

LINERS AND TEAT END HEALTH

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Introduction

In the dairy industry world wide, several hundred types of liners are used to milk dairy cows. The enormous amount of liner types with different characteristics in size, form, consistency and other design and manufacturing characteristics indicate that no ‘best’ liner has been identified in the last 60 or so years since machine milking has become the common method for milk harvesting. Mechanical liner characteristics have been studied using mathematical force models and observed collapse usually under laboratory conditions (Butler 1993, Harty et al. 2004). Recent work by Teat Club International (TCI) has mapped explanations and descriptions of teat and liner interaction. The most descriptive explanation of this complex phenomenon has been defined as “overpressure” or “compressive load” as that relates to the action of the liner, the efficiency of milking and the maintenance of teat and teat end condition (Mein et al. 2003). Preferences of farmers for liner type have been influenced by balancing different aspects of milking performance, replacement rate and price per milking. Liner performance may be assessed by milking performance (milking speed and milk out), incidence of intra-mammary infections (IMI), cow behavior and teat responses (Hillerton 2005). Although many criteria are used for selection of a liner, performance of a particular liner ultimately rests on the ability of the liner to efficiently remove fluid milk during the milk harvesting process and simultaneously maintain teat end condition. However, formal guidelines for evaluating liner performance do not exist. There are no guidelines that are, for example, comparable to the NMC teat disinfection evaluation protocol. This makes objective evaluation or recommendation of liners difficult if not impossible.

Milking performance and milk out can be measured with automated parlor systems in combination with milk flow curve evaluation. For example, we previously presented a comparison of milk flow curves using two different liners (Schukken et al. 2005). Incidence of intra-mammary infections is more difficult to measure, but some studies have now attempted to quantify this (Nijenhuis et al. 1998, Rasmussen et al. 1998). In most cases this would require a quite elaborate and expensive study design with multiple milk samples to be taken over time. Cow behavior is especially related to the willingness of the cow to come into the milking parlor and stepping on or kicking-off of milking units. This could also potentially involve evaluation of oxytocin profiles during milking. Finally, classification of bovine teat condition can be used to assess the effects of liners but is also affected by milking machines, milking management or environment on teat tissue (Mein et al. 2001).

The degree of teat-end hyperkeratosis (roughness, cornification or callosity) is a dynamic condition. Status of teat-ends for an individual cow or herd can change within days, especially in regions subject to harsh weather conditions or sudden weather changes. Seasonal conditions may affect dryness and hardness of keratin. In the absence of unusually harsh weather conditions,

however, changes in teat-end status occur over a period of 2-8 weeks. Apart from seasonal weather conditions, major factors affecting teat-end hyperkeratosis include teat-end shape, production level and stage of lactation, and interactions between milking management and machine factors (especially slow milking and over-milking) (Rasmussen et al. 1993). Hence when teat condition is used to evaluate milking machine liners, these effects should be controlled for in the study design or in the analysis of the data.

The objective of this study was to evaluate the effect of liner type (square vs. round) on the teat-end condition of lactating dairy cows. Additionally, we discuss the possibilities towards the establishment of a more formal evaluation of liners.

Materials and Methods

The study had two “Phases” aimed at meeting this objective. *Phase I* was a simple comparison of the teat-end conditions on farms that use square liners with farms that use traditional round liners. *Phase II* compared the teat-ends of cows within a herd, measured before and after the introduction (switch to) square liners, from the round style.

Phase I

A total of twelve farms were involved during this study, six which used square liners (ProSquare® styles DPX or SPX) and six that used round-shaped liners of various brands. All herds were considered well managed, with free-stall housing and low line parlors. Additionally, milking units in all parlors had automatic take-offs that were in good working order. Each farm that used round liners was matched with a farm that used square liners. Matching was based on the number of times they milk per day (MPD), the person who scored the herds, and the month that scoring took place. Furthermore, cow-level (parity, milk production, DIM) and herd-level (average claw vacuum and phases of pulsation) data were collected in order to account for variability caused by factors that are traditionally associated with teat-end condition. The average claw vacuum was calculated by averaging measurements taken for ten seconds, during the peak milk flow of six high-producing cows. The measurements were taken using electronic vacuum recorders that are periodically checked for accuracy using a mercury manometer. The phases of pulsation were also measured with electronic devices (PT-IV, www.exendis.com) for ten seconds and an average value was calculated. All equipment measurements were conducted according to NMC standards.

During each farm visit, cow’s teat-ends were evaluated according to the recommendations of the TCI (Mein et al. 2001, Neijenhuis et al. 1998) for two characteristics. The first characteristic was the amount of keratinization, and the second was whether the teat-end was cracked or not. The scoring system for keratinization ranged from 0 to 4, with 4 having the most callous tissue and 0 having none. A half point (0.5) was added to each whole number score if cracks were present. For example, a teat with moderate callosity and cracks would have been given a score of 2.5, where a teat with high callosity and no cracks would have been given a score of 4.0.

