A randomized trial to study the effect of automatic cluster remover settings on milking performance, teat condition, and udder health

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ABSTRACT

The objectives were to study the effect of 2 different automatic cluster remover settings on (1) milking characteristics, (2) milk component yields, (3) teat tissue condition, and (4) udder health. In a randomized controlled field trial, Holstein cows ($n = 689$) from 1 commercial dairy farm with a thrice-daily milking schedule were allocated to 2 treatment groups. Treatment consisted of a cluster remover take-off milk flow threshold of 1.2 (ACR1.2) or 0.8 kg/min (ACR0.8) for 57 d. Milking characteristics (milk yield; and milking unit-on time, MUOT) were obtained with electronic on-farm milk meters. Composite milk samples were collected and analyzed for fat, protein, lactose, and somatic cell count. Machine-milking-induced short- and long-term changes to the teat tissue condition were assessed visually. General linear mixed models demonstrated differences in MUOT, whereas no meaningful differences in milk yield were detected. Milk yield (least squares means, 95% confidence interval) was 11.3 (10.9–11.8) and 11.3 (10.8–11.8) kg in groups ACR1.2 and ACR0.8, respectively. The effect of treatment on MUOT was modified by parity. Milking unit-on time in first-, second-, and $\geq$ third-lactation cows, respectively, was 260.7 (252.0–269.4), 257.8 (247.4–268.1), and 260.2 (252.6–267.9) s in group ACR1.2; and 273.7 (264.9–282.5), 279.1 (269.4–288.8), and 295.7 (287.9–303.6) s in group ACR0.8. We detected no meaningful differences in milk component yields or linear somatic cell score. Least squares means in groups ACR1.2 and ACR0.8, respectively, were milk fat yield, 0.42 (0.40–0.44) and 0.42 (0.40–0.44) kg; milk protein yield, 0.36 (0.35–0.37) and 0.37 (0.36–0.37) kg; milk lactose yield, 0.61 (0.60–0.63) and 0.63 (0.61–0.64) kg, and linear somatic cell score, 1.9 (1.8–2.0) and 1.9 (1.8–2.0). A generalized

linear mixed model revealed an effect of treatment on machine-milking-induced short-term changes. The odds of short-term changes to the teat tissue were lower for cows in group ACR1.2 [odds ratio (95% confidence interval) = 0.78 (0.63–0.96)]. No meaningful differences were detected in machine-milking-induced long-term changes between treatment groups. Increasing cluster remover take-off milk flow threshold from 0.8 to 1.2 kg/min decreased individual milking duration and alleviated machine-milking-induced short-term changes to the teat tissue without adversely affecting milking performance or somatic cell count. Future studies are warranted to investigate the effect on milk production and udder health over a whole lactation period.

Key words: milking characteristic, take-off setting, teat tissue condition, time in low milk flow rate

INTRODUCTION

Since their advent in 1970 (Armstrong et al., 1970), automatic cluster removers (ACR) have fostered profitability in dairy operations by increasing the automation of the milking process, decreasing labor costs, and improving parlor efficiency. The basic concept of ACR is that they use the intrinsic nature of the milk flow curve to determine the optimal termination point of an individual milking (Krawczel et al., 2017). Removal of the milking unit is initiated once the milk flow drops below a preset threshold (Stewart et al., 2002). Early studies by Sagi (1978) and Rasmussen (1993) showed that an increase in the cluster remover take-off milk flow threshold from 0.2 to 0.4 kg/min led to a reduction in milking time without adversely affecting milk production. In addition, Rasmussen (1993) documented improved teat tissue conditions in cows that were milked with an increased ACR setting. These initial studies were followed by work from researchers around the globe investigating different ACR settings in conventional milking systems (Stewart et al., 2002; Magliaro and Kensinger, 2005), pasture-based systems (Clarke et al., 2004; Jago et al., 2010; Burke and Jago, 2011;

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Edwards et al., 2013a,b), confinement (Ferneborg et al., 2016, 2019; Krawczel et al., 2017), and pasture-based (Silva Boloña et al., 2019) automatic milking systems. The majority of these studies supported the results of the earlier works. The threshold values under investigation ranged between 0.2 and 0.82 kg/min (Stewart et al., 2002; Magliaro and Kensinger, 2005; Edwards et al., 2013a). Recent developments in milking machine settings in the industry support an increased threshold, and a cluster remover take-off milk flow threshold of up to 1 kg/min has been suggested (Besier and Bruckmaier, 2016). This trend was further supported by a recent field study on a commercial dairy farm in Michigan (Erskine et al., 2019) that applied a threshold of 1.1 kg/min, as well as studies from our own group on farms that applied a threshold of 1.3 kg/min (Wieland et al., 2017; Melvin et al., 2019). To our knowledge, no studies have investigated the effect of such high ACR settings on milking performance.

Milk fat yield has been shown to differ between fractions within individual milkings, with the highest milk fat concentration being extracted at the end of milking (Ontsouka et al., 2003). Consequently, a considerable reduction in harvested milk fat has been suggested in cases of incomplete milk removal (Ontsouka et al., 2003), which has been demonstrated in several studies investigating different ACR settings by increased residual milk (Clarke et al., 2004; Burke and Jago, 2011; Edwards et al., 2013a,b; Besier and Bruckmaier, 2016). Because dairy producers are compensated on the basis of milk fat, true protein, and other dairy solids (Bailey et al., 2005), milk component yields are of paramount importance and influence the overall profitability of dairy operations.

A common belief is that incomplete milking is detrimental to udder health and that “the oldest rule of good dairy cow management is the necessity for careful stripping at the end of milking” (Kingwill et al., 1979). Consequently, udder health parameters such as SCC and clinical mastitis incidence have been subject to investigation in studies evaluating different ACR settings (Clarke et al., 2004, 2008; Burke and Jago, 2011; Edwards et al., 2013a,b; Krawczel et al., 2017).

The objective of this study therefore was to investigate the effect of 2 different cluster remover take-off milk flow thresholds on (1) milking characteristics, (2) milk component yields, (3) teat tissue condition, and (4) udder health. We hypothesized that increasing the cluster remover take-off milk flow threshold from 0.8 to 1.2 kg/min would decrease the individual milking unit-on time (**MUOT**) and improve teat tissue condition, without adversely affecting milk production, milk component yields, or udder health.

MATERIALS AND METHODS

This randomized controlled field trial was conducted on 1 commercial dairy farm in northern New York between June and August 2018. The study protocol was reviewed and approved by the Cornell University Institutional Animal Care and Use Committee (protocol no. 2018-0003). A supporting letter from the farm owners was obtained before the start of the study.

Animals and Housing

The lactating herd consisted of approximately 800 Holstein cows. Cows were housed year-round in 6 freestall pens with sand bedding and fed a TMR that was formulated to meet or exceed the requirements outlined by the NRC (2001). The rolling herd key performance indicators were average milk production, 11,531 kg; bulk tank SCC, 210,000 cells/mL; monthly clinical mastitis incidence, 2.5%; 21-d pregnancy rate, 24.6%; and culling rate, 32.5%. Cows were milked 3 times per day, except for animals in the hospital pen, which were milked twice daily.

