HHS Public Access
Author manuscript
Int J Ind Ergon. Author manuscript; available in PMC 2020 February 26.

Published in final edited form as:
Int J Ind Ergon. 2016 November ; 56: 161–169. doi:10.1016/j.ergon.2016.10.003.

Effect of a novel teat preparation system on upper extremity muscle activity among U.S. large-herd dairy parlor workers

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Abstract

Background—Dairy production in the U.S. is moving towards large-herd milking operations resulting in an increase in task specialization and work demands. Large-herd dairy parlor workers experience a high prevalence of musculoskeletal symptoms in the upper extremity. The purpose of this study is to evaluate the effects of an alternative teat scrubber (TS) cow preparation method on upper extremity muscle activity among large-herd parlor workers, as well compare to muscle activity associated with conventional manual milking tasks.

Methods—Upper extremity muscle activity was recorded among U.S. large-herd parlor workers (n = 15) using surface electromyography. Participants performed multiple task cycles, using both conventional and TS methods. Muscle activity levels were then compared across conventional manual and TS milking tasks.

Results—Conventional manual milking tasks of dip, strip and wipe were associated higher muscle activity levels of the upper trapezius and anterior deltoid. Biceps muscle activity was greatest during teat dip and wipe. Forearm flexor and extensor muscle activity was greatest during teat wipe and dip. The TS system resulted in more desirable anterior deltoid EMG profiles, and less desirable biceps, forearm flexor and extensor profiles.

Conclusions—Results suggest that the TS system is effective in reducing anterior deltoid muscle activation levels. The TS system also appears to result in increased biceps, forearm flexor and extensor muscle activation levels. Increases in muscle activation levels could be offset by reduced repetitiveness resulting from three conventional manual milking tasks being replaced with one TS task.

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Author contributions statement
All authors attest that they have made substantial contributions to this manuscript including 1) the conception of the design of the study, 2) data acquisition, analysis and interpretation of work, 3) drafting the manuscript including revision for intellectual content, and 4), approving the submitted version of the manuscript. Authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflict of interest statement
All authors declare no conflicts exist in this study or manuscript.

Relevance to industry—If parlor production requirements (e.g., quality and onsistency) are maintained while simultaneously reducing cumulative muscle loading and worker fatigue, then TS use should be considered in milking parlor operations.

Keywords

Agriculture workers; Dairy; Musculoskeletal; Ergonomics; Farm; Injury

1. Introduction

Workers on dairy farms report 8.6 workers' compensation claims per 200,000 work hours (Douphrate et al., 2006), higher than the national injury rate (6.2 per 200,000 h) as reported by the U.S. Department of Labor and Bureau of Labor Statistics (2014). The body region experiencing the largest proportion (35%) of injury claims is the upper extremity, and nearly 50% of injuries occur inside the milking parlor (Douphrate et al., 2009). However, national injury estimates often underreport work-related musculoskeletal disorders (MSD) (Morse et al., 2005) and immigrant agriculture workers are less likely to report injuries or seek workers' compensation benefits (Azaroff et al., 2002). often resulting in an underestimation of injury burden.

Despite increased mechanization with dairy production, adverse musculoskeletal health outcomes remain prevalent among dairy workers. Over 83% of dairy workers experience musculoskeletal symptoms (MSS) (Pinzke, 2003, Kolstrup et al., 2006). Karttunen and Rautiainen (2011) reported a decline in working ability in 39% of dairy farmers which was attributed to musculoskeletal disorders. Kolstrup et al. (2006) reported 86% of Swedish dairy workers experienced a MSS which was most prevalent in the upper extremity (52%). Other European studies reported prevalences of shoulder and hand/wrist MSS exceeding 50% (Stål et al., 2000, Pinzke, 2003). Among dairy workers who worked specifically in the milking parlor, musculoskeletal symptoms remain prevalent in the neck, shoulder, and upper extremities despite advancements in milking technologies and automation (Arborelius et al., 1986, Jakob et al., 2012, Lunner Kolstrup, 2012, Douphrate et al., 2014). Douphrate et al. (2014) reported 76% of U.S. large-herd parlor workers experienced a work-related MSS in at least one body part, and the upper extremity was the most prevalent (55%) location of symptoms. More specifically, parlor workers reported MSS in the neck (25%), upper back (42%), shoulders (40%), elbows (19%), and wrist/hand (36%).

Kolstrup et al. (2006) reported non-neutral working postures and repetitive tasks were associated with work-related MSS among workers performing milking tasks in modern small-herd European milking parlors. Large-herd milking parlor job factors were also found to be associated with MSS in multiple body regions, including performing the same task repeatedly, insufficient rest breaks, working when injured, static postures, adverse environmental conditions, and reaching overhead (Douphrate et al., 2016). The milking process requires forceful arm and hand motions (Stål et al., 2000), and repeated attachment of the milking unit has been reported to be among the most physically demanding tasks (Pinzke et al., 2001) as milking units can weigh more than 3.0 kg (Schick, 2000, Stål et al., 2003). Douphrate et al. (2012) evaluated full-shift exposures of posture and motion of the shoulder among large-herd parlor milkers using wireless inclinometry. Results suggest large-herd parlor workers may be exposed to ergonomic risk factors associated with the development of shoulder pathology (e.g., posture, movement velocity, repetition, and inadequate rest). Douphrate et al. (2014) also reported 38% of large-herd parlor workers perceived teat stripping as the most strenuous milking task, followed by milking unit attachment (32%). These findings were consistent with other international studies which have identified the same milking tasks to be among the most demanding (Stål et al., 1996, Stål et al., 2003, Jakob et al., 2012). These findings support the need for engineering or administrative solutions aimed at reducing exposure to ergonomic risk factors among large-herd parlor workers (Douphrate et al., 2016).

The milking routine, as described in a previous publication (Douphrate et al., 2017), includes six primary tasks: 1) pre-dipping of teats with a cup or spray for sanitization (Fig. 1a); 2) teat strip to stimulate milk flow (Fig. 1b); 3) teat wipe (Fig. 1c); 4) milking unit attachment (Fig. 1d); 5) automatic detachment of milking unit after milk harvest; and 6) post-dipping of teats for sanitization. Milking tasks involve the worker reaching forward, between the hind legs of a cow, to access the udder. Constrained work involving repetitive movements of hands, and static muscle loading of the neck and shoulder have been shown to be risk factors for neck/shoulder musculoskeletal pathology (Winkel and Westgaard, 1992a, Winkel and Westgaard, 1992b). Additionally, risk factors for hand/wrist and elbow disorders include forceful or sustained gripping, high repetitions and awkward bending/twisting postures (Silverstein, 1985).

