Providing supplementary milk to suckling dairy calves improves performance at separation and weaning

J. F. Johnsen,^{*1} A. Beaver,^{†2} C. M. Mejdell,^{*} J. Rushen,[†] A. M. de Passillé,[†] and D. M. Weary[†]

^{*}Norwegian Veterinary Institute, Department of Health Surveillance, PO Box 750, 0106 Oslo, Norway

[†]University of British Columbia, Faculty of Land and Food Systems, 2357 Main Mall, Vancouver, BC V6T 1Z4, Canada

ABSTRACT

Dam rearing can provide health and welfare benefits, but separation and weaning are major welfare challenges. We investigated whether access to an additional source of milk from an automatic milk feeder (AMF) would improve weight gains after separation and weaning. During the first 6 wk of life (dam phase), calves were assigned to 1 of 3 treatments using a parallel group design with repeated measures: nursing ($n = 10$) and combined ($n = 10$) calves could suckle from their dams at night (between 2000 and 0800 h), and combined calves also had access to 12 L of milk/d accessible 24 h/d from an AMF. Milk feeder calves ($n = 10$) also had access to an AMF 24 h/d and were housed with the dam at night but were prevented from suckling by an udder net. Separation from the dam occurred after 6 wk in 2 phases with decreasing contact between cow and calf: partial separation (duration 4 d) and total separation (duration 3 d). At separation, all calves were granted access to 12 L of milk 24 h/d from the AMF until weaning began at 7 wk of age. We hypothesized that access to an AMF during the dam phase would result in less weight loss at separation and weaning compared with calves that had been nutritionally dependent upon the cow (i.e., nursing calves). Calf weight gain during the dam phase averaged ($\pm$ SD) 1.1 ± 0.26 kg/d and did not vary with treatment. Combined calves drank less milk from the AMF compared with milk feeder calves during the dam phase (mean $\pm$ SEM daily milk intake: 1.1 ± 0.38 vs. 8.2 ± 0.34 L/d) and tended to drink less during partial separation (6.7 ± 1.28 vs. 9.8 ± 1.02 L/d), but milk intake from the AMF did not differ between these treatments in the later phases. During the same phases, nursing calves consumed less milk from the AMF than the other treatments; of the 10 calves, 6 did not use the AMF (consuming <1.5 L/d) after the dam phase. After separation, nursing calves gained less weight than

calves in both the milk feeder and combined treatments (0.8 ± 0.16 vs. 1.2 ± 0.08 kg/d). Calves using the AMF after separation ($n = 23$; 4 nursing calves, 9 combined calves, and 10 milk feeder calves) had a higher average daily gain compared with calves that did not ($n = 7$; 6 nursing calves and 1 combined calf; 1.2 ± 0.07 vs. 0.6 ± 0.21 kg, respectively). In conclusion, use of the AMF after separation varied, but providing an additional milk source reduced nutritional dependency on the dam, improving calf performance at weaning and separation. **Key words:** body weight gain, welfare, dam rearing, milk production, behavior

INTRODUCTION

Dam rearing can provide health and welfare benefits for calves (Krohn, 2001; Flower and Weary, 2003). When compared with limit-fed calves, dairy calves nursed by their dams have higher conception rates, calve at an earlier age, and have higher milk production during their own first lactations (Bar-Peled et al., 1997). In addition, nursed calves show less cross suckling (Roth et al., 2009a), improved weight gain, and fewer bouts of diarrhea before weaning (Weary and Chua, 2000).

Cow-calf nursing during part of the colostrum period (defined as the first 3 d postpartum; Vaarst et al., 2001) is a requirement for organic dairy farms in some countries, including Denmark, Norway, and Sweden (Debio, 2005; KRAV, 2012; Vidensenteret for økologisk landbrug, 2012). Some farmers allow cows to nurse their calves for extended periods. We showed that calves in a partial suckling system can have high weight gains preweaning (Johnsen et al., 2015). However, calves reared with the dam show more signs of distress (Froberg et al., 2011) and gain less weight (Haley et al., 2005; Veissier et al., 2013) at weaning compared with calves raised without dams. The combination of separation from the dam, a change in diet from milk to solids, and introduction to new social partners and a new environment likely accentuate the distress response of the calf (see Weary et al., 2008).