Phase II

A total of four farms from *Phase I*, which used round liners, were enrolled in *Phase II*. The four farms composed of two matching pairs. Matching was based on MPD, the person who scored, and the month of scoring (and therefore switching). One farm from each pair switched from round to square liners immediately following the *Phase I* score date, while the other continued to use round liners in order to control for the effect of seasonal climate changes. A follow-up scoring occurred approximately three months after the initial scoring. Both the initial and follow-up scoring was conducted by the same person for each herd. Herds that switched to square liners were provided the appropriate liner style to fit their shell type. See Figure 1 for depiction of study design.

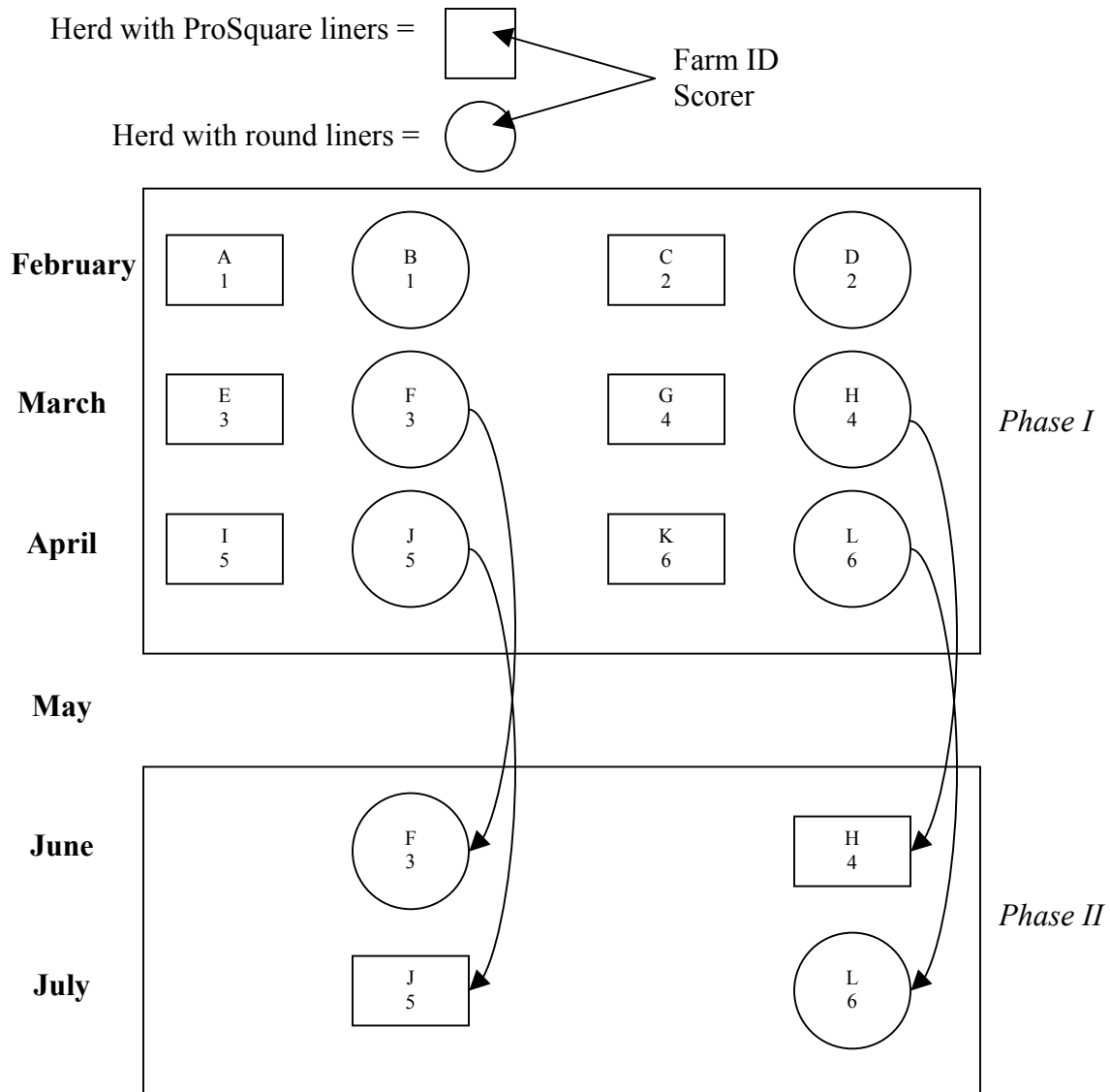


Figure 1. Depiction of study design. Each two subsequent letters form a pair. For example A and B, C and D.

