a) estimated digestibility at d 51 to 56 when calves were fed up to 1.07 kg/d of MR DM and found reduced digestibility of OM, NDF, and ADF (regardless of starter composition) compared with feeding 0.66 kg/d of MR DM. Quigley et al. (2018a) also reported that starch and NDF digestibility was influenced by

Table 2. Performance of calves fed milk replacers at moderate rates with (NTMOD) and without (MOD) neomycin-oxytetracycline and at a high rate (HI) in the nursery trial

Item	Diet ¹			SEM	Contrast <i>P</i> -value	
	MOD	NTMOD	HI		MOD vs. NTMOD	MOD vs. HI
Initial serum protein, mg/dL	5.7	5.5	5.4	0.2	0.33	0.18
Initial BW, kg	43.2	46.8	44.9	1.4	0.07	0.40
Initial hip width, cm	17.1	18.0	17.9	0.2	0.01	0.01
Initial BCS ²	2.2	2.2	2.2	0.03	1.00	0.37
Final BW, kg	80.8	82.6	85.8	2.0	0.51	0.07
Final hip width, cm	21.3	21.7	21.8	0.3	0.21	0.13
Final BCS	2.5	2.5	2.5	0.04	1.00	0.15
Preweaning (0 to 42 d)						
Starter intake, kg/d	0.556	0.596	0.347	0.055	0.60	0.01
ADG, kg/d	0.608	0.620	0.694	0.03	0.79	0.06
Gain to feed, ³ kg/kg	0.503	0.496	0.505	0.02	0.81	0.93
Hip width change, cm	3.3	2.9	3.4	0.2	0.19	0.85
BCS change	0.2	0.2	0.4	0.05	0.59	0.003
Fecal score ⁴	2.1	2.1	2.1	0.03	0.48	0.31
Abnormal fecal days ⁵	0.2	0.0	0.2	0.2	0.40	0.95
Medical days ⁶	1.1	0.3	0.6	0.2	0.01	0.14
Postweaning (42 to 56 d)						
Starter intake, kg/d	2.191	2.030	1.964	0.064	0.07	0.01
ADG, kg/d	0.861	0.694	0.844	0.054	0.02	0.82
Gain to feed, kg/kg	0.381	0.342	0.424	0.037	0.43	0.40
Hip width change, cm	0.9	0.8	0.5	0.1	0.80	0.08
BCS change	0.0	0.0	0.0	0.04	0.49	0.17
Fecal score	2.1	2.1	2.1	0.04	0.27	0.43
Abnormal fecal days	0.0	0.1	0.0	0.1	0.59	1.00
Medical days	0.0	0.0	0.1	0.1	1.00	0.44
Overall (0 to 56 d)						
Starter intake, kg/d	0.965	0.954	0.752	0.051	0.88	0.004
ADG, kg/d	0.672	0.638	0.732	0.028	0.39	0.12
Gain to feed, kg/kg	0.472	0.457	0.485	0.018	0.55	0.62
Hip width change, cm	4.2	3.7	3.9	0.3	0.20	0.41
BCS change	0.2	0.2	0.4	0.05	1.00	0.08
Fecal score	2.1	2.1	2.1	0.02	0.88	0.59
Abnormal fecal days	0.2	0.1	0.2	0.2	0.63	0.96
Medical days	1.1	0.3	0.8	0.3	0.03	0.36

¹MOD and NTMOD = 0.66 kg daily for 39 d, then 0.33 kg daily for 3 d; HI = 0.85 kg daily for 4 d, then 1.07 kg daily for 31 d, then 0.53 kg daily for 7 d (DM basis).

²1 to 5 point system, with 1 being thin and 5 being obese.

³BW gain divided by milk replacer plus starter intake.

⁴1 to 5 point system, with 1 = thick; 2 = less thick; 3 = abnormal, like batter; 4 = abnormal, watery with color; 5 = abnormal, watery with little color.

⁵Days with fecal scores >2.

⁶Days with antibiotic treatments for fever and lethargy, not including electrolytes.

cumulative intake of NFC and NDF. Therefore, factors that delay starter intake can reduce the calf's ability to digest solid feed before milk or MR is withdrawn from the diet. Observable reductions in growth rate often occur when calves are fed large amounts of milk or milk replacer and, presumably, cannot obtain enough ME from starter once MR is removed (Miller-Cushon et al., 2013; Steele et al., 2017). More information on how accumulation of nutrient intake from dry feed (particularly NFC) influences digestive development and energy available from calf starters has been reported elsewhere (Quigley et al., 2018b). We are not aware of other studies that have evaluated the effects of MR feeding rate on diet digestibility around weaning.

