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Effect of gradual or abrupt cessation of milking at dry off on milk yield and somatic cell score in the subsequent lactation

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ABSTRACT

The objective of this study was to assess the effect of milk cessation method (abrupt or gradual) at dry off on milk yield and somatic cell score (SCS) up to 120 d in milk during the subsequent lactation. Data from 428 cows from 8 dairy herds in Ohio were analyzed. Abrupt cessation cows kept the farm's regular milking schedule (2 or 3 times) through dry off and gradual cessation cows were milked once daily for the final week of lactation. Milk yield and SCS were collected using Dairy Herd Improvement Association test-day records. Aseptic quarter milk samples were collected approximately 1 wk before dry off, at dry off, and within 1 wk after calving for bacterial culture to determine the presence of intramammary infections. Overall, milk cessation method was not significantly associated with either milk yield or SCS in early lactation; however, interaction between the milk cessation method and herd was highly significant. Cows producing greater amounts of milk around dry off had significantly higher SCS in the following lactation. Shorter dry periods were significantly associated with decreased milk yield in the following lactation, especially among abruptly dried off cows. Additionally, as expected, several other factors, such as parity of cows and stage of lactation, were significantly associated with both outcomes. No interactions between the milk cessation method and the other explanatory variables in the final models were significant. The results of the current study suggest that higher milk yield at dry off was associated with higher SCS in the following lactation, even though milk cessation method at the end of lactation had a varying effect on test-day milk yield and SCS in different herds during the first 120 d in milk in the following lactation. The specific herd characteristics influencing this could not be identified within this study, warranting further research.

Key words: milk cessation method, dry off, milk yield, somatic cell score

INTRODUCTION

Mastitis is one of the most costly diseases of the dairy industry, partly due to its negative effect on milk production and quality (Seegers et al., 2003). Dairy producers in most countries are compensated based on milk components and the volume of milk shipped, along with the potential premiums they may be offered to improve milk quality by lowering SCC (Bailey et al., 2005). Therefore, prevention and control of mastitis is important for optimal milk production and milk quality and is also crucial due to animal welfare concerns associated with the disease (Leslie and Petersson-Wolfe, 2012).

The dry period is a crucial time in the lactation cycle for mastitis prevention and control (Neave et al., 1950; Oliver and Mitchell, 1983) and, under United Kingdom conditions, over 60% of new environmental IMI detected in early lactation were reported to been contracted during the dry period (Bradley and Green, 2004). The periods directly following dry off and before calving are associated with an increased susceptibility to new IMI (Oliver and Mitchell, 1983; Smith et al., 1985). This period of nonlactation allows producers to use antimicrobial dry-cow therapy (**DCT**), without needing to discard milk due to antibiotic residues, in an attempt to eliminate existing IMI and provide protection against new IMI during the early dry period (Natzke, 1981). However, many factors influence susceptibility to IMI (Dingwell et al., 2004) as well as efficacy of antimicrobial DCT products in prevention of new and elimination of existing IMI (Dingwell et al., 2002; Royster and Wagner, 2015); thus, use of DCT does not guarantee that all mammary glands will be free from IMI at calving. The use of antimicrobials in animal production, especially for prophylactic purposes, is under debate, as concerns about the development of antimicrobial resistance and its effect on human health have increased (Oliver et al., 2011; Landers et al., 2012). Identification of additional management practices that reduce disease

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risk around dry off and increase productivity would be beneficial to the dairy industry.

Multiple studies have been conducted to investigate what the best method to dry cows off is, often in regard to mammary health, but many of these studies were done when milk production per cow was substantially lower than what is seen in most dairies today (Wayne et al., 1933; Neave et al., 1950; Oliver et al., 1956a). Abrupt and gradual milk cessation were 2 commonly investigated approaches to discontinue milking (Wayne and Macy, 1933; Espe and Smith, 1952; Oliver et al., 1956b). Abrupt cessation, or stop milking, occurs when normal daily milking is terminated on a set day, which is typically determined by the expected calving date and a desired dry period length. Gradual cessation of milking (also referred to as intermittent milking or reduced milking frequency) occurs when cows are weaned from milking over a period of days or weeks. The frequency of milking and the duration until dry off have varied by study, but a once-daily milking schedule for a week or less before dry off has been used previously (Natzke et al., 1975; Oliver et al., 1990; Gott et al., 2016). Gradual cessation of milking has been shown to reduce milk yield before complete cessation of milking at dry off (Bushe and Oliver, 1987; Oliver et al., 1990; Newman et al., 2010). Additionally, gradual cessation was associated with improved udder health when compared with abrupt cessation, especially for quarters uninfected at the time of dry off, as measured by fewer IMI during the dry period or lower prevalence of IMI at calving (Oliver et al., 1956a; Newman et al., 2010).

