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Relationships Between Physical Characteristics And Milking Characteristics Of The Aging Milking Liner.

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ABSTRACT

The relationships between changes in the physical characteristics and milking characteristics of the aging milking liner were studied. The physical characteristics of mouthpiece lip flex, liner barrel tension and compressive load of the liner were measured. The milking characteristics of peak milk flow rate, average milk flow rate, average mouthpiece chamber vacuum, strip yield and irregular vacuum fluctuations (IVF) were measured. Measurement methodology was also developed or refined for the measurements of compressive load of the liner, strip yield and IVF. Physical and milking characteristics were measured on liners when new and after aging in a series of nine tests involving liners aged either artificially or naturally.

The device for compressive load measurement shows much promise, but further testing is required to better understand how the measurements made relate to the loading applied by a liner to a live teat. Currently, the liner load measurement device is suitable for comparison purposes only.

It is concluded that strip yield collected by a quarter milker may be the best method. We suggest these two levels of the combined criteria for vacuum range and rate of change in the claw to classify IVF:

IVF 1 = derivative ≥ 100 kPa/s and range ≥ 21 kPa

IVF 2 = derivative ≥ 56 kPa/s and range ≥ 14 kPa

Liners aged either naturally or artificially produced a decrease in peak milk flow rate of 0.5 kg/min (1.1 lb/min) (standard deviation = 0.3 kg/min) and a decrease in average milk flow rate of 0.3 kg/min (0.7 lb/min) (standard deviation = 0.4 kg/min). Liners aged either naturally or artificially produced an increase in average mouthpiece chamber vacuum of 2.2 kPa (0.6 in Hg) (standard deviation = 6.5 kPa). Naturally aged liners produced an increase in both classes of IVF of 1.4 class 1 and 4.6 class 2 (standard deviations = 1.7, 7.3 respectively).

Changes in liner barrel tension and compressive load were positively correlated, as were changes in mouthpiece lip flex and mouthpiece chamber vacuum. Mouthpiece chamber vacuum, along with mouthpiece lip flex, barrel tension and compressive load appears to influence the degree of teat tissue congestion, which in turn influences milking characteristics.

RELATIONSHIPS BETWEEN PHYSICAL CHARACTERISTICS AND MILKING CHARACTERISTICS OF THE AGING MILKING LINER

INTRODUCTION

The milking liner has often been termed “the most important part of the milking machine”, since it is the only part of the milking machine that touches the cow. The interaction between the teat and liner determines the performance of the milking machine. It is known that the aging milking liner changes in both physical (6,14) and milking characteristics (15, 16, 20, 31, 40) due to the deterioration of the rubber. A few studies have attempted to bridge the gap by investigating the relationships between the milking characteristics and physical characteristics of the aging milking liner (14, 19, 24).

LITERATURE REVIEW

The 1952 study of Gardner and Berridge may have been one of the first to establish the relationship between the aging liner and changes in its physical and milking characteristics. Gardner and Berridge found that aged liners slip more often - due to air leaks and reduced surface friction - and also have decreased liner barrel tension. Salvatierra (1978) observed that aged liners milked cows at a slower rate, left more milk behind and slipped or crawled up the teat late in milking more often. Recent work by Kelly et al. (1983a), following Kelly’s 1979 Masters of Science Thesis concerning liner deterioration, also noted the increased slips, slower milking and air leaks occurring when milking with aged liners. Gibb and Mein (1976) and Gleeson and O’Callaghan (1998) have measured the change in milking characteristics of the liner when new and after aging as well.

Past research on milking machine liners have used measures such as average and peak milk flow rate, unit stability during milking (number of liner slips) and completeness of milking to assess milking performance (2, 3, 12, 15, 16, 20, 21, 22, 25, 28, 30, 31, 32, 33, 35, 36, 37, 39, 40, 41, 42, 44). Other research has examined the physical characteristics of liners, such as mouthpiece lip flex, liner barrel tension and compressive load applied to the teat as well as mouthpiece chamber vacuum (1, 5, 11, 13, 21, 25, 27, 29, 33, 34, 43).

However, only a few studies have examined the relationships between the physical characteristics of the liner and resulting milking characteristics (14, 20, 24). These studies of measurement of change in milking and physical characteristics as the liner ages, and attempts to understand the relationship between them, provide the focus for this research.

The majority of research on liners has been conducted outside of the USA. Liners manufactured for use outside of the USA may typically contain 25% carbon black in the rubber mixture (24) which improves hardness, tear strength, abrasion resistance and liner life (19). US liners must have less than 10% carbon black to meet FDA requirements and consequently have a shorter service life. The lower carbon black content of US liners influences the physical properties of the liner when new as well as rate of change of the physical characteristics and presumably the change in milking characteristics of the liner with use. This study sought to document changes in both the physical and milking characteristics of a popular US liner as it was aged.

OBJECTIVES

The specific objectives of this study were to:

1. Develop or refine measurement methodology for the measurements of compressive load applied to the teat, strip yield and “liner slip” or IVF.
2. Measure the changes in the physical and milking characteristics of one commonly available US liner as it is aged either naturally or artificially.
3. Understand the relationships between the physical and milking characteristics of the aging liner.

MATERIALS AND METHODS

A series of nine tests were conducted to measure the change in the physical and milking characteristics of the liner as it was aged artificially or naturally. The tests were conducted at various dates over a yearlong period. Both physical and milking characteristic measurements were taken when the liners were new and throughout the aging intervals.

Six tests involved artificially aged liners, aged from 1.5 to 7 days. A series of three tests involved progressive natural aging of liners to 840, 1680 and 2520 cow milkings (10). Eight tests were a paired switchback design, the remaining test was a paired 2² factorial. Paired Student's t tests at the $\alpha=0.05$ level were done for the eight paired tests. The factorial was analyzed with a general linear model in SAS.

All milking time tests were conducted during the PM milking at the University of Wisconsin-Madison milking parlor. All tests were conducted in the same milking stall; all test cows were milked by the experimenter. Cows for each test were selected based upon days in milk, somatic cell count and milking duration. These parameters were chosen to reduce yield fluctuations, to test healthy cows and to use cows that spent much time in contact with the milking machine, respectively. Selected cows were more than 20 days in milk, had a somatic cell count < 200,000 and a duration of five minutes or more.

Cows used in the tests were multiparous and all Holsteins with the exception of two Brown Swiss.

The liners used in all tests were Bou-Matic R-2CV of the same lot (number 9082). Liners were artificially aged by soaking in clarified butter held at 100°C (212°F) in a constant air temperature oven; these conditions were based upon a British Standard for rubber absorption tests (4). Liners were submerged in butteroil in the same container, lying on their side and not touching each other to prevent distortion. Liners naturally aged were aged by use in the University of Wisconsin-Madison milking parlor. Liners were used for about three hours per milking, twice per day, followed by a regular wash by a CIP system.

Mouthpiece Lip Flex

Mouthpiece lip flex was measured using a device adapted from one devised at Moorepark Research Center, Fermoy, Co. Cork, Ireland. Refer to Davis et al. 1999 or Davis 2000 for a schematic.