Milking parlor productivity and efficiency involves interactions between the cows, the milking equipment/environment, and the workers (Douphrate et al., 2017). The quality of milking task performance has the potential to profoundly influence parlor productivity, milk production, and cow health. Within each milking parlor operation, milking routine consistency is paramount. Inconsistent or improper milking routine can prolong cow milk let-down, increase milking time, adversely affect teat health, and decrease optimization of milk harvest volume. Human error due to inadequate training, or fatigue may contribute to milking process drift and a reduction in milking consistency and productivity. To date, research emphasis has been placed on the cow or milking equipment and their effects on milk production. Little attention has been placed on the worker, and his/her interaction with the cow, equipment or working environment. Limited research has evaluated milking task-specific control interventions and their effectiveness in reducing biomechanical exposure during parlor milking (Pinzke et al., 2000, Stål et al., 2003, Jakob and Liebers, 2011, Douphrate et al., 2017).

A novel milking technology has been introduced into milking parlor systems. An automatic teat scrubbing (TS) system was designed to replace several conventional udder preparation, pre-milking tasks (i.e., pre-dip, strip, and wipe) in the milking routine, and has the potential to improve parlor efficiency and ensure cow preparation consistency. Automatic teat scrubbers are often introduced to remove human performance variability from the milking process. By replacing several conventional manual pre-milking tasks with one task, a TS system may also reduce biomechanical exposures and reduce adverse musculoskeletal outcomes among workers. The purpose of this study was to evaluate the effects of a commercially available TS on upper extremity muscle activity among large-herd parlor workers in comparison to conventional manual milking tasks. To our knowledge, no prior studies have attempted to quantify the health effect of TS technology and its ability to reduce biomechanical exposures (i.e., muscle load) among U.S. large-herd parlor workers.

2. Materials and methods

2.1. Study sample

A non-random sample of fifteen parlor workers was recruited from a Southwestern U.S. dairy farm with a milking herd of over 4000 cows. Full-time male workers aged 18 years or older and with no history of pain or pathology in the upper extremities were eligible for inclusion in the study. After meeting inclusion criteria, the study was explained and participants were asked to provide written informed consent. The informed consent document was available in both English and Spanish and a bilingual investigator was present for translation purposes. Each participant received $20 in appreciation for their time. The University of Texas Health Science Center at Houston, Committee for the Protection of Human Subjects approved all study procedures.

Age, height, weight, arm reach and years milking are summarized in Table 1. All participants were right hand dominant, with a mean age of 37.4 years (range: 23–53 years). Mean height was 170 cm (range: 160.0–175.0 cm) and mean body mass was 77.9 kg (range: 69.3–96.8 kg). Mean arm reach was 60.4 cm (range: 47.0–66.0 cm). Arm reach was defined as distance from acromion to styloid process when measured in a standing position with shoulder elevated to 90°.

2.2. Milking tool

We evaluated an automatic TS system (Future-COW®, Longwood, FL). The TS includes rotating brushes in a composite material enclosure with a handle for the worker to grasp. Unit mass was 1.8 kg (with hose attached) and measured 32 cm from end-to-end. The TS unit had a bent handle at 30° which was 11 cm in length. The handle was cylindrical in shape with a diameter of 41 mm without recessed finger grooves. A rectangular trigger, 21 mm in length and 13 mm in width, was positioned for index finger depression during operation (Fig. 2a).

Using a power grip, the participant grasped the TS handle and raised the unit to a cow's udder. The TS rotating brushes were positioned around each cow teat while simultaneously depressing the trigger with the index finger (Fig. 2b). Rotating brushes of the TS unit clean debris off the teat end while an antimicrobial disinfectant is applied. Rotating action of brushes also provide a tactile stimulation to promote milk let down. The TS system evaluated in this study replaced three manual tasks in the conventional pre-milking routine: pre-dip, strip, and wipe.

2.3. Work environment and milking routine

Data collection took place in Double-35 stall (i.e., 70 total cows) parallel milking parlor. Participants performed the conventional pre-milking routine in a manner consistent with production practices used during regular operation of the milking parlor. Specifically, each participant was responsible for 10 milking stalls on both sides of the milking pit. A group of cows would enter the parlor on one side of the pit. In sequential fashion, each participant performed the milking routine on 10 cows in their assigned milking stalls which included teat pre-dip on cows 1 through 10 (using a dip cup, Fig. 1a), followed by teat strip on cows 1 through 10, followed by teat wipe on cows 1 through 10, followed by milking unit attachment on cows 1 through 10.

During milk harvest (i.e., while the milking units were attached to the cows) and prior to beginning the pre-milking routine on new cows on the other side of the milking pit, participants performed 10 simulated teat preparations using the TS on an artificial udder positioned on the platform where cows stood for milking (Fig. 2c). The artificial udder was used to avoid parlor operational interruption or biological disruption of cows accustomed to manual milking tasks, and was designed using cow dimension data measured prior to data collection (i.e., mean teat height and mean hind leg-to-leg distance). Each artificial udder was constructed with four teats to simulate a milking cow udder, with a vertical distance from platform to teat-end being 46 cm.

Following completion of the milk harvest and the 10 simulated teat preparations, participants performed the teat post-dip task on cows 1 through 10 (using a dip cup, Fig. 1a) in the same fashion as pre-dip. Following post-dip, the 10 cows would leave the milking stalls to exit the parlor and a new group of 10 cows would enter. The full sequence of the milking routine and the simulated teat preparations using the TS system is depicted in Fig. 3.

2.4. Surface EMG methods

A task cycle was defined as a milking task performed on a single cow. Upper extremity muscular effort during 30 cycles (cows) of each milking task and 30 cycles of simulated teat preparation using the TS system was estimated using surface electromyography (EMG). Post-dip task was not digitally marked and analyzed separately because this task was performed in the same fashion as the pre-dip task, and is not a manual task replaced by the TS system.

Surface EMG data were recorded from the upper trapezius, anterior deltoid (shoulder flexor), biceps, flexor digitorum superficialis (forearm flexor), and extensor digitorum communis (forearm extensor). The EMG electrodes (Model SX230, Biometrics Ltd., UK) were positioned on the skin over each muscle using published guidelines (Criswell, 2010) and a reference electrode was placed over the non-dominant clavicle. Skin preparation including removal of excess hair with an electric trimmer and cleansing using a gauze pad dampened with alcohol. The dry EMG electrodes (37 × 20 × 6 mm) had dual 10 mm diameter, silver-silver chloride surfaces with an inter-electrode distance of 20 mm, on-site differential amplification (gain = 1000), a bandwidth of 20–460 Hz, and an input impedance of $>10^{12}\Omega$. Each electrode was connected to a portable EMG data logger (Datalog MWX8, Biometrics Ltd., UK) attached to a belt worn about the participant's waist. The data logger digitized the raw EMG signals at a sampling rate of 1000 Hz. The raw EMG recordings were stored on a compact flash memory card and transferred to a computer for signal processing and analysis.