Milking System

Cows were milked in a double-12 parallel milking parlor (Excalibur 2890, BouMatic, Madison, WI). The milking unit consisted of the top unloading parallel barrel claw with a 19-mm outlet (weight: 1.0 kg; BouMatic) and an Impulse IP4-LM milking liner (Milkrite, Johnson Creek, WI). Milking liners were changed after 2,500 milkings. The pulsator (HiFlo, BouMatic) was set to a pulsation rate of 65 cycles/min, a pulsation ratio of 65:35, and front-to-back alternating pulsation. The pulsation phases under load, as assessed with a digital vacuum recorder (VaDia, BioControl, Rakkestad, Norway), were a-phase, 100; b-phase, 505; c-phase, 104; and d-phase, 214 ms. The vacuum pump 7.5 kW (10 hp) was regulated by a variable frequency drive and set to supply a vacuum at the receiver jar of 46 kPa. These settings yielded an average claw vacuum of 42 kPa during the peak milk flow period. The milk line was installed 70 cm below the cow standing level. The parlor was equipped with electronic on-farm milk meters (Afimilk MPC Milk Meter, Afimilk, Kibbutz Afikim, Israel). All milking system settings were verified and assessed by the investigators according to the guidelines outlined by the National Mastitis Council (NMC, 2012) before the start of the study.

Milking routine was performed by 1 milking technician per milking session in sets of 6 for most cows (5 pens), whereas late-lactation animals in 1 pen were pre-

pared in sets of 12 to accommodate the preparation lag time to their physiological requirements (Bruckmaier and Hilger, 2001). Premilking udder preparation and teat sanitization were performed in 4 steps as follows: step 1 was to dip the teats with an iodine-based teat dip (d 1–18, Eco-Plus 100 S.A., Ecolab, St. Paul, MN; d 19–57, Eco-Plus 50 S.A., Ecolab); step 2 was to for-estrip all 4 teats; step 3 was to dry the teats with a single use clean cloth towel; and step 4 was to attach and align the milking unit. This routine resulted in an average (mean $\pm$ SD, range; assessed on 24 cows during 1 milking shift) dip contact time and preparation lag time of 94 ± 14 s (68–129) and 111 ± 34 s (51–227), respectively, for cows being prepped in a set of 6; and 152 ± 20 (124–192) and 181 ± 69 s (141–493), respectively, for cows being prepped in a set of 12. After unit detachment, a postmilking iodine-based teat dip (d 1–18, Eco-Plus 100 S.A. Ecolab, d 19–57, Eco-Plus 50 S.A., Ecolab) was applied.

Sample Size Calculation

The sample size calculation was based on the primary outcome of interest, which was the effect of treatment on MUOT. Using an α level of 0.05, a power of 0.95, and the ability to detect a meaningful difference of 15 s (280 vs. 265 s), a sample size of 292 cows per group was required. The calculated sample size of 584 cows was then inflated by a factor of 0.15 because of an assumed attrition rate of 15%, resulting in a pre-exclusion sample size of 672 cows (approximately 340 cows per group). This calculation was based on a presumed correlation between a within-cow measurement of 0.8, a total of 171 cow milking observations, a reported standard deviation of 56 s (Wieland et al., 2017), and a repeated measures ANOVA [G*Power version 3.1.9.2; Faul et al. (2007)].

Treatment Allocation

The 2 central components of the treatment allocation were the dairy farm management software program AfiFarm (Afirmilk) and electronic on-farm milk meters (AfiMilk MPC Milk Meter, Afirmilk). With AfiFarm, different milking machine settings can be applied to individual cows. For this purpose, a code entailing specific settings for operational parameters was assigned to individual cows based on treatment allocation for a specified duration.

The ACR of AfiFarm (Afirmilk) is based on 4 individual parameters. The F1 is defined as the ACR pre-milk time and determines the minimum amount of time the milking unit is attached. The ACR delay (F2) determines the milk flow rate at which milking will be

terminated. The F3 is often referred to as the vacuum decay time and controls the delay between the vacuum shut-off to the claw and the beginning of milking unit retraction. The F4 refers to auto adjust quick removal and, if activated, initiates removal of the milking unit before the delay time designated in F2 is reached if the following 3 conditions are met: first, the ACR pre-milk time is surpassed; second, the harvested milk yield (MY) exceeds the expected MY; and third, the milk meter body is less than half full after 50% of the ACR delay time.

All cows that were lactating throughout the entire study period were eligible for enrollment. Eligible cows were randomly assigned by the first author using simple randomization with the random number function in Microsoft Excel (2016 version, Microsoft Corp., Redmond, WA) into 1 of 2 treatment groups. Treatments consisted of 2 different F2 settings: **ACR1.2** (F2 = 10) and **ACR0.8** (F2 = 15) which corresponded to a cluster remover take-off milk flow threshold of 1.2 kg/min (ACR1.2) and 0.8 kg/min (ACR0.8). The other 3 parameters were consistent for all cows and set according to the farm's previous settings as follows: ACR pre-milk time (F1), 14 corresponding to 140 s; vacuum decay time (F3), 0 s; and auto adjust quick removal (F4), false. Before the start of the study, F2 was set to 11 (1.09 kg/min).

Cow Characteristics

Cow characteristics such as parity, DIM, and 305-d mature-equivalent milk production, were obtained from the dairy management software program (Dairy Comp 305, Valley Agricultural Software, Tulare, CA).

Milking Characteristics

Milk yield (kg), MUOT (s), average milk flow rate (**AMF**, kg/min), and time in low milk flow rate [**LMF**, s] were assessed at each milking with electronic on-farm milk meters (AfiMilk MPC Milk Meter, Afirmilk) and recorded using the dairy farm management software AfiFarm (Afirmilk).

Milk Sampling and Analyses

Composite milk samples were collected by DHIA service personnel (Dairy One Cooperative Inc., Ithaca, NY) 14 d before the start of the study, on d 16, and on d 48. Milk samples were analyzed for fat, true protein, and lactose using infrared analysis on an automated Fossomatic FT+ counter [Foss, Eden Prairie, MN; method 972.160; AOAC International (2012)], and

SCC (cells/mL) with optical fluorescence [Fossomatic FC, Foss, method 972.160; AOAC International (2012)] at Dairy One Cooperative Inc. Energy-corrected milk yield (kg/milking session) was calculated for 3.5% fat and 3.0% protein as previously described (Mann et al., 2015): $ECM = [(0.0929 \times \text{fat } \%) + (0.0563 \times \text{true protein } \%) + 0.192] \times \text{milk (kg)} / 0.68605$. Linear SCS (**LS**) were calculated according to Ali and Shook (1980): $LS = \ln[(SCC/100,000)/\ln(2)] + 3$. Values $<12,500$ cells/mL were 0 truncated. Further, milk fat, protein, and lactose yields (kg/milking session) were calculated as follows: component yield (kg) = MY (kg) $\times$ milk component (%) / 100.

