Effects of weaning strategies on health, hematology, and productivity in Holstein dairy calves

A. R. Wolfe,1 P. Rezamand,2 B. C. Agustinho,2 D. E. Konetchy,2 and A. H. Laarman1,2*
1Department of Animal, Veterinary and Food Science, University of Idaho, Moscow, ID 83843
2Department of Agriculture, Food, and Nutritional Sciences, University of Alberta, Edmonton, AB, Canada T6G 2P5

ABSTRACT

Weaning strategies in dairy calves vary considerably, though the effect on animal health is unclear. This study examined the effects of calf weaning age (6 vs. 8 wk) and pace (abrupt vs. gradual) on performance, blood, and health parameters in dairy calves. The experiment consisted of a 2 × 2 factorial arrangement of treatments, where the factors included weaning age (early vs. late) and weaning pace (abrupt vs. gradual). Holstein calves (n = 72), blocked by sex and birth weight, were randomly assigned to one of 4 treatments (n = 18 per treatment): early-abrupt (EA), early-gradual (EG), late-abrupt (LA), and late-gradual (LG). Milk replacer (24% crude protein, 17% fat; up to 1,200 g/d) was fed twice daily; water, calf starter (18% crude protein), and chopped alfalfa hay were fed ad libitum. Daily intakes of milk replacer, calf starter, and forage were recorded from birth until end of weaning. Body weight, selected health measures, blood hematology, and fecal scores were obtained 1 d preweaning and 1 d postweaning. Calves were orally bolused with a rumen pH logger for the last 3 d of the weaning transition and rumen pH was measured continuously. Data were analyzed with age, pace, age × pace interaction, birthweight, and sex as fixed effects, and starting date as a random effect. Greater age at weaning increased respiration, whereas gradual-weaned calves had lower respiration rate. Heart rate was lower in gradual than in abrupt weaned groups. Fecal score had a marginal increase in late-weaned groups and significantly increased in gradually weaned groups. No difference was detected in body core temperature by age, pace, or interaction. During the weaning transition, average daily gain was lower in LA than EA and gradually weaned groups had an increased average daily gain. Change in grain intake, but not forage intake, was greater in gradually weaned groups. Mean rumen pH marginally increased from EG to LG and from LA to LG. No difference was detected among treatments in red or white blood cell counts, and hemoglobin. Procalcitonin was marginally highest in the LA group, while blood hematocrit increased in abruptly weaned groups. Overall, calf health is affected by both age and pace of weaning, though the health parameters affected by age and pace differ.

Key words: calf health, weaning pace, weaning age

INTRODUCTION

Weaning is one of the most important transitions in a young ruminant’s life, because young calves rely on increased rumen function for growth and production. Weaning is often conjoined with a decrease in ADG, which could be related to reduced starter intake and feed efficiency (Strzetelski et al., 2001; Hill et al., 2006), reduced rumen development and function (Terré et al., 2006), or reduced digestion of the starter (Terré et al., 2007). Increasing milk provision before weaning does not necessarily eliminate the weaning and postweaning decrease in ADG (Bar-Peled et al., 1997; Jasper and Weary, 2002; Cowles et al., 2006). This suggests that the postweaning decrease in ADG is multifactorial and may change with age.

The age at weaning onset is one major factor in weaning strategies, with earlier weaning reducing the cost of a milk replacer (MR) program and associated labor costs, while late weaning confers performance benefits on calves. The reduction in ADG is far more pronounced for early-weaned (6 wk) calves compared with late-weaned (8 wk) calves (de Passillé and Rushen, 2012; Eckert et al., 2015). Calves weaned at 8 wk compared with 6 wk have higher intakes of starter and digestible energy, as well as greater weight gains during the weaning period (0.5 vs. 1.0 kg/d; (de Passillé and Rushen, 2012). When weaning is extended from 6 to 8 wk, calves fed an elevated plane of nutrition have higher starter intakes and ADG during the weaning period (Khan et al., 2007; Hill et al., 2010). Understanding the benefits of weaning at different ages is important when
considering cost of milk feeding regimen and labor as potential hindrances.