2.5. EMG signal processing

Custom LabVIEW programs (version 2013, National Instruments, Inc., Austin, TX) were used to process all EMG recordings. Signal quality was assessed visually following electrode placement and verified during post-processing of EMG recordings. Signal quality checks during post-processing included (i) examination of the mean value of 100-sample epochs of the raw EMG signal across the full recording duration for evidence of signal drift, (ii) examination of periods of very low muscle activity to identify the presence of electrocardiogram interference, and (iii) frequency domain analysis to identify the presence of electromagnetic interference (e.g., 60 Hz). When present, electrocardiogram interference was attenuated using a high pass filter (Redfern et al., 1993, Drake and Callaghan, 2006) and electromagnetic interference was attenuated using a notch filter. Finally, DC offset was removed and the signals converted to instantaneous root-mean-square (RMS) amplitude using a 100-sample moving window with a 50-sample overlap (Fethke et al., 2012).

2.6. EMG normalization procedures

For each muscle, RMS EMG voltage values recorded during the milking tasks were expressed as a percentage of the RMS EMG voltage observed during maximal, isometric reference exertions (%MVE, i.e., normalization in the bioelectric domain). Standing with the arm forward flexed to 120° and the elbow in full extension, participants performed a maximal, isometric contraction against a manual resistance applied at the wrist. This procedure produced maximum reference exertions for the upper trapezius and anterior deltoid (Boettcher et al., 2008). Normalization for the biceps involved the participant standing with shoulder at neutral and elbow at 90° flexion. Participants performed a maximal, isometric contraction against manual resistance applied at the wrist (Burden and Bartlett, 1999). For the forearm flexor and extensor, participants held a 0.4 kg hand grip dynamometer (Hydraulic Hand Dynonometer, Chattanooga Group, Hixon, TN, USA) and performed a maximal, isometric power grip with their elbow flexed to 90° and the forearm and wrist in neutral postures (Anton et al., 2005).

Participants performed three repetitions of each reference contraction, with a 2-min rest between repetitions. Each reference contraction was maintained for 5 s and, for each muscle separately, the greatest RMS EMG amplitude within the middle 3 s of the contraction was identified. The maximum RMS EMG amplitude was then defined as the maximum RMS EMG amplitude observed across the three repetitions (Mathiassen et al., 1995). Baseline noise was subtracted from all RMS EMG amplitudes in a power sense (Thorn et al., 2007).

2.7. EMG summary measures and statistical analysis

Each cycle of each milking task (dip, strip, wipe, attach and TS) was identified using a push-button digital event marker connected to the EMG data logger. For each cycle of each task, the arithmetic mean of the normalized RMS EMG amplitude (in %MVE) was calculated for each muscle. Additionally, the 10th (static), 50th (median) and 90th (peak) percentiles of the normalized RMS EMG amplitude probability distribution function were obtained (Jonsson, 1988). The mean duration of each milking task (i.e., cycle time) was also calculated based on the digital mark of the beginning and end of each cycle. To compare muscle activation levels between the TS system and the three conventional milking tasks it replaced (i.e., pre-dip, strip and wipe), we created a composite milking task (CMT) variable as the time-weighted-average (TWA) EMG summary metric across the three milking tasks.

The EMG summary measure distributions were described (i.e., using means and standard deviations) for each milking task across all participants. To test the effect of conventional milking task on each muscle activity summary measure we used multilevel linear mixed-effects models to account for nesting effects within each subject. We assumed residuals by milking task were independent but allowed for heteroscedasticity (variable variance) of the measures of muscle activity since these could change over time; therefore, we estimated distinct error variances for each milking task. We used the Scheffé method to perform post-hoc comparisons of muscle activity summary measure distributions between all pairwise combinations of conventional milking tasks. Similar models were constructed to compare EMG summary measures between the composite milking task (CMT_{TWA}) and the TS system. All statistical procedures were performed using Stata© (v. 14.1, StataCorp LP, College Station, TX).

3. Results

3.1. Conventional milking tasks

EMG summary measure distributions for all muscles by conventional manual milking task are provided in Table 2. No single task clearly resulted in the greatest or lowest EMG levels across all muscle groups, which was expected based on different upper extremity motions and forces required of each task. Still, some interesting observations can be highlighted. First, the effect of milking task on upper extremity and forearm flexor EMG summary measures was not statistically significant despite relatively large effect sizes (i.e., greater than one standard deviation) in some cases (e.g., mean forearm flexor 90th percentile APDF of 43.9% MVE during the pre-dip vs. 74.9% MVE during teat wipe). Second, contrary to our expectation, milking unit attachment resulted in lower upper trapezius and anterior deltoid muscle activity in comparison to the other conventional milking tasks. For the anterior deltoid, the difference between milking unit attachment (4.6 ± 2.6%MVE) and teat strip (7.2 ± 4.1%MVE) was statistically significant for the 10th percentile of the APDF summary measure.

Further inspection of the mean RMS EMG levels across muscles and tasks suggests that teat wipe (highest mean RMS across tasks for three of five muscles) and pre-dip (highest or second highest mean RMS for four of five muscles) were more strenuous than teat strip and milking unit attachment. Of the 17 statistically significant post-hoc comparisons of EMG summary measures between pairs of tasks, 10 involved either teat wipe or pre-dip in comparison to either teat strip or milking unit attachment, three involved teat wipe in comparison to pre-dip, and the remaining four involved teat strip in comparison to milking unit attachment.

3.2. Composite milking task vs. the teat scrubber system

In comparison to the composite milking task, use of the TS system was associated with modestly reduced anterior deltoid EMG activity levels (Table 3). Across EMG summary measures, the magnitude of the reduction ranged from about 25% to more than 150% of a standard deviation. The effect was statistically significant for all EMG summary measures except the 10th percentile of the APDF. In contrast, use of the TS system was associated with increased activity levels for all other muscles evaluated. While the observed increases were small and not statistically significant for the upper trapezius, modest-to-large and statistically significant increases were observed for the biceps (10th percentile APDF), forearm flexors (10th percentile APDF), and forearm extensors (all EMG summary measures). For the forearm extensors, the mean values of all EMG summary measures for the TS system were approximately twice the mean values for the composite milking task (e.g., 14.5 ± 2.6%MVE for CMT_{TWA} vs. 30.6 ± 5.0%MVE for TS).