Although research has focused on the effect on IMI status as measured by microbiological culture of milk, only a few studies have reported the effects of milk cessation method on milk production and milk quality (e.g., SCC) in the following lactation. These studies date back to the 1930s and 1950s and no significant differences were found in the quantity or quality of milk in the following lactation when various methods of milk cessation were used at dry off (Wayne et al., 1933; Oliver et al., 1956a,b). The effect of milk cessation method on milk yield and SCC in the subsequent lactation is not, however, well characterized and has not been reported among modern high-producing dairy cows.

Despite the studies indicating the beneficial effects of gradual cessation of milking on udder health, abrupt cessation of milking is commonly recommended in the United States. The National Animal Health Monitoring System Dairy 2014 study estimated that 90% of US dairy cows were abruptly dried off, whereas only 10% of cows were dried off via gradual cessation (Lombard et al., 2015). Herds which participate in a DHIA test program can use milk yield and SCC data obtained monthly to make important management decisions throughout lactation. The objective of the current study was to assess the effect of milk cessation method (abrupt or gradual) at dry off on milk yield and SCC up to 120 DIM during the subsequent lactation using DHIA test-day records. Our hypothesis was that gradual cessation of milking would improve udder health and productivity as measured by decreased SCC and increased milk yield in the subsequent lactation.

MATERIALS AND METHODS

Study Population

All procedures used in the present study were approved by The Ohio State University Institutional Animal Care and Use Committee. Eight dairy herds in Ohio were included in our study. Six herds were composed of Holstein cows and 2 herds were exclusively Jersey cows. Four of the study herds had less than 100 cows, 3 herds had between 100 and 499 cows, and 1 herd had over 500 cows. Herds were required to be enrolled in a DHIA testing program and willing to share their DHIA test-day data with the investigators to participate in the study. The willingness of the producers to follow study protocols was also a prerequisite for inclusion on the study. Dry off dates were based on breeding date and the individual herd's desired dry period length. All herds dried cows off abruptly once a week as their normal dry off protocol. After the final milking, all quarters of all cows were treated with a commercially available antimicrobial labeled for use in nonlactating cows, according to each herd's standard protocols. No alterations were made to the diet during the study period, so all cows remained on their farm's lactating ration for the final week of lactation.

Cows were enrolled and data were collected between May 2012 and October 2014. Clinically healthy cows were enrolled 7 to 14 d before their expected dry off date. All cows dried off in the same week within a herd were assigned to the same group to make management of the cows easier for the herd personnel. In each herd, the first set of cows was assigned to the abrupt cessation group; thereafter, group assignment alternated weekly between gradual and abrupt cessation groups. Cows were only enrolled on the study once, even if they were dried off again during the study period.

Abrupt cessation cows maintained the farm's regular milking schedule (2 or 3 times, depending on the herd) until the last day of lactation, whereas gradual cessation cows were milked once daily for the final week of lactation. Gradual cessation cows were housed and managed according to facility and labor confines in each of the 8 herds. One herd on the study was a tiestall operation and milked cows using a bucket milker at their stall. Three herds were able to separate gradual cessation cows from the main milking herd and only allowed these cows to go through the milking parlor once daily during the final week of lactation. In the other 4 herds, all cows went through the parlor during every milking, but cows in the gradual cessation group were only milked once per day according to the study protocol. Gradual cessation cows were identified with brightly colored leg bands on one hind leg so farm personnel knew to milk those cows only once daily during the final week of lactation. Participants were provided a small monetary incentive for every cow enrolled in the gradual cessation group to compensate for lost saleable milk during the study intervention; they were also compensated for collecting good-quality quarter milk samples from cows after calving.

Sample size for the current study was based on an expected difference of 50,000 cells/mL between study groups and calculated using a power of 0.8, significance level of 0.05, and a standard deviation of 250,000 cells/mL. To detect the expected difference between milk cessation groups, 173 cows were needed per study group. The use of repeated measures and the correlated structure of the data were also considered.

DHIA Test-Day Milk Yields and SCC

Test-day data were obtained electronically using PCDART Herd Manager Consultant version 7.16.6.0 (Dairy Records Management Systems, Raleigh, NC). Test-day milk yields represent daily cow-level milk production. Somatic cell counts were measured at the cow level during each test day from composite milk samples in the local DHI laboratory. Test-day records were obtained for all study cows for at least 1 test day before dry off and for all test days up to 120 DIM during the subsequent lactation.