Another consideration in weaning strategies is weaning pace. Abrupt weaning in restricted-fed and ad libitum-fed calves results in a greater depression in growth than does gradual weaning (Roth et al., 2008; Weary et al., 2008). Gradual weaning encourages the consumption of solid feed before weaning, reducing the lag between demand and supply of nutrients after weaning, thereby minimizing, or preventing depressed growth (Khan et al., 2007; Sweeney et al., 2010). In calves with an elevated plane of nutrition (e.g., 20% of BW or ~8 L/d for Holstein calves), gradual weaning can improve feed efficiency (Khan et al., 2011), reduce future incidence of disease (Soberon et al., 2012), provide greater opportunity to express natural behaviors, and potentially improve future lactation performance (Khan et al., 2011). On an elevated plane of nutrition and weaned at 7 wk, calves on a gradual step-down period had greater postweaning ADG and rumen VFA than those with an abrupt step-down or no step-down (Steele et al., 2017). To summarize, gradual weaning improved starter intake and performance, though great variability in pace of weaning exists; the effect of gradual weaning on health and immune function of calves is less well established.

Current research on weaning strategies focuses on either age or pace and its effect on growth, productivity, and clinical health, while frequently omitting subclinical hematological health indicators. Hematological markers of weaning stress that may appear before clinical morbidity or mortality. During the first month of life, calves exhibit a decrease in the overall number of white blood cell count (WBC), neutrophils, and lymphocytes, followed by an increase thereafter (Mohri et al., 2007; Roland et al., 2014). The variation in hematological measures in early life suggest they hold potential for monitoring of weaning stress. For instance, hematocrit and hemoglobin can be effectively used to determine anemia, dehydration, and potential iron levels (Mohri et al., 2007). Lymphocytes and neutrophils are also effective stress indicators (Roland et al., 2014). Using nonclinical tools to evaluate weaning stress will be key to better monitoring weaning stress and detecting adverse health events earlier. Even though hematological indicators are known to vary, their association with calf health productivity during weaning warrants further exploration.

How calf health is affected by weaning transition is unclear, and how age and pace interact to affect calf health may better identify optimal weaning strategies. Separately, weaning studies typically do not correct for total preweaning milk allowance (Sweeney et al., 2010; Parsons et al., 2020), so total preweaning liquid feed intake may confound weaning stress. We hypothesized that calves weaned closer to a natural progression (i.e., later and more gradual) would have increased growth, intake, and immune cell hematology. The objectives of our study were to examine the effects of calf weaning age (6 vs. 8 wk) and pace (abrupt vs. gradual) on production, health, and hematological parameters in dairy calves, and to determine if calves weaned abruptly will experience less-negative effects when weaned at later ages.

**MATERIALS AND METHODS**

All animal procedures were approved by the University of Idaho Institutional Animal Care and Use Committee (Protocol 2020–12 and 2021–51) and the University of Alberta Animal Care and Use Committee–Livestock (Protocol 3857). This study took place between September and November 2020 (n = 40 calves) and between October and December 2021 (n = 32 calves). There was no statistical difference between the 2 groups for any variables, implying there was no seasonal effect. Calf health was monitored daily; based on the recommendations of the attending veterinarian, calf morbidity was treated or calves were removed from the study. One calf died of pneumonia before treatments began so is not counted above; no other calves were removed from the study.

**Experimental Design**

Seventy-two Holstein calves, blocked by sex (40 females and 32 males) and birth weight (38.8 ± 4.4 kg), were randomly assigned using a number generator in Excel to treatments in a 2 × 2 factorial arrangement (n = 18 per treatment) of weaning age (early 6–7 wk vs. late 8–9 wk) and weaning pace (abrupt 3 d vs. gradual 14 d). Early groups were weaned after a total MR intake of 46.2 kg, at either 42 or 49 d (Figure 1), and late groups were weaned at a total of 63 kg, at either 56 or 63 d. Abrupt groups weaned in 4 equal step-downs over 3 d and gradual groups weaned in 7 equal step-downs over 14 d. The groups were early-abrupt (EA), whose weaning transition lasted from 40 to 42 d of age; early-gradual (EG), whose weaning transition lasted from 35 to 49 d of age; late-abrupt (LA), whose weaning transition lasted from 54 to 56 d of age; and late-gradual (LG), whose weaning transition lasted from 49 to 63 d of age.

