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CHANGES IN MILKING LINER PERFORMANCE WITH AGE

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ABSTRACT

The useful working life of the milking liner may be determined by how long milking performance is sustained, any effects on the cow's teat and the quality of milk collected. Working life is affected by the type of liner in use, its response to use and cleaning chemicals. In Europe liners are recommended for change usually after 2500 milkings, or a maximum of 6 months. Little obvious research data support this recommended life.

A uniform batch of milking liners produced from a single supply of synthetic rubber was aged for up to 6000 milkings by use in a commercial milking parlor. Periodically, a single cluster was removed and the milking performance tested in a controlled milking environment, using a single group of 8 cows. The effect of liner age on average milk flow rate, peak milk flow rate, completion of milk removal and condition of the cows' teats after milking were assessed. The composition, shape, structural integrity and the mechanical properties of the liners were determined.

It is apparent that liner deterioration occurs gradually and that this has some measurable effects on milking performance prior to 2500-milkings but does not induce any trauma to the teats within the recommended life of 2500 milkings. Statistically significant differences in liner performance are apparent by 3000-milkings of use. There is no obvious reason to change the recommended length of life of this type of milking liner. These determinations were made on one model of liner only. However, a large proportion of all liners in use are made from exactly the same material so the findings have a broad application.

KEYWORDS. Liners, cow's teat, milk flow rate, ageing of rubber, calcium salts

INTRODUCTION

The rubber liner of the teat cup is the only point of the milking machine in direct contact with the dairy cow. Rubber components have been used in milking machines since 1863 although their design and composition have changed greatly in the last 100 years of use. Work continues to optimize the materials and the structure of liners. Most interest in recent years has been in the operating conditions of the machine and how that affects the liner action, milking performance of the cow, the patho-physiological responses of the cow's teat and the rate of intra mammary infection. Consequently the influences of milking vacuum, pulsation rate and ratio and effects of poor teat preparation and over milking are relatively well understood.

Different formulations of rubber have been used to overcome particular problems encountered in milking including the swelling of natural rubbers by absorption of milk fats, loss of black fillers

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into milk, resistance to damage and etc. Most liners are now made of nitrile rubber with a minority being silicone formulations. The durability of liners is economically important but their longevity and replacement rate may vary with regulatory standards, hence nitrile liners in the US are recommended to be replaced after 1000 cow milkings but liners elsewhere are supposed to last for 2500 milkings or 6 months of use. The difference is due to a much higher proportion of carbon-black filler being used outside of the US (Davis et al., 2000). Relatively little is known of the basis for a recommended life of a liner. Much of the assessment of age appears to be subjective. Davis et al. (2000) have reported on the ageing of US liners up to 2500 milkings and Gleeson & O'Callaghan (1998) suggest the modern liner deteriorates by 7-months of use or 4200 milkings but when, and how quickly, the deterioration becomes marked is not known. The consequences of deterioration of liner performance are not well known.

The areas of primary importance when liners age include milking performance, especially the length of milking determined by the peak flow rate and durability of flow (average flow rate). This is influenced by milk yield, teat preparation prior to milking (milk availability) and the effects of the milking system on the cow's teat. The responses of the teat are indicators of welfare problems from the milking process and a significant risk factor for invasion of the gland by pathogenic bacteria and subsequent disease. This also affects milk quality. Milk quality may also deteriorate if bacterial contamination of ageing liners increases.

The effects of using a common, UK, nitrile rubber, milking liner for up to 6000 milkings have been determined by measuring milking performance and the responses of teats to milking of a group of 8 cows. Some chemical, mechanical and structural changes in the liner have also been investigated.

MATERIALS AND METHODS

A popular UK liner, made by Avon Rubber, Melksham, UK from the same rubber formulation as the majority of UK and European liners, was selected for study. A batch of DeLaval 960000-01 liners was obtained; all were made from the same mould and from the same batch of rubber. They were fitted into HC150 DeLaval clusters in a double 8 DeLaval milking parlor operating at 47 kPa plant vacuum and pulsation of 60 pulses/min and 60% ratio. A herd of approximately 230 cows was milked twice daily. All operating conditions were monitored including the appropriate use of wash chemicals. Approximately every 400-cow milkings a set of liners was removed for study. After 1500 milkings the liners were re-tensioned as recommended by the marketing company.

The detailed study involved liners aged from new (2 repeats) to 5800 milkings, being used to milk the same group of eight cows approximately every two weeks. The whole cluster was removed to an experimental milking parlor where the same operating conditions were employed. Cows were accustomed to the experimental conditions at one afternoon milking and at 09.00h the following day they were milked under study. Cluster take-off was at 400 ml/min with a 2 second delay.

