Effects of the step-up/step-down and step-down milk feeding procedures on the performance, structural growth, and blood metabolites of Holstein dairy calves

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ABSTRACT

The objective of this study was to compare the efficacy of the step-up/step-down (SUSD) and step-down (STP) methods of milk feeding on the performance, growth parameters, blood metabolites, and health of dairy calves. For this purpose, 45 Holstein male calves (3 d of age and 41 ± 3 kg of body weight) were randomly assigned to one of the following milk feeding groups: (1) conventional (CONV; 4 L/d milk from d 1 to 52, and 2 L/d milk from d 53 to 56 of the study), (2) STP (6 L/d milk from d 1 to 29, and 4 L/d milk from d 30 to 45 of the study followed by feeding 2 L/d milk from d 46 to 56 of the study), and (3) SUSD (6 L/d milk from d 1 to 5, 8 L/d milk from d 6 to 15, 10 L/d milk from d 16 to 35, 8 L/d milk from d 36 to 42, 6 L/d milk from d 43 to 47, 4 L/d milk from d 48 to 52 of the study followed by feeding 2 L/d milk from d 53 to 56 of the study). Calves were weaned on d 56 and followed until d 70 of the study period. Animals had ad libitum access to the same starter ration during the entire study period (d 3 to 70). Starter intake, total dry matter intake, and average daily gain were greater in the SUSD calves than those in the CONV and STP treatments during the preweaning period. The SUSD procedure was found to increase body weight during the entire study and improved body length, wither height, heart girth, hip height, and hip width on d 56 and 70 of the study compared with the STP and CONV calves. The SUSD treatment increased blood glucose concentration on d 35 compared with CONV and STP procedures. The STP group had a higher starter intake than the CONV and SUSD animals. The STP animals exhibited a higher plasma concentration of total pro-

tein and BHBA than did the SUSD animals during the preweaning period. Neither the SUSD nor the STP procedure negatively affected the fecal score. In conclusion, the SUSD milk feeding procedure was found to improve the performance of dairy calves compared with the STP and CONV procedures. However, it appears that the STP procedure induces earlier reticulo-rumen development in dairy calves than does the SUSD procedure.

Key words: dairy calf, performance, step-up/step-down, step-down

INTRODUCTION

Rearing healthy calves is crucial for the long-term success and sustainability of the dairy industry. Recently, in some studies, attention has been paid to the effect of increasing milk feeding on the early consumption of calf starter and rumen development in dairy calves (Brown et al., 2005; Silper et al., 2014). Controversial results have been reported in the literature on the performance of young calves fed large amounts of milk before weaning compared with that of calves fed on a conventional milk-feeding protocol. Although some studies have reported improvements in growth rates (Huuskonen and Khalili, 2008), feed efficiency, BW gain, and performance (Diaz et al., 2001; Khan et al., 2011; Silper et al., 2014), others have shown that feeding high amounts of milk to young calves could reduce starter intake, growth, and reticulorumen development (Baldwin et al., 2004; Terré et al., 2007). The discrepancies observed may be due to differences in the amounts, methods, and quality of the liquid feed (milk or milk replacer) fed, as well as to different management conditions among the studies.

Decades of research have focused on alternative procedures of milk feeding to dairy calves in attempts to improve weight gain and health without negative effects on starter intake or ruminal development. In