3.3. Milking task cycle durations

As expected, mean task cycle durations varied between conventional milking tasks. The conventional milking task with the longest mean task cycle duration was milking unit attachment (2.9 ± 0.81 s), and the task with the shortest duration was teat pre-dip (1.5 ± 0.36 s). Mean TS task duration was 3.5 s (±1.4 s) as compared to a CMT_{TWA} mean total duration of 5.5 s (±1.3 s).

4. Discussion

4.1. Muscle activation levels

Analysis of EMG activity levels during conventional milking routine tasks suggested a complex pattern, with the greatest overall muscular demand (based on the average mean RMS across n = 15 experienced parlor workers) observed for the forearm flexors during the teat wipe task. Furthermore, overall muscular demand was generally greater for the pre-dip and teat wipe tasks than for the milking unit attachment task (except for the forearm extensors). Although many of the differences in EMG levels between pairs of conventional milking tasks were not statistically significant, these trends suggest that substituting the conventional teat preparation tasks (i.e., pre-dip, strip and wipe) with the TS system may impact muscular load during the most demanding aspects of the milking routine.

Comparisons between TS and CMT_{TWA} EMG levels revealed that the TS system clearly resulted in more desirable anterior deltoid EMG profiles but less desirable biceps, forearm flexor and forearm extensor EMG profiles (Fig. 4. EMG traces). The decreased anterior deltoid and increased biceps EMG levels during TS use suggest an alteration of upper extremity posture in comparison to the conventional teat preparation tasks. Specifically, the length of the TS system likely reduced the upper arm elevation (thereby decreasing anterior deltoid activity) and increased the elbow flexion (thereby increasing biceps activity) required to engage the TS with the teats. The increased forearm flexor and forearm extensor EMG levels during TS use suggests increased grip force required to hold and position the TS unit in comparison to conventional methods. The increased grip force was likely the result of two attributes of the TS system: (i) its mass (1.8 kg), which was considerably greater than that of the conventional equipment (e.g., the dip cup and cloth towel) and (ii) the location of its center of gravity, which was beyond the hand grip position (with hose attached at handle base) and thus imposed a non-negligible external bending moment about the wrist joint.

In addition, although the TS handle was bent to 30°, greater ulnar deviation of the wrist was observed in comparison to the conventional tasks, which may have further increased biomechanical demands of the distal upper extremity muscles.

While our findings suggest increased muscle activity in certain muscle groups with use of the TS system, these exposures may be offset by a reduction in task repetitiveness and exposure duration involved with teat preparation of each cow. Consider the conventional milking routine, during which each of four teats of each cow was engaged three times during preparation: once for pre-dip, once for strip, and once for wipe. The average total duration of these tasks per cow was 5.5 ± 1.3 s. In contrast, each teat of each cow was engaged just once when using the TS system (67% reduction in repetition), with an average duration per cow of 3.5 ± 1.4 s (36% reduction in exposure duration). These reductions may substantially reduce cumulative muscle loading over time, which in turn may delay the onset of fatigue or (ultimately) the development of musculoskeletal health outcomes. Therefore, future studies involving the analysis of EMG signals collected over prolonged sampling durations (i.e., full-shift) may suggest that TS use promotes greater amounts of muscle rest and recovery in comparison to the conventional milking routine. In this context, if parlor production requirements (e.g., quality and consistency) are maintained while simultaneously reducing cumulative muscle loading, then TS use should be considered even in the absence of empirical evidence about its effect on worker health (e.g., through a randomized controlled trial).

However, while it’s true that the duration of teat preparation appears to be reduced with the TS system, this does not necessarily imply an overall reduction in exposure duration would be achieved over the course of an entire work shift. For example, a reduced teat preparation duration may enable more cows to be milked in a work shift. As a result, any gains made in reduced exposure through the use of the TS system would be offset by an increase in production demand. Data collected in the present study precludes answering this question, but can be a focus in future investigations.

Two previous studies reported milking task-specific muscle activity levels (Pinzke et al., 2001, Stål et al., 2003). Pinzke et al. (2001) reported median biceps APDF muscle activity levels (%MVE) of 5.3 ± 2.1 for strip, 9.7 ± 3.6 for wipe, and 1.8 ± 14 for attachment; and median forearm flexor muscle activity levels of 20 ± 11 for strip, 27 ± 8.4 for wipe, and 18 ± 7.5 for attachment. Stål et al. (2003) reported median APDF muscle activity levels of 6.1 ± 3.7%MVE for the biceps and 13.0 ± 5.0%MVE for forearm flexors during milking unit attachment. Our findings suggest higher muscle activity levels for the biceps for all tasks and comparable levels for the forearm flexors for the same muscles and tasks. Differences in findings may be related to differences in milking unit design and weight (Douphrate et al., 2017), and motor unit recruitment patterns associated with differing methods of attaching the milking unit. For example, Stål et al. (2003) reported workers held the milking unit with the left hand while attaching teat cups with the right hand. In our study, participants would hold and attach teat cups with both hands.

Other studies have evaluated task-specific engineering controls primarily directed at the attachment task. Stål et al. (2003) evaluated the effect of a prototype milking unit support arm on upper extremity muscular load during unit attachment. Surprisingly, only a minor decrease in muscular load during attachment was observed using the support arm as compared to no support arm. Pinzke et al. (2000) demonstrated workload reduction was possible by a reduction of milk tube weight. Jakob and Liebers (2011) investigated the effects of a quarter-individual milking unit on muscle activity and posture. Results suggested this alternative milking unit design has the potential to reduce muscle activity and non-neutral postures among parlor workers. Jakob et al. (2012) demonstrated an optimal working height during milking unit attachment was achieved when teat ends were at shoulder level of the parlor worker.

4.2. Relevance to industry

As described above, the TS system reduced the time required to prepare each teat for milking unit attachment. Thus, dairy owners may be encouraged to consider adoption of this new technology on the basis of increased productivity. While our study evaluated the effect of conventional and TS milking tasks on muscle activity, further studies are needed to evaluate effectiveness of TS in teat cleaning, cow stimulation, milking time and overall herd health (e.g., somatic cell counts). A review of the scientific literature revealed one study which compared reduction in bacterial counts of teats cleaned using a TS system or using conventional teat preparation methods (Baumberger and Ruegg, 2015). Results of this study suggest that TS can achieve similar reduction in bacterial count on teat skin as conventional teat preparation methods but its effectiveness is influenced by management practices that differ among farms.

4.3. Limitations

Although a sample size of 15 parlor workers was sufficient to detect statistically significant differences in EMG summary measures between milking tasks, we were not able to assess the effect of task by other variables. The effect of milking task on muscle activation may depend partly on anthropometric characteristics of the parlor worker. For example, workers with shorter arm lengths might experience higher levels of upper trapezius activity during teat strip or TS teat preparation than workers with longer arms. Additionally, while participants were given the opportunity to practice TS teat preparation prior to data collection, unfamiliarity with the TS tool may also influence muscle activation levels.