Statistical Analysis

The scoring system used had two components and therefore provided two outcome variables (keratinization, cracking). The whole number represents the amount of keratinization (0 – 4), where the decimal signified the presence (.5) or absence (.0) of cracks. In order to conduct the analysis of each outcome separately, each score was divided into a keratinization variable (0 – 4) and a crack variable (0 = no crack, 1 = cracks present). Crack data was aggregated at the cow-level in order to analyze it using PROC MIXED in Statistical Analysis System (SAS version 9.1). This was done because the estimation procedure used in PROC GLIMMIX (quasi-likelihood) is relatively unreliable in situations with few (generally < 5) observations per cluster.

Phase I

Descriptive statistics for both outcome variables (keratinization and crack) were calculated using PROC FREQ and PROC MEANS (SAS v9.1). Regression analysis was conducted using PROC MIXED (SAS v9.1). Cow, (cow nested in farm, which was nested in block) farm (farm nested in block) and block were considered random factors while liner type, parity, milk production, DIM, claw vacuum level, D-phase and MPD were considered fixed effects. Two-way interactions of fixed effects that included liner were also tested. The appropriate degrees of freedom were estimated using the Satterthwaite approximation (Littell et al. 1996). With the exception of vacuum, D-phase and MPD, terms that were not significant ($P > 0.05$) were removed from the model. Coefficient estimates of the remaining terms and their associated p-values were presented in tabular form. The initial linear model had the following generic format:

$$Y_{k(j(i))abcdef} = \mu + a_i + b_{j(i)} + c_{k(j(i))} + A_a + B_b + C_c + D_d + E_e + F_f + AB_{ab} + AC_{ac} + AD_{ad} + AE_{ae} + AF_{af} + e_{k(j(i))abcdef}$$

Where:

$Y_{k(j(i))abcdef}$ = keratinization score of the teat or proportion of cracks of the teat in the k^{th} cow on the j^{th} farm in the i^{th} block, milked with the a^{th} liner, subject to the b^{th} vacuum level and c^{th} D-phase, in the d^{th} parity group, e^{th} DIM category, and f^{th} milk production category, μ = grand mean, a_i = i^{th} block, $b_{j(i)}$ = j^{th} farm, in the i^{th} block, $c_{k(j(i))}$ = k^{th} cow, on the j^{th} farm, in the i^{th} block, **A_a = a^{th} liner group**, B_b = b^{th} vacuum level, C_c = c^{th} D-phase duration, D_d = d^{th} parity group, E_e = e^{th} DIM category, F_f = f^{th} milk production category, AB_{ab} = a^{th} liner group, subjected to the b^{th} vacuum level, AC_{ac} = a^{th} liner group, subjected to the c^{th} D-phase duration, AD_{ad} = a^{th} liner group and d^{th} parity group, AE_{ae} = a^{th} liner group and e^{th} DIM category, AF_{af} = a^{th} liner group and f^{th} milk production category and $e_{k(j(i))abcdef}$ = overall experimental error.

Phase II:

Only cows that were scored in both Phase I and II were part of the data set used in this analysis. Cows that either entered or were removed from the lactating herd were removed from the data set. This was a valid procedure since we controlled for the DIM of each cow at their initial score date. Descriptive statistics for both outcome variables (keratinization and crack) were calculated using PROC FREQ and PROC MEANS. Change in keratinization or cracks was evaluated using PROC MIXED. Cow, (cow nested in farm, which was nested in block) farm (farm nested in

block) and block were considered random factors, while switch-over, parity, milk production, DIM, vacuum, and D-phase were considered fixed effects. Two-way interactions of fixed effects that included switch-over were also tested. The appropriate degrees of freedom were estimated using the Satterthwaite approximation. Terms that were not significant ($P > 0.05$) were removed from the model. Coefficient estimates of the remaining terms and their associated p-values were presented in tabular form. The initial linear model had the following generic format:

$$\Delta K_{k(j(i))abcdef} = \mu + a_i + b_{j(i)} + c_{k(j(i))} + A_a + B_b + C_c + D_d + E_e + F_f + AB_{ab} + AC_{ac} + AD_{ad} + AE_{ae} + AF_{af} + e_{k(j(i))abcdef}$$

Where:

$\Delta Y_{k(j(i))abcdef}$ = change in keratinization score of the teat end or proportion of cracks on the k^{th} cow on the j^{th} farm in the i^{th} block, in the a^{th} liner switch group, subject to the b^{th} vacuum level and c^{th} D-phase, in the d^{th} parity group, e^{th} DIM category, and f^{th} milk production category, μ = grand mean, a_i = i^{th} block, $b_{j(i)}$ = j^{th} farm, in the i^{th} block, $c_{k(j(i))}$ = k^{th} cow, on the j^{th} farm, in the i^{th} block, **A_a = a^{th} liner switch group**, B_b = b^{th} vacuum level, C_c = c^{th} D-phase duration, D_d = d^{th} parity group, E_e = e^{th} DIM category, F_f = f^{th} milk production category, AB_{ab} = a^{th} liner switch group, subjected to the b^{th} vacuum level, AC_{ac} = a^{th} liner switch group, subjected to the c^{th} D-phase duration, AD_{ad} = a^{th} liner switch group and d^{th} parity group, AE_{ae} = a^{th} liner switch group and e^{th} DIM category, AF_{af} = a^{th} liner switch group and f^{th} milk production category and $e_{k(j(i))abcdef}$ = overall experimental error.