Cows were milked individually. Teats were cleaned with running water and dried with paper towels; all teats were fore milked with the preparation taking at least 30 seconds per cow. One minute after the start of preparation the first teat cup was attached, all being attached within 5 seconds. Milk letdown was always instantaneous.

Measurements were taken of teat length and width before milking, but after stimulation. The length of cluster attachment time, the whole udder yield every 30 seconds, and teat length and width after milking were also measured. Immediately after cluster removal each teat was scored for color, response to touch, any obvious deformation distally or proximally, and orifice status as described by Hillerton et al. (2000). Finally the completeness of milking was assessed by the stripping of milk from any teat for longer than 15 seconds.

Average milk flow rate was calculated as the total yield divided by the cluster attachment time. Peak flow rate was calculated from the change in yield from 1 minute to 3 minutes after cluster attachment.

All four liners, still in their shells, were removed to the Avon Rubber test laboratory where key dimensions were measured. The liners were then examined by scanning electron microscopy and energy dispersive x-ray spectrometry for changes inside the barrel. Gas chromatography and Thermo Gravimetric Analysis (TGA) were used to investigate the composition of the rubber. Changes in mechanical properties of the rubber were measured by Dynamic Mechanical Thermal Analysis (DMTA). Samples (6x10x2.5mm) were cut from the barrel, approximately 6cm from the top of left front liners.

Changes in properties between new liners and aged liners were compared using the Minitab statistical package (release 12.21 Minitab Inc., State College, PA, USA). Results have been described as averages for the eight cows at any one liner age or by pooling three successive ages other than new. This results in 6 categories, new (0) and then groups of ages to approximately 1250, 2400, 3600, 4800 and 5800 milkings.

RESULTS

Ageing of the liners lasted for approximately 5800 individual cow milkings, approximately 7-months. This is longer in time that the recommended 6-months of use, the 2500 recommended cow milkings occurred after 12 weeks of use. The milking plant was monitored to ensure appropriate use of chemicals in the wash system, especially chlorine formulations so that these did not unduly contribute to liner deterioration.

Milking Performance

The same 8-cows, within 10-weeks of calving at the start of the study, were used for 7-months and so yield at the milking used for study decreased with time, as would be expected (Fig. 1). The yield and average flow rate showed an initial peak with new liners then a slight but not significant drop. The average yield did not become significantly lower for the first 4800-milkings. The same average flow rate was sustained for 2800-milkings, only becoming statistically lower ($P<0.05$) after 4000-milkings (Fig. 2). A slight drop in average flow rate occurred at 1600-milkings. This was transitory. Immediately after this milking the liners were re-tensioned (recommended at 1500-milkings). Thus the same average flow rate was sustained for more that the supposed 2500-milkings of acceptable age. The peak flow rate showed a similar pattern (Fig. 3).

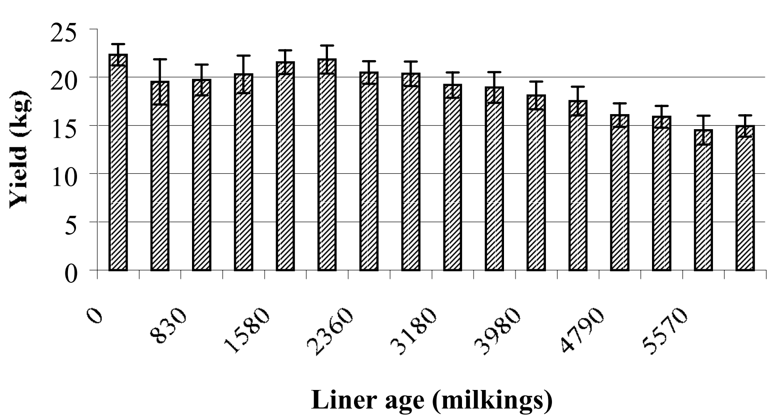


Figure 1 Change in yield (±SEM) over 5800 milkings of liner age.

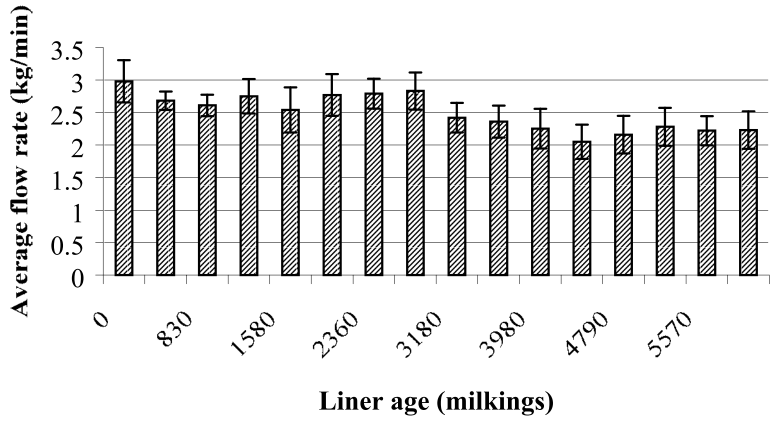


Figure 2 Change in average flow rate (±SEM) over 5800 milkings of liner age.