The non-random selection of both the work site and participants limits our ability to generalize the results of this study to all U.S. large-herd parlors and parlor workers. However, random selection of workers requires (i) a full enumeration of the population of workers and (ii) access to the population from which the random sample is to be selected. Satisfying both criteria was not feasible in the context of the resources available to execute the research and our study objective. Dairy operations are geographically dispersed and remote, so random selection of workers from multiple operations would introduce substantial logistical challenges. Although we have established excellent relationships with many dairy owners, the high worker turnover and multiple work shifts common to the industry create additional difficulties in identifying the pool of potential research participants. However, threats to the internal validity of this study as a result of non-random selection of participants were minimized with the use of a within-subjects experimental design in which each participant served as his own control. Additionally, the demographic characteristics of our study sample were consistent with the population of U.S. large-herd parlor workers as reported in prior studies (Douphrate et al., 2014, Douphrate et al., 2016). Future studies may include within-subject task comparisons in other parlor configurations (e.g., herringbone and rotary) to enhance generalizability of findings.

The limited set of summary measures used in this study may not consider other aspects of exposure. In addition to forceful exertion, other factors recognized to be associated with the development of work-related MSD include non-neutral postures and repetitive motion (Punnett and Wegman, 2004, Da Costa and Vieira, 2010). Repetitive motion and postures should be assessed during milking task performance using both conventional and TS milking methods.

This study used a task-based approach to estimate exposures associated with specific pre-milking tasks. Therefore, our task-specific exposure estimates should not be assumed to represent job exposures because task-based estimates of mechanical job exposures can be very imprecise (Svendsen et al., 2005). Lastly, the data included in our analysis were collected in a parallel milking parlor, and may not represent TS muscle activity levels in other parlor configurations, namely herringbone and rotary.

4.4. Conclusions

The primary objective of this study was to evaluate the potential of an alternative teat preparation system to reduce exposure to upper extremity muscle activation levels associated with conventional manual milking tasks. The results suggest that the alternate system is effective in reducing anterior deltoid muscle activation levels. The alternate system also appears to result in increased biceps, forearm flexor and extensor muscle activation levels. However, increases in muscle activation levels could be offset by reduced repetitiveness resulting from three conventional milking tasks being replaced with one TS task. The observed results should be interpreted with caution in light of the small sample size and non-random selection of study participants. Evaluation of the TS system should take place in other parlor configurations including herringbone and rotary. Further development and study of the alternate system is recommended. Possible design enhancement should focus on TS weight and handle design.

Acknowledgements

This project was a collaborative effort by researchers representing three National Institute for Occupational Safety and Health (NIOSH) Centers for Agricultural Health: the High Plains and Intermountain Center for Agricultural Health and Safety (HICAHS) at Colorado State University, the Great Plains Center for Agricultural Health at the University of Iowa, and the Southwest Center for Agricultural Health, Injury Prevention and Education at the University of Texas Health Science Center at Tyler. This work was supported by the Center for Disease Control and Prevention (CDC) /NIOSH through the HICAHS under grant number U54 OH008085–08. The contents of this report are solely the responsibility of the authors and do not necessarily represent the official views of the CDC or NIOSH. The authors would like to express their appreciation to the dairy owner and workers who were willing to participate in the study.

References

Anton D, Rosecrance J, Gerr F, Merlino L, Cook T, 2005. Effect of concrete block weight and wall height on electromyographic activity and heart rate of masons. Ergonomics 48, 1314–1330. [PubMed: 16253947]

Arborelius U, Ekholm J, Nemeth G, Svensson O, Nisell R, 1986. Shoulder joint load and muscular activity during lifting. Scandinavian Journal of Rehabilitation Medicine 18, 71–82. [PubMed: 3775305]

Azaroff LS, Levenstein C, Wegman DH, 2002. Occupational injury and illness surveillance: conceptual filters explain underreporting. 92, 1421–1429.

Baumberger C, Ruegg P, 2015. Effect of an automated teat preparation system on teat skin bacterial counts. Journal of Dairy Science 98 102.

Boettcher C, Ginn K, Cathers I, 2008. Standard maximum isometric voluntary contraction tests for normalizing shoulder muscle EMG. Journal of Orthopedic Research 26, 1591–1597.

Burden A, Bartlett R, 1999. Normalisation of EMG amplitude: an evaluation and comparison of old and new methods. Medical Engineering and Physics 21, 247–257. [PubMed: 10514043]

Criswell E, 2010. Electrodes and site selection strategies, Cram's introduction to surface electromyography. Jones and Bartlett Publishers, Sudbury, MA.

Da Costa B, Vieira E, 2010. Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies. American Journal of Industrial Medicine 53, 285–323. [PubMed: 19753591]

Douphrate D, Fethke N, Nonnenmann M, Rosecrance J, Reynolds S, 2012. Full-shift arm inclinometry among dairy parlor workers: a feasibility study in a challenging work environment. Applied Ergonomics 43, 604–613. [PubMed: 22019358]

Douphrate D, Gimeno D, Nonnenmann M, Hagevoort R, Reynolds S, Rodriguez A, Fethke N, 2017. Effects of milking unit design on upper extremity muscle activity during attachment among U.S. large-herd parlor workers. Applied Ergonomics 58, 482–490 [epub ahead of print]. [PubMed: 27633245]

Douphrate D, Gimeno D, Nonnenmann M, Rosas-Goulart C, Rosecrance J, 2014. Prevalence of work-related musculoskeletal symptoms among US large-herd dairy parlor workers American Journal of Industrial Medicine. 57, 370–379. [PubMed: 24338602]

Douphrate D, Nonnenmann M, Hagevoort R, Gimeno D, 2016. Work-related musculoskeletal symptoms and job factors among large-herd dairy milkers. Journal of Agromedicine In press.

Douphrate D, Rosecrance J, Stallones L, Reynolds S, Gilkey D, 2009. Livestock-handling injuries in agriculture: an analysis of Colorado workers' compensation data. American Journal of Industrial Medicine 52, 391–407. [PubMed: 19197949]

Douphrate D, Rosecrance J, Wahl G, 2006. Workers' compensation experience of Colorado agriculture workers, 2000–2004. American Journal of Industrial Medicine 49, 900–910. [PubMed: 17036351]

Drake J, Callaghan J, 2006. Elimination of electrocardiogram contamination from electromyogram signals: an evaluation of currently used removal techniques. Journal of Electromyography and Kinesiology 16, 175–187. [PubMed: 16139521]

Fethke N, Gerr F, Anton D, Cavanaugh J, Quickel M, 2012. Variability in muscle activity and wrist motion measurements among workers performing non-cyclic work. Journal of Occupational and Environmental Hygiene 14, 25–35.