**Animal Management**

Calves were housed in individual covered hutches (PolyDome, model PD-1185), on coarse sand (#8, from
North Idaho Crushing); the experimental unit was the calf. The hutch were cleaned daily and kept dry in the wet and colder months. Fresh water was provided ad libitum as soon as calves arrived onto facility grounds. Milk replacer (24% CP, 17% fat; Provimi) was bottle-fed up to 1,200 g/d for every treatment and was fed twice daily, once at 0600 h and again at 1800 h. Calf starter (18% CP; Calf Startena, Purina) was offered ad libitum at 3 wk of age and weighed every morning to ensure 5 to 10% orts. Chopped alfalfa hay (40% in the upper sieve >2 cm, 25% in the middle sieve 0.6–1.9 cm, and 35% in the bottom pan <0.5 cm) was offered at 4 wk of age and fed ad libitum.

**Sampling**

Weekly and daily intakes of MR, calf starter, and forage were recorded. Body weight, health measures, and fecal scores were obtained weekly. Calves’ weights were recorded using a portable digital calf scale (Digistar) calibrated before the start of the project and rectal temperature, respiration rate, and heart rate were measured at the same time. Heart rate and respiration were determined by palpation. Hydration levels were recorded on a 3-point scale with “good” being <5% dehydration and a normal eye position, “moderate” consisted of 6–8% dehydration with a slightly sunken eye position, finally “severe” dehydration was classified at >9% and having a pronounced gap between the eye and tissue (University of Wisconsin–Madison, 2023). Fecal scores were recorded on a 3-point scale with 0 being completely solid and 3 being watery diarrhea (University of Wisconsin–Madison, 2023). Visual fecal scores can be an accurate measurement of calf diarrhea and fecal dry matter decline (Renaud et al., 2020). Calf starter and chopped alfalfa samples were obtained at the start of each month and every new bale and composited for each trial period and stored at −20°C for later analysis.

**Rumen pH Sampling**

Male calves (n = 32) were orally bolused with a rumen pH logger (T-9) for the last 3 to 5 d of the weaning transition and rumen pH was measured continuously every 2 min. These pH loggers were then retrieved directly from the rumen on the day of euthanasia and data extracted. The subacute rumen acidosis threshold was set as below 5.8 pH.

**Blood Sampling**

Blood was collected via jugular venipuncture using one tube with no anticoagulant (BD Vacutainer) to collect serum, one tube containing 143 USP units of sodium heparin (BD Vacutainer) to collect plasma, and one tube containing EDTA (Vacuette, Greiner bio-one) to collect plasma. Three blood samples were taken once every week per calf between 0730 h and 0830 h. Once the blood samples were obtained, they were immediately put on ice to be transported. Samples were
centrifuged (TC-Spinplus-8, Walter Products) at 800 × g for 10 min and the serum or plasma layers were aliquoted into 1.5-mL microcentrifuge tubes (VWR) and then stored in −80°C freezers to be analyzed at a later date.

**Fresh Blood Analysis**

Fresh serum was analyzed in a hematology analyzer (VetScan HM5, Abaxis) to determine hematocrit percentage (HCT), hemoglobin count, lymphocyte percentage and amount (LYM), neutrophil percentage and amount (NEU), platelet numbers, and WBC.