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the conventional milk feeding method, calves receive a restricted amount of milk or milk replacer (4 L/d, equivalent to approximately 10% of birth weight) during the whole milk-feeding period (Khan et al., 2007a,b; Silper et al., 2014). According to Davis and Drackley (1998), the conventional milk feeding method results in decreased alimentary efficiency, thereby leading to suboptimal performance of dairy calves during the whole milk-feeding period. Alternatively, the step-down milk-feeding procedure allows calves to receive greater amounts of milk compared with the conventional method. In this procedure, animals receive more milk than in the conventional method during the early weeks of the milk feeding period (6 L/d milk from d 1 to 29), followed by a fixed amount of milk until weaning (4 L/d milk from d 30 to 60). Khan et al. (2007b) showed that using the step-down method rather than the conventional procedure for feeding milk to calves not only improved BW gain and feed efficiency but also prevented the problems associated with depressed solid feed intake. However, Silper et al. (2014) reported similar performance in calves fed milk replacer via both procedures. A third procedure for providing greater amounts of milk to calves with the aim of encouraging starter intake and promoting early rumen development and performance in calves is the step-up/step-down milk-feeding procedure. In this method, milk feeding is gradually increased to reach a peak in the middle of the milk-feeding period before it is gradually decreased to the original level toward the end of the period. Limited, if any, evidence is available on the effect of the SUSP procedure on the performance of dairy calves treated with this procedure. In one study, Terré et al. (2007) found that starter DMI decreased during the preweaning and postweaning periods when milk was fed to calves in the enhanced-growth feeding program that consisted of 4 L/d from d 1 to 6, 6 L/d from d 7 to 13, 7 L/d from d 14 to 20, 6 L/d from d 21 to 28, and 3 L/d from d 29 to 35. In that study, the calves in the enhanced-growth treatment exhibited lower nutrient digestibility coefficients compared with conventionally fed calves in the week after weaning.

Although previous studies have focused on the individual effects of step-down and step-up/step-down milk-feeding procedures on dairy calf performance, to the best of our knowledge, no study has been reported to compare the effects of these procedures on the performance, structural growth, and blood metabolites of dairy calves in a single study. It was the objective of this study, therefore, to determine the effects of 2 milk-feeding procedures (step-up/step-down vs. step-down) on BW gain, feed intake, feed efficiency, blood metabolites, and fecal score in dairy calves.

MATERIALS AND METHODS

Animals, Management, and Treatments

The current study was carried out in a local dairy farm (Ghiam Agri. Animal Production Co., Isfahan, Iran) according to the guidelines of the Iranian Council of Animal Care (1995). The 45 Holstein male calves used in this study were separated from their dams immediately after birth, weighed, and housed in individual pens (1.5 × 2.5 m) bedded with sawdust. The beddings were renewed as required (every 1–2 d). The animals (3 d of age, 41 ± 3 kg of BW) were randomly assigned to 1 of the following 3 groups (Figure 1): (1) conventional (CONV: 4 L/d milk from d 1 to 52, and 2 L/d milk from d 53 to 56 of the study); (2) step-down (STP; 6 L/d milk from d 1 to 29, and 4 L/d milk from d 30 to 45 of the study followed by feeding 2 L/d milk from d 46 to 56 of the study); and (3) step-up/step-down (SUSD; 6 L/d milk from d 1 to 5, 8 L/d milk from d 6 to 15, 10 L/d milk from d 16 to 35, 8 L/d milk from d 36 to 42, 6 L/d milk from d 43 to 47, 4 L/d milk from d 48 to 52 of the study followed by feeding 2 L/d milk from d 53 to 56 of the study). All calves received colostrum (at least 3–4 L within the first 8 h of birth) and were enrolled in the study within 72 h of birth. Calves were fed whole milk (temperature set at $39 \pm 0.5^\circ\text{C}$ using a water bath) containing $3.22 \pm 0.11\%$ fat, $2.96 \pm 0.07\%$ CP, $4.92 \pm 0.05\%$ lactose, and $11.77 \pm 0.15\%$ TS in steel buckets twice daily at 0800 and 1600 h. Calves were weaned on d 56 and the study was terminated on d 70. From d 3 to 70 of the study, all calves had free access to fresh water and the same starter ration formulated according to the Cornell Net Carbohydrate and Protein System, version 5.1 (CNCPS; Fox et al., 2000). The ingredients and nutrient compositions of the starter are given in Table 1.

Records and Sampling

Starter and milk intake were measured daily and BW were recorded weekly during the pre- (d 1 to 56) and postweaning (d 57 to 70) periods. Feces were scored daily according to the procedure of Larson et al. (1977) and categorized as firm and well-formed (score 1), soft and pudding-like (score 2), runny and similar in consistency to pancake batter (score 3), and liquid splatter and similar in consistency to pulpy orange juice (score 4). Body measurements including body length, body barrel, wither height, heart girth, hip height, and hip width of the calves were collected according to Lesmeister and Heinrichs (2005) at weaning (d 56) and at the end of study (d 70).