Presence of Nonlactating Quarter and Teat Tissue Condition

The assessment of the presence of a nonlactating quarter (**NLQ**) and the evaluation of the teat tissue condition were performed by 2 trained investigators (MW and PDV) who were blinded to the treatment. The presence or absence of a NLQ was visually assessed during milking on d 1 and 57. A NLQ was considered present if 1 teat cup was not attached to the respective quarter during the 2 evaluations.

Machine milking induced short-term changes to the teat tissue condition (**STC**) were visually assessed on d 15, 29, and 57 according to the scoring system described by Hillerton et al. (2000). Briefly, within 60 s after unit detachment, the condition of the teat base was classified as no visible mark present (score 1), visible mark present (score 2), or significant swelling (score 3); evaluation of consistency of the teat end was scored as soft (score 1), firm (score 2), or wedging present (score 3). The presence of a STC was considered if the condition of the teat base score was 3, or the consistency at the teat-end score was ≥ 2 for 1 or more teats; STC were absent otherwise.

Teat end callosity was scored on d 1, 15, 29, and 57 according to the 4-point scale as previously described by Mein et al. (2001). Briefly, teat end callosity was scored as no callosity ring present (score 1); callosity ring but no roughness present (score 2); callosity ring and roughness present, keratin fronds extending 1 to 3 mm from the teat orifice (score 3); and callosity ring present with excessive keratin fronds extending ≥ 4 mm from the teat orifice (score 4). The presence of hyperkeratosis (**HK**) was considered if 1 or more teats had a score ≥ 3 , whereas HK was absent otherwise.

Clinical Mastitis Detection

Clinical mastitis detection was performed by trained farm personnel during premilking udder preparations.

A cow was defined as having clinical mastitis if milk from 1 or more quarters was abnormal with or without signs of local inflammation of the affected quarter as previously described (Erskine et al., 2003). All clinical mastitis events were recorded in Dairy Comp 305. For subsequent analyses, a case was defined as the first case of clinical mastitis that occurred in a cow between d 2 and 57 of the study.

Analytical Approach

Data were maintained in an openly available spreadsheet (Microsoft Office Excel 2016, Microsoft Corp.). Before statistical analyses, data were screened for missing and erroneous values. Further, milking observations that were documented as (1) manual milking mode, (2) manual detachment of the milking cluster, or (3) reattachment of the milking cluster were excluded from the final analyses. Cows diagnosed with clinical mastitis remained in the study during treatment with antimicrobial therapy and the withholding period. Data from cows that were lost to follow-up were included in the analyses up until the dry day or the point of removal from the herd. Statistical analyses were performed with the software package SAS (version 9.4, SAS Institute Inc., Cary, NC). Individual cow was the experimental unit and the unit of analysis.

Baseline Characteristics. Descriptive statistics were generated with PROC MEANS and PROC FREQ. Chi-squared tests were generated using PROC FREQ for differences in parity, DIM, as a categorical variable (early, ≤ 100 ; mid, 101–200; and late lactation, >200 d), HK, and NLQ. Differences in DIM, 305-d mature-equivalent milk production, and LS from the first test day (14 d before the start of the study) were assessed with Student's *t*-test using PROC TTEST. Satterthwaite approximation was used to account for different sample variances in LS.

Milking Characteristics. Data from 7 milking sessions were missing. A total of 106,694 milking observations were obtained from the software program. A total of 6,990 (6.6%) observations were excluded due to (multiple numeration possible) erroneous values ($n = 1,182$; ACR1.2, $n = 565$; ACR0.8, $n = 617$), manual milking mode ($n = 2,287$; ACR1.2, $n = 1,116$; ACR0.8, $n = 1,171$), manual detachment ($n = 1,587$; ACR1.2, $n = 773$; ACR0.8, $n = 814$), and reattachment ($n = 3,790$; ACR1.2, $n = 2,337$; ACR0.8, $n = 1,453$). Consequently, 99,704 observations were available for analyses.

To study the effect of treatment on milking characteristics (MY, MUOT, AMF, and LMF), 4 separate general linear mixed models were generated with PROC MIXED. An initial analysis compared a wash-out period of 7 d (d 1 to 7) with the subsequent period

(d 8 to 57), but no meaningful differences between the 2 periods existed. Therefore, the entire study period (d 1 to 57) was analyzed together. The following steps were consistent for all 4 models. To account for the clustering of milking sessions within a day and a cow, a REPEATED statement for milking session was included. Three covariance structures were tested (autoregressive order 1, compound symmetry, and variance components) to model the covariance of repeated measurements, and the covariance structure with the smallest Akaike's information criterion was selected. Treatment was forced into the model as a fixed effect. The following additional independent variables were considered as covariates and screened for inclusion into each model initially through univariable analysis: parity (first, second, and $\geq$ third lactation), DIM (≤ 100 , 101–200, > 200 d), and NLQ (present or absent). For the dependent variables MUOT and LMF, MY was also considered. All variables with a P -value < 0.20 in this step were considered covariates in the initial models. Manual backward elimination was performed until each of the covariates had a P -value < 0.05 to establish the final model for each dependent variable. Confounding effects were monitored by observing regression coefficient changes. Variables that modified regression coefficients by $> 20\%$ were considered confounding factors. No confounding was observed. Finally, 2-way interactions between treatment group and parity and treatment group and DIM were tested and remained in the model if P -value < 0.05 . Tukey-Kramer's post hoc test was used to control for the experimental error rate. For all final models, the assumptions of homoscedasticity and normality of residuals were assessed by the inspection of residual plots versus corresponding predicted values and the examination of quantile-quantile residual plots. To satisfy these assumptions, data of the dependent variable LMF were log-transformed. The resulting coefficient and least squares estimates were consequently back transformed and presented as the geometric mean and 95% confidence interval.

ECM Yield, Milk Component Yields, and LS.

Data from 37 milking observations were missing. A total of 55 observations were excluded because of (multiple numeration possible) erroneous values ($n = 3$; ACR1.2, $n = 1$; ACR0.8, $n = 2$), manual milking mode ($n = 17$; ACR1.2, $n = 8$; ACR0.8, $n = 9$), manual detachment ($n = 19$; ACR1.2, $n = 7$; ACR0.8, $n = 12$), and reattachment ($n = 30$; ACR1.2, $n = 19$; ACR0.8, $n = 11$). Thus, 1,286 observations were used for the analyses. For the comparisons of ECM, milk fat, protein, lactose yields, and LS between treatment groups, 5 separate general linear mixed models were generated with PROC MIXED. The 5 models were built in accordance with

the procedure outlined above, with the exception of the 2 following differences. First, a REPEATED statement for test day was included to account for clustering of the test day within a cow. Second, for the dependent variable LS, the LS from the previous test day 14 d before the start of the study was also considered as a covariate and its interaction with the treatment group was tested.