Feed efficiency was not different between treatments from 0 to 56 d. These findings are not surprising because preweaning feed efficiency responses to milk or MR feeding rate are mixed, often with no improvement observed (Hill et al., 2016a,b; Rosenberger et al., 2017). In contrast to our findings, Brown et al. (2005) reported feed efficiency improved with increasing MR feeding rates. Brown et al. (2005) fed either a standard plane of nutrition (1.1% of BW of a 21% CP, 21% fat MR with a 20% CP starter) or a high plane of nutrition (2.0% of BW of a 30% CP, 16% fat MR with a 25% CP starter) and weaned calves at 7 wk of age. Feeding a higher plane of nutrition increased feed efficiency approximately 25% from birth to 8 wk of age; however,

Table 3. Performance of calves fed milk replacers at moderate rates with (NTMOD) and without (MOD) neomycin-oxytetracycline and at a high rate (HI) in the grower trial

Item	Diet ¹			SEM	Contrast <i>P</i> -value	
	MOD	NTMOD	HI		MOD vs. NTMOD	MOD vs. HI
Initial BW, kg	81.2	82.5	85.5	1.8	0.63	0.13
Initial hip width, cm	21.3	21.7	21.7	0.2	0.21	0.17
Initial BCS ²	2.4	2.5	2.5	0.0	0.69	0.05
Final BW, kg	143.7	145.0	146.2	3.2	0.78	0.60
Final hip width, cm	27.3	27.0	27.1	0.2	0.39	0.52
Final BCS	3.0	3.0	3.0	0.0	0.60	0.69
DMI, kg/d	3.20	3.35	3.22	0.1	0.37	0.90
ADG, kg/d	1.12	1.12	1.08	0.05	0.99	0.63
Gain:feed, ³ kg/kg	0.353	0.339	0.340	0.010	0.37	0.40
Hip width change, cm	6.0	5.3	5.3	0.1	0.006	0.008
BCS change	0.5	0.5	0.4	0.1	1.00	0.08

¹MOD and NTMOD = 0.66 kg daily for 46 d, then 0.33 kg daily for 3 d; HI = 0.85 kg daily for 5 d, then 1.07 kg daily for 37 d, then 0.53 kg daily for 7 d (DM basis).

²1 to 5 point system, with 1 being thin and 5 being obese.

³BW gain divided by starter plus hay intake.

values reported in their study were similar to those observed in the current study. Bartlett et al. (2006) also reported feed efficiency increased for calves fed MR at 1.75% of BW compared with 1.25% of BW, but calf starter was not offered and calves were not weaned in their study. As MR is considerably more digestible than calf starter, as evident in Dennis et al. (2018) when digestibility was estimated at 35 d of age, feed efficiency preweaning should improve with greater MR feeding rates. Bach et al. (2013b) reported insulin insensitivity caused by feeding large amounts of MR may partially explain lack of differences in feed efficiency compared with feeding less MR. However, we did not measure blood metabolites and cannot speculate if insulin insensitivity contributed to our observations.

In this study, BW and hip width change from 0 to 112 d did not appear to differ due to MR feeding rate (MOD vs. HI). This was also evident when MR were

fed at the same maximum rates in 2 different studies by Dennis et al. (2017, 2018). Similarly, Hill et al. (2016b) reported similar 112-d BW and hip width gains when MR were fed at 0.66 kg/d and weaning occurred at 42 d compared with feeding up to 1.1 kg/d and weaning at 49 d. When Hill et al. (2016a) fed calves up to 1.31 kg/d and weaned at 49 d, 112-d BW gain appeared to be slightly greater for calves fed 1.31 kg/d versus calves fed 0.66 kg/d and weaned at 49 d, but 112-d hip width gain appeared slightly less for calves fed 1.31 kg/d.

Effects of Antibiotics in Milk Replacer on Performance and Digestibility

In this study, no calves were treated for respiratory sickness or had signs of nasal discharges or labored breathing. Sicknesses were observed in the first 43 d of the study and lethargy, fever, and diarrhea were likely

Table 4. Digestibility of nutrients by calves (n = 5) fed milk replacers at moderate rates with (NTMOD) and without (MOD) neomycin-oxytetracycline and at a high (HI) rate postweaning during d 47 to 51

Item	Diet ¹			SEM	Contrast <i>P</i> -value	
	MOD	NTMOD	HI		MOD vs. NTMOD	MOD vs. HI
BW, kg	74.1	79.5	80.5	3.1	0.24	0.17
DMI, kg/d	2.19	2.12	2.01	0.10	0.62	0.21
Digestibility, %						
DM	74.4	71.3	70.8	0.8	0.01	0.006
OM	76.2	72.8	73.1	0.7	0.005	0.008
CP	68.5	65.7	62.6	2.4	0.41	0.10
ADF	20.6	8.2	8.9	2.5	0.004	0.006
NDF	27.9	16.9	17.8	2.7	0.01	0.02
Starch	97.0	95.9	96.8	1.0	0.44	0.90
Fat	81.4	83.8	74.3	1.7	0.34	0.01