Jakob M, Liebers F, 2011. Potential of a quarter individual milking system to reduce the workload in large-herd dairy operations. Journal of Agromedicine 16, 280–291. [PubMed: 21958402]

Jakob M, Liebers F, Behrendt S, 2012. The effects of working height and manipulated weights on subjective strain, body posture and muscular activity of milking parlor operatiaves-laboratory study. Applied Ergonomics 43, 753–761. [PubMed: 22153204]

Jonsson B, 1988. The static load component in muscle work. European Journal of Applied Physiology 57, 305–310.

Karttunen J, Rautiainen R, 2011. Risk factors and prevalence of declined work ability among dairiy farmers. Journal of Agricultural Safety and Health 17, 243–257. [PubMed: 21919320]

Kolstrup C, Stål M, Pinzke S, Lundqvist P, 2006. Ache, pain, and discomfort: the reward for working with many cows and sows? Journal of Agromedicine 11, 45–55. [PubMed: 17135142]

Lunner Kolstrup C, 2012. Work-related musculoskeletal discomfort of dairy farms and employed workers. Journal of Occupational Medicine and Toxicology 7, 1–9. [PubMed: 22264295]

Mathiassen S, Winkel J, Hagg G, 1995. Normalization of surface EMG amplitude from the upper trapezius muscle in ergonomic studies-a review. Journal of Electromyography and Kinesiology 5, 197–226. [PubMed: 20719652]

Morse T, Dillon C, Kenta-Bibi E, Weber J, Diva U, Warren N, Grey M, 2005. Trends in work-related musculoskeletal disorder reports by year, type, and industrial sector: a capture-recapture analysis. American Journal of Industrial Medicine 48, 40–49. [PubMed: 15940716]

Pinzke S, 2003. Changes in working conditions and health among dairy farmers in southern Sweden. A 14-year follow-up. Annals of Agricultural and Environmental Medicine 10, 185–195. [PubMed: 14677910]

Pinzke S, Stål M, Älveby N, 2000. Evaluation of new tubes for milking equipment, Proceedings of the Nordic Meeting on Agricultural Occupational Health (NMAOH). Swedish University of Agricultural Sciences, Department of Farm Buildings, Alnarp/Malmö, Sweden, p. 46.

Pinzke S, Stal M, Hansson GA, 2001. Physical workload on upper extremities in various operations during machine milking. Annals of Agricultural and Environmental Medicine 8, 63–70. [PubMed: 11426927]

Punnett L, Wegman D, 2004. Work-related musculoskeletal disorders: the epidemiologic evidence and the debate. Journal of Electromyography and Kinesiology 14, 13–23. [PubMed: 14759746]

Redfern M, Hughes R, Chaffin D, 1993. High-pass filtering to remove elecrocardiographic interference from torso EMG recordings. Clinical Biomechanics 8, 44–48. [PubMed: 23915829]

Schick M, 2000. Modellierung von Zeitbedarf und Massenfluss am Beispiel verschiedener Melkverfahren. 12. Arbeitswissenschaftliches Seminar, Weihenstephan, Tagungsband. Landtechnik-Schrift 11, 61–68.

Silverstein B, 1985. The prevalence of upper extremity cumulative trauma diosrders in industry, University Microfilm International. University of Michigan, Ann Arbor.

Stål M, Hansson G, Moritz U, 2000. Upper extremity muscular load during machine milking. International Journal of Industrial Ergonomics 26, 9–17.

Stål M, Moritz U, Gustafsson B, Johnsson B, 1996. Milking is a high-risk job for young females. Scandinavian Journal of Rehabilitation Medicine 28, 95–104. [PubMed: 8815994]

Stål M, Pinzke S, Hansson GA, 2003. The effect on workload by using a support arm in parlour milking. International Journal of Industrial Ergonomics 32, 121–132.

Svendsen S, Mathiassen S, Bonde J, 2005. Task based exposure assessment in ergonomic epidemiology: a study of upper arm elevation in the jobs of machinists, car mechanics, and house painters. Occupational and Environmental Medicine 62, 18–26. [PubMed: 15613604]

Thorn S, Sogaard K, Kallenberg L, Sandsjo L, Sjogaar G, Hermens H, Kadefors R, Forsman M, 2007. Trapezius muscle rest time during standardised computer work--a comparison of female computer users with and without self-reported neck/shoulder complaints. Journal of Electromyography and Kinesiology 17, 420–427. [PubMed: 16829137]

US Department of Labor, Bureau of Labor Statistics, 2014. Industry Injury and Illness Data. Retrieved September 19, 2016 from http://www.bls.gov/iif/oshsum.htm#14Summary_Tables.

Winkel J, Westgaard R, 1992a. Occupational and indivdual risk factors for shoulder-neck complaints: Part II-the scientific basis (literature review) for the guide. International Journal of Industrial Ergonomics 10, 85–104.

Winkel J, Westgaard R, 1992b. Occupational and individual risk factors for shoulder-neck complaints: Part I-guidelines for the practitioner. International Journal of Industrial Ergonomics 10, 79–83.

Highlights

- TS system has the potential to improve parlor efficiency and ensure cow preparation consistency.
- The effects of an existing TS system on upper extremity muscle activity was evaluated among large-herd parlor workers.
- TS system is effective in reducing anterior deltoid muscle activation levels.
- TS appears to result in increased biceps, forearm flexor and extensor muscle activation levels.
- Increases in muscle activity levels could be offset by reduced repetitiveness resulting from using TS system.