Figure 3 Change in peak flow rate (±SEM) with liner age.

There were some indications that other changes occurred in milking performance with time. The number of audible and visible liner slips increased with liner age. The most noticeable change was in the proportion of individual quarters that contained a measurable strip yield after cluster removal. This proportion increased before the reduction in average or peak milk flow rate occurred. A measurable reduction in the completeness of milking had occurred before the liners were 3000-milkings old (Fig. 4).

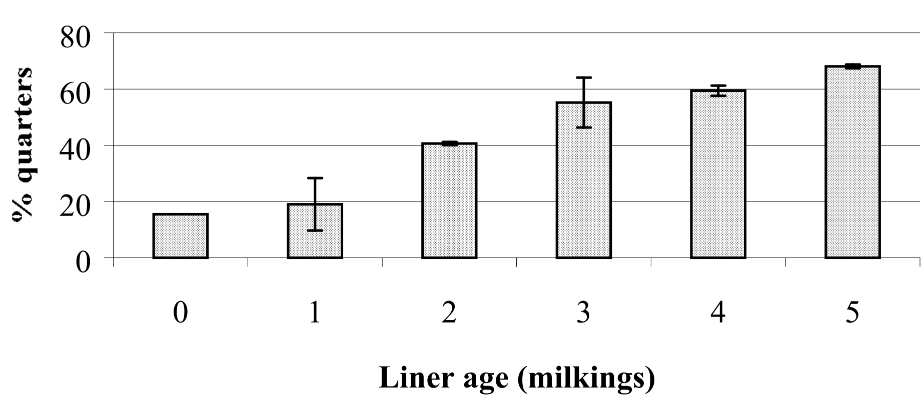
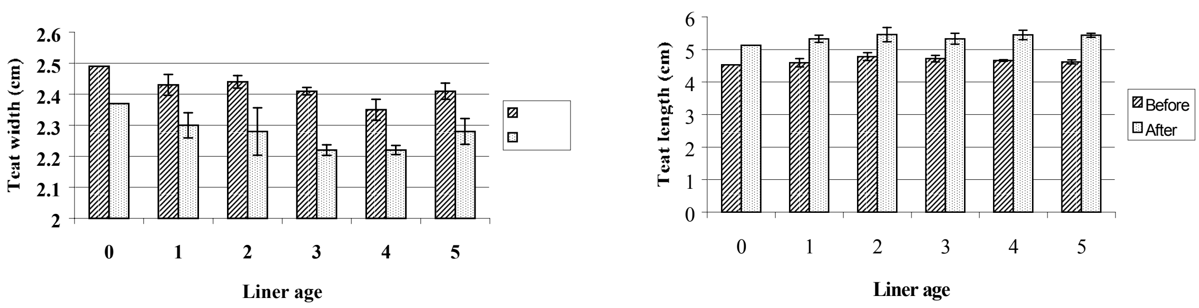


Figure 4 Completeness of milking with increasing liner age, the proportion of quarters from which milk could be obtained for more than 15 seconds after cluster detachment.

<u>Teat responses</u>

The method of teat preparation and the immediate availability of milk on cluster attachment indicate that teats were properly stimulated and that their dimensions were correct at the start of milking. No obvious changes in teat length or width immediately prior to milking occurred over the 7-months of the study. However, teats were significantly longer and narrower after milking (Fig. 5). There is some indication that teats were progressively narrower after milking with increasing liner age.



(a) length (b) width

Figure 5 Teat dimensions before and after milking with liner age

Two other obvious changes in teat response with liner age were observed. The proportion of discolored teats increased such that by 5000-milkings significantly more teats were blue or red on cluster removal (Fig. 6). Contrarily the proportion of teats with a visible mark or palpatable, thickened ring of tissue, caused proximally by the mouthpiece chamber, decreased with liner age. It was significantly lower after 3000-milkings (Fig. 7).