Figure 1. The schematic represents the amounts of milk consumed (kg/d) by calves fed milk by different procedures and weaned at 56 d of the study: conventional (4 L/d milk from d 1 to 52, and 2 L/d milk from d 53 to 56 of the study); step-down (6 L/d milk from d 1 to 29, and 4 L/d milk from d 30 to 45 of the study followed by 2 L/d milk from d 46 to 56 of the study), and step-up/step-down (SUSD; included 2 phases of milk feeding; 1 = pre-SUSD (6 L/d milk from d 1 to 5, 8 L/d milk from d 6 to 15, 10 L/d milk from d 16 to 35), 2 = post-SUSD (8 L/d milk from d 36 to 42, 6 L/d milk from d 43 to 47, 4 L/d milk from d 48 to 52 of the study followed by feeding 2 L/d milk from d 53 to 56 of the study).

Feed samples were collected weekly throughout the trial and stored at -20°C before chemical analysis. Blood samples were collected in all the treatments on d 21, 35, 49, 61, and 70 of the study 3 h after the morning feeding. Blood was withdrawn from the jugular vein into evacuated tubes containing K_2EDTA (Becton Dickinson Vacutainer Systems, Franklin Lakes, NJ) and immediately placed on ice. Tubes were centrifuged at $2,000 \times g$ for 20 min (4°C) within 2 h of sampling time. The plasma was separated and stored at -20°C until analysis.

Samples were collected for the determination of milk composition twice a week in the morning and in the afternoon of the same day. The milk samples were preserved using bronopol and stored at 8°C until analysis.

Chemical and Biochemical Analyses

Subsamples of feeds and refusals were mixed thoroughly and ground to pass a 1-mm screen in a Wiley mill (Ogaw Seiki Co. Ltd., Tokyo, Japan) before chemical analyses for DM content (method 934.01; AOAC, 1990), CP (method 988.05; AOAC, 1990), lipids (AOAC, 1990; method 920.39), calcium (method 985.35; AOAC, 1990), and phosphorus (method 986.24; AOAC, 1990). Neutral detergent fiber was analyzed without the use of sodium sulfite and with the inclusion of α -amylase (Van Soest et al., 1991). Milk samples were analyzed for fat, CP, lactose, and TS content by

Milkoscan (Foss Electric, Hillerød, Denmark; AOAC International, 1997).

Plasma glucose concentration [glucose oxidase-phenol 4-aminoantipyrine peroxidase (GOD-PAP) method; Barham and Trinder, 1972], total protein (Biuret

Table 1. Ingredients and chemical compositions (% of DM, unless otherwise noted) of the experimental starter feed

Item	Value
Ingredient	
Corn grain, ground	50.0
Soybean meal (45% CP)	41.0
Wheat bran	5.5
Vitamin and mineral mix ¹	1.5
Calcium carbonate	1.5
Salt	0.5
Chemical composition	
ME ² (Mcal/kg)	3.1
NE _G ² (Mcal/kg)	1.4
DM	89.0
CP	21.2
Ether extract	4.1
NDF	14.0
NFC ³	51.4
Ca	0.9
P	0.5

¹Contained per kilogram of supplement: 250,000 IU of vitamin A, 50,000 IU of vitamin D, 1,500 IU of vitamin E, 2.25 g of Mn, 120 g of Ca, 7.7 g of Zn, 20 g of P, 20.5 g of Mg, 186 g of Na, 1.25 g of Fe, 3 g of S, 14 mg of Co, 1.25 g of Cu, 56 mg of I, and 10 mg of Se.

²Calculated according to NRC (2001).

³Calculated as $\text{DM} - (\text{NDF} + \text{CP} + \text{ether extract} + \text{ash})$ (NRC, 2001).

method; Tomas, 1998), and albumin (bromocresol green method; Johnson et al., 1999) were determined by an automated biochemical analyzer (Technicon RA 1000, Bayer, Tarrytown, NY) using commercial kits (Pars Azmoon Co., Tehran, Iran) according to the manufacturer's instructions. Plasma concentrations of BHBA were determined by enzymatic analysis (BHBA dehydrogenase; kit no. 310, Sigma Chemical; Williamson et al., 1967).