Teat Tissue Condition. Data from 2,588 cow observations were obtained. A total of 202 observations were excluded because (multiple numeration possible) of manual milking ($n = 78$; ACR1.2, $n = 40$; ACR0.8, $n = 38$), manual detachment ($n = 61$; ACR1.2, $n = 32$; ACR0.8, $n = 29$), or reattachment ($n = 93$; ACR1.2, $n = 53$; ACR0.8, $n = 40$). Thus, 2,386 observations were used for the final analyses. To determine differences in STC and HK between the treatment groups, 2 separate generalized linear mixed models with a logit link and a binomial distribution were fitted with PROC GLIMMIX. For both models, 3 covariance structures (autoregressive order 1, compound symmetry, and variance components) were tested to model the covariance of repeated measurements within a cow, and the one that resulted in the smallest pseudo-Akaike's information criterion was selected. Treatment was entered into the models as a fixed effect. Parity (first, second, and $\geq$ third lactation), DIM (≤ 100 , 101–200, and > 200 d), and NLQ (present or absent) were considered as covariates and screened for inclusion in each model initially through the univariable analysis. All variables with a P -value < 0.20 in this step were considered covariates in the initial models. Manual backward elimination was used to reach the final model for each outcome of interest. Finally, the 2-way interaction between treatment and parity was tested.

Clinical Mastitis. To compare the effect of treatment on the incidence of clinical mastitis, a generalized linear model with a logit link and a binomial distribution was fitted with PROC LOGISTIC. Treatment was entered into the model as a fixed effect. The following additional independent variables were screened for inclusion in each model initially through univariable analysis: parity (first, second, and $\geq$ third lactation), DIM (≤ 100 , 101–200, and > 200 d), LS from the previous test day 14 d before the start of the study, and NLQ (present or absent). All variables with a P -value < 0.20 were considered covariates in the initial model and removed by manual backward elimination. Two-way interactions between the remaining variables were tested to fit the final model. Deviance and Pearson goodness-of-fit statistics were used to assess the final model fit and the presence of overdispersion. A post-hoc power analysis was performed with G*Power (Faul

et al., 2007) to determine the actual power value for detection of a difference in clinical mastitis incidence between the 2 treatment groups.

RESULTS

Description of Study Population

A total of 689 (ACR1.2, $n = 344$; ACR0.8, $n = 345$) cows were enrolled in the study. Thirty-four (ACR1.2, 14; ACR0.8, 20) animals were moved to a different farm. Twenty-one (ACR1.2, $n = 8$; ACR0.8, $n = 13$) cows were sold, 4 (ACR1.2, $n = 1$; ACR0.8, $n = 3$) cows were dried off early, and 7 (ACR1.2, $n = 3$; ACR0.8, $n = 4$) animals were killed. Cows were (mean $\pm$ SD) 151 ± 113 DIM (ACR1.2, 151 ± 116 ; ACR0.8, 151 ± 111 ; $P = 0.99$). Baseline characteristics are presented in Table 1. No differences existed in the distributions of parities, DIM, and HK or 305-d mature equivalent milk production at enrollment between treatment groups ($P \geq 0.54$). Linear SCS from the previous test day before the start of the study and the frequency distribution of NLQ were different between the groups ($P \leq 0.04$).

Milking Characteristics

The average (mean $\pm$ SD) values for milking characteristics were as follows: MY, 12.5 ± 3.4 kg (ACR1.2, 12.4 ± 3.4 ; ACR0.8, 12.5 ± 3.4); AMF, 2.8 ± 0.7 kg/min (ACR1.2, 3.0 ± 0.7 ; ACR0.8, 2.7 ± 0.7); MUOT,

269.9 ± 65.3 s (ACR1.2, 256.9 ± 59.9 ; ACR0.8, 283.0 ± 67.9); and LMF, 32.6 ± 22.1 s [ACR1.2, 24.0 ± 18.6 ; ACR0.8, 41.3 ± 22.0 (Table 2)]. Descriptive statistics (mean, SD, range, median, and 25th and 75th percentiles) stratified by treatment group are provided in Supplemental Table S1 (<https://doi.org/10.3168/jds.2019-17342>). The effect of treatment on milking characteristics was evaluated based on the outcomes MY, AMF, MUOT, and LMF. The results of general linear mixed models for each outcome variable are demonstrated in Supplemental Tables S2 to S5 (<https://doi.org/10.3168/jds.2019-17342>) and summarized in Figure 1.

For MY, the least squares means (95% CI) were 11.3 (10.9–11.8) and 11.3 (10.8–11.8) kg in the ACR1.2 and ACR0.8 groups ($P = 0.95$), respectively (Supplemental Table S2, <https://doi.org/10.3168/jds.2019-17342>). An interaction between the treatment group and DIM ($P = 0.04$) was found for AMF. The average milk flow rates in early-, mid-, and late-lactation cows were 3.1 (2.9–3.2), 2.7 (2.6–2.9), and 2.6 (2.5–2.7) kg/min in the ACR1.2 group and 2.7 (2.6–2.9), 2.6 (2.5–2.8), and 2.3 (2.2–2.4) kg/min in the ACR0.8 group, respectively. The average milk flow rate was different between the groups in early- ($P < 0.0001$) and late-lactation animals ($P = 0.0002$), but not in mid-lactation animals ($P = 0.66$; Supplemental Table S3, <https://doi.org/10.3168/jds.2019-17342>). There was an interaction between the treatment group and parity for MUOT ($P = 0.03$). The MUOT in the first, second, and $\geq$ third lactation cows were 260.7 (252.0–269.4), 257.8 (247.4–268.1),

Table 1. Baseline characteristics from 689 cows milked with 2 different cluster remover take-off milk flow thresholds stratified by treatment group¹

Item	Treatment		Overall	P-value
	ACR1.2	ACR0.8		
Number of cows	344	345	689	—
Parity				0.64
First (n, %)	115 (33.43)	112 (32.46)	227 (32.95)	
Second (n, %)	81 (23.55)	92 (26.67)	173 (25.11)	
$\geq$ Third (n, %)	148 (43.02)	141 (40.87)	289 (41.94)	
DIM				0.72
<100 (n, %)	133 (38.66)	123 (35.65)	256 (37.16)	
100–200 (n, %)	113 (32.85)	119 (34.49)	232 (33.67)	
>200 (n, %)	98 (28.49)	103 (29.86)	201 (29.17)	
ME ₃₀₅ ² (kg)	$11,974 \pm 2,081$	$12,074 \pm 2,193$	$12,024 \pm 2,136$	0.55
PLS ³	2.1 ± 2.0	1.8 ± 1.7	1.9 ± 1.9	0.04
NLQ ⁴ (n, %)	18 (5.23)	8 (2.32)	26 (3.77)	0.04
HK ⁵ (n, %)	112 (32.56)	120 (34.78)	232 (33.67)	0.54

¹Results presented as mean values $\pm$ SD unless otherwise stated. ACR1.2 = automatic cluster remover take-off milk flow threshold of 1.2 kg/min; ACR0.8 = automatic cluster remover take-off milk flow threshold of 0.8 kg/min.

