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Influence of starter crude protein content on growth and body composition of dairy calves in an enhanced early nutrition program

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ABSTRACT

Our objectives were to determine the effect of starter crude protein (CP) content on body composition of male Holstein calves from birth to 10 wk of age in an enhanced early nutrition program, and to compare the enhanced program to a conventional milk replacer program. Calves (n = 45) were purchased on the day of birth and assigned to a randomized block design. Eight calves were harvested at baseline and remaining calves were divided among the following 3 dietary treatments: (1) low rate of milk replacer [LMR; 20.6% CP, 21.7% fat; 1.25% of body weight (BW) as dry matter (DM)] plus conventional starter (CCS; 21.5% CP, DM basis); n = 11 calves; (2) high rate of milk replacer (HMR; 29.1% CP, 17.3% fat; 1.5% of BW as DM for wk 1, 2% of BW as DM wk 2–5, 1% of BW as DM wk 6) plus conventional starter; n = 12 calves; and (3) enhanced milk replacer (HMR) plus high-CP starter (HCS; 26% CP, DM basis); n = 14 calves. A subset of calves (n = 8) was harvested on d 2 to provide baseline data. Calves began treatments on d 2 or 3 of age. Calves were weaned at d 42. Starter was available ad libitum. Calves from each treatment were harvested at 5 (n = 18) and 10 (n = 19) wk of age and divided into 4 fractions: carcass; viscera; blood; and head, hide, feet, and tail. Fractions were analyzed for energy, CP, lipid, and ash. Average weekly starter intake did not differ between enhanced treatments. Gain of BW was greater for calves fed HMR than for LMR, but was unaffected by starter CP. Carcass weights at 5 wk were greater for HMR but did not differ between starter CP content. At 10 wk, carcass weights were heavier for HMR and had a greater percentage of empty BW for HMR + CCS than for HMR + HCS. At 10 wk, the weights of reticulorumen and liver were greater for calves fed HMR + HCS than for those fed HMR + CCS. At 5 wk, empty BW gain for HMR contained more water and less fat and ash than in calves fed LMR. At 10 wk, empty BW gain for calves fed HMR + HCS contained a greater percentage of water and less fat than for calves fed HMR + CCS. Plasma β-hydroxybutyrate was greater after weaning for calves fed HMR + HCS than for those fed HMR + CCS. After weaning, calves fed HMR had greater plasma total protein concentration than those fed LMR, and total protein was greater for calves fed HMR + HCS than those fed HMR + CCS. Plasma urea N was greater for calves fed HMR treatments, and postweaning was greater for calves fed HMR + HCS. A high-CP starter had minimal effect on empty BW gain before weaning, but after weaning it tended to increase mass of reticulorumen and liver.

Key words: calf, composition of gain, rumen development, milk replacer

INTRODUCTION

Traditional calf rearing programs decrease the cost of raising replacement heifers by encouraging earlier intake of dry starter feed and reducing the length of the milk feeding period. A more progressive approach is the use of enhanced early nutrition or intensive feeding programs in which greater amounts of milk solids are fed. These programs have the potential to increase growth rates and reduce age at first calving, potentially providing a greater long-run economic benefit to producers (Davis Rincker et al., 2011).

In young calves, consumption of dry feed stimulates the development of the reticulorumen and decreases nutritional deficiencies during the weaning transition from a liquid diet to a dry diet. To minimize nutritional deficiencies in the calf, starter intake at weaning must, at minimum, supply maintenance requirements for energy and protein. During the milk feeding period, calves fed milk or milk replacer at a higher rate will have an increased rate of gain and efficiency of gain (Diaz et al., 2001; Jasper and Weary, 2002; Blome et al., 2003; Bartlett et al., 2006); however, increased feeding rates of milk or milk replacer also reduce consumption of starter (Hodgson, 1971; Leaver and Yarrow, 1972; Stamey et

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al., 2012). Decreased starter intake might potentially limit rumen development and decrease gains as the calf transitions at weaning. Therefore, understanding how to better maintain or increase nutrient intake at weaning for calves in enhanced feeding programs is critical for successful calf rearing.

The NASEM (2001) model suggests that 18% CP (DM basis) in starter should be adequate for calves fed enhanced milk replacer. As a decrease in starter intake could limit the availability of essential AA, it might be possible to counter weaning stress by increasing starter CP content. Enhanced milk replacers contain more CP than conventional milk replacers to support greater rates of lean tissue deposition (Van Amburgh and Drackley, 2005). Thus, perhaps starter CP content should be increased to meet an increased CP requirement in a larger calf with low intake. Further, dry feed intake increases gut fill, so observations based solely on BW change might be misleading and not reflective of lean tissue gains (Diaz et al., 2001; Blome et al., 2003; Bartlett et al., 2006).

Body composition and composition of BW gain have been determined in several studies in which only milk or milk replacer was fed (Donnelly and Hutton, 1976a,b; Diaz et al., 2001; Mills et al., 2010). Both rates of gain and diet composition affect body composition and composition of gain (Diaz et al., 2001; Tikofsky et al., 2001; Bartlett et al., 2006). Blome et al. (2003) and Bartlett et al. (2006) demonstrated that increasing dietary CP in milk replacer increased lean tissue gain and decreased fat content of empty body (**EB**) gain. However, few studies have determined changes of body composition and EB gain in calves fed both starter feed and milk or milk replacer (Meyer, 2005; Silva et al., 2017).

The objectives of this experiment were (1) to quantify the effect of starter CP content on body composition of male Holstein calves from birth to 10 wk of age in an enhanced early nutrition program and (2) to compare changes in body composition between an enhanced early nutrition program and a conventional milk replacer program. Our hypothesis was that a higher CP concentration in the starter would help maintain lean growth during and after weaning for calves in an enhanced early nutrition program.

MATERIALS AND METHODS

Animals

All procedures were conducted under protocols approved by the University of Illinois Institutional Animal Care and Use Committee. Two groups (replicates) of 32 and 21 male Holstein calves were purchased from a commercial dairy in Bellflower, Illinois, on the day of birth. Each calf received 3 L of pooled, raw colostrum at birth via bottle or esophageal feeder. The first group was acquired during the first week of August 2004, and the second group during the first week of September 2004. Calves were selected based on body temperature, heart rate, respiration rate, hydration status, navel appearance, and overall thriftiness. Calves with a total plasma protein concentration below 5 g/dL at 48 h of age, indicating failure of passive transfer, were returned to the farm. Calves were picked up as available and transported via livestock trailer to the University of Illinois Nutrition Field Laboratory (approximately 40 km). Upon arrival, each calf was ad libitum bottle-fed previously frozen, pooled colostrum collected from cows from the herd of origin. All calves were vaccinated with TSV-2 (Pfizer Inc., New York, NY) and Quatracon 2X (Boehringer Ingelhiem Vetmedica Inc., St. Joseph, MO). Navels were coated with Betadine (Purdue Products LP, Stamford, CT). Each calf received 1.5 mL of Mu-Se (Shering-Plough Animal Health Corp., Union, NJ) and a prophylactic injection of 1.5 mL of Excenel RTU (Pharmacia & Upjohn Co., Kalamazoo, MI). Rectal temperatures were recorded daily for the first 3 d. Calves were housed in individual hutches (Calf-tel, Hamptel Corp., Germantown, WI), which were placed on 15 to 20 cm of crushed rock. No bedding was used. Water and starter were available at all times.

Feeding and Management of Calves

Calves were assigned to treatments in a randomized block design by initial BW. Calves were randomly assigned to either an initial harvest group (n = 8, 4 per block) or to 1 of 3 dietary treatments as follows: (1) low rate of milk replacer (**LMR**; 20.6% CP, 21.7% fat, DM basis) plus conventional starter (**CCS**; 21.5% CP, DM basis), **LMR + CCS**; n = 15 calves; (2) high rate of milk replacer (**HMR**; 29.1% CP, 17.3% fat, DM basis) plus CCS, **HMR + CCS**; n = 15; and (3) HMR plus high-CP starter (**HCS**; 26.0% CP, DM basis), **HMR + HCS**; n = 15. Calves began treatments on d 2 or 3 of age. The remaining calves were harvested at either 5 or 10 wk of age. Calves harvested at 10 wk of age were weaned at the end of wk 6. Starters were available for ad libitum intake starting on d 3 (Table 1). Data from the 8 baseline calves were pooled and used to calculate starting body composition of treatment calves. Treatments were compared during the milk-fed period (wk 0–5) and postweaning period (wk 6–10).