Under naturalistic conditions, weaning is gradual and involves both nutritional and social independence from

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¹Corresponding author: Julie.johnsen@vetinst.no

²Current address: Cornell University, College of Agriculture and Life Sciences, 149 Morrison Hall, Ithaca, NY 14853.

the dam (von Keyserlingk and Weary, 2007). Encouraging nutritional independence from the dam before separation may ease the transition from milk to solid food. This can be done by covering the dam's udder to prevent offspring from suckling (Orihuela and Hernandez, 2007) by or fitting an anti-sucking device that allows calves to eat solid food but not suckle (Haley, 2006).

Our aim was to investigate how calf access to an additional source of milk provided by an automatic milk feeder (AMF) would affect performance at separation and weaning. We hypothesized that calves accustomed to feeding from an AMF would continue to use this after nursing was prevented and that these calves would therefore lose less weight after separation compared with nursed calves not accustomed to feeding from an AMF. In this way, separation from the dam and weaning from milk could be separated in time. Once calves were established on the milk feeder after separation, milk intakes could be systematically reduced, easing the transition to solid feed.

MATERIALS AND METHODS

This study took place at the University of British Columbia's Dairy Education and Research Centre (Agassiz, Canada) from June to October 2012 and was part of a larger study that aimed to explore the bond between cow and calf (Johnsen et al., 2015). The university's animal care committee approved the study following the guidelines of the Canadian Council for Animal Care (2009).

Experimental Design

Thirty-three Holstein cow-calf pairs were included in the study, but 3 cow-calf pairs, 1 from each treatment, were excluded from the final analysis due to illness. Immediately following parturition and for 6 wk postpartum (dam phase), the pairs were assigned to 1 of 3 treatment groups (Figure 1 shows a schematic outline of the trial), each representing a different level of nutritional dependency on the dam. Nursing calves ($n = 10$) could only obtain milk by suckling from the mother; milk feeder calves ($n = 10$) could obtain milk only from an AMF (CF1000 CS-Combi automatic feeder, DeLaval, Tumba, Sweden) 24 h/d; and combined calves ($n = 10$) could obtain milk both by suckling and from the AMF 24 h/d. Pairs from all 3 treatments were kept together in the experimental area, which contained a cow pen, a calf creep, and a separation pen (Figure 2). Cows and calves were kept together at night (between 2000 and 0800 h) and housed in separate but adjacent

pens during the the day (between 0800 and 2000 h). During the day, calves were housed in a calf creep allowing visual, auditory, and limited tactile contact with the cows in the cow pen. Cow-calf pairs were enrolled over a 2-mo period, and cows and calves were included in the trial for 6.5 and 8 wk, respectively. A maximum of 24 cows were housed in the cow pen at any one time. The calf creep and separation pen housed a maximum of 24 and 12 calves at a time, respectively. All pens housed only animals included in the experiment. Cow-calf pairs were blocked by birth date into blocks of 3 cow-calf pairs and the maximum age difference within a triplet was 6 d. Treatment was assigned at random within the blocks, with one pair being assigned to each treatment. The separation of the calf from its dam occurred in 2 phases starting when the calves were 6 wk old: partial separation (duration 4 d), during which the calves were fence-line-separated from their dams (described below), and total separation (duration 3 d), when dams were in a remote pen. At the start of the partial separation, calves were granted 24 h/d access to 12 L/d of milk from the AMF (described in detail below). At 7 wk of age, calves were gradually weaned off milk from the feeder through a step-down procedure (described below).

Cows were milked twice daily throughout the study (at approximately 0800 and 1700 h) in a double-12 milking parlor. Four first-parity cows were included in both the nursing and the combined treatments, and 3 first-parity cows were included in the milk feeder treatment. Median parity for all 3 treatments was 2, and the mean ($\pm$ SD) 305-d lactation estimate was $11,730 \pm 3,189$ L.