Liner Barrel Tension

Liner barrel tension was measured when the liner was extended to its mounted length. Refer to Davis et al. 1999 or Davis 2000 for a schematic.

Compressive Load of the Liner

The device to measure compressive load of the closed liner on the teat is illustrated below in Figure 1. The device was developed to deform similar to a live teat and measure the force applied near the teat apex. A miniature load cell of 12.7 mm (0.5 in) diameter was mounted in a steel plate 2.4 mm (0.09 in) thick by 20 mm (0.79 in) wide. The load cell was mounted in the steel plate so that its sensing surface was flush with the surface of the steel plate. A rubber material with physical characteristics approximating teat tissue was glued on each side of the rigid plate. Refer to Davis 2000 for a thorough description of the device.

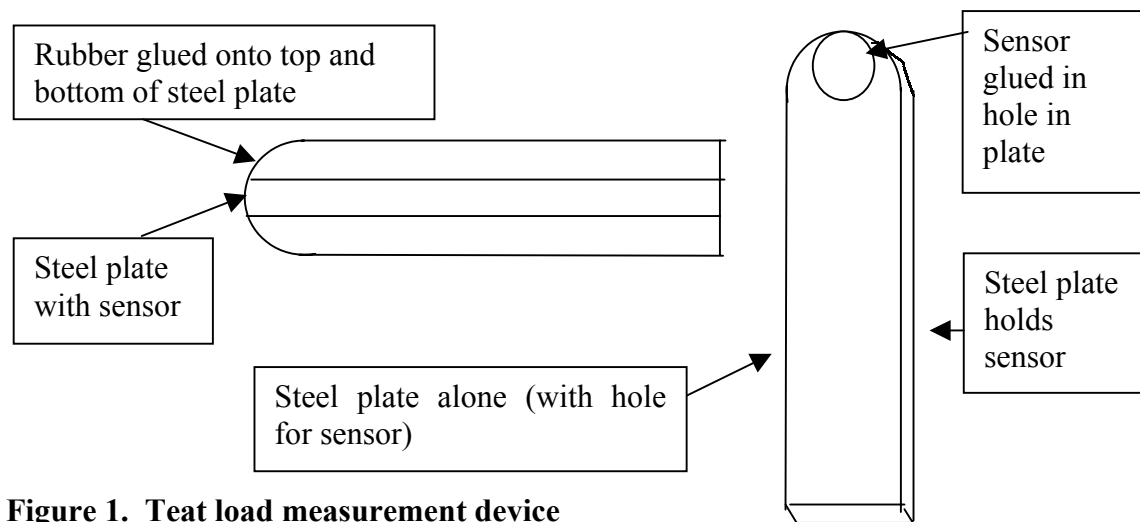


Figure 1. Teat load measurement device

Average and Peak Milk Flow Rate

The average milk flow was calculated as the nominal milk yield divided by the milking duration. The milk flow rate was measured using the signal generated by the milk meters. The peak milk flow rate was determined as the maximum 30-second average of the milk flow rate.

Mouthpiece Chamber Vacuum

Mouthpiece chamber vacuum was measured as recommended by Reinemann et al. (1997). Mouthpiece chamber vacuum was sampled at the right front teat at 100 Hz using a small vacuum transducer attached to a flexible tube (0.25 cm ID x 0.68 cm OD x 77 cm) attached to a small piece of metal tubing (1.7 mm ID). The metal tube was bent approximately 80° and inserted through the liner wall into the mouthpiece chamber.

Strip Yield Measurement

Strip yield was measured when the detacher removed the milking cluster; no oxytocin was injected. Strip yield collection by hand and machine was investigated. Strip yield collection by hand posed a problem with the large variation in amount of milk attainable and the lengthy collection time. Strip yield collection was lastly obtained by use of a quarter milker to enable quarterly data collection, as opposed to machine stripping.

The quarter milker consisted of a single teatcup and a sealed 500-ml collection vessel. The milk and pulsation tubes were plumbed into the milk and pulsation lines in the parlor. Each quarter was stripped with the quarter milker immediately after the cluster was removed. A volumetric limitation of 1500 ml per quarter was applied to avoid a second milk let-down during stripping. The operator applied pressure to stretch the teat to prevent occlusion of the teat sinus. Stripping continued until there was little or no milk flow.

IVF Measurement

The method of counting liner slips, or IVF, in this study was similar to the method used by Spencer and Voltz (1990). Claw vacuum was measured as recommended by Reinemann et al. (1997). Claw vacuum was sampled at 100 Hz using a small vacuum transducer attached to a flexible tube (0.25 cm ID x 0.68 cm OD x 2.9 cm) attached to a metal nipple threaded into the claw. The liner slip criterion of an 8 kPa vacuum deviation from the average claw vacuum in 0.25 seconds used by Spencer and Voltz (1990) was not suitable with this vacuum recording system due to higher sampling and response rates; therefore, new liner slip criteria were needed.

New liner slip criteria was developed based on the claw vacuum range and derivatives of a sample of 80 cows (7, 10). The purpose of these measurements was to identify fluctuations in vacuum during milking that may qualify as a “liner slip” but were not normal, hence the name *irregular* vacuum fluctuations. Two classification of IVF were developed and used in this study:

IVF 1 = derivative ≥ 100 kPa/s and range ≥ 21 kPa
IVF 2 = derivative ≥ 56 kPa/s and range ≥ 14 kPa

RESULTS AND DISCUSSION

Mouthpiece Lip Flex

Artificial aging

The means and standard deviations of mouthpiece lip flex measured in tests involving artificial aging of the liner are presented below in Table 1.

Table 1. Means and standard deviations of mouthpiece lip flex of liners at various ages, aged artificially.

Days of aging	n	Mean mouthpiece lip flex (mm)	Standard deviation (mm)
0	56	7.6	0.5
1.5	4	8.2	1.2
2	28	9.9	0.8
3	16	10.5	1.0
7	12	12.4	1.2

Mouthpiece lip flex progressively increased as the number of days of artificial aging increased. A significant change in mouthpiece lip flex from the new condition was observed after two days of artificial aging.

Natural aging

The means and standard deviations of mouthpiece lip flex measured in one test involving naturally aged liners are presented in Table 2.

Table 2. Means and standard deviations of mouthpiece lip flex of liners at various ages, aged naturally.

Liner age (cow milkings)	n	Mean mouthpiece lip flex (mm)	Standard deviation (mm)
0	64	7.6	0.5
840	8	10.4	0.6
1680	8	10.0	0.7
2520	8	10.6	0.3

Mouthpiece lip flex again progressively increased as the number of days of natural aging increased. A significant change in mouthpiece lip flex from the new condition was observed after 840 cow milkings.

Liner Barrel Tension

Artificial aging

The means and standard deviations of liner barrel tension measured in tests involving artificial aging of the liner are presented in Table 3.

Table 3. Means and standard deviations of liner barrel tension of liners at various ages, aged artificially.