²305-d mature-equivalent milk production.

³Linear SCS from previous test day 14 d before the start of the study (observations from 614 cows available).

⁴Presence of a nonlactating quarter.

⁵Presence of hyperkeratosis of 1 or more teats.

Table 2. Descriptive statistics from 689 cows milked with 2 different cluster remover take-off milk flow thresholds stratified by treatment group¹

Item	Treatment		Overall
	ACR1.2	ACR0.8	
Milk yield (kg)	12.4 ± 3.4	12.5 ± 3.4	12.5 ± 3.4
Milking unit-on time (s)	256.9 ± 59.9	283.0 ± 67.9	269.9 ± 65.3
Average milk flow rate (kg/min)	3.0 ± 0.7	2.7 ± 0.7	2.8 ± 0.7
Time in low milk flow rate (s)	24.0 ± 18.6	41.3 ± 22.0	32.6 ± 22.1
ECM yield (kg)	12.5 ± 3.3	12.6 ± 3.4	12.6 ± 3.3
Milk fat yield (kg)	0.45 ± 0.13	0.45 ± 0.13	0.45 ± 0.13
Milk protein yield (kg)	0.36 ± 0.09	0.38 ± 0.09	0.36 ± 0.09
Milk lactose yield (kg)	0.62 ± 0.17	0.63 ± 0.18	0.62 ± 0.18
Linear SCS	2.1 ± 2.0	1.9 ± 1.9	2.0 ± 2.0
Short-term changes (%)	45.6	51.5	48.5
Hyperkeratosis (%)	32.7	32.5	32.6
Clinical mastitis (n, %)	20 (5.8)	10 (2.9)	30 (4.4)

¹Results presented as mean values ± SD unless otherwise stated. ACR1.2 = automatic cluster remover take-off milk flow threshold of 1.2 kg/min; ACR0.8 = automatic cluster remover take-off milk flow threshold of 0.8 kg/min.

and 260.2 (252.6–267.9) s in the ACR1.2 group and 273.7 (264.9–282.5), 279.1 (269.4–288.8), and 295.7 (287.9–303.6) s in the ACR0.8 group, respectively. We detected differences in the MUOT between groups for cows in second ($P = 0.04$) and $\geq$ third lactation ($P < 0.0001$), whereas no meaningful differences were observed between the groups in primiparous animals ($P = 0.30$, Supplemental Table S4, <https://doi.org/10.3168/jds.2019-17342>). We observed an interaction between the treatment group and parity ($P < 0.0001$) for LMF. The times spent in the LMF in the first-, second-, and $\geq$ third-lactation animals were 23.2 (22.1–24.3), 20.4 (19.3–21.6), and 17.8 (17.1–18.6) s in the ACR1.2 group and 37.8 (36.1–39.7), 37.9 (36.0–40.0), and 37.8 (36.2–39.5) s in the ACR0.8 group, respectively, and were different between the groups in the first- ($P < 0.0001$), second- ($P < 0.0001$), and $\geq$ third- ($P < 0.0001$) lactation animals (Supplemental Table S5, <https://doi.org/10.3168/jds.2019-17342>).

ECM Yield, Milk Component Yields, and Least Squares Means

The average (mean ± SD) values for ECM and milk component yields were as follows: ECM, 12.6 ± 3.3 kg (ACR1.2, 12.5 ± 3.3; ACR0.8, 12.6 ± 3.4); milk fat yield, 0.45 ± 0.13 kg (ACR1.2, 0.45 ± 0.13; ACR0.8, 0.45 ± 0.13); milk protein yield, 0.36 ± 0.09 kg (ACR1.2, 0.36 ± 0.09; ACR0.8, 0.38 ± 0.09); and milk lactose yield, 0.62 ± 0.18 kg [ACR1.2, 0.62 ± 0.17; ACR0.8, 0.63 ± 0.18 (Table 2)]. Figure 2 depicts the least squares means from the general linear mixed models for ECM, milk fat yield, milk protein yield, and milk lactose yield. Detailed results depicting the final model

for each outcome variable are provided in Supplemental Tables S6 to S9 (<https://doi.org/10.3168/jds.2019-17342>). Treatment had no effect on ECM ($P = 0.33$), milk fat yield ($P = 0.70$), milk protein yield ($P = 0.20$), or milk lactose yield ($P = 0.24$). Least squares means (95% CI) in the ACR1.2 and ACR0.8 groups were as follows: ECM, 12.4 (12.1–12.7) and 12.6 (12.3–12.9) kg; milk fat yield, 0.42 (0.40–0.44) and 0.42 (0.40–0.44) kg; milk protein yield, 0.36 (0.35–0.37) and 0.37 (0.36–0.37) kg; and milk lactose yield, 0.61 (0.60–0.63) and 0.63 (0.61–0.64) kg, respectively.

The mean (±SD) LS was 2.0 ± 2.0 (ACR1.2, 2.1 ± 2.0; ACR0.8, 1.9 ± 1.9). The LS was not different between the groups ($P = 0.88$). Controlling for the effect of parity ($P < 0.0001$) and LS from the previous test day 14 d before the start of the study ($P < 0.0001$), LS (LSM, 95% CI) was 1.9 (1.8–2.0) and 1.9 (1.8–2.0) in the ACR1.2 and ACR0.8 groups, respectively (Table 3).

Teat Tissue Condition

The presence of STC was recorded in 1,158/2,386 (48.5%) cow observations [ACR1.2, 546/1,198 (45.6%); ACR0.8, 612/1,188 (51.5%)]. The final model for the presence or absence of STC is depicted in Table 4. The odds of STC were lower for cows in the ACR1.2 group [odds ratio (95% CI) = 0.78 (0.63–0.96)] than for those in the ACR0.8 group. Compared with cows in $\geq$ third lactation, the odds (95% CI) of STC were 1.65 (1.29–2.10) and 1.07 (0.83–1.39) for cows in the first and second lactation, respectively. The presence of HK was documented in 778/2,386 (32.6%) cow observations [ACR1.2, 392/1,198 (32.7%); ACR0.8, 386/1,188

(32.5%)). We detected no meaningful differences between the groups for the odds of HK ($P = 0.88$). Compared with cows in $\geq$ third lactation, the odds (95% CI) of HK were 0.26 (0.19–0.36) and 0.73 (0.54–0.99) for cows in first and second lactation, respectively (Table 5).