Calving Management

Calving took place in individual calving pens (4×4 m). The cow-calf pairs remained in the calving pens for 33 to 76 h postpartum. Established nursing (i.e., calf suckles without assistance) for the nursing and combined treatments was a prerequisite for moving a cow-calf pair to the group pen. Udder nets (model no. 87355301, DeLaval) were attached to cows in the milk feeder treatment directly following parturition. The udder nets covered the teats and prevented the calf from suckling. Calves were assisted to stand (milk feeder treatment) or stand and suckle (nursing and combined treatments) if the calves were not seen to do so on their own within 6 h of birth. All newborn calves were hand fed 2 to 4 L (depending on voluntary intake) of quality-controlled colostrum (i.e., colostrum with specific gravity >1.045 , corresponding to >32 g/L colostrum IgG; colostrum densimeter, Kruuse, Langeskov, Denmark)

Figure 1. Schematic outline of study design. As calves aged, each cow-calf pair transitioned through 4 distinct phases: dam phase, partial separation, total separation, and weaning. During dam phase, calves from the 3 treatments (milk feeder, combined, and nursing) differed in nutritional dependency on the dam: non-nursed calves with ad libitum access to an automated milk feeder (AMF; milk feeder; $n = 10$); calves with nighttime access to suckling the dam in addition to ad libitum access to an AMF (combined; $n = 10$); and calves with only nighttime access to suckling the dam (nursing; $n = 10$).

Figure 2. The 3 treatments were kept as one dynamic group. The cow pen (9.5×36.9 m) was in a naturally ventilated, wood-framed barn (width = 38 m, length = 156 m) with curtained sidewalls, and had 36 sand-bedded freestalls. Individuals from all treatments were present at all times. In this pen, cows and calves were kept together at night (between 2000 and 0800 h). During the day and for the first 6 wk, calves were housed adjacent to the cow pen (between 0800 and 2000 h) with visual and auditory contact in the calf creep (10.0×3.0 m). Cow-calf separation occurred when calves were 6 wk of age; the calves were moved to the separation pen (7.5×3.0 m). The 2 calf pens shared a milk feeder with 2 teats into each pen (M) and a grain feeder (G).

within the first 6 h after birth, and were weighed and fitted with an ear transponder. Milk feeder calves were hand fed whole pasteurized milk ad libitum 4 times daily during the period that cow-calf pairs spent in the maternity pen.

Management During Dam Phase

Until calves were 6 wk old (dam phase), cows and calves were allowed to mix in the cow pen at night (between 2000 and 0800 h). During the day (between 0800 and 2000 h), calves were housed in a separate pen adjacent to the cow pen and had visual, tactile, and auditory contact with the cows. Nursing calves could suckle their dam at night. Combined calves could suckle their dam at night and were granted access (24 h/d) to 12 L of warm (39°C), pasteurized, whole milk from an AMF located in the calf creep throughout day and night. Milk feeder calves were granted access (24 h/d) to 12 L of milk from the AMF but were unable to suckle their dams. Minimum and maximum milk meal sizes for the AMF were set to 0.5 to 6 L. The accumulation rate for milk allowance to the calf through the day was 0.5 L/h, so that a calf had a total milk allowance of 12 L by the end of a 24-h period. If a calf did

not consume the total allotted milk ration on one day, the remaining milk was carried over to the next day. The milk feeder also provided free access to concentrate for all calves throughout all phases (barley based, 21.6% CP; Unifeed Calf Tex, Chilliwack, BC, Canada). Throughout all phases, calves had ad libitum access to orchard grass hay (90.5% DM), the cows' TMR (22% corn silage, 19% grass silage, 10% alfalfa hay, and 49% concentrated mix), and water in the calf creep. Milk feeder and combined calves were assisted in learning to drink from the AMF by gently leading them to the feeder several times a day until the calves were recorded drinking on their own.

Management During Separation and Weaning

At 6 wk of age, calves were moved to the separation pen. This pen was also adjacent to the cow pen, allowing visual, auditory, and limited tactile contact with the cows. However, the calves were not able to suckle from their dams. All calves, regardless of treatment, were allowed to drink 12 L of milk (24 h/d) from the AMF but received no training on the use of the AMF during this phase. Over the next 4 d (partial separation), cows and calves could lick and sniff each other through the fence but calves no longer had nighttime access to the cow pen. The dam was then moved to another pen (with no visual or auditory contact; total separation), but the calf still had tactile, visual, and auditory contact with dams of other calves. Calf behavior and performance was followed over the next 3 d (total separation). Over the next 10 d, calves were weaned following a step-down procedure (weaning phase). Milk allowance was reduced by 1.5 L/d over 8 d, beginning with an allowance of 12 L on the first day of weaning.