Sample Collection and Milk Microbiology

At the time of enrollment (**PRE**), at the final milking before dry off (**DRY**), and within 7 d after calving (**CALV**), aseptic quarter foremilk samples were collected from all study cows by the study personnel or farm employees trained by the study personnel to collect milk samples using the aseptic technique. Milk samples collected by farm personnel were kept frozen on the farm until the next visit by the investigators. Milk samples were transported to the laboratory on ice and frozen at −20°C for at least 24 h before microbiological culture.

Milk samples were examined according to National Mastitis Council guidelines (NMC, 2004). Ten microliters of milk from each quarter sample was plated onto both 5% sheep's blood agar (Remel Inc., Lenexa, KS) and MacConkey agar (Remel Inc.) using sterile disposable calibrated loops. Plates were incubated at 37°C and bacterial growth was recorded at 24 and 48 h. Infection status determinations were based on the combination of colony counts, colony morphology, Gram stain reaction, and biochemical testing. A quarter was considered to have an IMI when 10 or more colonies (1,000 cfu/mL) of similar morphology were isolated (Andersen et al., 2010). Isolation of 3 or more colony morphologies was considered contamination.

Test-day milk yield and SCC measurements represent cow-level data; therefore, quarter-level IMI data from DRY and CALV were condensed into cow-level IMI observations for each time point. A cow was considered uninfected when all quarter samples within a time point were considered uninfected. If a cow had at least 1 contaminated quarter sample and all other quarters were uninfected for that time point, cow-level IMI status was categorized as unknown. When at least 1 quarter was infected, the cow was categorized as infected even if another quarter sample was contaminated during that time point. Nonfunctional quarters did not influence cow-level IMI status, as those quarters were not milked and did not affect test-day milk yield or SCC measurements.

Statistical Analysis

Descriptive statistics were calculated to summarize the data. Continuous predictors were initially compared between study groups with 2-sample *t*-test (SAS Institute Inc., Cary, NC). The distribution of the final test-day SCC and test-day SCC during the subsequent lactation were right-skewed, so these values were transformed into SCS to achieve normality using the equation: $SCS = [\log_e(SCC/100)/\log_e(2)] + 3$, where SCC is in cells per microliter (Shook, 1993). Days in milk at dry off were right-skewed and log-10 transformed to achieve normality to allow comparison between study groups.

Overall proportion of quarters infected at PRE and DRY was compared using chi-squared test (SAS Institute Inc.), and IMI status at each time point was compared within and between the study groups. No significant differences were found in IMI status from PRE to DRY, and IMI at DRY was determined to best represent IMI status before dry off. If cows had missing or contaminated quarter samples at DRY but had complete data from PRE, then, for those cows, DRY culture results were replaced with PRE results for all 4 quarters and were used in the final analyses (denoted as DRY IMI status). Cows with unknown IMI status (missing or contaminated samples) for 2 or more different quarters were excluded completely from analysis. Single quarters that were dead (nonfunctional), had contaminated samples, or otherwise had missing IMI status were not used in the analyses, but the data from the other 3 quarters from those cows were used to determine the cow-level IMI status.

Milk yield and SCS up to 120 DIM for the lactation following milk cessation intervention were modeled separately using repeated measures analysis in the MIXED procedure of SAS version 9.4 (SAS Institute Inc.). The heterogeneous first-order autoregressive (ARH-1) covariance structure was used to account for nonindependence of observations within cows and herd was included as a random effect in the models.

The lactation following study intervention was divided into 9 stages of 14-d periods so that test days for each cow could be categorized based on DIM. Test days which occurred on or before 120 DIM were considered for analyses, so the final stage was only 8 d in length to accommodate this restriction. Stage was included as the variable in the REPEATED statement. The main variable of interest in both models was milk cessation method (gradual vs. abrupt). Other potential predictors included stage of lactation, cow-level infection status at DRY (infected/uninfected/unknown), cow-level infection status at CALV (infected/uninfected/unknown), final test-day milk yield, final test-day SCS, parity at CALV (2 and 3 lactations vs. 4+ lactations), season at DRY, milking frequency (the farm's normal milking schedule; either 2 or 3 times), whether gradual cessation cows went through the parlor at every milking or not during the final week, interval from final test day to DRY, use of an internal teat sealant at DRY (yes/no), DIM at DRY, length of the dry period, and either test-day milk yield or test-day SCS, depending on what the outcome was being investigated. The study herds were composed of different breeds (6 Holstein herds, 2 Jersey herds), and breed was tested as a potential predictor in the univariate screening. Breed was not, however, included in the final models, as it was accounted for by the random herd effect. Dry period length was categorized into 4 categories (less than 45 d, 45–54 d, 55–64 d, and more than 64 d) for the analyses.