Clinical Mastitis

The total number of clinical mastitis cases during the study period was 30 (4.4%), with 20 (5.8%) cases in the ACR1.2 group and 10 (2.9%) cases in the ACR0.8 group. Two cows (0.57%) in group ACR0.8 had a repeated case of mastitis during the study period. The final model for the presence or absence of mastitis contained the treatment group ($P = 0.27$) and LS from the previous test day 14 d before the start of the study ($P = 0.002$). Compared with cows in group ACR0.8, the odds (95% CI) for a clinical mastitis case were 1.58 (0.70–3.54) for cows in the ACR1.2 group. A 1-unit increase in LS on the test day before the study increased the odds of clinical mastitis [odds ratio (95% CI) = 1.31 (1.10–1.55), Table 6]. The post-hoc power analysis showed that the study had an estimated power value of

0.47 to detect a difference between 5.8% (ACR1.2) and 2.9% (ACR0.8) using an α level of 0.05, a coefficient of determination of 0.02, and a one-tailed test. Using an α level of 0.05, a power of 0.8, the coefficient of determination value derived from the final model (0.02), and a one-tailed test, a sample size of 822 animals in each treatment group (1,644 animals total) would have been needed to detect a difference between 5.8% (ACR1.2) and 2.9% (ACR0.8).

DISCUSSION

The objective of this study was to investigate the effect of 2 different ACR settings on (1) milking characteristics, (2) milk components, (3) teat tissue condition, and (4) udder health. We included a study population from a commercial dairy farm milking 3 times daily to most closely represent modern dairy operations in the United States. We found that increasing the cluster remover take-off milk flow threshold of the ACR from 0.8 to 1.2 kg/min resulted in a significant decrease in milking duration and improved teat tissue condition without negatively affecting milk production, milk component yields, or udder health.

Figure 1. Least squares means from general linear mixed models showing the effect of 2 different automatic cluster remover (ACR) take-off milk flow thresholds (ACR1.2, 1.2 kg/min; ACR0.8, 0.8 kg/min) on milk yield, average milk flow rate, milking unit-on time, and time in low milk flow rate. Error bars represent 95% CI. (A) Main effect of treatment group, $P = 0.95$; (B) interaction term of treatment group $\times$ DIM, $P = 0.04$; (C) interaction term of treatment group $\times$ parity, $P = 0.03$; and (D) interaction term of treatment group $\times$ parity, $P < 0.0001$. For results of other main effects, see Supplemental Tables S2 to S5 (<https://doi.org/10.3168/jds.2019-17342>). The P -values for comparison of different levels of the interaction terms were controlled for multiple comparisons with Tukey-Kramer's post hoc procedure.

Table 3. Multivariable general linear mixed model showing the effect of treatment group, parity, and previous linear cell score test day 14 d before the start of the study (PLS) on linear SCS¹

Item ²	β^3 (SE)	P-value	LSM (95% CI)
Treatment group ⁴		0.88	
ACR1.2	−0.01 (0.1)		1.9 (1.8–2.0)
ACR0.8	Referent		1.9 (1.8–2.0)
Parity		<0.0001	
First	−0.5 (0.1) ^a		1.6 (1.5–1.8)
Second	−0.3 (0.1) ^{ab}		1.9 (1.7–2.0)
≥Third	Referent ^c		2.1 (2.0–2.3)
PLS	0.7 (0.0)	<0.0001	—

^{a-c}Groups with different superscript letters differ at a level of $P < 0.05$ in Tukey-Kramer's post hoc test.

¹Treatment group was forced into the model.

²Intercept omitted for clarity.

³Linear regression coefficient.

⁴Treatment consisted of 2 different automatic cluster remover (ACR) settings of the AfiFarm (Afimilk, Kibbutz Afikim, Israel): ACR1.2 (ACR delay = 10) and ACR0.8 (ACR delay = 15) corresponding to a cluster remover take-off milk flow threshold of 1.2 kg/min (ACR1.2) and 0.8 kg/min (ACR0.8).

Milking Characteristics

We detected no differences in MY between the treatment groups. Our findings are consistent with results reported by previous researchers (Sagi, 1978; Rasmussen, 1993; Ferneborg et al., 2016; Krawczel et al., 2017) but differ from those reported by Magliaro and Kensinger (2005) and Burke and Jago (2011). Discrepancies in study populations, milk production, milking frequencies, milking routines, and milking equipment could

be variables that account for the differences observed between these studies and the current one. Magliaro and Kensinger (2005) compared ACR settings of 0.48, 0.6, and 0.8 kg/min using 60 TMR-fed Holstein cows with a twice-daily milking schedule and found a MY reduction of 0.5 kg/milking for the 0.8 kg/min setting. The New Zealand study compared ACR settings of 0.2 and 0.4 kg/min and was conducted in a pasture-based system with 378 cows of mixed breed with a daily milk production of approximately 17 kg that were milked

Figure 2. Least squares means from general linear mixed models showing the effect of 2 different automatic cluster remover (ACR) take-off milk flow thresholds (ACR1.2, 1.2 kg/min; ACR0.8, 0.8 kg/min) on ECM yield (A), milk fat yield (B), milk protein yield (C), and milk lactose yield (D). Error bars represent 95% CI. For results of other main effects, see Supplemental Tables S6 to S9 (<https://doi.org/10.3168/jds.2019-17342>).

Table 4. Multivariable generalized linear mixed model showing the effect of treatment group and parity on machine-milking-induced short-term changes¹

Item ²	β^3 (SE)	P-value	aOR ⁴ (95% CI)
Treatment group ⁵		0.02	
ACR1.2	-0.25 (0.11)		0.78 (0.63–0.96)
ACR0.8	Referent		—
Parity		0.0001	
First	0.50 (0.12)		1.65 (1.29–2.10)
Second	0.07 (0.13)		1.07 (0.83–1.39)
≥Third	Referent		—

¹Treatment group was forced into the model.²Intercept omitted for clarity.³Linear regression coefficient.⁴Adjusted odds ratio.⁵Treatment consisted of 2 different automatic cluster remover (ACR) settings of the AfiFarm (Afimilk, Kibbutz Afikim, Israel): ACR1.2 (ACR delay = 10) and ACR0.8 (ACR delay = 15) corresponding to a cluster remover take-off milk flow threshold of 1.2 kg/min (ACR1.2) and 0.8 kg/min (ACR0.8).

twice daily (Burke and Jago, 2011). The researchers documented a daily MY decrease of 0.3 kg/cow in cows milked with the 0.4 kg/min setting.

In this study, the effect of the treatment on AMF was modified by DIM, which resulted in increased AMF in early- and late-lactation cows milked with the high ACR setting, whereas no meaningful differences were present between the groups in cows that were between 101 and 200 DIM. This unexpected finding is difficult to explain. Our results support those reported by previous investigators (Stewart et al., 2002; Edwards et al., 2013a,b). Stewart et al. (2002) investigated the effect of 2 different ACR settings, between 0.5 and 0.82 kg/min, on 5 commercial US dairy farms (1 herd, 0.5 and 0.64 kg/min; 4 herds, 0.73 and 0.82 kg/min). Four farms applied a thrice-daily milking schedule, whereas the cows on 1 farm were milked 2.5 times per day. The researchers observed an increase in AMF between 0.05 and 0.19 kg/min at the high ACR setting. The New Zealand researchers tested the effect of 4 different