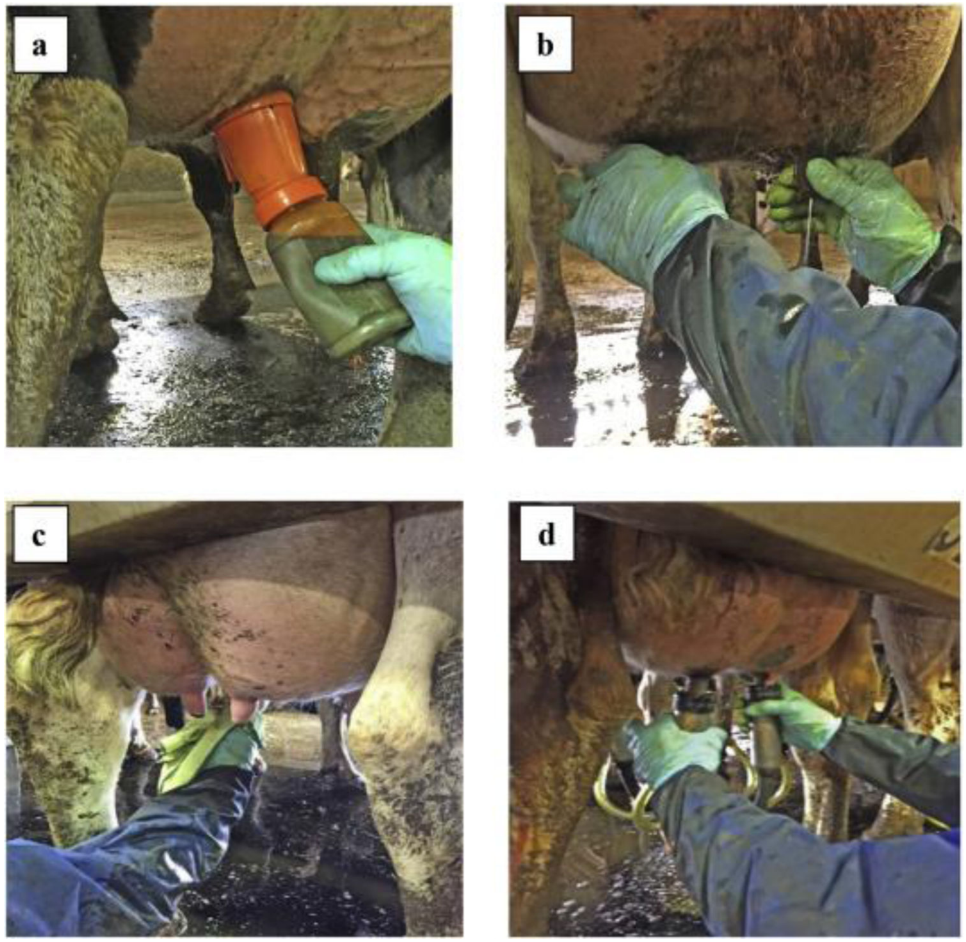

Fig. 1.
Milking tasks: (a) dip, (b) strip, (c) wipe and (d) milking unit attachment.

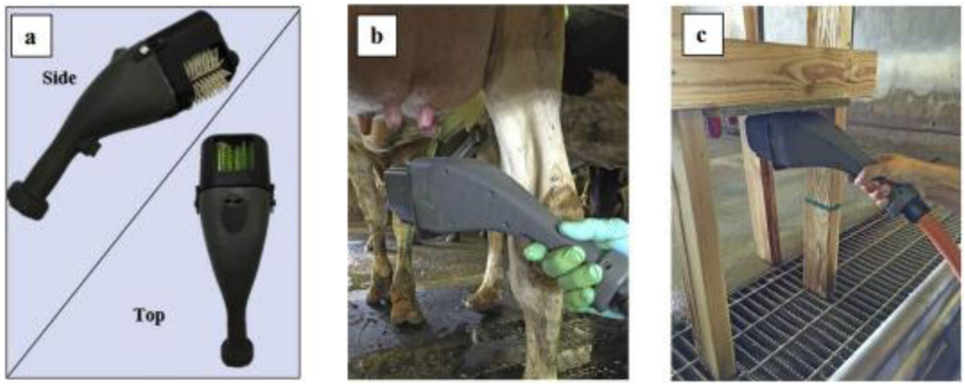

Fig. 2.
(a) Teat Scrubber (b) Teat Scrubber on cow; and (c) Teat Scrubber on artificial udder.

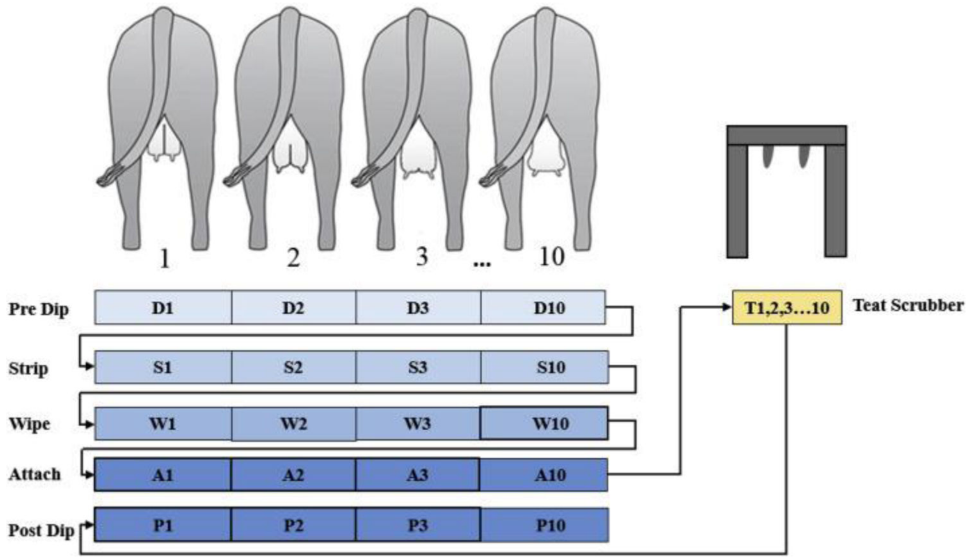

Fig. 3.

EMG recording sequence of milking tasks. The same recording sequence was repeated three times (every 2 h) within the same work shift for each participant.