Initial univariable screening was performed to identify potential predictors of test-day values, separately for milk yield and SCS. All variables with P-values <0.25 were included in a full model for both outcomes. Univariable testing of parity as a predictor in the models revealed that cows starting their second and third lactation did not differ significantly from each other in regard to milk yield or SCC, but these younger cows differed from older cows. Therefore, parity was categorized as cows starting their second or third lactation versus cows starting their fourth or greater lactation in both models. Nonsignificant variables were eliminated one at a time, starting with the least significant one, until all variables remaining in each model were significant with $P < 0.05$. To evaluate whether a variable was a confounder between the outcome of interest and milk cessation method and should be kept in the model, the change in the coefficient of milk cessation method was calculated after the variable in question had been dropped from the model. Any variable that induced a change >10% was kept in the model as a confounding factor. Biologically relevant 2-way interactions between the main effects (such as interaction between milk cessation method and parity, final test-day milk yield, final test-day SCS, IMI status at calving, dry period length, DIM at DRY, stage of lactation, and herd) in each final model were investigated. Significant associations were considered at $P < 0.05$.

RESULTS

Study Population

Four hundred fifty cows from 8 herds were enrolled on the study. Cows with a dry period <25 or ≥80 d in length were removed from the data set (n = 10). Eight cows (3 gradual; 5 abrupt) were culled from their herds before the first DHIA test day and were dropped from analysis. Four cows had 1 DHIA test day before being culled, but were missing either a test-day milk yield, a test-day SCC, or both measurements and were also excluded (2 gradual; 2 abrupt). According to DHI records, the reasons for removal were feet and legs (2 cows), injury or other (5 cows), died (3 cows), sold for dairy (1 cow), and unknown (1 cow). Thus, observations from a total of 428 cows (197 gradual cessation; 231 abrupt cessation) were used in the analyses. The study population is characterized in Tables 1 and 2. No significant differences were seen among average lactation number ($P = 0.706$), final test-day milk yield ($P = 0.627$), final test-day SCS ($P = 0.222$), DIM at DRY ($P = 0.274$), or dry period length ($P = 0.294$) of cows in different milk cessation groups.

IMI

Of the 197 gradual cessation cows, 76 (38.6%) had at least 1 quarter IMI at DRY, 116 (58.9%) were uninfected, and 5 (2.5%) had unknown IMI status due to missing or contaminated quarter foremilk samples. In the abrupt cessation group, 81 (35.1%) of the 231 cows had at least 1 quarter IMI at DRY, 144 (62.3%) were uninfected, and 6 (2.6%) were categorized as unknown IMI status. At CALV, 43 (21.8%) gradual cessation cows were considered infected, 134 (68.0%) were unin-

Table 1. Distribution and characteristics of cows in gradual and abrupt cessation of milking groups[1]

Item	Gradual cessation (n = 197)	Abrupt cessation (n = 231)
Second lactation	98	109
Third lactation	50	62
Fourth and greater lactation	49	60
Breed		
Holstein	83	111
Jersey	114	120
Internal teat sealant (ITS)[3]		
Treated	172	199
Not treated	25	32
Milking frequency		
Twice daily	96	118
Thrice daily	101	113

[1]Gradual cessation cows were milked once daily for the final week of lactation and then dried off. Abrupt cessation cows kept their farm's normal milking schedule until dry off. No values differed between the study groups.

[2]No difference was seen in the proportion of cows of different breeds between the study groups.

[3]Significantly more cows were treated with ITS than not treated in both study groups ($P < 0.0001$).

fected, and 20 (10.2%) had unknown IMI status. Fifty-three (22.9%) abrupt cessation cows were categorized as infected at calving, 156 (67.5%) were uninfected, and 22 (9.5%) had unknown IMI status. No significant differences in the proportion of cows with different IMI status were found between study groups at either time point ($P > 0.05$).