Milk replacers were formulated and manufactured by Milk Specialties Company (Dundee, IL) and did not contain growth-promoting antibiotics. Milk replacers contained only whey proteins and were supplemented

with DL-methionine to the concentration found in skim milk protein. Fat was provided from tallow. Conventional milk replacer was reconstituted to 12.5% solids and fed at 1.25% of birth BW (DM basis) daily in 2 feedings from wk 1 to 5 and at 0.625% of birth BW as DM once daily during wk 6. Enhanced milk replacer was reconstituted to 15% solids and fed at 1.5% of BW as DM during wk 1, and 2% of BW as DM during wk 2 to 5, divided into 2 daily feedings. During wk 6, enhanced milk replacer was fed at 1% of BW as DM once daily. Milk replacer was fed daily at 0600 and 1800 h and intake was recorded. Water was available at all times, and water intake was recorded daily. Milk replacers and starters were sampled weekly and composited monthly. Milk replacers were analyzed for concentrations of CP, crude fat, Ca, P, Mg, K, Na, Fe, Zn, Cu, Mn, and Mo, and starters were analyzed for concentrations of CP, ADF, NDF, Ca, P, Mg, K, Na, Fe, Zn, Cu, Mn, and Mo by standard wet chemistry methods (https://dairyone.com/resources/forms-and-documents/) at a commercial laboratory (Dairy One Cooperative Inc., Ithaca, NY).

Calves were offered starter for ad libitum intake starting on d 3. Calves were initially offered 0.23 kg of starter once daily, with amounts increasing by 0.23 kg/d as intake increased. Calf starter intake was recorded once daily.

Health

Calf health was monitored throughout each day. Fecal scores were recorded once daily using the following guidelines: 1 = firm, well formed (not hard); 2 = soft, pudding-like; 3 = runny, pancake batter; and 4 = liquid, splatters. Entrolyte HE (Pfizer Animal Health, Exton, PA) or Arrest (Milk Specialties Co., Dundee, IL) were offered 1 h postfeeding to calves with fecal scores ≥3. As necessary, calves were administered lactated Ringers solution intravenously and antibiotics by a veterinarian. Respiratory scores were recorded once daily using the following guidelines: 1 = normal; 2 = runny nose; 3 = heavy breathing; 4 = cough, moist; 5 = cough, dry; and 6 = fever. Rectal temperatures were recorded for the first 3 d and whenever a calf received electrolytes. All calves received *Clostridium perfringens* types C and D antitoxin (Boehringer Ingelheim, St. Joseph, MO) at 10 d of age. At 2 wk of age, all calves were vaccinated with Bovishield Gold 5 (Pfizer Animal Health). At 6 wk of age, calves remaining on the experiment received a second dose of TSV-2.

Table 1. Ingredient composition of conventional (CCS) and high-CP calf starter (HCS)

	Starter	
Ingredient, % of DM	CCS	HCS
Pellet	45.00	45.00
Wheat middlings	46.75	5.29
Soybean meal	34.43	77.48
Dried distillers, corn	10.00	5.00
Calcium carbonate	5.44	4.98
Alfalfa, 17% CP	—	3.00
21% Monocalcium phosphate	1.78	2.12
Salt	0.70	0.70
Dynamate	0.50	1.137
Vitamin E	0.171	0.171
Magnesium oxide	0.128	0.025
Vitamin A	0.045	0.045
Dairy trace mineral mix	0.044	0.044
Vitamin D	0.006	0.006
Copper sulfate	0.003	0.002
Cracked corn	22.50	21.25
Oats	15.00	15.00
Steam crimped corn	12.50	13.75
Molasses, cane	5.00	5.00

Body Growth and Measurements

Calves were weighed on arrival and each Monday at 1600 h. Withers height, length, and heart girth were also measured. Calculations of ADG of BW and stature growth rate were made from these measurements.

Blood Sampling and Analysis

Blood was collected each Monday at 0500 h, before the morning feeding, via jugular venipuncture. Samples were collected into evacuated test tubes (Vacutainer, Becton Dickinson, Rutherford, NJ) containing sodium heparin or EDTA as anticoagulants. Heparin and EDTA tubes were placed on ice and centrifuged at 1,300 × *g* at 4°C for 10 min within 1 h to harvest plasma. An additional blood sample was collected into evacuated serum tubes (SST; Becton Dickinson Vacutainer Systems, Franklin Lakes, NJ) containing clot activator. Serum samples were allowed to clot for 1 h before centrifugation at 1,300 × *g* for 15 min at 4°C. Serum and plasma were aliquoted into polypropylene tubes and frozen (−20°C) until analysis. Serum concentrations of nonesterified fatty acids (**NEFA**; NEFA C kit, Wako Chemical, Richmond, VA) were determined using the procedures of Johnson and Peters (1993). Plasma concentrations of glucose, BHB, urea, and total protein were determined at the University of Illinois College of Veterinary Medicine diagnostic laboratory using automated analysis procedures and validated enzyme assay kits.

Harvesting Procedure

Eight calves were killed and analyzed for initial body composition data at 2 or 3 d of age. The remaining

calves were killed at 5 or 10 wk of age. Calves were transported to the University of Illinois Meat Science Laboratory via livestock trailer after the second feeding on the day before harvest. Calves were weighed immediately before harvesting, approximately 13 h after the last feeding to determine shrunk BW (**SBW**). All calves were killed via captive bolt stunning followed by exsanguination. During exsanguination, blood was collected and the final weight was recorded. Blood collected during the harvesting procedure was not combined with any fraction. Calves were eviscerated, the hide was removed, and the body was divided into 3 fractions: carcass; viscera; and head, hide, feet, and tail (**HHFT**). Additionally, the gastrointestinal tract (**GIT**) was weighed before and following the removal of digesta. Digesta was removed by thoroughly rinsing the GIT with water. The empty GIT was then reweighed, and the amount of digesta at the time of slaughter was determined as the difference in weight between the full and empty GIT. The reticulorumen was separated from the GIT and weighed. Individual weights were recorded for the heart, liver, and kidneys. All organ weights were then pooled to form the visceral fraction. The HHFT from each calf was weighed and composited by treatment, age, and replicate, creating 2 baseline composites and 12 final composites. Each fraction was refrigerated overnight and processed the following day.

Whole carcasses and HHFT composites were ground twice through a 1.27-cm die using an Autio Model 801GP1B grinder (Autio Co., Astoria, OR). The visceral fraction was coarsely ground once through a 1.27-cm die, and then ground through a 0.32-cm die (model 52HF; Butcher Boy Ltd., Beith, UK). Two homogeneous samples for proximate analysis were collected from each fraction after the final grind and were frozen (−20°C) until analysis.

Proximate Analysis of Body Tissues

Frozen tissue samples were used for all assays with the exception of energy determination. Freeze-dried tissues were analyzed for gross energy content using an adiabatic bomb calorimeter (Parr Instrument Co., Moline, IL). Fractions were analyzed for water, N, lipid, and ash. Duplicate 5-g samples were used for proximate analysis for water and fat using the procedures described by Novakofski et al. (1989). Water content was determined by drying in an oven at 110°C for 24 h. Lipid content was then determined gravimetrically by extraction with a 4:1 solution of chloroform and methanol. Ash (AOAC International, 1995) was determined in each tissue sample by combustion at 500°C for 12 h using a box furnace (Lindberg/Blue, Asheville, NC). Nitrogen was determined using the Kjeldahl digestion procedure according to AOAC (1984), and CP calculated as N × 6.25.

Calculation of Body Composition and Composition of Gain

The sum of carcass, digesta-free viscera, HHFT, and blood constituted empty body weight (**EBW**). Baseline body composition was determined as the sum of amounts of water, protein, fat, and ash for each calf harvested at the start of the experiment. The mean baseline composition was applied to the beginning BW of each calf and subtracted from the composition of each calf harvested at wk 5 to determine composition for the milk-fed period. For the starter-fed period, the mean composition of calves harvested at wk 5 for each treatment was used as the baseline for their treatment peers harvested at 10 wk.

Energy and Protein Utilization

Dietary ME was calculated as described by NASEM (2001). Maintenance ME was calculated as 0.100 Mcal/kg of $BW^{0.75}$ (NASEM, 2001). The ME available for gain was calculated as total ME intake minus ME for maintenance. Efficiency of ME use for gain was calculated by regression of retained energy (**RE**) in Mcal/d on ME available for gain (Mcal/d). Caloric values of fat and protein retained in EB were assumed to be 9.51 and 5.82 Mcal/kg, respectively.