**Feed Analysis**

Milk replacer, commercial calf starter, and alfalfa hay were sent to a commercial laboratory (Dairy One Inc., Ithaca, NY) to determine the chemical composition of each item (Table 1). The dry matter content was determined using an oven according to method no. 930.15 (AOAC, 1990). Ash was determined by combustion according to method no. 942.05 (AOAC, 1990). Organic matter was determined by the difference of 100% and ash concentration. Neutral detergent fiber was determined, according to Mertens et al. (2002), using thermostable α-amylase and sodium modified for Ankom Fiber Analyzer (Ankom Technology). Acid detergent fiber was determined according to method no. 973.18 (AOAC, 1990). Starch concentration was determined using a YSI 2700 SELECT Biochemistry Analyzers (YSI Inc.). Fat concentration in the MR was determined by bases hydrolysis according to method no. 932.06 (AOAC International, 1996), whereas the fat concentration for commercial calf starter and alfalfa hay was determined using an ANKOM XT15 Extractor (Ankom Technology). Calcium and phosphorus concentrations were determined using inductively coupled plasma spectroscopy, according to the method described by Wolf et al. (2003).

**Statistical Analysis**

By allocating 18 animals per treatment, an a priori power analysis estimates that the data analysis can detect a 10% difference between treatments with a coefficient of variation of 10%, with 80% power (Berndtson, 1991). Statistical analysis was performed using PROC GLIMMIX in SAS software (version 9.1, SAS Institute Inc.). All data were analyzed in a 2 × 2 factorial arrangement of treatments (weaning age and weaning pace) in a completely randomized block design. No exclusion of data points was applied. Data were analyzed with weaning age, pace, and age × pace interaction, BW at birth, and calf sex as fixed effects, while study start date was used as fixed effect, using the following model:

\[ Y = A_i + P_j + A \times P_{ij} + W_k + S_l + C_m + \varepsilon_{ijklmn} \]

where Y is the dependent variable, P is the weaning pace, A is the age at weaning, A × P is the interaction of age and pace, W is the body weight at the beginning of the experiment, S is the sex of the calf, C is the cohort of calves (start date), and ε is the error term. Each treatment group had 10 heifers and 8 bulls due to the use of sexed semen from the source farm. Our treatment groups initial weight averages were EA: 38.59 ± 0.84 kg, EG: 38.09 ± 1.68 kg, LA: 38.80 ± 1.79 kg, and LG: 39.1 ± 1.15 kg. Initial weight and sex demonstrated no significance for any measured variable. Repeated measures were analyzed by testing 5 variance-covariance structures. The structure with the lowest Akaike information criterion was used in statistical analysis. After testing the data for fit of 5 data distributions in PROC UNIVARIATE, the distribution of best fit was used in PROC GLIMMIX; results were further investigated when P ≤ 0.10 by calculating 95% confidence intervals (CI). All least squares means and standard error of the mean were back-transformed as necessary to improve ease of reading.

**RESULTS**

Before application of treatment at d 35, no significant differences in health, production, rumen, and hematol-ogy data were found from d 1–35 (Figures 2 and 3).

**Production Performance**

During the weaning transition, calves weaned in late groups had a 0.4 ± 0.03 kg/d decrease in ADG (CI: 0.37–0.43, P < 0.01; Figure 4). However, calves weaned gradually had a 0.29 ± 0.03 kg/d increase in ADG regardless of age (CI: 0.26–0.32, P = 0.03). The change

<table>
<thead>
<tr>
<th>Item</th>
<th>Milk replacer</th>
<th>Starter</th>
<th>Alfalfa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingredient, % DM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM, % (as fed)</td>
<td>96.7</td>
<td>87.0</td>
<td>81.7</td>
</tr>
<tr>
<td>CP</td>
<td>22</td>
<td>20.4</td>
<td>15.1</td>
</tr>
<tr>
<td>Crude fat</td>
<td>16.4</td>
<td>3.94</td>
<td></td>
</tr>
<tr>
<td>NFC</td>
<td>—</td>
<td>52.0</td>
<td>26.6</td>
</tr>
<tr>
<td>NDF</td>
<td>—</td>
<td>14.1</td>
<td>47.8</td>
</tr>
<tr>
<td>ADF</td>
<td>—</td>
<td>6.0</td>
<td>38.6</td>
</tr>
<tr>
<td>Ash</td>
<td>7.23</td>
<td>9.54</td>
<td>8.09</td>
</tr>
<tr>
<td>NEE, Mcal/kg</td>
<td>2.64</td>
<td>3.19</td>
<td>1.28</td>
</tr>
<tr>
<td>NE, Mcal/kg</td>
<td>2.90</td>
<td>3.32</td>
<td>1.19</td>
</tr>
<tr>
<td>NEC, Mcal/kg</td>
<td>2.09</td>
<td>2.18</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Wolfe et al.: EFFECT OF WEANING STRATEGY ON CALF HEALTH