Performance Measurements

Calves were weighed twice weekly during all phases. At each weighing, each calf was weighed 3 times using a walk-on scale (Smart 1, Western Scale Inc., Port Coquitlam, BC, Canada), and the median weight was recorded. Daily milk and concentrate intakes were also recorded by the automated feeders. Milk intake from the dams was not assessed, but the time spent nursing was comparable for calves in the nursing and combined treatments (Johnsen et al., 2015). Calf health checks were performed twice weekly by a veterinarian. Any signs of diarrhea and coughing were recorded but these were rarely observed after 3 wk of age. Cow milk production was recorded automatically twice daily at milking.

Behavioral Observations

Observations of feeding behaviors (specified below) were carried out during the dam phase, partial separation, total separation, and weaning phases for 9, 3, 2, and 2 d, respectively. The observations during dam phase were performed on 3 × 3 consecutive days spread over the period when calves were between 3 and 6 wk old. The observations occurred between 1800 and 2000 h (i.e., before opening the gate allowing cows and calves to mix at night). During the 3 other phases, the observations were carried out on consecutive days, in the period between 1900 and 2100 h. This included the time shortly before and after the gate was opened in the calf creep, an event that calves in the separation phases could see, as it was adjacent to the separation pen. During the weaning phase, calves were observed on the first 2 d when they were no longer allowed milk from the feeder. The times for observation were selected because the animals showed a high activity level, probably associated with anticipation to enter the cow pen (dam phase) or increased general activity in the trial area around gate opening (remaining phases). During each observational period, each calf within a given block was observed 6 times for 3 min on a rotating basis (6 rotations = 18 min/calf). Observer software (version 11; Noldus Information Technology Wageningen, the Netherlands) was used to record direct, live, focal animal observations using continuous sampling. Using the start/stop option in Observer, the durations (s) of each behavior was calculated. The following behaviors were recorded: eating TMR (taking TMR into mouth or positioned with head <5 cm from TMR in feed alley or calf creep), eating hay (taking hay into mouth or positioned with head <5 cm from hay in feed alley or calf creep), and rumination (chewing cud, moving jaw in a rhythmic manner, or regurgitating swallowed material). A single observer followed all calves within each block. Observers were trained, but blinding to treatment was not possible.

Statistical Analyses

Scatterplots of the residuals were used to assess normality; this was confirmed for all variables. If Levene's test (SPSS, version 21; IBM Inc. Chicago, IL) revealed that the variable did not meet the assumption of homogeneity of variances, a correction factor was used to correct for this. This fractional value, which varies depending upon the level of heterogeneity, was multiplied by the degrees of freedom that would ordinarily be used, yielding fractional degrees of freedom. Average daily milk intake from the AMF and grain intake were

averaged within each phase and treatment. For the analyses of daily milk yield, morning and evening milk yields were summed to calculate average daily yield per cow and phase using days in milk. Durations (s) of feeding behaviors (ruminating, eating hay, and eating TMR) were averaged over the days within each phase; results are presented as percentage of total observed time.

The analyses of the data gathered after the dam phase were done in 2 different ways depending on the variable. For descriptive purposes, we first evaluated partial separation, total separation, and weaning separately for all variables except weight gain (described below), applying planned contrasts to test our specific hypotheses. For this, we compared only 1 treatment to another or grouped 2 treatments and compared them, combined, to the third treatment according to our hypotheses. For milk intake, we hypothesized that combined calves would drink the same amount of milk from the AMF as milk feeder calves after the dam phase, and that nursing calves would drink less milk from the AMF than would both milk feeder and combined calves once separated from the dam. For milk yield, we predicted that the production (mean daily milk yield and 305-d lactation estimate) of suckled cows combined (nursing and combined) would be lower than that of nonsuckled cows (milk feeder). For intake of solid feed, we hypothesized that nursing calves would not use the milk feeder after separation from the dam and thus would eat more solid feed and ruminate more than both milk feeder and combined calves. We analyzed milk intake from the AMF (L/d), grain intake (g/d), cow milk yield (L/d), and time spent eating hay (% of total observed time), time spent eating TMR (%), and time spent ruminating (%) using a one-way ANOVA within each phase separately (dam phase, partial separation, total separation, and weaning). Milk yields were also collected and analyzed for d 50 to 150 in milk (100 d following the treatment period, allowing 3 d for cows to acclimate to the new group after leaving the experimental pen).