Statistical Analysis

Data were subjected to ANOVA using the MIXED procedure in SAS (SAS Institute Inc., Cary, NC). The model used for variables for repeated measures (intakes, BW, body measurements, and blood variables) was as follows:

$$Y_{ijk} = \mu + \mathrm{B}_i + D_j + \left(B \times D\right)_{ij} + T_k + \left(D \times T\right)_{jk} + \beta\left(X_i - \bar{X}\right) + \varepsilon_{ijk},$$

where Y_{ijk} is the dependent variable; μ is the overall mean; B_i is the random effect of replicate; D_i is the effect of diet; $(B \times D)_{ij}$ is the effect of the interaction between the random effect of replicate and diet, used to test the subject effect of diet and time; T_j is the repeated effect of time (week or day); $(D \times T)_{ik}$ is the effect of the interaction between diet and time; $\beta\left(X_i - \bar{X}\right)$ is the covariate variable (for initial BW, structural data, and blood components); and ε_{ijk} is the overall error term. The model used to test nonrepeated

variables (body components) had the time effect and interactions removed. The covariance structure that gave the lowest Akaike's information criterion was used (Littell et al., 1998). Initial measurements of BW, withers height, length, heart girth, and blood samples collected at birth (before treatments were assigned) were used as covariates when analyzing the respective measurements. Treatment comparisons were made using the following 2 preplanned orthogonal contrasts: (1) LMR versus the 2 treatments with HMR and (2) CCS versus HCS within the HMR groups. The overall *P*-values for treatment are not presented. Least squares means and standard errors are reported. Significance was declared at $P < 0.05$ and trends discussed when $0.05 < P \leq 0.15$. In the instance of a treatment × time interaction ($P \leq 0.10$), the PDIFF statement in SAS was used to determine differences between treatments at specific time points ($P \leq 0.05$).

RESULTS

Nutrient Composition of Diets

The measured chemical composition of the milk replacers and starter can be found in Table 2. The LMR and HMR were formulated to contain 20% and 28% CP (as-fed basis), respectively, and actual analyzed CP on a DM basis was 21% and 29%, respectively. The starters were formulated to contain 18% and 22% CP on an as-fed basis. The measured chemical CP content was 22% and 26% CP, on a DM basis, respectively, equivalent to 19% and 23% CP on an as-fed basis. The AA composition of starters was not measured, but using NASEM (2001) values, the HCS pellet contained approximately 74% more Lys, 40% more Met, and 50% more Thr than CCS.

Environment and Calf Health

According to the National Oceanic and Atmospheric Administration (United States Department of Commerce, 2004), average monthly temperatures for replicate 1 were 20.2°C, 20.3°C, and 12.5°C (August, September, and October, respectively) and for replicate 2 were 20.3°C, 12.5°C, and 7.3°C (September, October, and November, respectively). Thus, calves were within their thermoneutral zone (NASEM, 2001) for most of the trial.

In the first replicate, 2 calves died of severe scours and dehydration within 48 h of arrival before treatments were initiated. Two other calves in replicate 1 died due to clostridial infection at 8 and 10 d of age, 1 assigned to each milk replacer treatment. One calf assigned to the conventional treatment in replicate 1 was removed from the trial. The calf was obtained as a replacement for a calf not accepted due to failure of passive transfer, and the replacement calf was too small to accurately compare compositional gains. Three calves in replicate 2 died due to severe scouring in wk 2. One of these calves was assigned to the conventional milk replacer diet and 2 received the enhanced milk replacer. Treatment was not a suspected cause of death for these calves.

Fecal scores, respiratory scores, and electrolyte intake were evaluated in the milk-fed period through wk 5. Calves fed HMR had more fluid feces than those fed LMR ($P < 0.001$). Mean fecal scores for calves fed LMR + CCS, HMR + CCS, and HMR + HCS were 2.4, 2.7, and 2.7, respectively. Electrolyte intake did not differ ($P > 0.1$) by treatment. Mean respiratory scores were 1.1, 1.1, and 1.2 for calves in LMR + CCS, HMR + CCS, and HMR + HCS, and were not affected ($P > 0.1$) by treatment. Calves in replicate 2 were less thrifty across all treatments, which was reflected in water intake and growth performance. Although precautions were taken to disinfect hutches between calves and minimize stressors on calves, the calves in replicate 2 likely had increased environmental exposure to pathogens, as they were housed in the same area. Treatment was not a suspected cause of lower health status in replicate 2.

Table 2. Measured chemical composition of the experimental milk replacers and starters

	Milk replacer[1]		Starter[2]	
Component	LMR	HMR	CCS	HCS
DM, %	96.00	95.50	88.20	88.30
CP, % of DM	20.60	29.10	21.50	26.00
Crude fat, % of DM	21.70	17.30	—	—
NDF, % of DM	—	—	19.30	15.60
ADF, % of DM	—	—	9.10	7.70
Gross energy, Mcal/kg of DM	5.26	5.20	4.43	4.52
ME, Mcal/kg of DM	4.95	4.72	3.16	3.20
Ca, % of DM	1.20	1.15	2.32	1.99
P, % of DM	0.65	0.64	0.91	0.78
Mg, % of DM	0.13	0.12	0.37	0.30
K, % of DM	1.98	1.81	1.32	1.38
Na, % of DM	0.77	0.51	0.24	0.21
Fe, mg/kg	85	71	359	353
Zn, mg/kg	106	106	83	79
Cu, mg/kg	8.0	9.0	38	38
Mn, mg/kg	42	68	68	54
Mo, mg/kg	0.40	0.70	2.4	4.2

[1]LMR = conventional milk replacer; HMR = high plane of nutrition from enhanced milk replacer.

[2]CCS = conventional starter; HCS = high-CP starter.

Table 3. Least squares means for average daily intakes of DM, CP, and ME from milk replacer and starter for calves fed a low plane of nutrition from conventional milk replacer (LMR) or a high plane of nutrition from enhanced milk replacer (HMR), with either a conventional starter (CCS) or a high-CP starter (HCS)

	Treatment				*P*-value	
Variable	LMR + CCS	HMR + CCS	HMR + HCS	SEM	Milk feeding rate	Starter
Weeks 1 through 5	(n = 5)	(n = 6)	(n = 7)			
Milk replacer DM, g/d	533	977	944	62	<0.001	0.67
Starter DM, g/d	225	72	85	24	<0.001	0.66
Total DM, g/d	758	1,049	1,029	68	0.003	0.81
Milk replacer CP, g/d	112	205	198	9	<0.001	0.67
Starter CP, g/d	44	14	22	5	<0.001	0.28
Total CP, g/d	156	219	220	15	0.002	0.98
Milk replacer ME, Mcal/d	2.640	4.613	4.455	0.291	<0.001	0.67
Starter ME, Mcal/d	0.711	0.228	0.274	0.076	<0.001	0.63
Total ME, Mcal/d	3.35	4.84	4.73	0.31	0.001	0.77
Water, L/d	1.99	2.16	3.02	0.58	0.21	0.10
Weeks 6 through 10	(n = 6)	(n = 6)	(n = 7)			
Milk replacer DM, g/d	56	136	139	8	<0.001	0.74
Starter DM, g/d	1,748	1,798	1,894	217	0.71	0.75
Total DM, g/d	1,804	1,933	2,033	221	0.51	0.74
Milk replacer CP, g/d	12	28	29	2	<0.001	0.74
Starter CP, g/d	342	352	483	50	0.23	0.07
Total CP, g/d	354	381	512	50	0.15	0.07
Milk replacer ME, Mcal/d	0.277	0.641	0.657	0.037	<0.001	0.75
Starter ME, Mcal/d	5.522	5.680	6.078	0.690	0.68	0.68
Total ME, Mcal/d	5.800	6.321	6.735	0.711	0.41	0.67
Water, L/d	4.95	5.47	6.95	0.83	0.20	0.18

Intakes

Before weaning, calves fed HMR had greater milk replacer intakes of DM, CP, and ME than calves fed LMR ($P < 0.001$) due to differences in milk replacer composition and feeding rate (Table 3). Intakes of starter DM, CP, and ME were greater ($P < 0.001$) for calves fed LMR than for calves fed HMR. Total intakes of DM, CP, and ME were greater ($P < 0.001$) for calves fed HMR due to differences in milk replacer composition and feeding rate.

As expected, weekly starter DM intake (Figure 1) was greater for calves fed LMR than calves fed HMR in wk 4 ($P < 0.02$) and 5 ($P < 0.001$). In wk 5, intake of CP from starter (data not shown) was greater ($P < 0.01$) for calves fed LMR. Starter ME intake (data not shown) was greater ($P < 0.03$) for calves fed LMR from wk 4 to 6. From wk 2 to 5, total DMI ($P < 0.001$) and total ME intake ($P < 0.001$) were greater for calves fed HMR. Total CP intake was greater ($P < 0.01$) from wk 1 to 5 for calves fed HMR.