ACR settings (0.2, 0.4, 0.6, and 0.8 kg/min) and their interaction with different premilking stimulation regimens in a pasture-based system using Friesian-Jersey cross cows with a twice-daily milking schedule. In both studies, they detected an increase in AMF between 0.3 and 0.4 kg/min with the 0.8 kg/min setting compared with the lowest ACR setting (Edwards et al., 2013a,b). Both research groups attributed these differences to a truncation of the MUOT at the end of milking with the high ACR settings, resulting in a mathematical increase in AMF due to shorter MUOT in the absence of a decrease in MY. Edwards et al. (2013a) suggested that the maintenance of milk production in the presence of shorter MUOT with the high ACR settings was caused by an alteration of the milk flow curve. Unfortunately, we had no methods to obtain individual milk flow curves to validate these possible explanations in the current study. Conversely, Krawczel et al. (2017) observed no differences in AMF between groups when comparing different thresholds of ACR settings on the

Table 5. Multivariable generalized linear mixed model showing the effect of treatment group and parity on machine-milking-induced long-term changes (i.e., hyperkeratosis)¹

Item ²	β^3 (SE)	P-value	aOR ⁴ (95% CI)
Treatment group ⁵		0.88	
ACR1.2	0.02 (0.13)		1.02 (0.79–1.32)
ACR0.8	Referent		—
Parity		<0.0001	
First	-1.36 (0.17)		0.26 (0.19–0.36)
Second	-0.31 (0.16)		0.73 (0.54–0.99)
≥Third	Referent		—

¹Treatment group was forced into the model.²Intercept omitted for clarity.³Linear regression coefficient.⁴Adjusted odds ratio.⁵Treatment consisted of 2 different automatic cluster remover (ACR) settings of the AfiFarm (Afimilk, Kibbutz Afikim, Israel): ACR1.2 (ACR delay = 10) and ACR0.8 (ACR delay = 15) corresponding to a cluster remover take-off milk flow threshold of 1.2 kg/min (ACR1.2) and 0.8 kg/min (ACR0.8).

Table 6. Multivariable generalized linear model showing the effect of treatment group and previous linear cell score at test day 14 d before the start of the study (PLS) on clinical mastitis incidence of 689 cows

Item ¹	β^2 (SE)	P-value	aOR ³ (95% CI)
Treatment group ⁴		0.27	
ACR1.2	0.23 (0.21)		1.58 (0.70–3.54)
ACR0.8	Referent		—
PLS	0.27 (0.09)	0.002	1.31 (1.10–1.55)

¹Intercept omitted for clarity.²Linear regression coefficient.³Adjusted odds ratio.⁴Treatment consisted of 2 different automatic cluster remover (ACR) settings of the AfiFarm (Afimilk, Kibbutz Afikim, Israel): ACR1.2 (ACR delay = 10) and ACR0.8 (ACR delay = 15) corresponding to a cluster remover take-off milk flow threshold of 1.2 kg/min (ACR1.2) and 0.8 kg/min (ACR0.8).

quarter level (0.06, 0.3, and 0.48 kg/min) in conjunction with different teaser feed regimens in a cohort of Swedish Red and Holstein cows milked with an automatic milking system.

The high ACR setting in the current study yielded a 35.5-s reduction in MUOT in cows in the $\geq$ third lactation and a 21.3-s reduction in second-lactation cows. In contrast, no meaningful differences between settings were detected in primiparous animals. A reduction in MUOT with increased ACR settings has been shown in previous studies (Sagi, 1978; Rasmussen, 1993; Stewart et al., 2002; Magliaro and Kensinger, 2005; Jago et al., 2010; Burke and Jago, 2011; Edwards et al., 2013a,b; Besier and Bruckmaier, 2016; Ferneborg et al., 2016, 2019; Krawczel et al., 2017). Differences in the magnitude of the time-saving effects among studies are most likely due to discrepancies in the dimensions of incremental differences between the settings, the scale of the lowest setting, the milking routine, and additional settings (e.g., auto adjust quick removal) involved in the ACR systems (Stewart et al., 2002; Magliaro and Kensinger, 2005; Jago et al., 2010). Our results support the existing literature that suggests that cows with different parities warrant different management strategies, such as segregation into different milking strings, to fully benefit from the time-saving potential of increased ACR settings within a dairy operation.

As expected, LMF was different between the treatment groups. The interaction term between treatment group and parity resulted in the lowest LMF in cows in the $\geq$ third lactation in the ACR1.2 group, with the greatest difference (i.e., 20 s) between treatments (ACR1.2 $\times$ $\geq$ third parity, 17.8 s; ACR0.8 $\times$ $\geq$ third parity, 37.8 s). The modifying effect of parity on the effect of treatment could be explained by the different shapes of the milk flow curve among cows of different parities. Specifically, differences in the steepness of the decline phase among cows may have affected the duration of time spent in the LMF, as suggested by Ferneborg et al. (2019). This is further supported by

the findings of previous researchers (Tančin et al., 2006; Sandrucci et al., 2007), who reported that the duration of the decline phase was longer in multiparous cows than in primiparous cows. However, because we had no means to obtain information about the milk flow curves, this possible explanation remains speculative.

ECM Yield and Milk Component Yields

The absence of differences in ECM or milk component yields between the treatment groups in this study is in accordance with the findings by previous researchers (Rasmussen, 1993; Edwards et al., 2013a,b; Krawczel et al., 2017). Together, these studies and the current experiment suggest that increasing the ACR settings does not alter milk component yields. Our results are in contrast to a study reported by Ferneborg et al. (2016), who investigated the effect of 2 different ACR settings (0.2 and 0.8 kg/min) at the udder level in conjunction with 2 different feeding protocols using Swedish Red cows milked in an automatic milking system. Ferneborg et al. (2016) found a 0.02% decrease in milk lactose in cows that were milked with the high ACR setting (4.76 vs. 4.78%).

Teat Tissue Condition

Increasing the ACR settings decreased the odds of STC. Machine-milking-induced short-term changes are related to impairment of the teats' defense mechanisms, susceptibility to new IMI (Zecconi et al., 1996; Neijenhuis et al., 2001), and diminished animal well-being (Hillerton et al., 2002). Our findings are therefore of particular importance as they indicate the potential to improve both udder health and animal well-being. Our findings support reports by Rasmussen (1993) who investigated the effect of 2 different ACR settings (0.2 and 0.4 kg/min) on teat tissue condition in Danish Holstein cows over a period of 12 (parity ≥ 2) and 36 (parity = 1) wk. The author used a spring-loaded

caliper (i.e., cutimeter) to assess the relative change in teat tissue thickness during milking and found a significant decrease in the hind teats of primiparous cows in the group with the high ACR setting. Our results support the idea that decreased MUOT (Magliaro and Kensinger, 2005) and less overmilking (Stewart et al., 2002; Clarke et al., 2004; Krawczel et al., 2017) with increased ACR settings improve teat tissue condition. We hypothesize that the reduced odds of STC were caused by a decrease in LMF in cows in the ACR1.2 group. Due to an inverse relationship between milk flow rate and milking unit vacuum (Bade et al., 2009; Ambord and Bruckmaier, 2010), LMF increases the vacuum-induced strain at the teat ends, which in turn generates forces on the teat creating congestion and edema of the teat end tissue (Williams and Mein, 1982). The higher LMF in the ACR0.8 group may therefore have yielded more congestion and edema, resulting in more STC. The overall frequency of STC was 48.53%, which is within the range reported by 2 recent studies from our group [29.7% (Wieland et al., 2018); 57.8% (Wieland et al., 2019)] but higher than recommendations proposed by Mein et al. (2001). In this study, the vacuum settings yielded an average claw vacuum of 42 kPa (12.4 inHg), which is at the upper level of the current guidelines from the National Mastitis Council (NMC, 2012) of 32.2 to 42.3 kPa (9.5–12.5 inHg). Hamann et al. (1993) indicated that vacuum levels have a greater effect on teat tissue changes compared with MUOT, which may partially explain the high frequency of STC.