Second, we evaluated partial separation, total separation, and weaning combined (hereafter referred to as "after separation"). We did this because calves may have experienced "weaning off milk" at different times, depending on whether they were relying on the AMF for milk intake. Calves that did not use the milk feeder may start eating grain sooner and thus be weaned from milk already during partial separation, but calves using the feeder would likely be weaned only at the weaning stage of the study. After separation, we compared calves depending on whether or not calves used the milk feeder: Calves were defined as not using the milk feeder if their average daily milk intake from the AMF after separation was <1.5 L/d,

whereas all calves consuming an average of >1.5 L/d were defined as using the AMF. This cut-off point was chosen because it identified calves that did not regularly use the AMF on a daily basis. Grain intake, time spent eating hay, time spent eating TMR, and time spent ruminating were averaged over the after separation phase, and the >1.5 and <1.5 L/d groups were compared using *t*-tests.

We hypothesized that combined and milk feeder calves would gain weight similarly after separation but that nursing calves would gain less weight. For analyses of calf weight gain during the dam phase, we calculated ADG across the last 5 weighings, as these values were believed to provide the best estimate. To estimate ADG after separation, we calculated ADG across the first 5 weighings after calves were partly separated from their dams. Mean ($\pm$ SD) calf age at first weighing during the dam phase and last weighing after separation were 26 ± 2.9 d and 60 ± 3.3 d, respectively, the last weighing corresponding to the second day of 0 L of milk from the AMF. Because partial and total separation only lasted for 3 and 4 d, respectively, and calves were weighed just twice a week, weights were pooled for these phases. One-way ANOVA was used to test treatment differences. To estimate the effect of separation and weaning on gains, we calculated the difference between the ADG during the dam phase and ADG after separation. A positive difference reflects that gains were higher after separation, and a negative difference shows a decline in the rate of weight gain relative to the dam phase. We also compared weight gains depending on whether calves used the AMF after separation from the dam ($n = 23$; 4 nursing calves, 9 combined calves, and 10 milk feeder calves) or not ($n = 7$; 6 nursing calves and 1 combined calf).

Pearson correlation was used to test the association between milk intake and grain intake for each treatment separately, during both the partial and total separation phases. The same test was used for weight gain difference after separation relative to dam phase and milk intake during both partial and total separation phases.

Cows with <200 DIM ($n = 4$) or >400 DIM ($n = 1$) were excluded from the analyses of 305-d lactation estimates. Data on milk yield were excluded from 2 cows (milk feeder and combined cows respectively) that were diagnosed with mastitis.

Due to technical difficulties, behavioral data were available for only 22 of 30 calves (8 milk feeder, 7 combined, and 7 nursing calves) during partial separation and 25 of 30 calves during total separation and weaning phases (9 milk feeder, 8 combined, and 8 nursing calves).

Means are reported $\pm$ standard errors of the mean for all inferential comparisons and $\pm$ standard devia-

Figure 3. Mean ($\pm$ SE) grain intake (A; g) and daily milk (B; L) intake from the automated milk feeder (AMF) and for non-nursed calves with ad libitum access to an AMF (milk feeder; $n = 10$); calves with nighttime access to suckling the dam in addition to ad libitum access to an AMF (combined; $n = 10$); and calves with only nighttime access to suckling the dam (nursing; $n = 10$). Different letters (a–c) in the same phase indicate significant treatment differences ($P < 0.05$), and letters in parentheses indicate a tendency ($P < 0.10$). Milk intake was measured throughout the dam, partial separation, total separation, and weaning phases.

tions when no comparisons are made. P -values between 0.05 and 0.1 were considered as tendencies.

RESULTS

Milk Intake from the AMF

During the dam phase, intake from the milk feeder averaged 8.2 L/d for milk feeder calves (Figure 3); the

calf with the lowest intake in this treatment averaged 5.2 L/d. Compared with that of milk feeder calves, milk intake from AMF was lower for combined calves during this phase ($t_{27} = 13.93$, $P < 0.001$) with an average milk intake of 1.1 ± 0.32 L/d. Of the 10 combined calves, 4 calves averaged 2.3 ± 0.16 L/d and the other 6 calves consumed <1.5 L/d (one of which did not drink any milk from the feeder).