Statistical Analyses

Data were analyzed separately for the preweaning (from d 1 to 56 of the study), postweaning (from d 57 to 70 of the study), and overall (from d 1 to 70) periods. Dry matter intake, BW, ADG, feed efficiency, and blood variables (BHBA, glucose, total protein, and albumin) were analyzed by using the MIXED procedures of SAS (version 9.2; SAS Institute Inc., Cary, NC), considering milk-feeding procedure as a fixed effect and animal as a random effect. The effect of dietary treatment on the categorical responses related to fecal score was tested using the GLIMMIX procedure of SAS version 9.2. The measurements recorded in different weeks were considered as repeated measures using a first-order autoregressive type 1 covariance structure. When differences were detected in the dietary treatments or interactions, means separation was conducted using a Tukey's adjustment for the probability. Significance was declared at $P \leq 0.05$ and trends were considered when $0.05 < P < 0.10$.

RESULTS AND DISCUSSION

Calf Performance

The results on feed intake, ADG, and feed efficiency are presented in Table 2. As provisioned, SUSD calves consumed more milk (424 L) than those in the STP (262 L) or CONV (209.0 L) treatments ($P < 0.01$). The SUSD calves recorded higher values of starter intake and total DMI (solid feed and milk; $P < 0.01$) than the CONV and STP animals during the preweaning period. Several other studies have also reported that starter feed intake increases as milk or milk replacer allowance increases (Kristensen et al., 2007; Hill et al., 2009). However, there are reports to the contrary; calves fed more milk replacer exhibited decreased solid feed consumption (Khalili et al., 1992; Jasper and Weary, 2002; Terré et al., 2007). Terré et al. (2007) reported lower starter intake for their step-up/step-down calves than conventionally fed cows during the pre- and postweaning periods. The discrepancies observed among the different studies could be attributed to differences in the weaning methods applied or to variations in the amounts of milk or milk replacer fed before weaning.

In the current study, starter intake was greater ($P < 0.01$) in the STP group than in the CONV and SUSD treatments during the postweaning period. Differences between the STP and SUSD animals in their starter intakes during the postweaning period might be related to the greater dependence of SUSD animals on milk. In agreement with our data, Khan et al. (2007a,b) reported that dairy calves fed milk through the STP pro-

Table 2. Average DMI of starter, total DMI, ADG, and feed efficiency in calves fed milk through different procedures

Item ¹	Treatment ²			SEM	P-value
	CONV	STP	SUSD		
Total DMI (kg/d)					
Prewaning	0.89 ^c	1.01 ^b	1.30 ^a	0.02	0.01
Overall	1.08 ^c	1.21 ^b	1.43 ^a	0.03	0.01
DMI of starter (kg/d)					
Prewaning	0.49 ^b	0.43 ^b	0.61 ^a	0.02	0.01
Postweaning	1.90 ^b	2.00 ^a	1.83 ^b	0.07	0.01
Overall	0.77	0.75	0.85	0.08	0.17
ADG (kg/d)					
Prewaning	0.40 ^c	0.55 ^b	0.66 ^a	0.05	0.01
Postweaning	0.73 ^b	1.08 ^a	0.99 ^a	0.07	0.02
Overall	0.48 ^c	0.63 ^b	0.73 ^a	0.08	0.05
Feed efficiency ³					
Prewaning	0.56 ^b	0.65 ^{ab}	0.67 ^a	0.03	0.05
Postweaning	0.44 ^b	0.55 ^a	0.51 ^{ab}	0.02	0.01
Overall	0.54 ^b	0.63 ^a	0.64 ^a	0.02	0.02

^{a-c}Means within a row with different superscripts are significantly different ($P < 0.05$).

¹Periods: preweaning = from 1 to 56 d of age; postweaning = from 57 to 70 d of age.

²CONV = conventional milk feeding; STP = step-down milk feeding; SUSD = step-up/step-down milk feeding.

³Feed efficiency = kg of BW gain/kg of total DMI.

cedure had a greater starter intake than those fed milk through the CONV method during their postweaning period.