Test-Day Milk Yield in the Subsequent Lactation

The final model for test-day milk yield is presented in Table 3. Milk cessation method was not significantly associated with milk yield in the subsequent lactation ($P = 0.3485$); however, the interaction between herd and milk cessation method was highly significant ($P < 0.0001$), suggesting that the effect varied between herds. Breed was significant in the univariable model, but the model did not converge when breed and interaction term between herd and milk cessation method were in the model simultaneously. Thus, breed was omitted from the final model, as it was accounted for in the herd effect. Final test-day milk yield and increasing DIM at dry off were positively associated with test-day milk yield during the subsequent lactation ($P < 0.0001$). Shorter dry periods were associated with decreasing test-day milk yield in the following lactation ($P < 0.0085$): Cows with shorter than a 45-d dry period produced 3.8 kg/d less milk than cows that were dry 65 d or longer ($P = 0.0010$) and 1.3 kg/d less milk than cows that were dry 55 to 64 d ($P = 0.0993$). Dry period length was initially tested as a continuous variable and its interaction with milk cessation method was highly significant ($P < 0.0001$, results not shown). However, for easier interpretation, the use of a categorical dry period length variable was chosen. Whereas the interaction between the categorical dry period length and milk cessation method as a cluster was not significant ($P = 0.1314$) and not kept in the final model, results of the model with the interaction suggested that dry period length had a different effect on milk yield in the first 120 d of the subsequent lactation among cows dried off differently (Figure 1). Cows that were dried off abruptly and had short dry periods (<45 d) produced significantly less milk than abruptly dried off cows with longer short periods, but no differences in milk yields were observed among gradually dried off cows with different dry period lengths. This was based on pairwise comparisons of least squares means, with P-values adjusted for multiple comparisons.

For every 1-unit increase in test-day SCS, test-day milk yield decreased by 0.7 kg ($P < 0.0001$). Cows in their fourth or greater lactation produced 1.3 kg more milk per test day than cows in their second or third lactation ($P = 0.0296$). Stage was also significantly associated with test-day milk yield ($P < 0.0001$), with cows on average reaching their peak milk yield between 43 and 56 DIM.

Table 2. Descriptive statistics of gradual cessation and abrupt cessation cows[1]

Item	Gradual cessation (n = 197 cows)				Abrupt cessation (n = 231 cows)				
	Mean	SEM	Minimum	Maximum	Mean	SEM	Minimum	Maximum	P-value
Lactation number at calving	2.9	0.1	2.0	7.0	2.9	0.1	2.0	8.0	0.706
FTD milk yield,[2] kg	22.2	0.5	5.3	55.9	21.8	0.4	7.0	41.9	0.627
FTD SCS[3]	2.8	0.1	0.1	7.6	2.6	0.1	0.1	7.9	0.222
DIM at dry off	336.8	4.3	262.0	619.0	343.2	4.0	251.0	568.0	0.274
Dry period length, d	57.8	0.6	29.0	79.0	56.8	0.6	29.0	77.0	0.294

[1]Gradual cessation cows were milked once daily for the final week of lactation and then dried off. Abrupt cessation cows kept their farm's normal milking schedule until dry off.

[2]FTD = final test day, final DHIA test day before dry off data.

[3]Actual SCC values were converted to SCS according to the formula by Shook (1993).

Test-Day SCS in the Subsequent Lactation

The final model for test-day SCS is presented in Table 4. Milk cessation method was not significantly associated with test-day SCS in the subsequent lactation ($P = 0.5503$), but, again, the interaction between herd and milk cessation method was highly significant ($P < 0.0001$). Cows which had at least 1 quarter-level IMI at calving had 1.1 units higher test-day SCS than uninfected cows at calving ($P < 0.0001$). Final test-day milk yield was positively associated with increasing SCS ($P < 0.0001$), and cows with higher final test-day SCS before dry off also had higher test-day SCS (by 0.3 units) during the following lactation ($P < 0.0001$). Cows in their fourth or greater lactation had higher test-day SCS (by 0.3 units) than cows in their second or third lactation ($P = 0.048$). Increasing test-day milk yield during the lactation was associated with lower test-day SCS ($P < 0.0001$). Stage was also associated with test-day SCS ($P = 0.0003$), with the lowest SCS observed between 57 and 70 DIM. No other interactions between milk cessation method and other main effects in the model besides the interaction with herd were significant.