After the calves were moved to the separation pen, use of the AMF continued to differ between treatments: partial separation ($F_{2,29} = 13.84$, $P < 0.001$), total separation ($F_{2,29} = 4.08$, $P = 0.028$) and weaning ($F_{2,29} = 3.98$, $P = 0.030$). During partial separation, milk feeder calves tended to drink more milk from the AMF than combined calves ($t_{27} = 2.04$, $P = 0.051$). However, during the total separation and weaning phases, all but one of the combined calves drank more than 1.5 L/d from the AMF, and intake did not differ between the combined and milk feeder treatments during the total separation ($t_{13.86} = -0.84$, $P = 0.414$) and weaning phases ($t_{16.88} = -1.05$, $P = 0.309$). Nursing calves consumed less milk from the AMF than did combined and milk feeder calves together after dam phase: partial separation ($t_{27} = 4.85$, $P < 0.001$), total separation ($t_{12.95} = -2.43$, $P = 0.031$), and weaning ($t_{12.79} = -2.34$, $P = 0.036$). Only 4 of the 10 nursing calves used the AMF after separation. Calves that used the AMF had mean milk intakes of 3.9 ± 2.4 and 10.5 ± 0.8 L/d during partial and total separation phases, respectively.

Calf Grain Intake

Grain intake (Figure 3) during the dam phase averaged just 22 ± 3 g and did not vary with treatment ($F_{2,29} = 1.11$, $P = 0.345$). Nursing calves consumed more grain than did milk feeder and combined calves during partial separation ($t_{27} = 2.48$, $P = 0.020$); nursing calves also tended to eat more grain during weaning ($t_{27} = 1.86$, $P = 0.073$) but not during total separation ($t_{10.36} = 1.79$, $P = 0.103$). Calves not using the AMF after separation ate more grain than did calves that drank more milk (675 ± 139 vs. 324 ± 34 g/d; $t_{27} = 2.51$, $P = 0.045$).

Grain and milk intakes were correlated for combined calves only. For these calves, grain intake was negatively correlated with milk intake during the partial separation ($r = -0.71$, $P = 0.030$) and total separation ($r = -0.95$, $P < 0.001$) phases.

Calf Weight Gain

Weight gain (Figure 4) during the dam phase averaged ($\pm$ SD) 1.1 ± 0.26 kg/d, with no effect of treatment ($F_{2,29} = 0.05$, $P = 0.670$). After separation, the ADG of combined and milk feeder calves averaged ($\pm$ SD) 1.2 ± 0.36 kg and did not differ ($t_{27} = 1.44$, $P = 0.163$), but nursing calves gained less than milk feeder together with combined calves (0.8 ± 0.16 vs. 1.2 ± 0.08 kg; $t_{27} = 2.37$, $P = 0.032$). We observed no effect of treatment on the difference in weight gain after separation relative to the dam phase ($F_{2,27} = 2.19$, $P = 0.131$), and no difference between combined and milk feeder calves ($t_{27} =$

Figure 4. Mean ($\pm$ SEM) ADG during the dam phase and after separation (partial separation, total separation, and weaning combined) for non-nursed calves with ad libitum access to an automatic milk feeder (AMF; milk feeder; $n = 10$); calves with nighttime access to suckling the dam in addition to ad libitum access to an AMF (combined; $n = 10$); and calves with only nighttime access to suckling the dam (nursing; $n = 10$). Different letters (a,b) in the same phase indicate significant treatment differences ($P < 0.05$).

1.36, $P = 0.187$) or between nursing and combined and milk feeder together ($t_{27} = 1.61$, $P = 0.122$). However, milk intakes were correlated with a positive weight gain difference after separation relative to the dam phase. The correlation between milk intake and weight gain difference was significant during total separation ($r = 0.4$, $P = 0.028$) and tended to be significant during partial separation ($r = 0.4$, $P = 0.057$). After separation, the calves drinking >1.5 L/d had a higher ADG than the calves that drank <1.5 L/d, respectively (1.2 ± 0.07 vs. 0.6 ± 0.21 kg; $t_{28} = 3.351$, $P = 0.002$).