Average daily gain ($P < 0.01$) among the SUSD calves was greater than that among the STP and CONV calves, and ADG was higher among the STP animals than among CONV animals during both the preweaning and overall periods (Table 2). During the postweaning period, ADG was greater ($P < 0.01$) for calves receiving milk through the STP and SUSD methods than for those fed through the CONV procedure. The improved ADG in the SUSD calves relative to the CONV calves during the preweaning, postweaning, and overall periods could be due to the greater milk intake in the SUSD animals. This is in line with the findings reported in previous studies in which greater amounts of milk (Jasper and Weary, 2002; Borderas et al., 2009) or milk replacer (Quigley et al., 2006; Hill et al., 2009) were fed to dairy calves.

Previous studies have shown that improvements in growth and feed efficiency occur as a result of feeding greater quantities of milk or milk replacer, providing nutrient levels above the animal's maintenance requirements (Jasper and Weary, 2002; Bartlett et al., 2006; Silper et al., 2014). Overall, in the current study, STP and SUSD calves had greater feed efficiency than the CONV animals. Feed efficiency during the preweaning period was higher in calves receiving milk through the SUSD procedure than in those on the CONV procedure. During postweaning, STP calves improved their feed efficiency compared with the CONV calves. This might be because SUSD and STP calves had higher total DMI than CONV animals during their pre- and postweaning periods, respectively. In agreement with our observations, Khan et al. (2007a) reported greater values of feed efficiency and ADG for their step-down calves compared with calves fed conventionally during the pre- and postweaning periods.

BW, Body Measurements, and Fecal Score

Body measurements and fecal score data are presented in Table 3. Body weight was greater ($P < 0.01$) in SUSD calves than in STP and CONV calves during the preweaning, postweaning, and overall periods. The STP animals had greater BW than did the CONV animals throughout the study ($P < 0.01$). The SUSD procedure improved ($P < 0.01$) body length, wither height, heart girth, hip height, and hip width compared with the other 2 treatments on d 56 and 70 of the study. No differences ($P > 0.05$) were observed in body measurements between STP and CONV calves. The higher values of body measurements in the SUSD-fed calves could be attributed to the greater consumption

of starter and milk in these animals. Previous studies have shown the beneficial effects of feeding larger amounts of milk to dairy calves on growth, age at first calving, and milk production during first lactation compared with the conventional method (Jasper and Weary, 2002; Khan et al., 2007a,b). Khan et al. (2007a) reported improved body measurements in calves fed through the step-down procedure compared with those fed conventionally.

Young calves are particularly susceptible to respiratory diseases and diarrhea during the milk-feeding period (Svensson et al., 2003). No differences ($P > 0.05$) were observed for fecal score among the treatments during the preweaning, postweaning, and overall periods. This is confirmed by findings of previous studies that reported no change in fecal scores of dairy calves as a result of employing different milk-feeding methods (Khan et al., 2007a).

Blood Metabolites

The results for blood metabolites are presented in Table 4. Overall, no differences ($P > 0.05$) were observed in blood glucose concentrations between the STP and the CONV animals; however, blood glucose concentration showed a significant increase ($P < 0.05$) in the SUSD calves compared with the CONV and STP animals on d 35 of the study. This increase in plasma glucose concentration could be due to their augmented preweaning total DMI and, in particular, to the increased milk intake as a source of lactose. A recent study (Silper et al., 2014) showed that the step-down milk replacer feeding strategy did not affect glucose concentration in dairy calves. In the current study, as calves grew older, plasma glucose concentration decreased in the animals assigned to different milk-feeding procedures. This change might have been due to the shift in the source of energy from glucose to VFA when the rumen became sufficiently functional (Hammon et al., 2002). Our data are in agreement with the findings of Khan et al. (2007a).

No differences ($P > 0.05$) were observed in blood albumin concentration among the treatments. Blood concentrations of total protein and BHBA were lower ($P < 0.01$) in the SUSD than in the STP animals during the preweaning period; however, they were not different ($P > 0.05$) across the treatments during the postweaning period (Table 4). No changes were detected in plasma BHBA concentrations ($P > 0.05$) between STP and CONV calves throughout the study. Plasma BHBA is a measure of rumen epithelial development indicating ruminal conversion of butyrate to BHBA as it passes across the reticulo-rumen wall in sheep (Lane et al., 2000). This may indicate earlier initiation of ru-

Table 3. Body weight, body measurements, and fecal score of calves fed milk through different procedures