Days of aging	n	Mean barrel tension (N)	Standard deviation (N)
0	55	74.8	5.7
1.5	3	70.1	4.5
2	28	50.6	7.2
3	16	40.4	3.3
7	12	31.3	6.1

Liner barrel tension progressively decreased as the number of days of artificial aging increased. A significant change in tension from the new condition was observed after one day of artificial aging (one-day aging trial not reported here).

Natural aging

The means and standard deviations of liner barrel tension measured in two different tests involving naturally aged liners are presented in Table 4.

Table 4. Means and standard deviations of liner barrel tension of liners at various ages, aged naturally.

Liner age (cow milkings)	n	Mean barrel tension (N)	Standard deviation (N)
0	63	75.3	5.4
840	8	52.2	1.6
1680	8	53.8	1.2
2520	8	51.7	1.3

A significant decrease in tension was observed between new and 840 cow milkings and between 1680 and 2520 cow milkings.

Compressive Load of the Liner

Compressive load measurements were made on one group of new liners, two groups of naturally aged liners and six groups of artificially aged liners. Sample size was three for all liner groups except the 7 days artificially aged liners, which consisted of two test groups of three liners. The compressive load measurements of each liner group were tested against the new liner group using independent Student's t tests. The average compressive load, standard deviation and p values for each liner group are presented in Table 5.

Table 5. Averages and standard deviations of compressive load measurements on new and aged liners (n=3 for all groups).

Liner	Average (kPa)	Standard Deviation (kPa)	p value
new	46.4	1.6	n/a
1.5 days	42.6	0.1	0.014
2 days	36.0	5.9	0.042
3 days	37.6	1.5	0.002
7 days	35.6	6.3	0.024
840 cow milkings	44.7	0.7	0.158
2520 cow milkings	44.8	3.4	0.520
aged mouthpiece (2 days)	41.0	4.6	0.126
aged barrel (2 days)	42.9	3.4	0.185

None of the naturally aged liners produced results significantly different from new liners. The four artificially aged liner groups all produced significantly less compressive load than new liners of the same type and lot. The liners with the aged mouthpiece and “new” barrel were not significantly different than new liners; the liners with the two-day aged barrel and “new” mouthpiece were not significantly different than the liners aged completely for two days.

One possible problem with these measurements is that they were not made immediately after the liners were removed from their shells. When the liners were finally measured for compressive load, they had been aged from three to 13 months prior. All test liners had been stored with the respective test group, to prevent cross absorption of fat, in boxes in a dark cabinet to minimize further degradation from sunlight. The liner properties may have partially recovered during storage, thus it is likely that these measurements have underestimated the effects of aging. These results must be interpreted with caution.

The three liners with the lowest compressive load, those artificially aged to two, three and seven days, also had the lowest barrel tension. The new liners and the two naturally aged liner groups had the highest compressive load. This may have been due to many differences between the artificial and naturally aged liners.

The artificially aged liners were exposed to fat on both the inside and outside of the liner, thus the liner absorbed more fat than the naturally aged liners. This resulted in less tension and a thicker barrel wall. Since the artificial liners were not aged by use in a milking machine, they never attained a teat-shaped barrel. The naturally aged liners had an enlarged, elliptical shaped barrel to a depth of about 7 cm. This is where the liner was in contact with milk and teat skin, which made it soft and enlarged in this region. From this point downward, the barrel narrows and approaches a circular cross-sectional shape. The compressive load measurement device was inserted into the liner to a depth of 8 cm. It is speculated that at this depth, the barrels of the naturally aged liners were in fairly good shape and produced a compressive load similar to a new liner. Conversely, the

barrels of the artificially aged liners were thicker, softer and grossly larger with a consistent circular cross-sectional shape. The artificially aged liners may have produced the smaller compressive load due to the thicker wall, lower tension or difference in cross-sectional shape.

Peak Milk Flow Rate

The data for peak milk flow rate are summarized in Table 6. The effect is calculated as the peak milk flow rate measured with treatment (aged liners) minus that measured with control (new liners).

Table 6. Peak milk flow rate.

Treatment	n (paired)	Average treatment (kg/min)	Average control (kg/min)	Average effect (kg/min)	Standard deviation of effect (kg/min)	p value
Artificially aged 2 days	6	3.9	4.6	-0.7	1.1	0.009
Artificially aged 3 days	4	5.2	5.6	-0.4	0.5	0.035
Naturally aged 840 cow milkings	16	4.1	4.7	-0.6	0.6	0.000
Naturally aged 1680 cow milkings	16	4.7	5.2	-0.5	0.5	0.001
Naturally aged 2520 cow milkings	15	3.5	3.8	-0.3	0.4	0.003
Mouthpiece chamber artificially aged 2 days	16	4.0	3.8	0.2	0.9	0.422
Barrel artificially aged 2 days	16	3.5	5.0	-1.5	0.8	0.000

The trend in peak milk flow rate was very consistent. Aged liners produced a decreased peak milk flow rate in all tests except the test involving liners with an aged mouthpiece chamber. These results were statistically significant ($p < 0.05$) in six of seven tests. The largest decrease was observed with a liner with an aged barrel. The one test in which increased peak milk flow rate was observed involved liners with an aged mouthpiece lip.

Aged liners produced a strong trend of decreasing peak milk flow rate. Peak milk flow rate was the most sensitive indicator of liner age as it experienced significant changes for all but one aging treatment. It is difficult to determine exactly what made the peak milk flow decrease. Mein and Reid (1996) state that “the mean peak milking rate...is a sensitive and repeatable indicator of the effects of good milk ejection and/or vacuum level, pulsator settings and restrictions to milk flow.” Though liner condition does not affect vacuum or pulsation, it does affect restriction to milk flow. Increased teat penetration due to a greater mouthpiece flex as well as a higher mouthpiece chamber vacuum both may congest the tissue surrounding the teat sinus, restricting the milk flow. Aged liners had a significantly lower tension and some had a lower compressive load as a

probable result. This lower compressive force may not have been adequate to relieve teat end congestion during the period of peak flow and may have restricted the flow as well.

It was surprising then that the peak milk flow rate increased when cows were milked with the liners with the aged mouthpiece chamber, which should have increased teat penetration thus occluding the teat sinus and restricted the milk flow. It is postulated that perhaps the significantly higher barrel tension prohibited the teat from penetrating too far, which may have minimized occlusion of the teat sinus. The aged mouthpiece chamber liners also produced a significantly higher mouthpiece vacuum, opposite of expected, which should have congested tissue surrounding the teat canal as well and decreased the peak milk flow rate. However, these liners had significantly higher tension, yet they produced a compressive load no different than new liners. Therefore, it is postulated that the positive effect of the compressive load, equal to that of a new liner, in combination with the adequate teat penetration, due to the high barrel tension, enabled the treatment liner to perform similar to a new liner.