During wk 6 to 10, mean intake of starter and total DMI did not differ among treatments, and there were no significant interactions (Table 3). During wk 6, when milk replacer offered was decreased, calves fed HMR + HCS consumed more starter DM (340 g/d vs. 559 g/d; $P = 0.03$), CP (73.4 g/d vs. 143.7 g/d; $P < 0.001$), and ME (1.02 Mcal/d vs. 1.75 Mcal/d; $P = 0.001$) than calves fed HMR + CCS. Calves on all treatments consumed over 2,000 g/d of starter by wk 8 (Figure 1). Consequently, the lag in starter intake for calves fed HMR was eliminated quickly after calves were weaned. Intake of CP from starter and total CP intake was greater ($P = 0.07$) for calves fed HMR + HCS than for calves fed HMR + CCS. Although

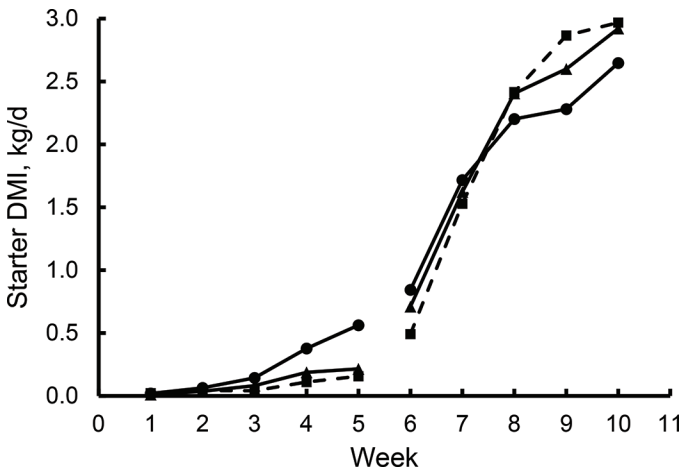

Figure 1. Starter DMI for calves fed a low plane of nutrition from conventional milk replacer (circles and solid line) or a high plane of nutrition from enhanced milk replacer, with either a conventional starter (squares, dashed line) or a high-CP starter (triangles, solid line). Weeks 1 to 5: treatment × week, $P < 0.001$, greatest SEM = 0.058 kg/d; wk 6 to 10: treatment × week, $P = 0.03$, greatest SEM = 0.37 kg/d.

Table 4. Least squares means for body measurements for calves fed a low plane of nutrition from conventional milk replacer (LMR) or a high plane of nutrition from enhanced milk replacer (HMR), with either a conventional starter (CCS) or a high-CP starter (HCS)

	Treatment				*P*-value	
Variable	LMR + CCS	HMR + CCS	HMR + HCS	SEM	Milk feeding rate	Starter
Weeks 1 through 5	(n = 5)	(n = 6)	(n = 7)			
Withers height, cm	80.5	81.4	81.0	1.8	0.12	0.42
Body length, cm	66.5	68.2	68.2	0.6	0.007	0.99
Heart girth, cm	85.0	87.5	87.6	1.0	<0.001	0.95
Weeks 6 through 10	(n = 6)	(n = 6)	(n = 7)			
Withers height, cm	85.5	89.7	89.2	1.8	0.006	0.70
Body length, cm	75.2	80.2	80.8	0.9	0.009	0.76
Heart girth, cm	95.4	100.8	101.2	1.2	0.003	0.79

contrasts for treatment means of water intake did not differ significantly, the treatment by week interactions were significant for water intake during both wk 1 to 5 and wk 6 to 10 (Figure 2).

Body Measurements

During wk 1 to 5, average withers height did not differ due to milk replacer treatment (Table 4). Withers height at wk 5 ($P = 0.04$) was greater for calves fed HMR than for those fed LMR; means at wk 5 were 82.7 cm, 84.7 cm, and 84.5 cm for calves fed LMR + CCS, HMR + CCS, and HMR + HCS, respectively. The mean body length (Table 4) and body length at wk 5 were greater ($P < 0.001$) for calves fed HMR, with body lengths at wk 5 of 70.9 cm, 74.1 cm, and 74.2 cm for LMR + CCS, HMR + CCS, and HMR + HCS, respectively. Also, the mean heart girth (Table 4) and heart girth at wk 5 were greater ($P < 0.01$) for calves fed HMR; wk 5 heart girth was 88.9 cm, 94.2 cm, and 94.3 cm for LMR + CCS, HMR + CCS, and HMR + HCS, respectively. Starter protein content did not alter any of these measurements.

During wk 6 to 10, average withers height, body length, and heart girth were greater for calves fed HMR than for those fed LMR (Table 4). Body measurements remained greater ($P < 0.001$) at wk 10 for HMR than for LMR. Withers height was 88.3 cm, 91.7 cm, and 91.3 cm for calves fed LMR + CCS, HMR + CCS, and HMR + HCS, respectively. Body length was 78.1 cm, 82.8 cm, and 84.4, and heart girth was 102.1 cm, 106.7 cm, and 106.4 cm, respectively.

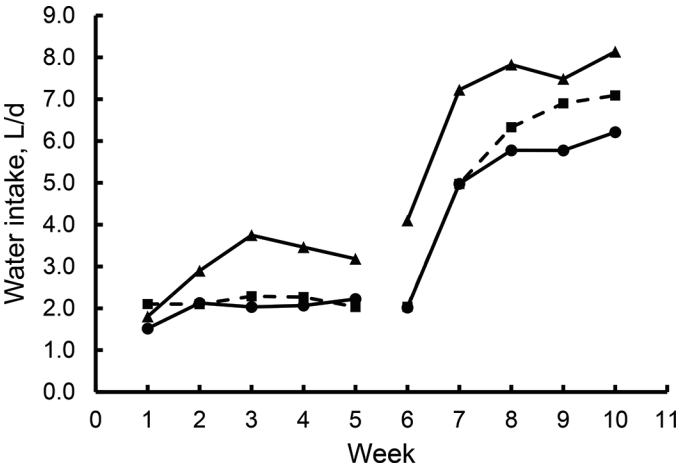

Figure 2. Water intake for calves fed a low plane of nutrition from conventional milk replacer (circles and solid line) or a high plane of nutrition from enhanced milk replacer, with either a conventional starter (squares, dashed line) or a high-CP starter (triangles, solid line). Weeks 1 to 5: treatment × week, $P = 0.02$, greatest SEM = 0.62 kg/d; wk 6 to 10: treatment × week, $P = 0.04$, greatest SEM = 0.98 kg/d.

Growth and Gross Body Composition at 5 Wk

Initial BW did not vary by treatment. Mean BW ($P < 0.01$, data not shown) and BW at wk 5 ($P = 0.07$) were greater for calves fed HMR than for those fed LMR (Table 5). The average BW and ADG were greater ($P < 0.01$) for calves fed HMR. Calves fed HMR had improved ($P < 0.01$) feed efficiency. The average gain to feed ratios were 0.36, 0.49, and 0.55, respectively, for calves fed LMR + CCS, HMR + CCS, and HMR + HCS.

Shrunk BW and EBW at 5 wk were significantly greater for calves fed HMR than for those fed LMR (Table 5), as were their ratios to full BW (**FBW**). Weights of blood ($P = 0.04$), carcass ($P = 0.02$), HHFT ($P = 0.06$), and total viscera ($P = 0.10$) were less for calves fed LMR than for those fed HMR. As a percentage of EBW, only HHFT differed, being greater for LMR than for those fed HMR. Among components of total viscera, weights of GIT, reticulorumen, heart, and kidneys did not differ among treatments, whereas liver weight tended to be greater ($P = 0.11$) for calves fed HMR than for those fed LMR. When expressed as a percentage of EBW, however, GIT ($P = 0.07$) and reticulorumen were greater for calves fed LMR. Digesta

Table 5. Gross composition of male Holstein calves at baseline and at 5 wk when fed a low plane of nutrition from conventional milk replacer (LMR) or a high plane of nutrition from enhanced milk replacer (HMR), with either a conventional starter (CCS) or a high-CP starter (HCS)

		Treatment				*P*-value	
Item[1]	Baseline	LMR + CCS	HMR + CCS	HMR + HCS	SEM	Milk feeding rate	Starter
n	8	5	6	7	—	—	—
Final full BW (FBW), kg	41.10	58.32	69.40	66.80	4.20	0.07	0.62
Gain, kg	—	11.59	22.84	21.48	3.51	<0.01	0.60
ADG, kg/d	—	0.34	0.67	0.65	0.10	<0.01	0.74
Shrunk BW (SBW), kg	41.14	56.00	68.52	64.97	3.95	0.04	0.48
SBW:FBW	1.00	0.96	0.99	0.97	0.01	0.05	0.11
Empty BW (EBW), kg	40.59	53.50	65.95	63.04	3.83	0.03	0.55
EBW:FBW	0.99	0.92	0.95	0.95	0.01	<0.01	0.62
EBW:SBW	0.99	0.96	0.96	0.97	0.008	0.32	0.38
Blood, kg	2.02	2.24	3.16	3.17	0.43	0.04	0.97
Blood, % of EBW	4.87	4.11	4.71	4.95	0.52	0.12	0.61
Carcass, kg	24.09	33.09	41.29	39.25	2.41	0.02	0.51
Carcass, % of EBW	58.51	61.85	62.59	62.29	0.50	0.33	0.63
HHFT, kg	8.79	10.66	12.54	12.15	0.71	0.06	0.66
HHFT, % of EBW	21.33	19.92	18.98	19.28	0.32	0.02	0.35
Total viscera, kg	5.69	7.56	9.00	8.50	0.70	0.10	0.49
Total viscera, % of EBW	13.85	14.20	13.76	13.54	0.64	0.21	0.61
GIT, kg	2.36	4.39	4.81	4.76	0.56	0.36	0.90
GIT, % of EBW	5.70	8.13	7.35	7.49	0.70	0.07	0.73
Reticulorumen, kg	0.19	0.92	0.86	0.84	0.25	0.60	0.90
Reticulorumen, % of EBW	0.46	1.76	1.30	1.29	0.42	0.02	0.97
Heart, kg	0.38	0.50	0.58	0.59	0.05	0.19	0.96
Heart, % of EBW	0.91	0.94	0.88	0.94	0.05	0.68	0.46
Kidneys, kg	0.33	0.41	0.51	0.45	0.06	0.33	0.48
Kidneys, % of EBW	0.81	0.76	0.77	0.71	0.09	0.87	0.62
Liver, kg	0.97	1.97	2.16	2.23	0.10	0.11	0.59
Liver, % of EBW	2.35	2.06	2.24	2.30	0.11	0.13	0.70
Digesta, kg	1.04	2.84	1.54	1.48	0.34	<0.01	0.90
Digesta, % of SBW	2.60	5.04	2.28	2.22	0.49	<0.01	0.93