DISCUSSION

Results of our study indicate that milk cessation method was not significantly associated with test-day milk yield or test-day SCS in the subsequent lactation; however, the interaction between dry off method and herd was highly significant in both the milk yield and SCS models. Two of the study herds were exclusively composed of Jersey cows and the rest were Holstein herds. Breed was not included in the final models, as it was a herd-level variable and it was accounted for in the models by the herd effect. Also, no differences in the proportion of the different breeds were seen between the study groups. The significant interaction between herd and milk cessation method suggests that the effect of the drying off protocol varied from herd to herd, which may partially be due to breed differences, but other factors likely also play a role. It has been common to give uniform management recommendations to

Table 3. Final model estimating the effects of milk cessation method on test-day milk yield (kg/d) in the first 120 DIM in the subsequent lactation; herd was included as a random effect in the model

Variable	Estimate	SE	*P*-value
Milk cessation method[1]			0.3485
Gradual	1.616	2.719	0.5525
Abrupt	Referent	—	—
FTD milk yield,[2] kg/d	0.313	0.042	<0.0001
DIM at dry off	0.021	0.005	<0.0001
Dry period length, d			0.0085
25–44	−3.792	1.152	0.0010
45–54	−1.336	0.810	0.0993
55–64	−0.330	0.686	0.6304
65–79	Referent	—	—
Test-day SCS[3]	−0.694	0.100	<0.0001
Age at calving			
4+ lactations	1.293	0.594	0.0296
2 and 3 lactations	Referent	—	—
Stage[4]			<0.0001
Two: 15 to 28 DIM	6.340	0.854	<0.0001
Three: 29 to 42 DIM	7.819	0.791	<0.0001
Four: 43 to 56 DIM	8.536	0.805	<0.0001
Five: 57 to 70 DIM	7.787	0.742	<0.0001
Six: 71 to 84 DIM	8.018	0.769	<0.0001
Seven: 85 to 98 DIM	6.836	0.735	<0.0001
Eight: 99 to 112 DIM	6.235	0.689	<0.0001
Nine: 113 to 120 DIM	5.651	0.834	<0.0001
One: 0 to 14 DIM	Referent	—	—
Milk cessation × herd interaction	NA[5]	NA	<0.0001
Intercept	23.876	2.689	—

[1]Gradual cessation cows were milked once daily for the final week of lactation and then dried off, whereas abrupt cessation cows kept their farm's normal milking schedule until dry off.

[2]FTD = final test day; data from the final DHIA test day before dry off.

[3]Actual SCC values were converted to SCS according to the formula by Shook (1993).

[4]Stages were created based on 14-d intervals of DIM when test-day data were collected.

[5]NA = data not presented.

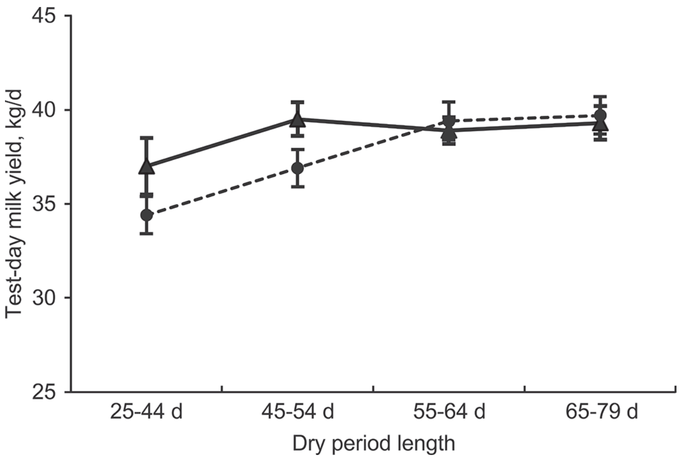

Figure 1. Test-day milk yields (kg/d) during the first 120 DIM in the subsequent lactation among cows that were dried off gradually (solid line, ▲) or abruptly (dashed line, ●) and had different dry period lengths. Gradual cessation cows were milked once daily for the final week of lactation and then dried off, whereas abrupt cessation cows kept their farm's normal milking schedule until dry off. Among gradually dried off cows, milk yields were not different ($P > 0.05$) between cows with different dry period lengths; however, abruptly dried-off cows with the shortest dry period (25–44 d) produced significantly less have than those with dry periods of 55 to 64 ($P = 0.0171$) and 64 to 79 d ($P = 0.0156$). Additionally, abruptly dried off cows with the shortest dry period produced less than gradually dried off cows with longer dry periods ($P < 0.05$). The values are LSM (± SE) from a multivariable model with a milk cessation method and dry period length interaction in it and P-values based on multiple pairwise comparisons with Tukey adjustment.

all herds, such as applying blanket dry cow therapy and drying cows abruptly, even though it is widely acknowledged that all herds, their facilities, and managers are different (Barkema et al., 1999; Huijps and Hogeveen, 2007; Rajala-Schultz et al., 2011). A recent investigation on the dynamics of IMI during the dry period also observed substantial variation in etiology and prevalence of different pathogens across herds (Bradley et al., 2015). The results of the current study agree with the observations about herd variation and suggest that herd-specific and even cow-specific management recommendations could improve udder health and milk yield in dairy herds. The current study, however, was not able to identify those unmeasured factors and more research on the topic is needed.