¹MOD = 0.66 kg daily for 46 d, then 0.33 kg daily for 3 d; HI = 0.85 kg daily for 5 d, then 1.07 kg daily for 37 d, then 0.53 kg daily for 7 d (DM basis).

all indicative of digestive disease when detected. Overall, the calves were generally healthy. Antibiotics in the MR reduced medical days preweaning as expected, but the longer term effect on postweaning digestibility, postweaning ADG, and structural growth from d 56 to 112 was not expected. Reductions in digestibility due to extended antibiotic feeding has been previously observed in calves, as feeding chlortetracycline to milk-fed calves receiving dry feed reduced crude fiber digestibility at 9 (chopped alfalfa hay) and 13 wk (ground oats) of age (Bartley et al., 1956). However, Zinn (1993) reported only slight reductions in total-tract OM and starch digestibility in 164 kg Holstein steers fed diets with 71% concentrate and supplemented with chlortetracycline (350 mg/steer per day). Direct observations of reduced diet digestibility to feeding neomycin or oxytetracycline have not been reported in the literature, but some in vitro culture data have shown mixed results on cellulose digestibility. Fulghum et al. (1968) showed major cellulolytic species of rumen bacteria were susceptible to oxytetracycline, but not neomycin. Baldwin et al. (1982) reported chlortetracycline, oxytetracycline, and penicillin at 2.5 µg/mL concentrations inhibited in vitro cellulose degradation in mixed rumen cultures. In pure bacterial cultures, neomycin and oxytetracycline were shown to reduce specific growth rates of some fiber-digesting bacteria (Beharka and Nagaraja, 1998). Although in vitro data may not translate directly to in vivo feeding trials, substantial reductions in NDF and ADF digestibility observed for NTMOD immediately postweaning with no difference in starter intake suggest some inhibitory effects of antibiotics on fiber-digesting bacterial populations throughout the gastrointestinal tract. Therefore, negative effects may exist with continual antibiotic feeding, particularly during establishment of the rumen microbiome in pre-weaned calves.

In this study, antibiotics were fed for 40 of 42 d and between the duration and amount may have reduced rumen microbial populations and development. Presumably, milk or MR would be shunted to the abomasum due to esophageal groove closure. However, some calves may experience incomplete esophageal groove closure resulting in milk or MR flowing into the rumen. Using ultrasonography, Labussière et al. (2014) estimated about 20% of a MR meal (range of 0 to 39%) can flow to the rumen in bucket-fed heavy veal calves not receiving solid feed. Berends et al. (2015) reported MR flowing to the rumen of nipple-fed veal calves given solid feed (measured using cobalt recovery) averaged about 20% of a meal. However, other researchers have reported even with meal sizes as large as 6.8 L, nipple-fed calves offered whole milk did not experience any liquid feed entering the rumen (Ellingsen et al.,

2016). Despite conflicting evidence, it is reasonable to assume that some calves may experience liquid feed entering the rumen and therefore have exposure of the rumen microbiome to orally administered antibiotics on a regular basis. Exposure to antibiotics is a growing concern due to antibiotic-resistant genes manifesting in pathogenic bacteria, but may also be an issue when the rumen microbiome is developing in a young calf. Metagenomic analysis of rumen contents of calves fed waste or saleable milk has shown the phylum *Bacteroidetes* was the most susceptible to milk containing antibiotic residues (pasteurized or unpasteurized waste milk; Li et al., 2017). This is important as more than 50% of the relative abundance of bacterial phyla in the developing calf rumen microbiome comes from *Bacteroidetes* (Rey et al., 2014). Many of the bacterial species under *Bacteroidetes* are major utilizers of complex carbohydrates and potentially cellulose (Naas et al., 2014), making them indispensable when calves are first consuming solid feed.

CONCLUSIONS

Feeding up to 1.07 kg of MR or feeding neomycin with oxytetracycline with 0.66 kg of MR did not increase growth to 4 mo of age compared with feeding 0.66 kg of MR/d without antibiotics using a 25% CP, 17% fat MR. Although extra MR may have offered more preweaning growth, it did not improve calf health and reduced nutrient digestibility and structural growth postweaning. Feeding neomycin with oxytetracycline reduced medical days during the preweaning period, but reduced postweaning diet digestibility and structural growth. The current growth and digestibility measurements for these moderate and high MR feeding rate treatments were in agreement with numerous other measurements in the literature.

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