Results

Phase I:

A comprehensive summary of study data, at the farm level, is provided in Table 1. This table shows farm characteristics (e.g. herd size) along with procedural information (e.g. score date), averages of important study variables (e.g. DIM), and percentages of teat-ends at each response variable level. The average percentages for keratinization were used to construct Figure 2, which shows graphically, a potential benefit to using square liners (i.e. a lower percentage of cows in the square group had keratinization scores greater than two). There was also a lower percentage of teat-ends with cracks, with an average value that is 14% lower compared to the round liner group. Both keratinization and cracking are graphically depicted in figure 2 and 3 respectively.

Table 1. Descriptive summary of farm-level data.

Block	Liner	# Cows	mpd	Score Date	Scorer	Milk (lbs)	DIM	Vacuum ("Hg)	D-phase (ms)
1	RL A	185	2	2-22-05	1	83	175	11.6	313
1	Square	121	2	2-21-05	1	81	201	12.5	234
2	RL B	88	2	3-16-05	2	80	197	11.1	212
2	Square	117	2	2-18-05	2	74	179	11.7	200
3	RL C	222	3	3-22-05	3	68	182	11.6	249
3	Square	87	3	3-21-05	3	72	229	13.5	219
4	RL D	166	3	3-30-05	1	81	175	12.6	206
4	Square	154	3	3-29-05	1	80	155	12.7	260
5	RL E	199	2	5-3-05	4	58	206	11.0	250
5	Square	357	2	5-12-05	4	47	189	10.5	248
6	RL F	95	2	4-21-05	5	69	221	11.6	237
6	Square	83	2	5-3-05	5	64	167	11.8	184
Avg	Round	154	-	-	-	73	193	11.6	245
Avg	Square	153	-	-	-	70	183	12.1	219

Block: Each farm was matched within a block with another farm, which used the opposite type of liner. Matching criteria was based on the number of milkings per day, the person who scored and the month of scoring.

RL: Round Liner.

mpd: The number of milkings per day.

Milk: Average milk per day per cow in pounds.

DIM: Average days in milk at the time of scoring.

Keratinization: Percent of teat-ends at each score level. Scoring was based on the condition (callousness) of the teat-end.

%Cracked: Percent of teat-ends that had cracks.