[1]HHFT = head, hide, feet, and tail; GIT = gastrointestinal tract.

mass, both as kilograms and percentage of SBW, was greater for calves fed LMR. With the exception of the ratio of SBW to FBW ($P = 0.11$), starter protein content did not affect any measures of gross body composition.

Composition of Body and Gain at 5 Wk

Calves fed HMR had greater ($P = 0.03$) EBW at wk 5 than calves fed LMR (Table 6). Gain of EBW and ADG of EBW were greater ($P < 0.01$) for calves fed HMR. Increased milk feeding rate affected final body composition at 5 wk. The final body composition included greater amounts of water ($P = 0.02$), protein ($P = 0.04$), fat ($P = 0.04$), and ash ($P = 0.13$). Body composition expressed as percentages of EBW did not differ among treatments. Gains of water, protein, fat, ash, and energy were greater ($P \leq 0.01$) for calves fed HMR than for those fed LMR. For calves fed HMR, the composition of gain included more water ($P = 0.02$) but less fat ($P < 0.01$), ash ($P < 0.01$), and energy ($P < 0.01$) than for calves fed LMR. Protein content of gain as a percentage of EBW gain was not altered by feeding rate ($P = 0.41$). Starter protein content did not alter body composition in the milk-fed period. Visceral protein gain accounted for 9.6, 10.0, and 9.5% of total body protein gain for calves fed LMR + CCS, HMR + CCS, and HMR + HCS, respectively; statistical contrasts did not approach significance.

Growth and Gross Body Composition at 10 Wk

At 10 wk, FBW ($P = 0.09$), SBW ($P = 0.09$), and EBW ($P = 0.07$) tended to remain greater for calves fed HMR than for those fed LMR, but total gain of FBW and ADG from wk 5 to wk 10 did not differ among treatments (Table 7). Weights of carcass ($P = 0.05$), HHFT ($P = 0.10$), and total viscera ($P = 0.13$) were also greater for calves fed HMR than for those fed LMR. When expressed as a proportion of EBW, carcass ($P = 0.01$) and HHFT ($P = 0.03$), but not total viscera ($P = 0.23$), were greater for calves fed HMR. Mass of GIT ($P = 0.10$) and reticulorumen ($P = 0.04$) were greater for calves fed HMR than for those fed LMR. As a percentage of EBW, kidneys ($P < 0.01$) were greater for calves fed HMR than for those fed LMR. Digesta as a percentage of SBW was greater ($P = 0.02$) for calves fed LMR than for calves fed HMR.

Table 6. Least squares means for composition at 5 wk of Holstein bull calves fed a low plane of nutrition from conventional milk replacer (LMR) or a high plane of nutrition from enhanced milk replacer (HMR), with either a conventional starter (CCS) or a high-CP starter (HCS)

	Treatment					*P*-value	
Item	Baseline	LMR + CCS	HMR + CCS	HMR + HCS	SEM	Milk feeding rate	Starter
Empty BW (EBW), kg	40.59	53.50	65.95	63.04	3.82	0.03	0.55
Gain, kg	—	9.25	21.66	19.99	2.80	<0.01	0.48
ADG, kg/d	—	0.27	0.64	0.60	0.08	<0.01	0.62
Final composition, kg							
Water	29.99	38.76	48.02	45.66	2.74	0.02	0.50
Protein	7.56	9.60	11.74	11.33	0.71	0.04	0.65
Fat	1.55	3.06	3.78	3.66	0.25	0.04	0.71
Ash	1.48	2.07	2.41	2.38	0.17	0.13	0.92
Final composition, % EBW							
Water	73.89	72.45	72.82	72.49	0.29	0.57	0.39
Protein	18.64	17.94	17.81	17.96	0.24	0.83	0.62
Fat	3.82	5.72	5.73	5.78	0.14	0.86	0.80
Ash	3.65	3.90	3.66	3.79	0.13	0.17	0.31
Gain of components, kg							
Water	—	5.97	15.24	13.79	2.10	<0.01	0.39
Protein	—	1.36	3.50	3.32	0.53	<0.01	0.70
Fat	—	1.41	2.11	2.04	0.18	0.01	0.76
Ash	—	0.50	0.81	0.84	0.09	0.01	0.80
Energy, Mcal	—	18.64	35.31	33.27	4.01	<0.01	0.63
Composition of EBW gain, %							
Water	—	65.01	69.92	69.12	2.08	0.02	0.67
Protein	—	15.27	15.87	16.59	0.95	0.41	0.55
Fat	—	14.08	10.07	10.10	1.31	<0.01	0.98
Ash	—	5.85	4.25	4.34	0.85	0.04	0.90
Energy, Mcal/kg EBW gain	—	1.89	1.62	1.64	0.10	<0.01	0.87

Calves fed HMR + HCS had a greater ($P = 0.03$) ratio of SBW:FBW, but tended ($P = 0.12$) to have a smaller ratio of EBW:SBW than calves fed HMR + CCS, although differences were small. As percentages of EBW, the greater starter protein content also resulted in a smaller ($P = 0.02$) carcass, but tended to increase ($P = 0.07$) total viscera. Greater starter protein increased mass of reticulorumen ($P = 0.07$), reticulorumen as a percentage of EBW ($P = 0.03$), kidneys as a percentage of EBW ($P = 0.04$), liver mass ($P = 0.10$), and liver as a percentage of SBW ($P < 0.01$).

Composition of Body and Gain at 10 Wk

At wk 10, calves previously fed HMR tended to have greater ($P = 0.07$) EBW than those calves fed LMR (Table 8). Gain of EBW and ADG of EBW did not differ from wk 5 to 10. Calves fed HMR tended to have greater amounts of water ($P = 0.07$), and had greater amounts of protein ($P = 0.05$) and ash ($P = 0.05$) in the final EB, but the larger means for amount of fat did not reach significance ($P = 0.17$). As percentages of final EBW, water tended ($P = 0.14$) to be less, and protein was greater ($P = 0.01$) for calves previously fed HMR. Gains of components did not differ among treatments. As percentages of EBW gain, water tended to be less ($P = 0.06$), but protein ($P = 0.06$), fat ($P = 0.09$), and energy ($P = 0.11$) tended to be greater for calves previously fed HMR. Final composition and component gains did not differ between starter protein contents. However, as percentages of EBW gain, calves fed HMR + HCS had greater content of water and lower fat ($P = 0.02$) in gain than calves fed HMR + CCS. Energy content of gain was lower ($P = 0.06$) for calves fed HMR + HCS than for those fed HMR + CCS. Visceral protein gain accounted for 16.4, 6.2, and 19.7% of total body protein gain for calves fed LMR + CCS, HMR + CCS, and HMR + HCS, respectively (HMR + HCS vs. HMR + CCS, $P = 0.009$).

Utilization of Energy and Protein

For the preweaning period, maintenance ME did not differ among treatments, but ME available for gain and RE were greater for calves fed HMR than for those fed LMR (Table 9). The gross efficiency of use of dietary ME for gain was greater for calves fed HMR than for calves fed LMR. Partial efficiency of use of ME available for gain did not differ among treatments. The partial efficiency of use of dietary CP for EB protein gain was greater for calves fed HMR. Energy retained as fat and protein were greater for calves fed HMR than for calves fed LMR. Calves fed LMR retained a greater proportion of energy as fat than calves fed HMR, but the

reverse was true for energy retained as protein. Starter CP content did not affect any measurement of energy or protein use before weaning.