Table 1. Nutrient analysis averages

Journal of Dairy Science Vol. 106 No. 10, 2023
in relative grain intake during weaning increased by 1.1 ± 0.1% BW with gradual weaning (CI: 1.08–1.12, \( P < 0.01 \); Figure 5), irrespective of weaning age; additionally, LG had greater relative grain intake than EG by 0.19 ± 0.14% BW (CI: 0.16–0.22, \( P = 0.02 \)) but there was a 0.13 ± 0.13% BW decrease from EA to LA (CI: 0.10–0.16, \( P = 0.03 \)). The change in forage intake during weaning was not detectably affected by weaning age (\( P = 0.48 \)), pace (\( P = 0.75 \)), or age × pace interaction (\( P = 0.48 \); Figure 5).

**Rumen Fermentation**

Mean rumen pH was unchanged between treatments (\( P = 0.11 \); Figure 6). The minimum rumen pH was also unchanged by treatments (\( P = 0.50 \)); however, maximum rumen pH marginally increased with age (\( P = 0.05 \)) and with gradual weaning (\( P = 0.06 \)). Maximum rumen pH was greater in LA than EA by 0.03 ± 0.19 (CI: −0.16–0.22, \( P = 0.05 \)) and from LA to LG by 2.30 ± 0.18 (CI: 2.11–2.48, \( P = 0.06 \)). The duration of SARA showed no difference among treatments (\( P = 0.52 \); Figure 7).

**Health Parameters**

Late-weaned groups showed a 4.2 ± 0.42 breaths per minute increase in respiration rate (CI: 3.78–4.62, \( P = 0.02 \); Figure 8), compared with that for the early-weaned groups whereas gradual groups had lower respiration rate (\( P = 0.01 \)) compared with that for abrupt groups. Calf heart rate was faster in abrupt than in...
gradual weaning groups by 9.3 ± 0.81 beats per minute (CI: 8.49–10.1, \( P = 0.01 \)). Fecal score slightly increased with age from the early groups to the late groups (\( P = 0.07 \)) and with the gradual-weaned groups compared with abrupt groups (\( P = 0.04 \)). Body core temperature was unaffected by age (\( P = 0.23 \)) or pace (\( P = 0.18 \)) of weaning.

**Immune Hematology**

Calf WBC (\( P = 0.47 \); Figure 9) and hemoglobin (\( P = 0.39 \); Figure 10) counts showed no detectable difference among treatments. Lymphocyte counts increased in late-weaned groups (\( P = 0.01 \); Figure 11) but was not affected by weaning pace. Contrary, LYM percentage in fresh blood demonstrated a marginal decrease in late-weaned groups (\( P = 0.07 \)). Neutrophil counts (\( P = 0.01 \)) and neutrophil percentage increased (\( P = 0.04 \)) with the age of calf (Figure 12). Procalcitonin was slightly affected by the age × pace interaction (\( P = 0.07 \)), with the LA group having the highest percentage of procalcitonin by 0.03% (CI: 0.01–0.03, \( P = 0.07 \)). Red blood cell (RBC) counts demonstrated a marginal increase by 0.33 ± 0.18 for calves weaned at a later age (CI: 0.29–0.37, \( P = 0.07 \); Figure 13). Blood HCT increased by 1.4 ± 0.13% when weaned abruptly versus gradually (CI: 1.37–1.63, \( P = 0.01 \); Figure 14). Calf platelet number counts slightly increased with age (\( P = 0.06 \)) but not pace of weaning (\( P = 0.51 \); Figure 15).