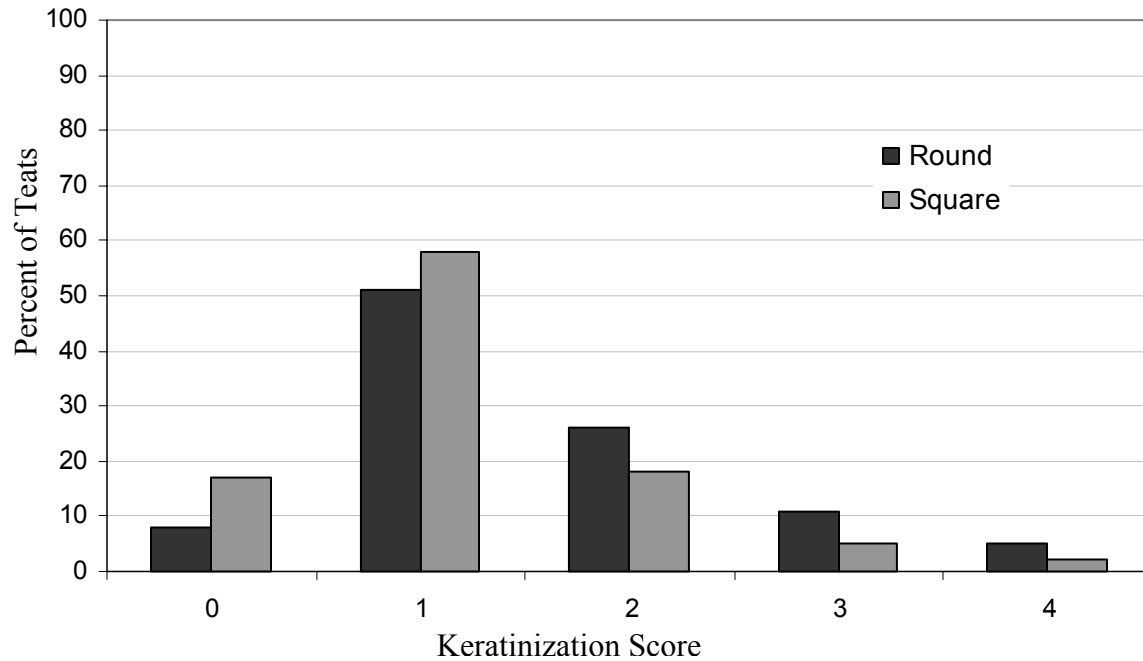


Figure 2. Distribution of teat-ends, amongst keratinization scores, within each liner type. The higher the score, the more callous tissue present at the teat-end. In all parity groups, ProSquare herds had a lower percentage of teat-ends with a score keratinization >2 (Figure 3) and cracks (Figure 4).

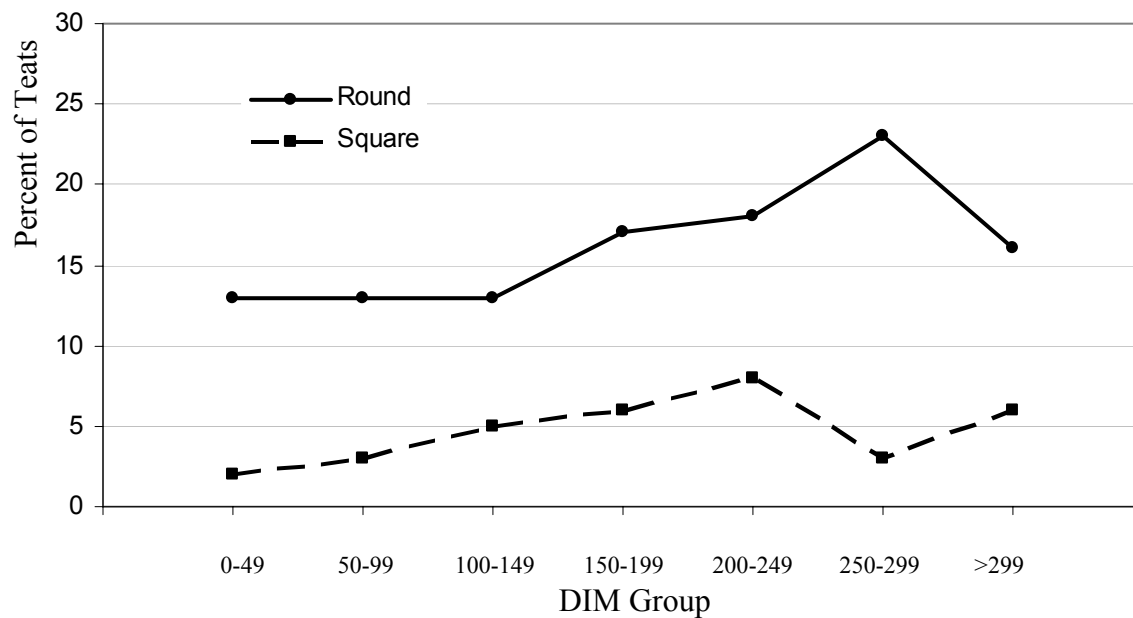


Figure 3. Percentage of teat-ends with a keratinization score greater than two, within DIM category, for each liner type.