For wk 6 to 10 (postweaning), maintenance ME was greater for calves fed HMR than for those fed LMR, but ME available for gain and RE did not differ among treatments (Table 9). Efficiency of ME use did not differ among treatments. The gross partial efficiency of CP use for EB protein gain was greater for calves fed LMR than for those fed HMR. Energy retained as fat or protein did not differ among treatments. The proportion of RE as fat was less, and the proportion retained as protein was greater, for calves fed HMR + HCS than for those fed HMR + CCS. Starter CP content did not affect any other measures of energy or protein use. The efficiency of ME use for RE was lower after weaning than before weaning (Figure 3).

Blood Metabolites

Before weaning, concentrations of BHB in HMR-fed calves were lower ($P = 0.05$) than for calves fed LMR (Table 10). Postweaning concentration of BHB was greater ($P = 0.08$) for calves fed HMR + HCS than for those fed HMR + CCS. Mean blood glucose was greater ($P < 0.001$) during the milk-fed period for calves fed HMR than for those fed LMR. The treatment by time interaction is shown in Figure 4. Postweaning, there were no differences in blood glucose among treatments. The preweaning concentration of NEFA was greater ($P = 0.06$) for calves fed HMR than for those fed LMR, and was greater ($P = 0.05$) for calves fed HMR + HCS than for those fed HMR + CCS. Mean concentrations of total protein did not differ among treatments before weaning. Postweaning, total protein was greater ($P = 0.01$) for calves previously fed HMR and was greater ($P = 0.08$) for calves fed HMR + HCS than for those fed HMR + CCS. Urea N concentrations were greater ($P < 0.001$) before weaning for calves fed HMR than for those fed LMR, but were not affected by starter protein content. Plasma urea N concentrations were greater ($P < 0.001$) postweaning for calves previously fed HMR, and were greater for calves fed HMR + HCS than for those fed HMR + CCS. The interaction of treatment and time was significant (Figure 4); calves fed HMR+ CCS had increased urea N relative to LMR + CCS only in wk 7; whereas for calves fed HMR + HCS, urea N remained elevated from wk 7 to 10.

Table 7. Gross composition of male Holstein calves at 10 wk when fed a low plane of nutrition from conventional milk replacer (LMR) or a high plane of nutrition from enhanced milk replacer (HMR), with either a conventional starter (CCS) or a high-CP starter (HCS)

	Treatment				*P*-value	
Item[1]	LMR + CCS	HMR + CCS	HMR + HCS	SEM	Milk feeding rate	Starter
n	6	6	7	—	—	—
Final full BW (FBW), kg	84.87	98.37	102.65	7.10	0.09	0.66
Gain, kg	31.31	28.98	32.13	4.00	0.88	0.57
ADG, kg/d	0.89	0.83	0.92	0.12	0.89	0.55
Shrunk BW (SBW), kg	80.60	92.46	98.23	6.85	0.09	0.50
SBW:FBW	0.95	0.94	0.96	0.006	0.86	0.03
Empty BW (EBW), kg	70.54	82.49	86.68	6.04	0.07	0.62
EBW:FBW	0.83	0.84	0.84	0.01	0.39	0.62
EBW:SBW	0.87	0.89	0.88	0.01	0.28	0.12
Blood, kg	3.47	3.88	4.03	0.38	0.31	0.77
Blood, % of EBW	4.88	4.67	4.65	0.27	0.44	0.96
Carcass, kg	41.63	50.61	51.95	3.84	0.05	0.80
Carcass, % of EBW	58.83	61.31	59.78	0.74	0.01	0.04
HHFT, kg	13.17	14.38	15.71	0.90	0.10	0.29
HHFT, % of EBW	18.88	17.47	18.22	0.35	0.03	0.13
Total viscera, kg	12.27	13.62	14.99	1.05	0.13	0.35
Total viscera, % of EBW	17.41	16.55	17.36	0.55	0.23	0.07
GIT, kg	7.52	8.74	9.21	0.67	0.10	0.61
GIT, % of EBW	10.66	10.62	10.68	0.44	0.98	0.78
Reticulorumen, kg	1.78	2.12	2.70	0.22	0.04	0.07
Reticulorumen, % of EBW	2.53	2.54	3.10	0.16	0.17	0.03
Heart, kg	0.62	0.66	0.74	0.06	0.29	0.34
Heart, % of EBW	0.88	0.80	0.85	0.04	0.36	0.40
Kidneys, kg	0.58	0.56	0.66	0.06	0.71	0.23
Kidneys, % of EBW	0.85	0.67	0.76	0.04	<0.01	0.04
Liver, kg	1.84	1.89	2.32	0.18	0.23	0.10
Liver, % of EBW	2.60	2.30	2.66	0.09	0.24	<0.01
Digesta	10.29	9.54	11.32	0.94	0.90	0.18
Digesta, % of SBW	12.83	10.38	11.38	0.64	0.02	0.28

[1]HHFT = head, hide, feet, and tail; GIT = gastrointestinal tract.

Table 8. Least squares means for composition at 10 wk of Holstein bull calves fed a low plane of nutrition from conventional milk replacer (LMR) or a high plane of nutrition from enhanced milk replacer (HMR), with either a conventional starter (CCS) or a high-CP starter (HCS)

	Treatment				*P*-value	
Item	LMR + CCS	HMR + CCS	HMR + HCS	SEM	Milk feeding rate	Starter
Empty BW (EBW), kg	70.54	82.49	86.68	6.04	0.07	0.62
Gain, kg	21.40	16.54	20.13	3.20	0.44	0.42
ADG, kg/d	0.61	0.47	0.58	0.09	0.45	0.41
Final composition, kg						
Water	50.57	58.53	61.77	4.1	0.07	0.57
Protein	12.47	14.96	15.73	1.13	0.05	0.62
Fat	4.84	5.83	5.93	0.60	0.17	0.90
Ash	2.65	3.17	3.24	0.22	0.05	0.82
Final composition, % EBW						
Water	71.86	70.98	71.36	0.36	0.14	0.46
Protein	17.63	18.13	18.14	0.15	0.01	0.96
Fat	6.74	7.03	6.76	0.25	0.61	0.45
Ash	3.77	3.86	3.75	0.10	0.77	0.37
Gain of components, kg						
Water	14.97	10.51	13.57	2.16	0.28	0.32
Protein	3.66	3.21	3.77	0.62	0.82	0.52
Fat	2.03	2.06	2.07	0.41	0.95	0.98
Ash	0.74	0.77	0.73	0.11	0.97	0.80
Energy, Mcal	35.72	32.17	35.15	6.34	0.79	0.73
Composition of EBW gain, %						
Water	70.29	59.37	67.56	3.00	0.06	0.05
Protein	17.01	20.73	18.55	1.11	0.06	0.17
Fat	9.10	14.67	9.77	1.41	0.09	0.02
Ash	3.60	5.23	4.07	0.73	0.19	0.20
Energy, Mcal/kg EBW gain	1.60	2.15	1.71	6.25	0.11	0.06

Table 9. Utilization of energy and protein by Holstein bull calves fed a low plane of nutrition from conventional milk replacer (LMR) or a high plane of nutrition from enhanced milk replacer (HMR), with either a conventional starter (CCS) or a high-CP starter (HCS)

	Treatment				*P*-value	
Item	LMR + CCS	HMR + CCS	HMR + HCS	SEM	Milk feeding rate	Starter
Week 5 (Preweaning)						
Maintenance ME, Mcal/d	1.834	2.014	1.950	0.091	0.19	0.58
ME for gain, Mcal/d	1.516	2.826	2.779	0.221	<0.001	0.87
Retained energy (RE), Mcal/d	0.544	1.038	1.000	0.100	0.001	0.76
Gross partial efficiency of ME use for gain, Mcal/Mcal	0.16	0.21	0.20	0.020	0.007	0.67
Efficiency of use of ME for gain for RE, Mcal/ Mcal	0.35	0.36	0.35	0.036	0.80	0.66
Gross partial efficiency of CP intake for empty body protein gain, kg/kg	0.27	0.46	0.45	0.065	0.002	0.91
RE as fat, Mcal/d	0.380	0.602	0.571	0.059	0.01	0.67
RE as protein, Mcal/d	0.248	0.590	0.593	0.086	0.001	0.98
Proportion of RE as fat	0.60	0.51	0.50	0.036	0.005	0.69
Proportion of RE as protein	0.40	0.49	0.50	0.036	0.005	0.69
Wk 10 (Postweaning)						
Maintenance ME, Mcal/d	2.142	2.527	2.583	0.126	0.02	0.75
ME for gain, Mcal/d	3.658	3.793	4.152	0.607	0.67	0.67
Retained energy (RE), Mcal/d	1.020	0.919	1.010	0.182	0.80	0.72
Gross partial efficiency of ME use for gain, Mcal/Mcal	0.17	0.14	0.15	0.016	0.28	0.87
Efficiency of use of ME for gain for RE, Mcal/Mcal	0.27	0.24	0.25	0.027	0.44	0.84
Gross partial efficiency of CP intake for empty body protein gain, kg/kg	0.291	0.238	0.210	0.027	0.06	0.48
RE as fat, Mcal/d	0.555	0.586	0.557	0.111	0.90	0.85
RE as protein, Mcal/d	0.621	0.534	0.632	0.104	0.77	0.50
Proportion of RE as fat	0.46	0.53	0.46	0.020	0.26	0.02
Proportion of RE as protein	0.54	0.47	0.54	0.020	0.26	0.02