**DISCUSSION**

This study’s objectives were to investigate how weaning pace affects calf productivity and health, and how...
the effect of weaning pace changes as calves age. The results observed for grain intake, ADG, fecal score, LYM, NEU, platelet counts, and respiration suggest weaning pace strongly affects calf performance, but the effect of weaning pace changes as calves age.

Effect of Weaning Pace on Growth and Health

Even as growth in young calves is heavily influenced by milk allowance, weaning can compromise the growth advantage. Before weaning, elevated milk allowance (~20% of birth weight) improves health, growth rates, feed efficiency, and lifetime production (Soberon et al., 2012; Steele et al., 2017). However, when calves fed an elevated milk allowance are abruptly weaned at 6 wk, metabolizable energy intake and ADG decreases for several weeks (Eckert et al., 2015), suggesting that managing weaning age and pace is key to maintaining preweaning growth advantages.

In our study, gradual weaning, independent of age, improved production response of calves. Calves weaned gradually increased daily relative grain intake without affecting mean rumen pH or duration of SARA, and increased ADG and fecal score. Rumen pH in young calves appears to be unrelated to calf starter intake, in agreement with other studies (McCurdy et al., 2019). Interestingly, fecal score increased in gradually weaned calves. As a result, increased relative grain intake may be more effectively correlated with BW gain, in agreement with other studies (Sweeney et al., 2010; Khan et al., 2011; Parsons et al., 2020). Despite the positive effect on productivity, this study demonstrates that gradual weaning did increase fecal scores, which may be indicative of increased passage rate seen in cattle on high-concentrate diets (Zebeli et al., 2007; Genís et al., 2021), though fecal score is affected by multiple factors.

The effect of weaning pace becomes considerably more complex once hematological indicators are considered. Clinical measures such as increased respiration and heart rate could indicate stress (Lorenz, 2021), so clinical measures could be used as an additional as-
sessment to evaluate weaning stress beyond productivity. In previous studies, calves weaned abruptly have decreased neutrophil responses, increased leukocytes and LYM, increased vocalization, yet have greater ADG (Haley et al., 2005; Lynch et al., 2010; Hulbert et al., 2011; Lambertz et al., 2015). In our study, neither ADG nor hematological indicators were associated with weaning pace. The only exception is hematocrit, which was lower in gradually weaned calves whereas RBC counts were unaffected. As hematocrit is a ratio of RBC to total blood volume, the lack of change in RBC counts suggests that the lower hematocrit in gradually weaned calves is likely indicative of a greater blood volume, not reduced red blood cell counts. In other words, because calves weaned gradually had lower HCT they likely were better hydrated, even if that is not detectable clinically via the clinical eye-and-gum test. Clinically their hydration levels were no different. Why hydration, but not circulating immune cells, were affected by weaning pace is unclear but could relate to the increased fecal score seen in these gradual groups. The main effect of weaning pace, independent of age, is the promotion of a stable rumen environment that is conducive to increased grain intake and growth.

**Effect of Weaning Age on Weaning Stress**

*Is Dependent on Immunocompetence*

Because weaning is a stressful event, calf age at weaning is also critically important. At birth, calves are born aglobulinemic, and are fully reliant on innate immune defenses to protect against pathogens (Chase et al., 2008; Chase, 2018). Intestinal diseases in neonatal and preweaning dairy calves have been associated with morphological and functional immaturity (Osorio,
Around 2 wk after birth, there is an increase in fecal score (Rosa et al., 2018) and upregulation of proinflammatory genes (TLR4, TNF, IL8, and IL1B) in calf feces, as well as increased soluble proinflammatory blood biomarkers (e.g., IL6, ceruloplasmin, and haptoglobin; Osorio, 2020) and upregulation of proinflammatory genes (i.e., TLR4, TNF, IL8, and IL1B) in fecal RNA. Therefore, as calves age, there are drastic systemic changes in immune responses.