A test completely opposite of this was the milking time test involving liners with an aged barrel only. This test generated the largest result, a peak milk flow rate decrease of 1.5 kg/min. Given that the barrel was aged for 2 days, it was expected to produce results similar to the liners aged completely for two days. The liner aged completely for 2 days did produce a decrease in peak milk flow rate, but not as large. The aged barrel liner had a significantly stiffer mouthpiece lip, produced a significantly lower mouthpiece chamber vacuum, had a significantly lower barrel tension yet had a compressive load measurement no different than that of a new liner. Therefore, it appears that peak milk flow rate may be dependent upon the stiffness of the mouthpiece lip, as this was the only characteristic of this liner that would have decreased peak milk flow rate.

Average Milk Flow Rate

The data for average milk flow rate are summarized in Table 7. The effect is calculated as the average milk flow rate measured with treatment (aged liners) minus that measured with control (new liners).

Table 7. Average milk flow rate.

Treatment	n (paired)	Average treatment (kg/min)	Average control (kg/min)	Average effect (kg/min)	Standard deviation of effect (kg/min)	p value
Artificially aged 1.5 days	8	2.7	2.8	-0.1	0.3	0.564
Artificially aged 2 days	6	2.4	2.7	-0.3	0.7	0.128
Artificially aged 3 days	8	3.1	3.4	-0.3	0.3	0.010
Artificially aged 7 days	8	2.1	3.0	-0.9	0.5	0.598
Naturally aged 840 cow milkings	16	2.7	3.0	-0.3	0.5	0.120
Naturally aged 1680 cow milkings	16	3.0	3.2	-0.2	0.5	0.207
Naturally aged 2520 cow milkings	16	2.3	2.4	-0.1	0.3	0.597
Mouthpiece chamber artificially aged 2 days	16	2.5	2.4	0.1	0.5	0.322
Barrel artificially aged 2 days	16	1.9	2.6	-0.7	0.7	0.242

Aged liners produced a consistent trend of decreased milk flow rate. Aged liners produced decreases in average milk flow rate in eight of nine tests conducted. The change in average milk flow was statistically significant ($p < 0.05$) only for the test of liners aged artificially for 3 days. One test in which an increased average milk flow rate was observed involved liners with an aged mouthpiece chamber.

Average milk flow rate behaved similar to peak milk flow rate. All tests but the one involving the aged mouthpiece chamber liners produced decreases in average milk flow rate. However, average milk flow rate is not as sensitive to liner age as peak milk flow rate since it is an average over the whole milking. As stated earlier, peak milk flow rate is dependent upon restriction of the teat sinus or canal. Peak milk flow rate is usually attained in the first two minutes of milking, while average milk flow rate is the total yield divided by the total milking duration. When the low flow period starts, even liners in good condition will start to congest teat tissue. Measurement of average flow accounts for this late-milking congestion, which is not indicative of liner condition, and therefore does not serve as a good indicator of liner condition. However, congestion during the first two minutes of milking, that affects the peak milk flow rate, is indicative of poor liner condition and is more sensitive to changes than average milk flow rate.

The largest effect, though insignificant, was observed with liners artificially aged for seven days. These liners had a very low barrel tension and were very soft. It is postulated that the lower barrel tension was a factor in producing the decrease in average milk flow rate. There is reluctance to add softness of the mouthpiece lip as a factor in determining average milk flow rate, as one of the second largest effects, a decrease of 0.7 kg/min, was observed with a liner with an aged barrel but stiff mouthpiece lip.

Average Mouthpiece Chamber Vacuum

The data for mouthpiece chamber vacuum are summarized in Table 8. The effect is calculated as the average mouthpiece chamber vacuum measured with treatment (aged liners) minus that measured with control (new liners).

Table 8. Average mouthpiece chamber vacuum.

Treatment	n (paired)	Average treatment (kPa)	Average control (kPa)	Average effect (kPa)	Standard deviation of effect (kPa)	p value
Artificially aged 2 days	6	14.9	8.7	6.1	6.2	0.060
Artificially aged 3 days	4	16.6	12.8	3.8	2.8	0.073
Naturally aged 840 cow milkings	15	10.2	8.1	2.1	6.9	0.259
Naturally aged 1680 cow milkings	16	12.8	13.3	-0.5	6.4	0.765
Naturally aged 2520 cow milkings	15	16.7	10.4	6.3	5.5	0.001
Mouthpiece chamber artificially aged 2 days	15	11.4	8.1	3.3	3.6	0.004
Barrel artificially aged 2 days	8	6.9	10.0	-3.0	4.6	0.103

Aged liners produced higher mouthpiece chamber vacuum in five of seven tests; two of which were statistically significant. Lower mouthpiece chamber vacuum was observed in liners naturally aged to 1680 cow milkings and liners with an artificially aged barrel; however, neither of these findings were statistically significant.

Average mouthpiece chamber vacuum increased in most of the aged liner studies. It is curious that the mouthpiece chamber vacuum decreased, though not significantly, in the test involving liners naturally aged to 1680 cow milkings. This decrease in vacuum may have been caused by a poor seal at the mouthpiece lip. After these same liners were aged to 2520 cow milkings however, the largest effect, an average increase of 6.3 kPa was recorded. If the liner had been leaking air at the mouthpiece lip at 1680 cow milkings, it should have leaked more air and decreased the mouthpiece chamber vacuum further at 2520 cow milkings. Though one must remember, different groups of cows produced these different results. Teat size or shape may have been a factor in average mouthpiece chamber vacuum during milking (8). For a given teat, mouthpiece chamber vacuum depends upon the quality of the seal at both the barrel and mouthpiece lip of the liner. As

the liner ages, both the barrel and mouthpiece lip bore become larger and create a poorer seal between it and the teat. If the seal at the mouthpiece lip is poor, the mouthpiece chamber vacuum approaches atmospheric conditions, if the seal between the teat and barrel is poor, the mouthpiece chamber vacuum approaches claw vacuum.

It was very surprising to find that the aged mouthpiece chamber liners produced a significantly higher mouthpiece chamber vacuum while the aged barrel liners produced a lower mouthpiece vacuum. It was anticipated that the opposite would occur! Cross sections of each of the partially aged liners were examined. It was found that the aged barrel liners decreased dramatically in barrel bore just below the mouthpiece chamber, in relation to the level of butteroil during aging. It is postulated that the claw vacuum did leak past the sides of the teat, but was prevented from entering the mouthpiece chamber by this dramatic, unplanned feature.

The significantly higher mouthpiece chamber vacuum of the aged mouthpiece chamber liners is a bit more complex. The only possible way to generate high mouthpiece chamber vacuum is leakage of claw vacuum past the sides of the teat into the mouthpiece chamber. This could only occur if teat penetration was not adequate, allowing claw vacuum to bypass the smaller diameter of the teat apex and leak into the mouthpiece chamber causing the higher mouthpiece vacuum. However, given the faster milking time, average and peak milk flow rates observed in this test, the teat must have had adequate penetration. Rasmussen et al. (1996) reports increased mouthpiece chamber vacuum with high tensioned liners, due to the lack of conformity to the teat exhibited by the tight liner. These conditions may have been present in this test. It was expected that the soft mouthpiece lip would produce a poor seal at the base of the teat. It is now postulated that the soft mouthpiece lip may have done just the opposite and conformed quite well to the teat base, creating a seal sufficient to contain the higher vacuum from the claw that surpassed the poor seal between the stiff liner wall and soft teat.