Table 10. Least squares means for concentrations of plasma and serum metabolites of calves fed a low plane of nutrition from conventional milk replacer (LMR) or a high plane of nutrition from enhanced milk replacer (HMR), with either a conventional starter (CCS) or a high-CP starter (HCS)

					P-value	
Variable	LMR + CCS	HMR +HCS	HMR + HCS	SE	Milk feeding rate	Starter
BHB, mmol/L						
Preweaning[1]	0.063	0.037	0.049	0.011	0.12	0.42
Postweaning	0.217	0.167	0.229	0.046	0.53	0.08
Glucose, mg/dL						
Preweaning[1]	89.3	101.2	99.4	2.6	0.003	0.63
Postweaning	71.8	71.8	75.8	10.3	0.55	0.29
Nonesterified fatty acids, μEq/L						
Preweaning	199	207	238	11.5	0.06	0.05
Postweaning	92	101	106	8.4	0.26	0.68
Total protein, g/dL						
Preweaning[2]	5.46	5.40	5.49	0.30	0.96	0.75
Postweaning	4.71	5.12	5.64	1.00	0.013	0.08
Urea N, mg/dL						
Preweaning[2]	5.12	8.18	9.14	0.52	<0.001	0.11
Postweaning[3]	8.74	9.86	14.47	0.88	<0.001	<0.001

[1]Diet × time ($P < 0.07$).
[2]Diet × time ($P < 0.05$).
[3]Diet × time ($P < 0.001$).

DISCUSSION

Ratios of EBW to BW

Across all ages, SBW averaged 96.7% of FBW, which is similar to values reported by others for calves fed milk replacer only (97.3%; Bartlett et al., 2006) or milk replacer plus starter (95.8%; Meyer, 2005). Calf EBW as a percentage of FBW decreased from baseline (99%) to 5 wk (94%) to 10 wk (84%) as solid feed intake, and thus rumen and gut development increased. The proportion of FBW represented by EBW was in close agreement with other reports (Diaz et al., 2001; Meyer, 2005; Bartlett et al., 2006). In contrast, daily gain of EBW was 79, 96, and 92% of FBW ADG for calves fed LMR + CCS, HMR + CCS, and HMR + HCS, respectively, at 5 wk, and 68, 57, and 63%, respectively, at 10 wk. These results highlighted the disproportionate effect of changes in the ratio of EBW:FBW due to rumen and gut development on the relationship between EBW gain and FBW gain, which should be in the same ratio as EBW:FBW if that ratio is constant. The rapid changes in the ratio EBW:FBW before and after weaning complicate predictions of nutrient requirements for calves around weaning. Further, the increase in gastrointestinal contents with solid feed should be considered when evaluating management and feeding practices around weaning based solely on FBW gain.

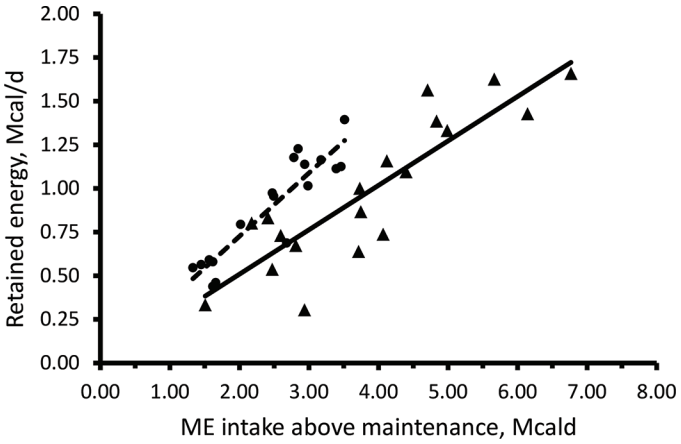

Figure 3. Retained energy (RE) as a function of ME intake above maintenance for calves before weaning (circles and dashed line) and after weaning (triangles and solid line). The regression equation for preweaning was RE (Mcal/d) = 0.364 ± 0.014 ME gain (Mcal/d); adjusted $R^2 = 0.98$. The regression equation for postweaning was RE (Mcal/d) = 0.254 ± 0.011 ME gain (Mcal/d); adjusted $R^2 = 0.96$.

Intakes, Growth, and Composition of Gain to 5 Wk

Intakes of starter DM, as well as starter CP and ME, were greater for calves fed LMR, a finding that is consistent with previous reports (Jasper and Weary, 2002; Brown et al., 2005; Kristensen et al., 2007). Increased starter intake for calves fed LMR reflects the promotion of dry feed intake to meet CP and ME requirements for growth, whereas increased liquid feeding rate largely provided these requirements for calves fed enhanced milk replacer (Hodgson, 1971). Water intakes tended to track intakes of starter, as reported by others (Kertz et al., 1984; Eckert et al., 2015).

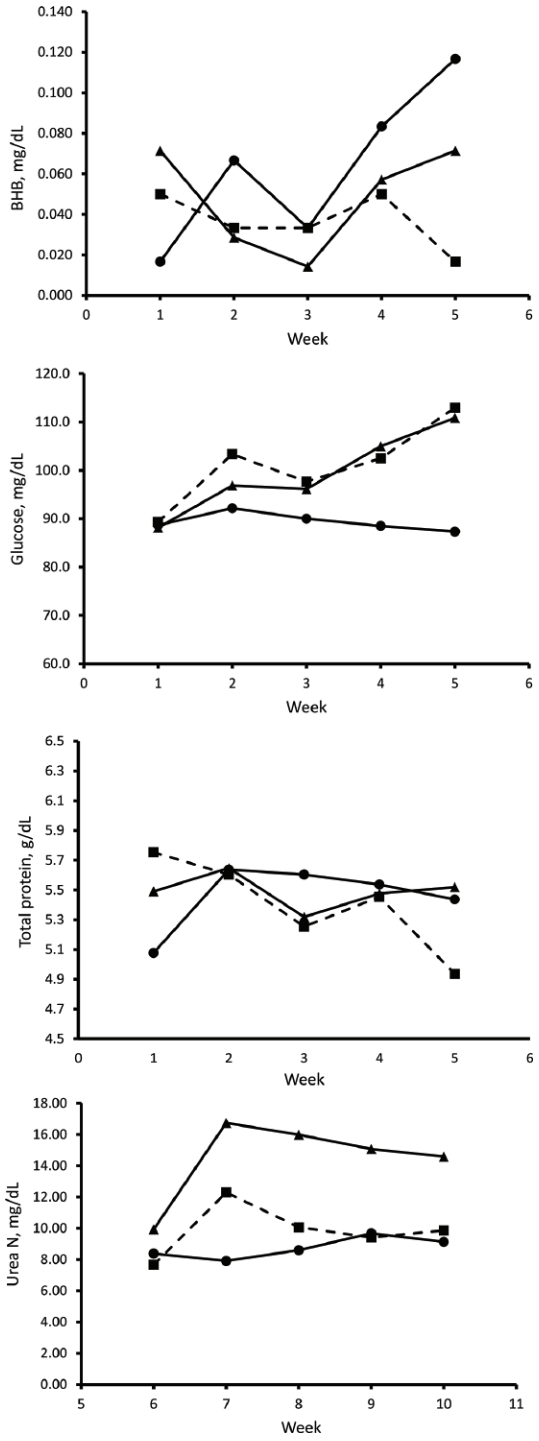

Figure 4. Mean concentrations of metabolites in plasma of calves fed a low plane of nutrition from conventional milk replacer (LMR; circles and solid line) or a high plane of nutrition from enhanced milk replacer (HMR), with either a conventional starter (CCS; squares, dashed line) or a high-CP starter (HCS; triangles, solid line). (A) Plasma BHB preweaning; treatment × time, $P = 0.06$; greatest SEM = 0.021 mg/dL. (B) Plasma glucose preweaning; treatment × time, $P = 0.07$; greatest SEM = 4.1 mg/dL. (C) Plasma total protein preweaning; treatment × time, $P = 0.02$; greatest SEM = 0.33 g/dL. (D) Plasma urea N postweaning; treatment × time, $P = 0.001$; greatest SEM = 1.15 mg/dL.

Greater nutrient intakes by calves fed HMR resulted in greater growth for those calves, with all body fractions being larger except for the visceral components. Indeed, the mass of reticulorumen and total gastrointestinal tract as percentages of SBW were lower for calves fed HMR than for those fed LMR. Similar results were obtained from experiments in which calves were fed milk replacers containing different amounts of protein at different feeding rates (Donnelly and Hutton, 1976a,b; Blome et al., 2003; Bartlett et al., 2006). The growth data corresponded with those obtained in a companion study (Stamey et al., 2012).