Calf Feeding Behavior

During the dam phase, milk feeder and combined calves tended to spend more time eating hay than did calves from the nursing treatment (Figure 5; $t_{27} = 1.77$, $P = 0.087$). After the dam phase, we detected no treatment differences in feeding behaviors. After separation, calves drinking >1.5 L/d from the AMF tended to spend more time eating TMR ($5 \pm 0.6\%$ vs. $3 \pm 1.0\%$; $t_{20} = 1.95$, $P = 0.066$), but no differences were found for the other feeding behaviors (eating hay: $8 \pm 4.3\%$, $t_{20} = -0.04$, $P = 0.972$; ruminating: $23 \pm 6.4\%$, $t_{20} = -1.51$, $P = 0.147$).

Cow Milk Production

During the dam phase, cows in the combined and nursing treatments were able to nurse their calves, and these cows yielded less milk in the parlor than did cows in the milk feeder treatment (41 ± 3.6 vs. 26 ± 1.8 L/d; $t_{27} = 4.05$, $P < 0.001$). However, milk yield did

Figure 5. Time (% of observational period; mean $\pm$ SE) spent (A) eating hay, (B) eating TMR, and (C) ruminating for non-nursed calves with ad libitum access to an automatic milk feeder (AMF; milk feeder; $n = 10$); calves with nighttime access to the dam in addition to ad libitum access to an AMF (combined; $n = 10$); and calves with only nighttime access to suckling the dam (nursing; $n = 10$). Planned contrasts tested whether or not nursing calves spent more time eating solid feed than milk feeder and combined calves combined. Different letters (a,b) within the same phase indicate a contrast tendency ($P < 0.10$). Behaviors were measured throughout the dam phase, partial separation, total separation, and weaning.

not vary with treatment in any subsequent phase of the study ($P > 0.3$ for all phases), averaging 38 ± 2.1 L/d during partial separation, 39 ± 1.72 L/d during total separation, and 40 ± 1.7 L/d from 50 to 150 DIM. The 305-d lactation estimated yield also did not differ between nursed (combined and nursing combined) and non-nursed cows (milk feeder; $t_{22} = 0.59$, $P = 0.561$), averaging $12,130 \pm 1,984$ L.

DISCUSSION

To our knowledge, this is the first study to describe how calves use a milk feeder during and after separation from their dams. The feeding strategy chosen by the calf in reaction to separation and weaning varied in relation to the calf's nutritional dependency on the dam while the cow and calf were together (dam phase). Most of the calves that were accustomed to use the AMF continued to do so once they were no longer able to suckle their dams.

We expected that calves that could suckle and drink milk from the AMF during the dam phase would drink from the AMF during the day and suckle from the dam during the night. However, many of these calves drank little milk (i.e., <1.5 L/d) from the AMF; most of the milk they consumed likely came from the dam. This result indicates that, given the choice, calves preferred suckling to using the AMF. However, even this limited exposure improved transition to the AMF during the partial separation, total separation, and weaning phases. As hypothesized, the milk intake of the combined calves was comparable to that of milk feeder calves once they were separated from the dam. Periods of forced separation, as occurred for calves during the day, may have promoted the calves' social and nutritional independency from the dam, as described by others (Lay et al., 1998; Veissier et al., 2013).

After separation, calves using the AMF gained more weight than did calves not using the AMF. In addition, a high milk intake during partial and total separation was correlated with a positive weight gain difference after separation relative to the dam phase, and nursing calves gained less than that of combined and milk feeder calves during this phase. Calves that suckle the dam show high weight gains (Grøndahl et al., 2007; Khan et al., 2011), but gains often decline when calves are weaned from milk (Roth et al., 2009a; Veissier et al., 2013). Our results indicate that providing access to an additional milk source can counteract the nutritional dependency on the dam and thus help the calf adjust to separation. Allowing young calves to become nutritionally independent before separation from the dam is a key element for low-stress weaning (Haley et al., 2005; Weary et al., 2008). We did not find treat-