Strip Yield

Strip yield was obtained by hand in seven studies and by use of the quarter milker in two studies. Strip yield was limited to 20, 100 and 500 ml per quarter or measured as the volume attained in 10 squirts of the teat when collected by hand. The quarter milker was limited to 1500 ml per quarter to avoid second let-downs.

Generally, aged liners produced less strip yield, though insignificantly, by the hand-strip methods. When strip yield was collected with the quarter milker, more milk was usually attained. It is speculated that the downward pressure applied by the operator may have relieved congestion of proximal teat tissue, thus allowing more milk to pass from the gland cistern to the teat sinus. In contrast, the hand-stripping method involves gripping the proximal teat base and wrapping each successive finger around the teat. If the proximal tissue were fully congested, only milk in the teat sinus would be removed; which may explain why the hand-stripping methods usually resulted in less strip yield with aged liners. The only significant effect was a finding of more strip yield with liners

with an aged barrel as compared to new liners. This occurred with collection of strip yield with the quarter milker. Data for each strip method is tabulated in the Appendix, Tables 1-4.

Class 1 IVF

Class 1 IVF, the more severe classification of IVF, was an occurrence of a claw vacuum range ≥ 21 kPa and a claw vacuum derivative ≥ 100 kPa/s. Due to vacuum transducer failure, only seven of nine tests conducted have data for IVF measurement.

Class 1 IVF were measured in four artificial aging tests and a progressive, three-month natural aging study. The data set is presented below in Table 9. The average effect is calculated as the number of class 1 IVF measured with treatment (aged liners) minus number measured with control (new liners).

Table 9. Class 1 IVF.

Treatment	n (paired)	Treatment average (no. of)	Control average (no. of)	Average effect (no. of)	Standard deviation of effect (no. of)	p value
Artificially aged 2 days	6	3.8	0.5	3.3	7.7	0.157
Artificially aged 3 days	4	1.0	6.0	-5.0	8.7	0.335
Naturally aged 840 cow milkings	16	0.8	0.5	0.3	1.7	0.572
Naturally aged 1680 cow milkings	16	0.5	0.1	0.4	0.8	0.048
Naturally aged 2520 cow milkings	15	0.9	0.3	0.6	2.3	0.334
Mouthpiece chamber artificially aged 2 days	16	0.4	1.2	-0.8	1.2	0.014
Barrel artificially aged 2 days	16	0.5	1.3	-0.9	1.7	0.047

Though all three natural aging tests found a trend of increased class 1 IVF with aged liners, this increase was only significant ($p < 0.05$) in one test. Liners artificially aged for two days produced more class 1 IVF while the liners aged for three days produced less; however, neither of these results were significant. Two more experiments involved artificial aging for two days of the mouthpiece or barrel *only*. Both tests found significantly less class 1 IVF with the partially aged liners.

Aged liners were expected to produce more class 1 IVF. The naturally aged liners did produce this result but was only significant in one of three tests. It is believed that this lack of significance may have been due to confounding of the measurement with cow, since the three tests involved three different groups of cows. The liners artificially aged for two days produced more class 1 IVF, but not significantly, while the liners aged for three days produced fewer class 1 IVF, though insignificantly. It is believed here that the small sample size of the two artificial aging trials, $n=6$ for two days of aging and $n=4$ for three days of aging, as compared to $n=16$ for the natural aging trials, may have influenced the significance of the results.

The liners with the artificially aged mouthpiece lip were expected to leak air at the mouthpiece lip and increase teat penetration while maintaining the seal between the liner and teat barrel, consequently decreasing IVF. However, the aged mouthpiece lip liners experienced significantly less class 1 IVF, though the mouthpiece chamber vacuum was significantly decreased (5.6 kPa lower than the new liners, standard deviation=3.6, p -value=0). Therefore, there existed a good seal between the teat barrel and liner to prevent the air leaking past the mouthpiece into the claw. Increased teat penetration would have increased the surface area of this seal, also resulting in fewer IVF.

The liners with the artificially aged barrel were expected to produce a poor seal between the teat barrel and liner, thus producing a high mouthpiece vacuum. The elevated mouthpiece vacuum should have resulted in less class 1 IVF, but actually resulted in significantly more. One is inclined to postulate that the decreased class 1 IVF may have resulted from a good seal at the mouthpiece lip, however, increased class 2 IVF challenge this postulation. This test, involving aged barrel liners, produced results similar to liners aged completely for 3 days. These liners produced less class 1 IVF, while producing more class 2 IVF. It is postulated here that the seal at the mouthpiece admitted only enough air to generate class 2 IVF, while not enough air was admitted to generate class 1 IVF.

Class 2 IVF

Class 2 IVF was an occurrence of a claw vacuum range ≥ 14 kPa and a claw vacuum derivative ≥ 56 kPa/sec. Class 2 IVF were measured in four artificial aging tests and a progressive, three-month natural aging study. The data set is presented below in Table 10. The average effect is calculated as the number of class 2 IVF measured with treatment (aged liners) minus number measured with control (new liners).

Table 10. Class 2 IVF.

Treatment	n (paired)	Treatment average (no. of)	Control average (no. of)	Average effect (no. of)	Standard deviation of effect (no. of)	p value
Artificially aged 2 days	6	17.0	22.7	-5.7	19.9	0.116
Artificially aged 3 days	4	23.5	13.5	10.0	11.9	0.192
Naturally aged 840 cow milkings	16	10.2	0.8	9.4	9.0	0.001
Naturally aged 1680 cow milkings	16	3.4	0.1	3.3	2.8	0.000
Naturally aged 2520 cow milkings	15	2.4	1.5	0.9	5.6	0.574
Mouthpiece chamber artificially aged 2 days	16	1.0	12.6	-11.6	10.8	0.001
Barrel artificially aged 2 days	16	13.0	2.0	11.0	13.0	0.000

All three natural aging tests found increased class 2 IVF with aged liners, two tests found this increase significant ($p < 0.05$). Liners aged for two days produced less class 2 IVF while liners aged for three days produced more class 2 IVF; however, neither were significant. Again, liners with a two-day aged *barrel* produced significantly more class 2 IVF while liners with a two-day aged *mouthpiece* produced significantly less class 2 IVF.

Liners artificially aged for three days produced increased class 2 IVF as expected; however, small sample size may be responsible for the insignificance of these results. Liners aged for two days generated 5.7 less class 2 IVF on average, however insignificant, perhaps due to small sample size as well.

The naturally aged liners also produced more class 2 IVF, as expected, though only significantly in two of three tests. Again, this may be due to measurement confounding with cow groups. For example the last group tested, which had no significant changes in IVF of either class, may have contained many cows with teat shapes with a greater

resistance to IVF. Further study is needed on the relationship between IVF during milking and teat shape.