Conversely, increasing ACR settings had no effect on HK, which was an unexpected finding in this study. Our results are consistent with those reported by Edwards et al. (2013a), who detected no differences in HK when comparing 4 different ACR settings (0.2, 0.4, 0.6, and 0.8 kg/min) in combination with 3 different premilking treatments in a pasture-based system over a 9-wk period. In contrast, Rasmussen (1993) observed significant differences in teat end callosity after 8 and 4 wk in first- and $\geq$ second-lactation animals, respectively. In a recent Irish study (Edwards et al., 2013c), the investigators tested the effect of different overmilking durations on teat end conditions in a pasture-based system using late-lactation Holstein-Friesian cows milked twice daily. Treatments were applied over a 6-wk period and consisted of automatic unit removal when the milk flow rate reached 0.2 kg/min and 120, 300, and 540 s after the milk flow rate reached 0.2 kg/min, respectively. Edwards et al. (2013c) found that HK scores increased with an increasing duration of overmilking. We believe that the absence of differences between the groups in this study can be attributed mostly to the duration of the experiment in relation to the relatively small

differences between treatments. To a lesser extent, the lack of differences could have been due to the scoring system implemented at the cow level, which diminished the ability to detect more subtle changes, such as differences in the number of teats with different degrees of teat end callosity.

Udder Health

Our data show that ACR settings were not associated with LS, which is in accordance with the results from multiple previous studies (Clarke et al., 2004, 2008; Burke and Jago, 2011; Edwards et al., 2013a,b,c; Krawczel et al., 2017). The pretrial LS explained most of the variability in the LS between the treatment groups. The interaction term between treatment group and LS before the start of the study was not significant, indicating that cows with increased SCC pretrial did not respond differently to treatments, which is in accordance with the results from Burke and Jago (2011). Relatively fewer studies found differences in SCC when comparing different ACR settings in a pasture-based system (Jago et al., 2010) and automatic milking system (Ferneborg et al., 2016). A popular belief exists that incomplete milking causes increased SCC. Clarke et al. (2008) tested this hypothesis in 2 cohorts of 25 Holstein cows on pasture milked 2 times per day; they found no evidence that supported the hypothesis and concluded that “a milking regime that leaves on average ~ 0.5 L of strip milk behind did not cause a detectable increase in cell counts in infected or uninfected quarters.”

The differences in the odds of clinical mastitis incidence between the 2 groups were likely due to chance, a finding which is consistent with previous reports (Rasmussen, 1993; Jago et al., 2010; Burke and Jago, 2011). The final model indicated that pretrial LS explained most of the variability in clinical mastitis incidence. However, the sample size of this study was based on the ability to detect differences in MUOT between treatment groups; differences in clinical mastitis incidence were not considered. This is further supported by the post-hoc power analysis indicating that more than twice as many animals (1,644 animals total) would have been necessary to declare a difference between 5.8% (ACR1.2) and 2.9% (ACR0.8) with 95% confidence and a power of 0.8. Consequently, caution is in order when trying to infer from the clinical mastitis data of the study described herein. Instead, the incidence data generated from the current study should be considered a reference point for sample size calculations of future studies investigating the effect of different ACR settings on clinical mastitis. Future studies with larger samples sizes should reexamine the effect of different

ACR settings on clinical mastitis incidence and LS over the entire lactation, as well as the interactive effects between different levels of LS and ACR settings on these outcome variables.

Study Limitations and Future Directions

Although our findings are encouraging for the further investigation of the potential of different milking regimens on milking efficiency, udder health, and animal well-being, our study had several limitations that the reader should consider when making inferences from these findings. First, we conducted our study on one New York dairy farm with Holstein cows on a thrice-daily milking schedule. Our results are therefore likely to reflect what would happen in a commercial operation in this region. However, the external validity of our study may be limited to similar operations applying ACR settings that are within the range of 0.8 and 1.2 kg/min. Second, the study period was limited to a duration of 2 mo during the summer season. Although our results indicating no adverse effects on milk production and udder health are consistent with the majority of the existing literature, caution should be taken when trying to extrapolate these findings to lactation performance. Future studies investigating the effect of ACR settings on milk production and udder health over a whole lactation period are required (Edwards et al., 2013b).

In this study, we assessed teat tissue condition at the cow level. Our reasoning was that we wanted to minimize interference with the dairy's milking routine. However, we acknowledge that this likely yielded a failure to detect subtle differences that may have occurred at the quarter level.

Last, cows in our study were randomly allocated into treatment groups across pens, which resulted in cows of both groups being milked within the same parlor row. Thus, we were not able to study the effect on parlor efficiency metrics such as parlor turns/hour per milking session. The cow with the slowest milking time determines the row time in a parallel parlor (Jago et al., 2010; Edwards et al., 2013a,b). The potential of increased ACR settings to improve parlor efficiency may therefore be limited by the frequency of cows with slow milking times and their distribution across the herd or, more specifically, parlor rows during milking. In the current study, the MUOT ranged between 292 and 717 s for 25% of all milking observations in cows in the ACR1.2 group (Supplemental Table S1, <https://doi.org/10.3168/jds.2019-17342>), suggesting the presence of cows with slow milking times whose MUOT was not greatly affected by the ACR. To take the greatest ad-

vantage of the reduction in MUOT, our work should be extended to identify machine settings that further improve parlor efficiency. A possible extension could be a combination of different ACR settings with a maximum unit-on time as described in pasture-based systems in Australia (Clarke et al., 2004, 2008) and New Zealand (Jago et al., 2010).

CONCLUSIONS

Increasing ACR settings from 0.8 to 1.2 kg/min decreased individual milking duration and alleviated milking-machine-induced short-term changes to the teat tissue condition without adversely affecting the amount of milk harvested, milk component yields, or SCC. No meaningful differences were detected in machine-milking-induced long-term changes between treatment groups. We conclude that modification of ACR settings has the potential to improve parlor efficiency and animal well-being. Future studies investigating the effect of different ACR settings on milk production and udder health over a whole lactation period on farms with different operational systems are warranted. Such studies with larger sample sizes should reevaluate the interactive effects between different levels of LS and ACR settings on both subclinical and clinical mastitis incidence.

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