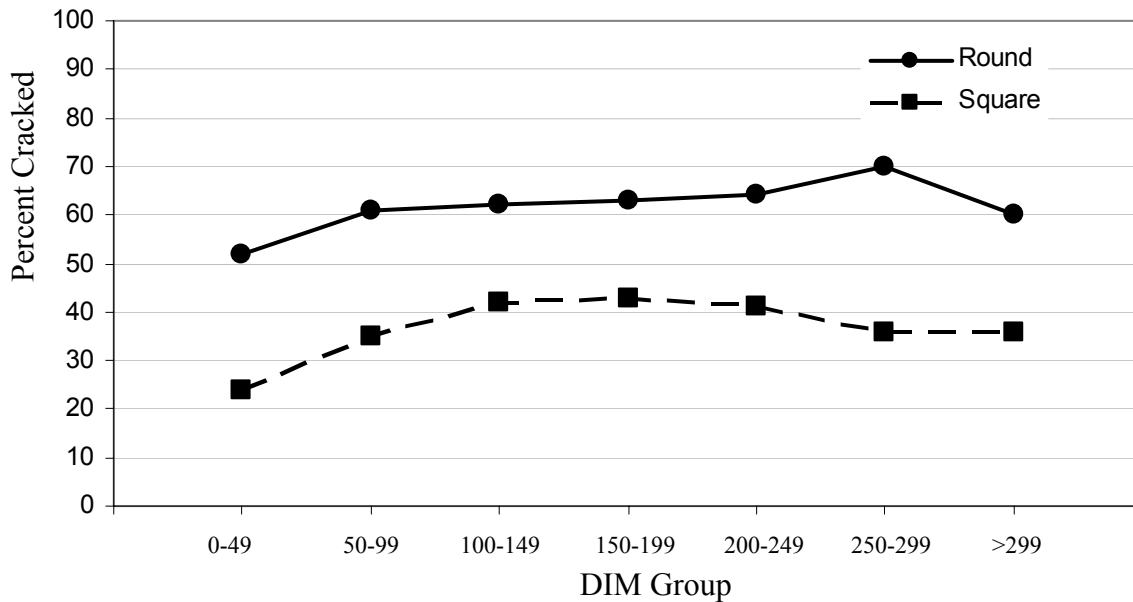


Figure 4. Percentage of cracked teat-ends, within each DIM category, for each liner type.

The results of the final statistical analysis, after controlling for important variables showed a significant effect of liner type on both keratinization and the proportion of cracked teat ends. The keratinization model predicted that, overall, herds with round liners will have a keratinization score 0.43 greater than herds that use square liners (Table 2, Appendix 3a). Keratinization was also significantly affected by milk production, parity and DIM, and furthermore, there was a liner*parity interaction. The model for the proportion of cracked teat ends predicted that, overall; a cow in a herd that is milked with round liners will have, on average, 20 percent more cracked teat ends than a cow in a herd that is milked with square liners (Table 2, Appendix 3b). The proportion of cracked teat ends was also significantly affected by milk production, vacuum, parity and DIM (Table 2).

Estimates for variable coefficients showed a decrease in keratinization with lower milk production and earlier in lactation. In the square liner herds, all parity groups showed less keratinization compared to parity group 5+, except cows that were in their second lactation. In herds milked with round liners, more keratinization was observed in all lactations compared to parity group 5+, except in heifers.

Table 2. Fixed effect p-values for the keratinization (A) and proportion of cracked teat ends per cow (B).

(A) Keratinization						
Effect		Estimate (SE)	NDF	DDF	F value	p-value
Liner	round	0.426 (0.153)	1	3.18	19.95	0.0185
	square	Baseline	-	-	-	-
Milk production		-	1	1750	26.56	<.0001
D-phase		-	1	4.42	2.40	0.1894
Vacuum		-	1	4.23	0.37	0.5726
Parity		-	4	1761	17.14	<.0001
MPD		-	1	4.99	2.29	0.1908
DIM category		-	6	1750	8.67	<.0001
Liner*Parity		-	4	1761	3.56	0.0068

(B) Proportion of cracked teat ends per cow						
Effect			NDF	DDF	F value	p-value
Liner	round	0.201 (0.032)	1	3.6	40.40	0.0045
	square	Baseline	-	-	-	-
Milk production		-	2	1374	12.48	<.0001
Vacuum		-	1	4.78	14.27	0.0141
Parity		-	4	1755	20.85	<.0001
DIM category		-	6	1755	7.71	<.0001

Phase II:

The descriptive analysis of the change in keratinization score implied that switching to square liners decreases keratinization (Figure 5). A reduction in mean keratinization score was observed throughout lactation but to a greater extent in the group that switched to square liners (except in DIM categories 250 - 299 and 300+). The mean keratinization score was also reduced across all parity groups, but again, the change was greater in the group that switched to square liners (Figure 6).

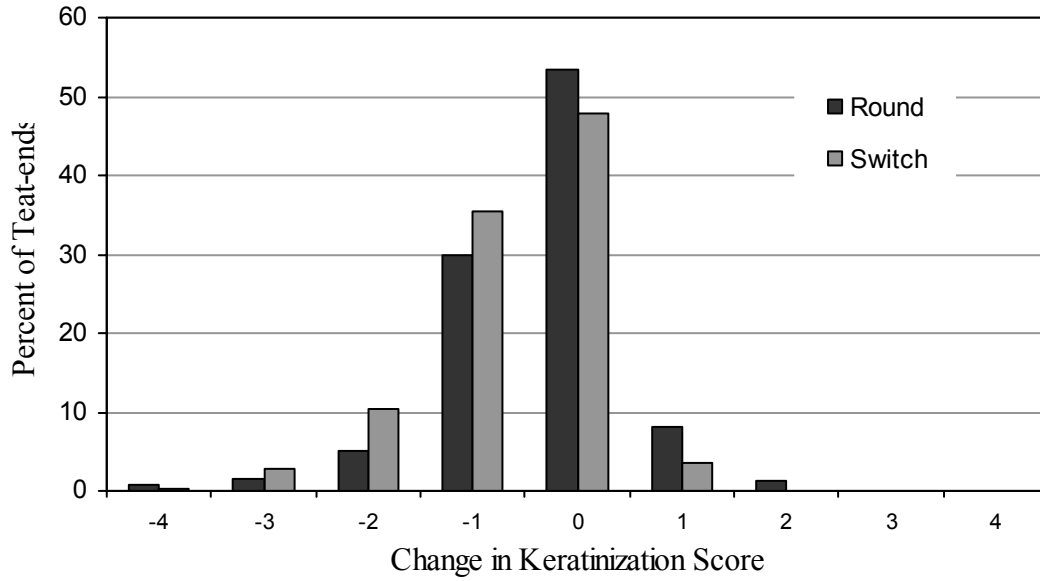


Figure 5. Distribution of keratinization score differences among control and switch treatment groups.