Similar to class 1 IVF, significantly less class 2 IVF were measured with liners with an aged mouthpiece lip. Again, it is postulated that this was an effect of the good seal between the deeply penetrated teat and liner wall. The liners with the aged barrel produced significantly more class 2 IVF. As discussed previously, it is postulated that the mouthpiece lip admitted only enough air to generate class 2 IVF.

Similar to naturally aged liners, artificially aged liners produced a trend of increased IVF of class 2, though none of these findings were significant. It is speculated that the softer mouthpiece lip of the artificially aged liners allowed the lip to conform better to the base of the teat thus creating a better seal, minimizing IVF. This good quality seal is also evident in the trend of high mouthpiece chamber vacuum produced by the artificially aged liners. The lack of significance may be due to the small sample size due to vacuum transducer failure.

Relationships between the Physical and Milking Characteristics

This study has provided much information on liners as they were aged either naturally or artificially. It is difficult to think of the information as a whole. Table 11 below summarizes the information on eight different measurements over nine aging trials. Note: mouthpiece chamber is abbreviated MPC in Table 11.

Table 11. Summary of effects of aged liners on physical and milking characteristics.

Treatment	Peak flow	Average flow	MPC vacuum	Strip yield	IVF 1 2	Flex	Tension	Comp. load
1.5 days artificial	×	↓	×	↑	×	↑	↓	↓
2 days artificial	↓	↓	↑	↓	↑↓	↑	↓	↓
3 days artificial	↓	↓	↑	↓	↓↑	↑	↓	↓
7 days artificial	×	↓	×	↑	×	↑	↓	↓
840 cow milkings	↓	↓	↑	↑	↑↑	↑	↓	↓
1680 cow milkings	↓	↓	↓	↓	↑↑	↑	↓	×
2520 cow milkings	↓	↓	↑	↓	↑↑	↑	↓	↓
MPC 2 days	↑	↑	↑	↓	↓	↑	↑	↓
Barrel 2 days	↓	↓	↓	↑	↓↑	↓	↓	↓

Up arrows designate an average measurement trend higher than that observed with new liners while down arrows designate an average measurement trend lower than that observed with new liners. An X designates no measurement due to transducer problems. Shading indicates a significant difference from new liners; underlined arrows designate an effect different from other tests, or unexpected.

Table 11 reveals positive correlations between barrel tension and compressive load and a second between mouthpiece lip flex and mouthpiece chamber vacuum. A decrease in barrel tension yielded a decrease in compressive load in nine of ten tests. This finding agrees with the work of Mein (1992) and Muthukumarappan et al. (1994).

The compressive load measurements on the artificially aged liners were significantly lower than that observed with new liners; the only exception to this was the liner with an aged barrel. Both Mein (1992) and Muthukumarappan et al. (1994) describe a positive correlation between compressive load and liner wall tension. These artificially aged liners, that produced a compressive load significantly lower than new liners, had a lower barrel tension as well. The naturally aged liners, all with a barrel tension higher than all but one of the artificially aged liners, produced a compressive load not significantly different than new liners.

Contrary to Mein (1997), an increase in mouthpiece lip flex tended to increase mouthpiece chamber vacuum. It was originally thought that a softer mouthpiece lip would reduce the effectiveness of the seal between the lip and proximal teat (20), decreasing the mouthpiece chamber vacuum. It is postulated that a stiff, rather than soft, mouthpiece lip may be the source of a poor seal due to poor conformation between the teat and lip.

The positive correlation between barrel tension and compressive load and between mouthpiece lip flex and mouthpiece chamber vacuum were true in seven of eight and six of seven tests, respectively. It is concluded that trends in mouthpiece vacuum can generally be predicted from measurements of mouthpiece lip flex; likewise, trends in compressive load can be predicted from measurements of barrel tension.

Peak and average milk flow rate are a function of restriction to flow, or teat congestion (26). So, if all but one of the liner treatments produced this reaction to teat congestion of decreased milk flow rates, what caused the congestion?

In order to understand the cause and effects of teat tissue congestion, the location of the congestion must first be understood. Congestion can occur at the proximal or distal region of the teat. Congestion of the tissue surrounding the teat sinus may be caused by high mouthpiece chamber vacuum while congestion of the tissue surrounding the teat canal may be caused by inadequate massage force, or compressive load, of the closed liner.

Referring back to Table 11, peak milk flow rate measurements are missing for a few tests due to transducer failure. Average milk flow rate and peak milk flow rates were positively correlated in all tests. Decreased peak milk flow together with a trend of increased mouthpiece chamber vacuum occurs in four of seven tests; two of these four tests also found significantly lower compressive load of the liner, which may have congested the distal region of the teat. It is postulated that congestion of teat tissue surrounding the sinus, combined with congestion of tissue surrounding the teat canal in two tests, caused the decreases in peak and average milk flow rates.

It appears that congestion of the tissue at the proximal and distal regions of the teat may also influence strip yield, as an inverse relationship between strip yield and mouthpiece

chamber vacuum is apparent in five of eight trials. This seems only logical, as cisternal milk may not be able to pass through a congested teat. Hillerton et al. (1998) also suggests a relationship between strip yield and teat tissue congestion from elevated mouthpiece chamber vacuum.

As stated earlier, a decreased peak milk flow rate may indicate teat congestion and may result in a lower strip yield. Grimm and Schlaiss (1994) found a relationship between a slow opening liner, due to low tension, and decreased strip yield. This study found a positive correlation between peak milk flow rate and liner barrel tension. Decreased strip yield occurs with a lower barrel tension occurs in four of nine tests.

Mein (1997) notes a positive correlation between mouthpiece lip flex and IVF. This relationship was also found in these tests. One is inclined to postulate that the increased flex of the mouthpiece lip admits air that causes the vacuum fluctuations; however, if this were true, mouthpiece chamber vacuum would be decreased (28) in conjunction with increased IVF. An increase in IVF was found in three of seven tests; of these three tests, only one involved a decrease in mouthpiece chamber vacuum. It is postulated that IVF may not be solely dependent upon mouthpiece chamber vacuum.

CONCLUSIONS

The device for compressive load measurement shows much promise, but further testing is required to better understand how the measurements made relate to the loading applied by a liner to a live teat. Currently, the liner load measurement device is suitable for comparison purposes only.

It is concluded that strip yield collected by a quarter milker may be the best method. This method had less variability and more consistency than collection by hand due to operator hand strength and style of excreting the milk. Though collection requires a quarter milker and a trained operator, it is consistent and may give the best measurement of cisternal milk yield.

We suggest these two levels of the combined criteria for vacuum range and rate of change in the claw to classify IVF:

<p>IVF 1 = derivative ≥ 100 kPa/s and range ≥ 21 kPa IVF 2 = derivative ≥ 56 kPa/s and range ≥ 14 kPa</p>
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Liners aged either naturally or artificially produced a decrease in peak milk flow rate of 0.5 kg/min (1.1 lb/min) (standard deviation = 0.3 kg/min) and a decrease in average milk flow rate of 0.3 kg/min (0.7 lb/min) (standard deviation = 0.4 kg/min). Liners aged either naturally or artificially produced an increase in average mouthpiece chamber vacuum of 2.2 kPa (0.6 in Hg) (standard deviation = 6.5 kPa). Naturally aged liners produced an

increase in both classes of IVF of 1.4 class 1 and 4.6 class 2 (standard deviations = 1.7, 7.3 respectively).