Item ¹	Treatment ²			SEM	P-value
	CONV	STP	SUSD		
BW (kg) ²					
Prewaning	53.8 ^c	56.3 ^b	64.8 ^a	0.98	0.01
Postweaning	73.6 ^c	79.1 ^b	88.2 ^a	1.65	0.01
Overall	57.7 ^c	60.9 ^b	69.5 ^a	0.95	0.01
Body length (cm)					
d 56	51.1 ^b	51.1 ^b	55.2 ^a	0.70	0.01
d 70	53.3 ^b	55.2 ^b	58.9 ^a	0.70	0.01
Wither height (cm)					
d 56	84.2 ^b	82.9 ^b	86.7 ^a	0.83	0.01
d 70	86.2 ^b	87.2 ^{ab}	89.3 ^a	0.91	0.01
Heart girth (cm)					
d 56	93.6 ^b	94.5 ^b	99.6 ^a	0.91	0.01
d 70	97.6 ^b	99.1 ^b	103.5 ^a	0.86	0.01
Hip width (cm)					
d 56	15.2 ^b	17.1 ^{ab}	19.2 ^a	0.95	0.01
d 70	19.2 ^b	19.9 ^b	21.7 ^a	0.24	0.01
Hip height (cm)					
d 56	88.4 ^b	88.5 ^b	92.6 ^a	0.71	0.01
d 70	90.7 ^b	91.1 ^b	94.3 ^a	0.60	0.01
Fecal score ³					
Prewaning	2.21	2.22	2.24	0.02	0.61
Postweaning	2.11	2.07	2.10	0.02	0.54
Overall	2.19	2.18	2.21	0.02	0.55

^{a-c}Means within a row with different superscripts are significantly different ($P < 0.05$).

¹Periods: preweaning = from 1 to 56 d of age; postweaning = from 57 to 70 d of age.

²CONV = conventional milk feeding; STP = step-down milk feeding; SUSD = step-up/step-down milk feeding.

³Scale of 1 to 4.

minimal fermentation and better ruminal function in STP animals compared with the SUSD group. The lower BHBA concentration in SUSD group from wk 3 to 7 in this study could be due to the higher milk intake (Figure 1; 10 L/d milk from d 21 to 35, and 8 L/d milk from d 36 to 42) and lower starter intake in the SUSD group compared with the other 2 treatments. Similar to the data obtained here, Khan et al. (2007a) reported a higher blood concentration of BHBA in calves on the

step-down procedure than those on a conventional procedure during the weaning and postweaning periods.

CONCLUSIONS

The SUSD milk feeding procedure improved the performance (total DMI, BW, growth, and blood glucose concentration) of dairy calves compared with the STP and CONV methods. The better performance of

Table 4. Blood metabolite concentrations in calves fed milk through different strategies

Item ¹	Treatment ²			SEM	P-value
	CONV	STP	SUSD		
Glucose (mg/dL)					
Prewaning	94.5	96.8	101.9	6.90	0.23
Postweaning	85.5	81.1	83.6	9.90	0.74
Albumin (g/dL)					
Prewaning	3.7	3.7	3.5	0.09	0.21
Postweaning	3.7	4.1	3.9	0.11	0.12
Total protein (g/dL)					
Prewaning	5.9 ^{ab}	6.1 ^a	5.2 ^b	0.26	0.05
Postweaning	6.6	6.1	6.1	0.29	0.11
BHBA (mmol/L)					
Prewaning	0.13 ^{ab}	0.18 ^a	0.08 ^b	0.02	0.01
Postweaning	0.39	0.43	0.37	0.05	0.44

^{a,b}Means within a row with different superscripts are significantly different ($P < 0.05$).

¹Periods: preweaning = from 1 to 56 d of age; postweaning = from 57 to 70 d of age.

²CONV = conventional milk feeding; STP = step-down milk feeding; SUSD = step-up/step-down milk feeding.

dairy calves in the SUSD group could be explained by the higher nutrient availability due to the considerably greater milk intake. However, the STP procedure improved blood BHBA concentration during the pre-weaning period compared with the SUSD procedure, which is suggestive of the earlier initiation of ruminal fermentation in the STP-fed animals.

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