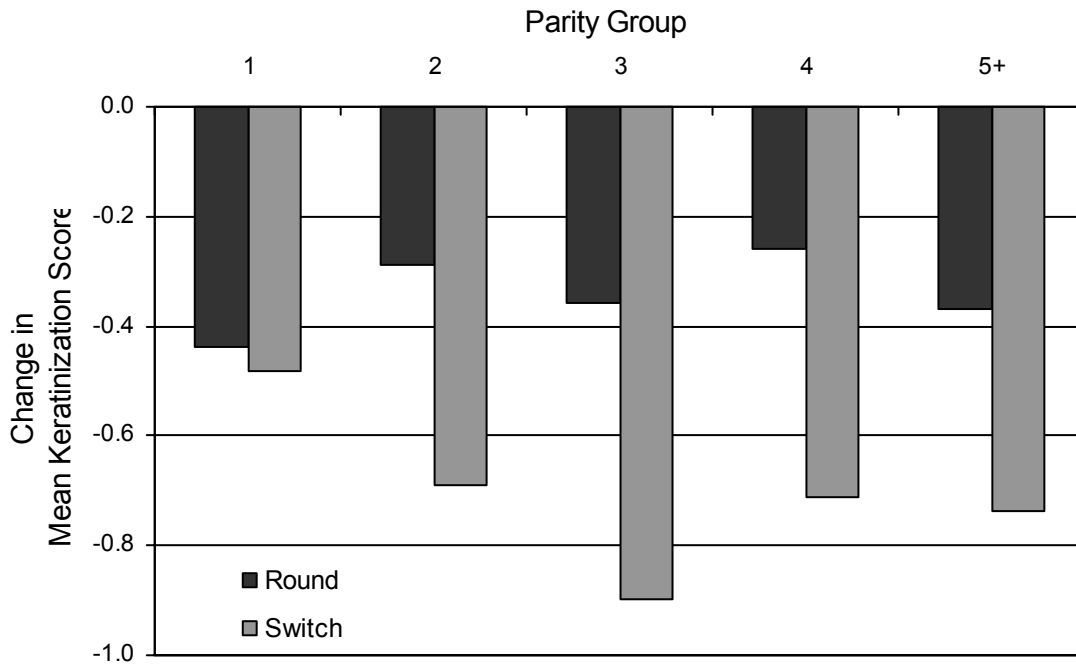


Figure 6. Mean change in keratinization score, across DIM categories, for each treatment group.

A similar trend was observed for the percent of teat-ends that had cracks during the Phase I evaluation, but not during the Phase II evaluation (i.e. lost cracks). While a certain percentage of teat-ends from each treatment group lost cracks, the percentage was consistently higher in the group that changed to square liners. This was true across all DIM and parity groups (Figure 7).