Changes in liner barrel tension and compressive load were positively correlated, as were changes in mouthpiece lip flex and mouthpiece chamber vacuum. Tension and compressive load affect the speed of milking while mouthpiece lip flex and mouthpiece vacuum affect the “comfort” of milking by affecting teat tissue congestion which in turn affects the speed of milking. Future study should include further investigation of the interactions between measurements.

Congestion of tissue surrounding the teat sinus from the high mouthpiece vacuum produced in aged liners may decrease the peak milk flow rate and average milk flow rate. Contrary to popular belief, it is postulated that a stiffer mouthpiece lip may be the source of a poor seal due to poor conformation between the teat and mouthpiece lip. Mouthpiece vacuum alone may not influence IVF, further study is needed to determine the relationships between IVF and other physical characteristics.

This study has validated most of the theoretical relationships between the physical and milking characteristics of the aging liner. However, this study has only looked at one liner. Further study is recommended with a collection of popular liners to validate these relationships between the physical and milking characteristics of the aging liner.

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REFERENCES

- 1 Adley, N.J.D. and M.C. Butler. 1994. Evaluation of the use of an artificial teat to measure the forces applied by a milking machine teatcup liner. *Journal of Dairy Research* **61**: 467-472.
- 2 Baxter, J.D., G.W. Rogers, S.B. Spencer and R.J. Eberhart. 1992. The effect of milking machine liner slip on new intramammary infections. *Journal of Dairy Science* **75**: 1015-1018.
- 3 Brandsma, S. 1978. The relation between milking, residual milk and milk yield. *Proceedings of 17th Annual Meeting*, National Mastitis Council, pp. 47-56.
- 4 British Standards Organization. 1969. British Standard 903, Part A6.
- 5 Caruolo, E.V. 1983. Measuring force of massage produced by the teatcup liner. *Journal of Dairy Science* **66**: 2441-2445.
- 6 Cooper, J.H and E.R. Gardner. 1953. The deterioration of milking rubbers. III. The effect of farm treatment. *Journal of Dairy Research* **20**: 340-354.
- 7 Davis, M.A. 2000. Relationships between changes in the physical characteristics and milking characteristics of the aging milking liner. *M.Sc. Thesis*, University of Wisconsin-Madison.
- 8 Davis, M.A., E. Maltz and D.J. Reinemann. 2000. Consideration of teat morphology and milking characteristics for robot milking conditions. In *International Symposium of Robotic Milking*, August 17-19, Lelystad, Netherlands. In press.
- 9 Davis, M.A., D.J. Reinemann and G.A. Mein. 1999. Measurement of change of liner properties with age. Presented at the 1999 ASAE Annual International Meeting, ASAE Paper No. 99-3017. St. Joseph, MI.: ASAE.
- 10 Davis, M.A., D.J. Reinemann and G.A. Mein. 2000. Effect of liner age on milking characteristics. In *Proc. of 39th Annual Meeting*, National Mastitis Council, Atlanta, GA, pp. 186-187.
- 11 Dodd, F.H., P.A. Clough, J.H. Cooper and E.R. Gardner. 1954. Tension in the teatcup liner. *National Institute for Research in Dairying Report* pp. 28, 29.
- 12 Dodd, F.H. and A.S. Foot. 1948. Residual milk. *Agriculture: Journal of the Ministry of Agriculture, Great Britain* **55**: 238-242.
- 13 Gates, R.S. 1984. Biomechanics of Teat/Liner Interactions: A finite deformation approach. *Ph.D. Thesis*. Cornell University, Ithaca, NY.
- 14 Gardner, E.R. and N.J. Berridge. 1952. The deterioration of milking rubbers. II. The effect of fat. *Journal of Dairy Research* **19**: 31-38.
- 15 Gibb, I. McD. and G.A. Mein. 1976. A comparison of the milking characteristics of teatcup liners. *The Australian Journal of Dairy Technology* **31**: (4) 148-153.

- 16 Gleeson, D.E. and E.J. O'Callaghan. 1998. A note on the effect of aging on teatcup liner performance. *Irish Journal of Agricultural and Food Research* **37**: 93-95.
- 17 Grimm, H. and G. Schlaiss. 1994. The formation of strippings. In *Proc. of the International Symposium, Prospects for Future Dairying: A Challenge for Science and Industry*, eds. O. Lind and K. Svennersten. Uppsala, Sweden, June 13-16.
- 18 Kelly, T.G. 1979. The deterioration of milking machine liners and the use of milking machine simulator to accelerate endurance testing. *M.Sc. Thesis*, National University of Ireland, Dublin.
- 19 Kelly, T.G., B. McKenna, and J. O'Shea. 1983. Milking machine liners- a review of their chemical and physical characteristics and factors affecting their deterioration. *Milking Machine Research at Moorepark 1978-82*, pp. 14-23. Published by An Foras Taluntais; Dublin, Irish Republic.
- 20 Kelly, T.G., J. O'Shea, E. O'Callaghan and B. McKenna. 1983. Comparisons of milking characteristics of new and used liners. *Milking Machine Research at Moorepark 1978-82*, pp. 44-55. Published by An Foras Taluntais; Dublin, Irish Republic.
- 21 McGrath, D.M. and J. O'Shea. 1972. Effect of teat-cup liner design on milking characteristics. *Irish Journal of Agricultural Research* **11**: 339-349.
- 22 Matthes, Frau H.D. 1973. In *Proc. of Symposium Fortschritte, Probleme und Entwicklungstendenzen bei der Industriemassigen Milchgewinnung*: 152-159. Published by Karl Marx Universitat Leipzig.
- 23 Mein, G.A. 1992. Action of the cluster during milking. In *Machine Milking and Lactation*, eds. A.J. Bramley, F.H. Dodd, G.A. Mein and J.A. Bramley, ch. 4, pp. 121-122. Vermont, USA: Insight Books.
- 24 Mein, G.A. 1997. Teatcup Liners: Where the rubber meets the teat. *Proceedings of Advanced Milking Systems*. Milking Research and Instruction Laboratory, University of Wisconsin-Madison.
- 25 Mein, G.A., P.A. Clough, D.R. Westgarth and C.C. Thiel. 1970. A comparison of the milking characteristics of transparent and conventional teatcup liners. *Journal of Dairy Research* **37**: 535-548.
- 26 Mein, G.A. and D.A. Reid. 1996. Milking-time tests and guidelines for milking units. In *Proc. of 35th Annual Meeting*, National Mastitis Council, Nashville, Tennessee, pp. 235-243.
- 27 Muthukumarappan, K., D.J. Reinemann and G.A. Mein. 1994. Compressive load applied to the bovine teat by the teatcup liner. Presented at the December 1994 ASAE International Winter Meeting, ASAE Paper No. 943568. St. Joseph, MI.: ASAE.
- 28 Newman J.A., R.J. Grindal and M.C. Butler. 1991. Influence of liner design on mouthpiece chamber vacuum during milking. *Journal of Dairy Research* **58**: 21-27.