Higher final test-day milk yield and increasing final test-day SCS were associated with increasing test-day SCS in the subsequent lactation in the present study. Higher milk yield before dry off has been associated with a higher probability of developing new IMI during the dry period (Dingwell et al., 2002) and an increased risk of IMI at calving (Rajala-Schultz et al., 2005), especially in quarters that were uninfected at dry off (Newman et al., 2010). When quarter-level IMI data from the current study was analyzed, higher milk yield at the final test day before dry off was also associated with an increased risk of IMI caused by major mastitis pathogens at calving, despite all cows having been treated with intramammary antimicrobials at dry off (P. Gott, P. Rajala-Schultz, G. Schuenemann, J. Hogan, and K. Proudfoot). Gradual cessation of milking was shown to significantly decrease milk yield before dry off (Gott et al., 2016); however, in the current study, the milk cessation method was not significantly associated with SCS in the following lactation when final test-day milk yield was controlled for in the model. Both higher milk yield before dry off and SCC >199,000 cells/mL within the final 60 d of lactation have been associated with elevated SCC early in the subsequent lactation (Green et al., 2008). This is in agreement with the current results, which also suggest that reducing milk yield before dry off, regardless of how the lower milk production level is achieved, may help improve milk quality in the following lactation.

Several factors aside from milk cessation method were associated with milk yield and SCS in the following lactation. When test-day milk yield was the outcome of interest, increasing test-day SCS decreased test-day milk yield. In contrast, when test-day SCS was the outcome, an increase in test-day milk yield was associated with a decrease in test-day SCS; this is likely related to a dilution effect as reported by Green et al. (2006). Cows in their fourth or greater lactation had higher test-day milk yields and test-day SCS in comparison with younger cows in their second or third lactation, as expected and in agreement with other studies (Smith et al., 1985; Dingwell et al., 2002; Green et al., 2008). The fact that increasing final test-day milk yield from the previous lactation was associated with increased test-day milk yield in the following lactation is likely due to superior genetics and higher milk production potential.

It has been reported that dry periods shorter than 20 or 30 d and longer than 70 d decrease future milk production (Kuhn et al., 2006; Steeneveld et al., 2013). Despite the fact that no excessively long or short dry periods were analyzed in the current study, number of days dry was significantly associated with future milk yield. Interestingly, our results suggested that abruptly dried off cows and their milk production in the following lactation may benefit from having longer dry periods, whereas no such effect was noticed among gradually dried off cows. Dry period is important for cell turnover and replacement of senescent alveolar cells responsible for expanding and maintaining the number of secretory cells (Capuco et al., 1997; Bachman and Shairer, 2003; Pezeshki et al., 2010). This process occurs in bovine mammary gland after milk cessation; however, no reports were found on how the initiation of this process (i.e., milk cessation method) may affect this.

No difference was observed in the proportion of cows with IMI at calving between study groups and both study groups experienced a decrease in the number of cows with IMI from dry off to calving. All cows on the study were treated with intramammary antimicrobial products at the time of dry off, so the effect of milk cessation method alone on the reduction of IMI from dry off to calving cannot be distinguished from the effect antimicrobial treatment might have had on IMI. However, quarters of abruptly dried off cows have been reported to develop more new infections than gradually dried off cows, whether or not quarters were infused with antimicrobial DCT at dry off (Natzke et al., 1975). Higher milk yield at dry off can lead to milk leakage and open teat ends and increase the risk of new IMI (Dingwell et al., 2002; Odensten et al., 2007). Milk production level at dry off in the Natzke et al. (1975) study had no effect on the rate of new IMI; however, the production levels were substantially lower then than in the modern dairy herds. Natzke et al. (1975) recommended gradual cessation of milking when antimicrobial DCT was not going to be administered to cows at dry off, but suggested that either dry off method was satisfactory when cows were infused with antimicrobials at dry off. Further investigation into the potential benefits of gradual cessation of milking when antimicrobials are not used is of further interest.

To ease the management of study cows, all cows dried off in the same week within each herd were assigned to the same study group. Enrollment of cows on each farm began randomly during the study, and was implemented by the investigators based on the herd records made accessible to them, the expected calving dates, and targeted dry period lengths in each herd. Thus, study group assignment was considered to be sufficiently random. Study groups did not differ in regard to basic characteristics, but fewer gradual cessation cows than abrupt cessation cows were enrolled in the

Table 4. Final model estimating the effects of milk cessation method on test day SCS[1] in the subsequent lactation up to 120 DIM.