ment differences in weight gain after separation relative to the dam phase. The lack of effect may result from variation among calves in how much milk they drank from the AMF; weight gains were correlated with milk intake during total separation, with a similar trend during partial separation. Many calves that used the AMF after separation increased ADG after separation, whereas calves not using the AMF after separation often experienced lesser gains in the transition from dam phase to after separation. For all treatment groups, calf weight gains during the dam phase were comparable to those reported for calves fed high amounts of milk (Sweeney et al., 2010). The weight gains of combined and milk feeder calves after separation from the dam (more than 1 kg/d) were comparable to those of calves weaned gradually from high milk allowances (Roth et al., 2009b) or by gradual weaning based on each animal's capacity to eat concentrate (de Passillé and Rushen, 2012). Gradual weaning methods encourage consumption of solid feed and minimize the imbalance between supply and demand of nutrients (Khan et al., 2007).

In agreement with other authors (Sweeney et al., 2010), grain intake was negligible before separation. Nursing calves that were nutritionally dependent on the dam consumed more grain during partial separation and weaning than did the 2 other treatment groups. Additionally, calves that did not use the AMF after separation consumed more grain than those that did use it. These findings were as expected; it is well established that a high milk intake is associated with low grain intake (Jasper and Weary, 2002). A negative correlation between milk and grain intake after separation was found only for the combined calves. All combined calves except one were accustomed to drink from the AMF, which may have caused them to be less motivated to eat grain. However, the grain intake of milk feeder calves should have been similarly influenced by milk intake. One possible explanation might be that combined calves compensated for reduced milk intake by consuming roughage rather than grain. Interestingly, combined and milk feeder calves tended to spend more time eating hay during the dam phase, and a high milk intake after separation was coupled with increased time spent eating the TMR. Because the TMR contained a large amount of grain, the calves may have been less motivated to eat grain from the grain feeder. We did not quantify the intakes of TMR and hay, which could have allowed us to estimate total digestible energy. However, other studies have shown that time spent eating hay and TMR gives a reasonable estimate of intake (Costa et al., 2013).

As a consequence of the partial suckling system, nursing calves had no access to milk from 0800 to 2000

h, potentially increasing interest in solids during the dam phase. It was therefore surprising that nursing calves tended to spend less time eating hay during the dam phase, and we found no difference in grain intake or other measures of solid feed intake. These results indicate that independent of whether the calves used the feeder after separation from the dam, suckling calves can quickly adjust to eating solid food (Khan et al., 2011). We hypothesized that nursing calves would not use the AMF after separation and thus eat more solids. Although we detected no difference in the time spent eating roughage after separation, nursing calves consumed less milk and more grain after the dam phase. Nursing calves gained less weight after separation, indicating that these calves were not able to fully compensate for the loss of milk at separation with higher grain intake. Because these calves lacked any other source of milk, they were effectively weaned at the time of partial separation. Compared with gradual weaning, abrupt weaning is associated with a distress response (Jasper et al., 2008) and weight loss (Sweeney et al., 2010).

Young cattle likely learn to recognize suitable feed-stuffs by mimicking the dam (Phillips, 1993). However, calves in all 3 treatments had access to their dams at night and spent the same amount of time together (Johnsen et al., 2015). Calves can also learn feeding behaviors from their companions (De Paula Vieira et al., 2012), but most of the nursing calves drank little or no milk from the milk feeder when provided access after the dam phase. The nursing calves did not receive training on the AMF, perhaps explaining why few calves learned to use it. Guiding calves to the AMF during partial separation may have improved access.

Not surprisingly, cows providing milk to their calves (nursing and combined treatments) yielded less milk in the parlor during the dam phase. However, this initial deficit had no detectable effect on yield in the subsequent phases or on total lactational yield; estimated 305-d milk production did not vary with treatment. These results are consistent with earlier work (e.g., Flower and Weary, 2001; de Passillé et al., 2008). This study was not designed to assess the effect of nursing on milk yield, but our findings are consistent with the conclusion that yields of nursed cows recover after weaning to the extent that total yields over the lactation are indistinguishable from those of cows that do not nurse their calves.

CONCLUSIONS

An additional milk source in a partial suckling system can counteract nutritional dependency on the dam and help the calf transition to separation from the dam and weaning from milk. Distress at separation and weaning

have been viewed as one limitation to allowing calves access to their dams. We conclude that a combined system that allows calves some access to the dam (with or without nursing) as well as access to an alternative milk supply may be promising in terms of calf performance.

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