- 29 Nowak, C., Z. Gil, J. Szarek and K. Pelc. 1985. A new method of testing teat rubber stretchability. In *Proc. of 5th International Symposium on Mastitis Control* Bydgoszcz, Poland, pp. 490-504.
- 30 O'Callaghan, E.J. 1996. Measurement of liner slips, milking time, and milk yield. *Journal of Dairy Science* **79**: 390-395.
- 31 O'Shea, J. and E. O'Callaghan. 1980. Milking performance of full udder clusters with standard pulsation: effect of cluster weight and cluster weight distribution; and comparisons of 'original' and 'imitation' liners and new and used liners. *Experiments on Milking Machine Components at Moorepark 1976-79*, pp. 104-114. Published by An Foras Taluntais; Dublin, Irish Republic.
- 32 Rasmussen, M.D. 1997. The relationship between mouthpiece vacuum, teat condition, and udder health. In *Proc. of 36th Annual Meeting*, National Mastitis Council, Albuquerque, New Mexico pp. 91-96.
- 33 Rasmussen, M.D., E.S. Frimer and H.C. Larsen. 1996. Dynamic testing during milking, an indicator of teat handling. In *Proc. of Symposium on Milk Synthesis, Secretion and Removal in Ruminants*, eds. J.W. Blum and R.M. Bruckmaier, University of Berne, Switzerland, pp. 120.
- 34 Reinemann, D.J., K. Muthukumarappan, and G.A. Mein, 1994. Forces applied to the bovine teat by the teatcup liner during machine milking. Proc. XII CIGR World Congress and AgEng 94' Conference on Agricultural Engineering, Milano, Italy, September 1994.
- 35 Reinemann, D.J., M.D. Rasmussen, E.S. Frimer, and G.A. Mein, 1996. Test equipment and its application for measuring vacuum in the short milk tube. Paper No. 963018, Written for presentation at the 1996 International Meeting sponsored by ASAE: the Society for Engineering in Agriculture, Food and Biological Systems, Phoenix, Arizona, USA, 14-18 July 1996.
- 36 Reinemann, D.J., M.D. Rasmussen, G.A. Mein. 1997. Characteristics of vacuum changes in the short milk tube, and liner mouthpiece during milking. Presented at the 1997 ASAE Annual International Meeting, ASAE Paper No. 97-3038. St. Joseph, MI.: ASAE.
- 37 Roets, E., G. Vandeputte-Van Messom and G. Peeters. 1985. Relationship between milkability and adrenoceptor concentrations in teat tissue in primiparous cows. *Journal of Dairy Science* **69**: 3120-3130.
- 38 Salvatierra, S. 1978. Causes of inflation failure. *New Zealand Journal of Agriculture* **136**: 50-54.
- 39 Schatzl, D., H. Worstorff, R. Fischer. 1999. Effect of the linear properties shore hardness and wall thickness on buckling pressure and milking performance. *Milchwissenschaft* **54** (4): 183-187.
- 40 Schwiderski, H. 1965. Life of milking stockings. *Tierzucht* **19**: 637-638.
- 41 Spencer, S.B and C. Voltz. 1990. Measuring milking machine liner slips. *Journal of Dairy Science* **73**: 1000-1004.

- 42 Swanson, E.W. and Hinton, S.A. 1951. Residual milk from oxytocin injections throughout the lactation. *Journal of Dairy Science* **34**: 419-426.
- 43 Szlachta, J. 1985. Effect of geometrical and mechanical parameters of the teat liner on the intensity of teat massage. In *Proc. of 5th International Symposium on Mastitis Control*, Bydgoszcz, Poland, pp. 474-487.
- 44 Walsh, J.P., P.V. Kinsella, J.M.A. Palmer and J. Connolly. 1970. Tests on the milking performance of six milking machines. *Irish Journal of Agricultural Research* **9**: 127-141.

APPENDIX

Strip yield limited to 20 ml per quarter

Two studies measured strip yield as the number of quarters with more than 20 ml. The results (number of quarters containing more than 20 ml) for each test are given below in Table 1. The average effects are calculated as number of quarters containing >20 ml for treatment minus that observed with control (new liners).

Table 1. Strip yield measured as the number of quarters with more than 20 ml.

Treatment	n (paired)	Treatment average (no. of quarters)	Control average (no. of quarters)	Average effect (no. of quarters)	Standard deviation of effect (no. of quarters)	p value
Artificially aged 1.5 days	8	1.8	1.5	0.3	2.0	0.732
Artificially aged 3 days	8	1.1	2.0	-0.9	1.8	0.213

Strip yield limited to 100 and 500 ml per quarter

The results for each test are given below in Table 2. The last test, involving liners aged naturally for 1680 cow milkings involved a limit of 500 ml per quarter while the others used a limit of 100 ml per quarter. The average effects are calculated as total udder strip yield obtained for treatment minus control (new liners).

Table 2. Strip yield limited to 100 and 500 ml per quarter.

Treatment	n (paired)	Treatment average (ml)	Control average (ml)	Average effect (ml)	Standard deviation of effect (ml)	p value
Artificially aged 7 days	8	190.3	227.0	-36.7	96.3	0.316
Naturally aged 840 cow milkings	16	91.1	57.9	33.2	105.7	0.228
Naturally aged 1680 cow milkings	9	834.1	1078.2	-244.1	420.8	0.120

Strip yield limited to amount obtained in 10 squirts from each teat

Four studies involved measuring strip yield as the amount obtained in 10 squirts from each teat. The data for these four studies are shown below in Table 3. The average effects are calculated as total udder strip yield obtained for treatment (aged liners) minus control (new liners).

Table 3. Strip yield limited by number of squirts from each teat.

Treatment	n (paired)	Treatment average (ml)	Control average (ml)	Average effect (ml)	Standard deviation of effect (ml)	p value
Artificially aged 2 days	6	55.0	80.8	-25.8	19.3	0.477
Naturally aged 1680 cow milkings	7	104.1	121.1	-17.0	29.5	0.178
Naturally aged 2520 cow milkings	16	56.3	61.6	-4.8	35.6	0.588
Mouthpiece chamber artificially aged 2 days	16	36.9	45.4	-8.5	22.9	0.158

Strip Yield Obtained with the Quarter Milker

Three studies obtained strip yield by use of the quarter milker. The data for these three studies are shown below in Table 4. The average effects are calculated as total udder strip yield obtained for treatment (aged liners) minus control (new liners).

Table 4. Strip yield obtained with the quarter milker.

Treatment	n (paired)	Treatment average (ml)	Control average (ml)	Average effect (ml)	Standard deviation of effect (ml)	p value
Artificially aged 2 days	6	1105.0	1085.8	19.2	243.6	0.563
Barrel artificially aged 2 days	16	1267.5	775.0	492.5	531.4	0.002
Mouthpiece chamber artificially aged 2 days	16	790.6	792.2	-1.6	365.6	0.987