When calves are weaned later, the weaning stress will engage with a more immunocompetent animal. In our study, late-weaned calves had increased respiration, fecal score, lymphocytes, neutrophils, and platelets, showing a more comprehensive stress response. The stress response is further illustrated by the decreased ADG, suggesting that the increased stress response at late weaning may be enough to compromise growth. However, other studies demonstrate that late weaning has increased growth over early-weaned calves, which contrast with the current findings (Sweeney et al., 2010; de Passillé and Rushen, 2012). In our study, late-abrupt calves also had a lower grain intake and higher circulating procalcitonin than early-abrupt calves, suggesting the stress of abrupt weaning actually increased with late-weaned calves. Again, the stress may be the result of immunocompetence more
so than age, but that is not immediately clear from these data.

**CONCLUSIONS**

Based on these results, we conclude that gradual weaning improves productivity primarily through greater relative grain intake and stable rumen pH, while having little association with clinical and hematological parameters. Conversely, later weaning increased neutrophils and lymphocytes, and reduced ADG, suggesting that maturation of the immune system may increase calf sensitivity to weaning stress. Data from this study suggest early-weaned calves elicit a lower immune response to abrupt weaning than late-weaned calves, suggesting early-weaned calves may have lower immunocompetence than older calves. Whether these results apply more broadly to other breeds in other countries is not immediately clear, further supporting the need for future studies on immunological development in calves and its role in the weaning transition.

**ACKNOWLEDGMENTS**

The authors thank technical support from students and technicians in the Rezamand laboratory and the University of Idaho Dairy and Beef Centers. Funding was provided by United States Department of Agriculture (NIFA AFRI 2019-05914) to PR, DEK, and AHL; Alberta Milk, Results Driven Agricultural Research, and the Canadian Agricultural Partnership (AFC 2021F185R) to AHL, PR, and DEK. Funding agencies played no role in design, execution, or analysis of this study. The authors have not stated any conflicts of interest.
Figure 12. Neutrophil counts and percentage during the weaning transition. Treatments are denoted as EA (early-abrupt), EG (early-gradual), LA (late-abrupt), and LG (late-gradual). Daggers denote difference in effect of weaning age (P < 0.05); letters denote difference in pace × age interaction (P < 0.05). Neutrophil counts significantly increased with age of calf (P = 0.01) and neutrophil percentage in the blood also increased with age (P = 0.04). However, neutrophil percentage increased when weaned EG (14.16 ± 5.6%, P = 0.01). Error bars denote mean ± SEM.

Figure 13. Red blood cell absolute counts during weaning transition. Treatments are denoted as EA (early-abrupt), EG (early-gradual), LA (late-abrupt), and LG (late-gradual). Calf red blood cell counts marginally increased with age (P = 0.07) but not pace (P = 0.39) of weaning or interaction of age and pace (P = 0.33). Error bars denote mean ± SEM.

Figure 14. Hematocrit percentage during weaning. Treatments are denoted as EA (early-abrupt), EG (early-gradual), LA (late-abrupt), and LG (late-gradual). Asterisks denote difference in effect of weaning pace (P < 0.05). The percentage of hematocrit in the blood increased when weaned abruptly (39.8 vs. 41.3 ± 2.84 SE, P = 0.01). However, it was found nonsignificant for both age (P = 0.17) and the interaction of age × pace (P = 0.96). Error bars denote mean ± SEM.

Figure 15. Platelet absolute counts during weaning transition. Treatments are denoted as EA (early-abrupt), EG (early-gradual), LA (late-abrupt), and LG (late-gradual). Calf platelet counts marginally increased with age (P = 0.06) but not pace (P = 0.23) of weaning. Error bars denote mean ± SEM.

REFERENCES

Cowles, K. E., R. A. White, N. L. Whitehouse, and P. S. Erickson. 2006. Growth characteristics of calves fed an intensified milk re-


ORSICDS

A. R. Wolfe https://orcid.org/0000-0001-7404-0593

P. Rezamand https://orcid.org/0000-0002-1014-7140

A. H. Laarman https://orcid.org/0000-0003-4805-2793