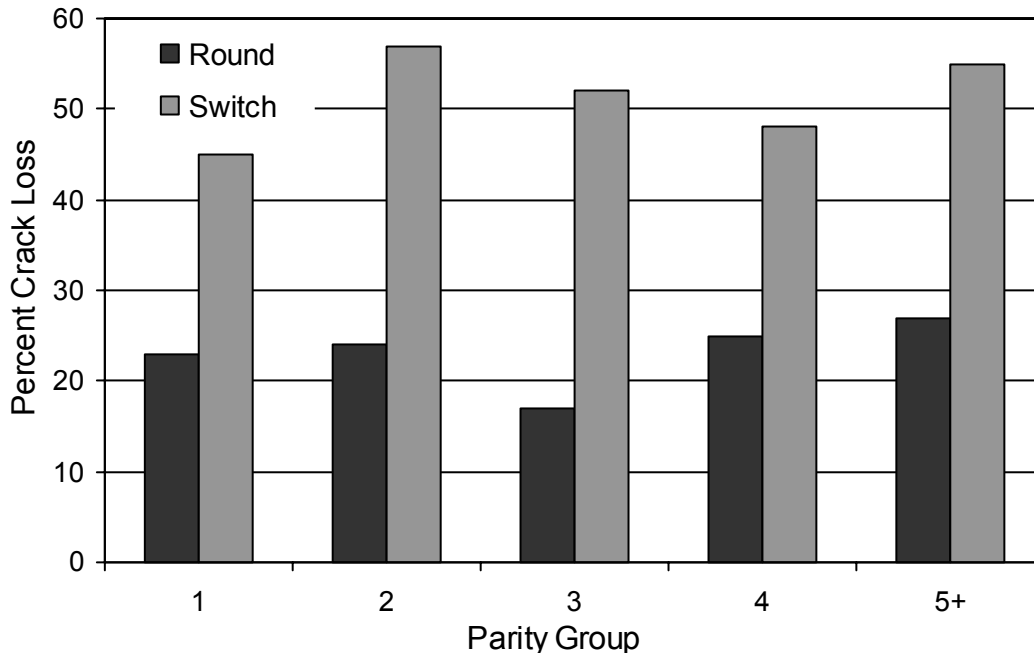


Figure 7. Percent of teat-ends that lost cracks, across parity, for each treatment group.

The results of the final statistical analysis, showed a significant effect of switching liner type on both the change in keratinization and the change in proportion of cracked teat ends. The change in keratinization model predicted that, over a three month period, herds that switch to square liners will have a keratinization score 0.17 less than herds that continue use of round liners (Table 3), but this effect was dependent on which lactation group the cow was in. Keratinization was also significantly affected by DIM. The model for the change in proportion of cracked teat ends predicted that, over a three month period, cows in herds that switched to square liners had approximately a 27 percent greater reduction in cracked teat ends compared to herds that continued to use round liners. While this numeric difference existed and followed the same trend as farms in Phase I, the p-value of this effect was .29 and hence not statistically significant. (Table 3). The change in the proportion of cracked teat ends was significantly affected by DIM and milk production (Table 3). The interactions of parity*switch and DIM*switch were left in the model in order to calculate more accurate coefficients even though they had a p-value greater than 0.05.

Table 3. Fixed effect p-values for the change in keratinization (C) and proportion of cracked teat ends (D).

(C) Change in Keratinization						
Effect		Estimate (SE)	NDF	DDF	F value	p-value
Switch	No	0.175 (0.433)	1	1.26	1.83	0.3688
	Yes	Baseline	-	-	-	-
DIM category		-	6	471	2.52	0.0209
Parity		-	4	472	0.72	0.5815
Switch*Parity		-	4	472	2.72	0.0293
Switch*DIM category		-	6	471	1.09	0.3698

(D) Change in the proportion of cracked teat ends						
Effect		Estimate (SE)	NDF	DDF	F value	p-value
Switch	No	0.160 (0.245)	1	1.16	3.35	0.2914
	Yes	Baseline	-	-	-	-
DIM category		-	6	467	2.59	0.0177
Parity		-	4	467	1.09	0.3626
Milk production		-	2	468	3.52	0.0304
Switch*Parity		-	4	467	0.60	0.6640
Switch*DIM category		-	6	467	0.76	0.6012

Discussion

A total of 12 herds (6 square; 6 round) were evaluated for both keratinization and cracking of cows' teat-ends. Four of the six herds that were milked with round liners were evaluated, again, three months later. Two of these four herds were switched to square liners immediately after the first evaluation. This study design provided two methods of evaluating the association between liner type and teat-end condition.

Results indicated that herds that have been milking with square liners for some time have an average keratinization score 0.43 less than herds being milked with round liners. Although, this was somewhat dependent on which lactation the cow was in. Additionally, herds that use round liners had approximately 20 percent more cracked teat ends. In a three month period, use of

square liners reduced both keratinization and cracking in herds that switched from traditional round-style liners. The average reduction in keratinization score was estimated to be approximately 0.18, while the reduction in the proportion of cracked teat ends was 0.16. The differences we observed were large and, in some of the herds, were noticeable while observing the teat-ends on farm. Given the variation in liner design and the resulting differences in characteristics, the differences shown in this study would be specific to the square liners used in this study and not to be assumed to be the same or similar for other square liners.

This study provided more insight in the abilities of comparative studies for different liner types. We were able to show that liners differ in their activation of teat end tissue. In our study, round liners evoked a more severe response from the teat end tissue compared to square liners. The observed differences were large, and this provides optimism that a study design such as used in this study may lend itself for more general comparison of liners. If these observations are combined with quantitative differences in milk flow as we observed before (Schukken et al. 2005), and potentially with additional information on IMI and SCC collected again in a comparative method, a more complete picture of liner performance on commercial dairy farms emerges. A similar comparison of milking systems was performed by Gleeson et al. (2005), they also compared milking characteristics, teat end characteristics but also included IMI. In their study no significant differences between milking systems were observed.

Acknowledgements

The participation of the farmers in this study is greatly acknowledged. The QMPS staff that participated in the scoring of the herds is thanked for their support.

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