Variable	Estimate	SE	*P*-value
Milk cessation method[2]			0.5503
Gradual	−0.165	0.224	0.4606
Abrupt	Referent	—	—
Cow-level IMI[3] status at calving			<0.0001
Infected	1.106	0.1663	<0.0001
Unknown	0.249	0.272	0.314
Uninfected	Referent	—	—
FTD milk yield,[4] kg/d	0.045	0.011	<0.0001
FTD SCS[4]	0.268	0.046	<0.0001
Test-day milk yield, kg/d	−0.050	0.007	<0.0001
Age at calving			
4+ lactations	0.308	0.155	0.0480
2 and 3 lactations	Referent	—	—
Stage[5]			0.0003
Two: 15 to 28 DIM	−0.490	0.196	0.0128
Three: 29 to 42 DIM	−0.679	0.197	0.0006
Four: 43 to 56 DIM	−0.749	0.198	<0.0001
Five: 57 to 70 DIM	−0.864	0.182	<0.0001
Six: 71 to 84 DIM	−0.692	0.197	0.0005
Seven: 85 to 98 DIM	−0.675	0.181	0.0002
Eight: 99 to 112 DIM	−0.628	0.179	0.0005
Nine: 113 to 120 DIM	−0.786	0.210	0.0002
One: 0 to 14 DIM	Referent	—	—
Milk cessation × herd interaction	NA[6]	NA	<0.0001
Intercept	1.647	0.387	0.0007

[1]Actual SCC values were converted to SCS according to the formula by Shook (1993). Herd was included as a random effect in the model

[2]Gradual cessation cows were milked once daily for the final week of lactation and then dried off, whereas abrupt cessation cows kept their farm's normal milking schedule until dry off.

[3]Cow-level IMI was based on quarter-level aseptic foremilk samples collected within 7 d of calving. Cows with at least 1 quarter-level IMI were considered infected even if they had a missing or contaminated sample from another quarter. Cows which had a missing or contaminated sample, but were otherwise uninfected, were classified as having an unknown cow-level IMI status. Cows with all uninfected quarter samples were considered uninfected.

[4]FTD = final test day; data from the final DHIA test day before dry off.

[5]Stages were created based on 14-d intervals of DIM when test-day data were collected.

[6]NA = data not presented.

study. This is likely to have occurred due to chance and the fact that enrollment began with the abrupt group in all study herds.

One of the concerns during the study was the fact that, due to facility and labor confines, in some herds the gradual cessation cows went through the parlor at every milking even though they were only milked once a day during the final week of lactation. Going through the parlor likely caused normal milk letdown among these cows, but the udder was only emptied once daily. Whereas the concern was that this could increase the risk of new infections during this period, no differences in the IMI status between PRE and DRY among the gradual cows were observed. Also, the variable parlor (indicating how many times per day the gradual cows went through the parlor during the final week) was not significant in the univariable screening, so this is not believed to have affected the results. This would suggest that it is possible to reduce the milking frequency during the final week of lactation without negative consequences even in herds, where sorting or separating cows is not feasible and where cows would need to go to the parlor during every milking even if milked only once a day.

The majority of US dairy cows are currently dried off abruptly (Lombard et al., 2015). Uncertainty about the effects of a new management practice in a herd can deter producers from trying different methods. Modern dairy cows often produce considerable amounts of milk at dry off, which is a known risk factor for IMI during the dry period and at calving. Similarly, high-producing dairy cows have been reported to experience some level of discomfort for several days due to the increasing pressure within the udder after abrupt cessation of milking (Bertulat et al., 2013), and the milk cessation method has also been reported to affect behavior of cows and motivation to be milked (Zobel et al., 2013). Thus, reducing milk yield before dry off may help improve milk quality in the following lactation and cow comfort around the time of dry off. Further consideration of the effect of the milk cessation method on cow activity and cow comfort is warranted and merits further study.

CONCLUSIONS

Gradual and abrupt cessation of milking at the end of lactation were equivalent in regard to their effect on milk yield and SCS in the subsequent lactation. Higher milk yield before dry off, however, was associated with higher SCS in the following lactation. Also, the effect of milk cessation method on milk yield and SCS varied between herds, and among abruptly dried off cows dry period length had an effect on milk yield. The udder health and productivity of dairy cows are influenced by many factors, but milk cessation method did not directly affect these traits. Decreasing milk yield before dry off had positive effect on milk quality (lower SCS) during the first 120 DIM in the following lactation; the effects, however, may be herd-specific.

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