During the first 5 wk, increased gains (kg/d) of all chemical components resulted in greater amounts of water, protein, fat, and ash in the final body, but final EBW composition (%) did not vary among treatments. Composition of the EBW gain, however, was altered significantly by diet, with HMR resulting in a greater proportion of water, lesser proportions of fat and ash, and lower energy densities than in calves fed LMR. The proportion of protein in gain was not affected, which supports previous data showing that protein content of gain is relatively constant (Van Amburgh et al., 2019). Protein content of starter had little effect on growth during this stage, which is not surprising given the dominance of milk replacer protein intake in total supply. Such changes agree with previous data from calves fed greater amounts of milk replacer without (Donnelly and Hutton, 1976a,b; Diaz et al., 2001; Bartlett et al., 2006) or with starter (Meyer, 2005).

The average BW gains were less than predicted by the NASEM (2001) model, which were 0.45 kg/d for LMR + CCS and 0.73 kg/d for groups fed HMR. The overall health status of the calves, particularly in replicate 2, may have resulted in decreased growth. Comparison of body composition across treatments, however, should not have been affected.

Intakes, Growth, and Composition of Gain to 10 Wk

The period from 6 to 10 wk included weaning and the early postweaning period. Intakes of starter were similar among treatments, and thus intakes of ME did not differ significantly; consequently, ADG and EBW gain were similar among treatments. The differences in stature and BW realized during the first 5 wk remained until wk 10, with EBW for calves fed HMR + CCS and HMR + HCS being 16.9 and 22.9% heavier at the end of the experiment than the LMR + CCS group. These results reinforce the benefits on growth and feed efficiency resulting from an enhanced plane of nutrition before weaning and further support that the BW advantage can be maintained after weaning (Stamey et al., 2012; Rosenberger et al., 2017).

Although the mass gains of chemical components did not differ, the percentage composition of the gain was different. When compared with the composition of gain for calves fed LMR + CCS, calves fed HMR with either starter tended to have greater percentages of fat and protein and less water in gain. Most noteworthy, however, is the difference in percentage composition of EBW gain due to starter protein content (Table 7). Calves fed HMR + HCS had less fat and tended to have lower energy content and more water in gain than calves fed HMR + CCS. Although the pattern of means for mass gains followed the same trends as for percentages of gain, they were not statistically different due to larger standard errors and the addition of relatively small daily gains to a large existing tissue mass. Our findings indicated that the CCS did not supply adequate protein relative to ME to maintain lean tissue growth compared with HCS; in consequence, more fat was deposited at a similar ME intake. This was an important finding because previous studies that evaluated different CP contents in the starter were limited to the analysis of FBW measurements (Luchini et al., 1991; Hill et al., 2007) and failed to identify the potential advantages on composition of gain noted here with the HCS.

Also of interest were the effects of starter CP content on the components of BW gain. The percentage of EBW as carcass was actually 1.5 percentage units greater for calves fed HMR + CCS than for those fed HMR + HCS, although the average of both was greater than the calves fed LMR + CCS. However, calves fed HMR + HCS tended to have heavier reticulorumens that represented 0.56 percentage unit greater EBW than calves fed HMR + CCS. In a study using these same calves, Naeem et al. (2012) showed that these tissues from HMR + HCS were more metabolically developed than tissue from HMR + CCS. Likewise, liver mass and percentage of EBW were greater for the calves fed HCS. Although both groups fed HMR had larger reticulorumen mass than calves fed LMR, the CCS limited growth of the highly metabolically active GIT and liver for calves fed HMR. Thus, while starters similar to CCS may provide similar growth as HCS, they may limit development of the GIT and reticulorumen. This observation might be responsible for the improved BW gains realized during the period of weaning for calves fed HMR + HCS and reported in the companion study (Stamey et al., 2012). Further, this agrees with the evaluation by Van Amburgh et al. (2019) indicting that meeting the protein requirement of gastrointestinal development is important for enhancing postweaning BW gain. It is well known that solid feed intake and fermentability are key stimulatory factors of ruminal development (Warner et al., 1956; Sander et al., 1959). Nonetheless, the importance of the starter as source of protein to support this process is often overlooked, despite the large need for protein for developing lean tissue during the weaning transition (Van Amburgh et al., 2019). Our results indicated that starters with conventional CP content might not meet those protein requirements, which might result in lower rumen capacity and function, leading to reduced weaning efficiency. Additionally, this finding further confirms the ontogenetic importance of reticulorumen development in the transitioning ruminant (Baldwin et al., 2004).

Energy and Protein Utilization

Before weaning, calves fed at the greater MR intake retained approximately twice as much energy as calves fed the lower amount of MR. Greater gains increased the partial efficiency of ME use for gain because of the dilution of maintenance effect. However, all groups had similar efficiency of use of ME above maintenance. This effect was not expected because calves fed the greater amounts of MR deposited a greater proportion of RE as protein compared with calves fed LMR, which is more expensive energetically. Bartlett et al. (2006) observed a tendency for decreasing efficiency of use of ME above maintenance as dietary CP increased for calves fed MR at 1.25% of BW (DM basis), but not for calves fed at 1.75% of BW. Values for efficiency of ME used in our study were lower than observed in studies with calves fed milk only (Donnelly and Hutton, 1976b; Tikofsky et al., 2001; Bartlett et al., 2006), likely due to the consumption of solid feed by our calves (Labussière et al., 2009). Our values were also lower than observed by Silva et al. (2017) for crossbred calves fed whole milk and solid feed. After weaning, calves in our study retained similar amounts of energy at similar efficiency regardless of treatment, but efficiency of ME use was lower than before weaning. The limitation of MP for deposition in viscera discussed already resulted in calves fed HMR + CCS retaining a greater proportion of RE as fat and less as protein.

The apparent efficiency of dietary CP use for EB protein gain was lower after calves were weaned, in agreement with the lower efficiency of protein use in ruminants compared with nonruminants (Thorbek, 1977; Williams and Jenkins, 2003). Despite having a greater efficiency of protein use before weaning, calves fed HMR had lower efficiencies after weaning. This could be partially attributable to the major change in the quality of the dietary protein and the upregulation of ruminal function that, in turn, alters protein and energy sources available to the calf (Reid et al., 1980; Quigley et al., 1985).

Blood Metabolites

During the first 5 wk, concentration of BHB in blood was lower for calves fed HMR than for those fed LMR + CCS, which corresponded to the lower starter intake for those calves. Between wk 6 and 10, however, calves fed HMR + HCS had greater BHB than those fed HMR + CCS, supporting the differences in reticulorumen mass between the 2 HMR groups. Glucose and NEFA concentrations were higher for calves fed HMR, which agreed with previous findings (Bartlett et al., 2006). Glucose concentration increased in response to greater lactose consumption and NEFA to greater fat intake. The greater NEFA for calves fed HMR + HCS than for those fed HMR + CCS was difficult to explain, although absolute differences were of questionable biological significance.

Although total protein in blood did not differ among treatments during the first 5 wk, calves fed HMR were higher than those fed LMR, and calves fed HMR + HCS were greater than those fed HMR + CCS in the postweaning period. Because total protein in blood is responsive to protein status in young calves (Bartlett et al., 2006), greater total protein for calves fed HMR + HCS further indicated that the higher protein starter was able to improve protein status.

Conversely, lower urea N for calves fed LMR + CCS than for the groups fed HMR before weaning indicated that protein was deficient for optimal growth. Normal urea N is >7 mg/dL, whereas urea N for calves fed LMR + CCS was only 5.1 mg/dL. After weaning, urea N was greater for both groups fed HMR than for the group fed LMR, as expected, but was also 4.6 mg/dL greater for calves fed HMR + HCS than for calves fed HMR + CCS. Because excessive dietary protein is degraded and the nitrogen is excreted as urea in urine, these data may indicate that the enhanced starter diet contained excessive protein relative to energy or was not appropriately balanced for rumen degradable and rumen undegradable protein. The CP content of the HCS was increased mainly by a greater inclusion of soybean meal that was prone to rumen degradation in comparison to other sources, which could have contributed to the greater levels of circulating urea N.

CONCLUSIONS

Our results describe the response of young calves to increased milk feeding rate and increased starter CP content. Composition of EBW gain was appreciably altered with increased milk feeding rate. Protein deposition and rate of gain increased with milk feeding rate, and fat content of EBW gain was decreased with greater milk feeding rate. The higher CP starter promoted greater visceral tissue gains and lessened fat content of EBW gain on a proportional basis during the postweaning period. Greater BHB concentration in plasma supported the greater GIT development in calves fed higher CP starter, even though EBW gains were not different between the 2 starter CP contents. Plasma urea N increased with milk feeding rate and starter protein content; the increase in plasma urea N indicated that the enhanced starter formulation did not optimize MP or its AA profile supplied by the starter.

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