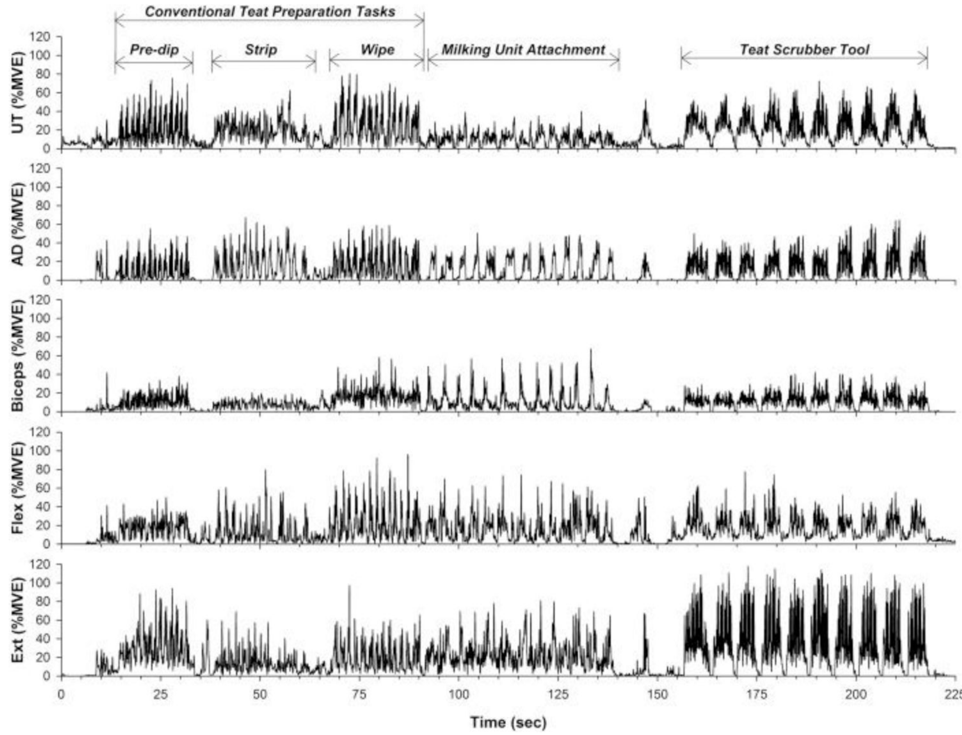

Fig. 4.

Sample of electromyographic (EMG) data collected from one participant during the performance of conventional and teat scrubber milking tasks. Each task includes 10 cycles (cows).

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Table 1.

Summary of demographic variables (n = 15).

	Mean (SD)	Min	Max
Age (years)	37.4 (10.6)	23	53
Milking (years)	7.5 (5.0)	1	16
Weight (kg)	77.9 (9.2)	69.3	96.8
Height (m)	1.7 (0.1)	1.6	1.8
BMI (kg/m ^{2})	27.3 (3.5)	22.6	31.5
Arm Reach (cm)	60.4 (5.4)	47.0	66.0

Table 2.

Distributions [mean (SD)] of EMG summary measures and cycle duration of milking tasks and results of post-hoc pairwise comparisons.[a]

Summary measure (%MVE)	Milking task			
	Pre-dip	Strip	Wipe	Attach
	Upper trapezius			
Mean RMS	19.2 (4.1)	17.2 (4.4)	19.0 (5.3)	14.9 (3.5)
10th APDF	5.0 (2.3)	6.2 (3.5)	5.9 (3.0)	5.1 (2.6)
50th APDF	18.6 (4.4)	16.3 (4.7)	17.9 (5.5)	14.8 (3.6)
90th APDF	35.3 (8.0)	30.9 (11.0)	34.3 (9.8)	25.5 (6.5)
	Anterior deltoid			
Mean RMS	23.0 (4.3)	25.6 (5.4)	25.9 (5.3)	21.5 (5.5)
10th APDF[1,5]	4.6 (2.1)	7.2 (4.1)	6.3 (3.3)	4.6 (2.6)
50th APDF	21.9 (5.0)	24.6 (5.8)	25.2 (6.2)	21.4 (6.2)
90th APDF	43.6 (8.5)	46.5 (10.1)	47.6 (9.9)	40.3 (10.9)
	Biceps			
Mean RMS	14.4 (2.8)	9.6 (2.47)	16.1 (3.7)	14.1 (3.0)
10th APDF[1,2,6]	5.4 (1.7)	3.1 (1.5)	6.5 (2.7)	4.5 (1.8)
50th APDF[1,4]	13.9 (2.9)	9.0 (2.7)	15.5 (4.0)	11.8 (3.1)
90th APDF[4,5]	24.5 (5.6)	17.8 (4.8)	27.3 (6.7)	28.6 (7.3)
	Forearm flexors			
Mean RMS	23.4 (6.2)	18.6 (7.8)	32.8 (9.9)	22.6 (6.2)
10th APDF	9.4 (5.3)	3.9 (2.6)	7.1 (3.8)	5.5 (2.6)
50th APDF	21.3 (6.0)	14.0 (8.0)	25.2 (12.1)	17.9 (5.7)
90th APDF	43.9 (13.5)	46.8 (18.4)	74.9 (20.5)	53.2 (18.2)
	Forearm extensors			
Mean RMS[1]	21.7 (4.3)	6.9 (2.7)	13.5 (4.5)	16.4 (3.3)
10th APDF[1,2,5]	9.9 (3.3)	2.9 (1.0)	4.9 (1.9)	5.5 (1.7)
50th APDF[1,2,5]	20.0 (4.0)	5.3 (2.3)	10.9 (4.1)	14.4 (3.9)
90th APDF[1]	37.6 (10.2)	15.3 (7.3)	27.9 (11.3)	31.3 (6.6)
Task cycle duration (sec)	1.5 (0.3)	2.1 (0.7)	1.9 (0.7)	2.9 (0.8)

[a]Significant post-hoc comparisons with adjusted $p<0.05$:

[1]= pre-dip v strip;

[2]= pre-dip v wipe;

[3]= pre-dip v attach;

[4]= strip v wipe;

[5]= strip v attach;

[6] = wipe v attach.

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Table 3.

Comparison of EMG summary measures [mean (sd)] during milking tasks.

Summary measure (%MVE)	Milking task[b]	
	CMT_{TWA}	TS
Upper trapezius		
Mean RMS	19.0 (2.9)	21.3 (3.4)
10th APDF	6.3 (1.9)	9.8 (2.4)
50th APDF	18.2 (3.0)	21.0 (3.4)
90th APDF	34.4 (6.1)	34.2 (6.3)
Anterior deltoid		
Mean RMS[a]	26.1 (3.3)	20.8 (3.1)
10th APDF	6.1 (2.0)	5.7 (2.1)
50th APDF [a]	24.7 (3.8)	19.6 (3.5)
90th APDF[a]	49.7 (5.9)	38.9 (5.8)
Biceps		
Mean RMS	13.2 (1.9)	17.0 (2.4)
10th APDF[a]	4.5 (1.2)	8.1 (1.7)
50th APDF	12.5 (2.0)	16.5 (2.3)
90th APDF	23.2 (3.5)	26.4 (4.8)
Forearm flexors		
Mean RMS	28.1 (5.6)	33.9 (5.2)
10th APDF[a]	7.4 (2.4)	17.6 (4.3)
50th APDF	23.3 (6.1)	32.8 (5.6)
90th APDF	58.8 (11.8)	52.4 (8.6)
Forearm extensors		
Mean RMS[a]	14.5 (2.6)	30.6 (5.0)
10th APDF[a]	6.0 (1.3)	12.8 (3.0)
50th APDF[a]	12.2 (2.3)	27.4 (5.0)
90th APDF[a]	26.7 (6.0)	52.5 (10.4)
Task cycle duration (sec)	5.5 (1.3)	3.5 (1.4)

[a]Adjusted $p < 0.05$.

[b]CMT_{TWA} = Composite Milking Task (Time weighted average); TS = Teat scrubber.