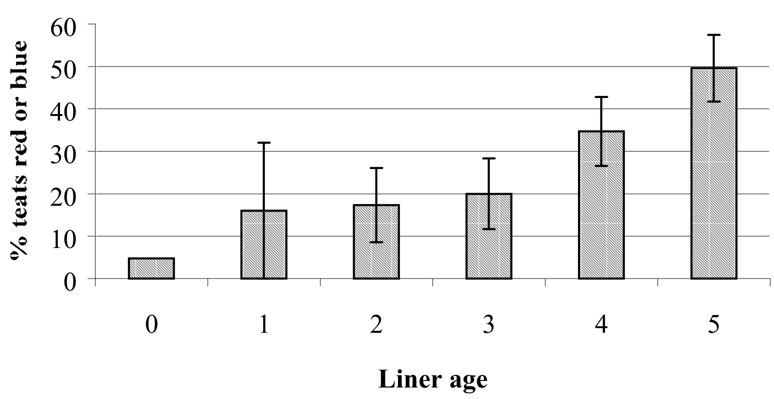


Figure 6 Change in color of teats with liner age; proportion (±SEM) with red or blue teats after cluster detachment.

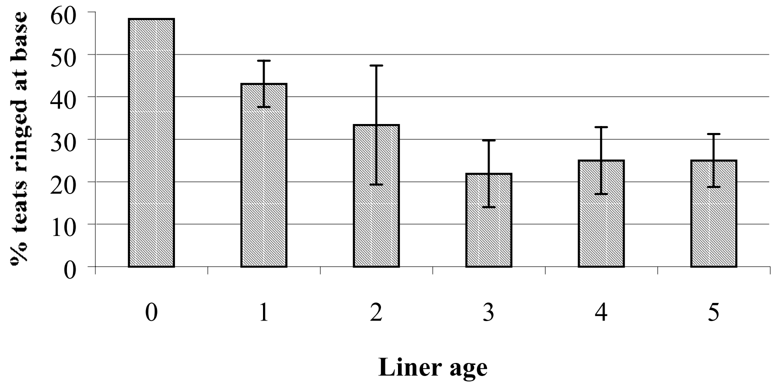


Figure 7 Change in average proportion (±SEM) of teats with a ring of tissue proximally.

<u>Linear Properties</u>

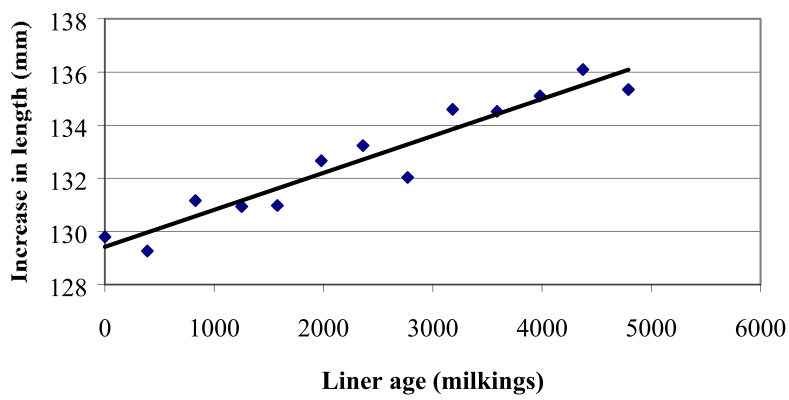


Figure 8 Change in liner length with age.

The liners were found to lengthen with increasing age (Fig. 8). There was an inflection at 1580-milkings consistent with the re-tensioning. The diameter of the liner mouthpiece orifice also increased slightly with age but it also became more variable with age possibly related to its distortion (Fig. 9).

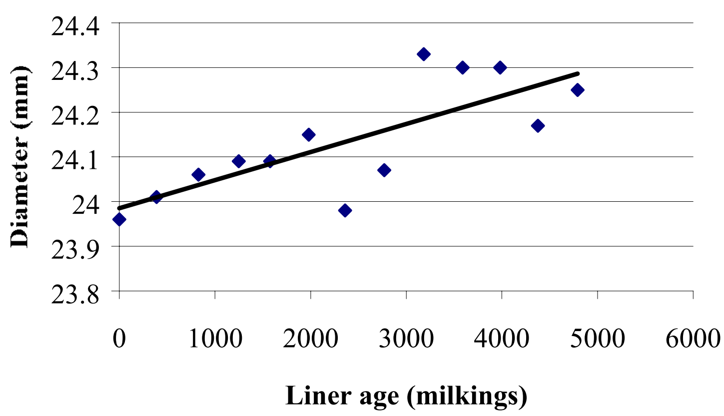


Figure 9 Change in mouthpiece orifice diameter with age.

The dynamic analyses of liner properties suggests that as the number of milkings increases, the elastic modulus, tan delta and the hysteresis all increased. Importantly, the strain amplitude at which maximum tan delta occurs reduced as the number of milkings increased indicating an increase in strain dependency (Fig. 10). This feature may be explained as being a consequence of permanent disruption and weakening of the filler network on working.

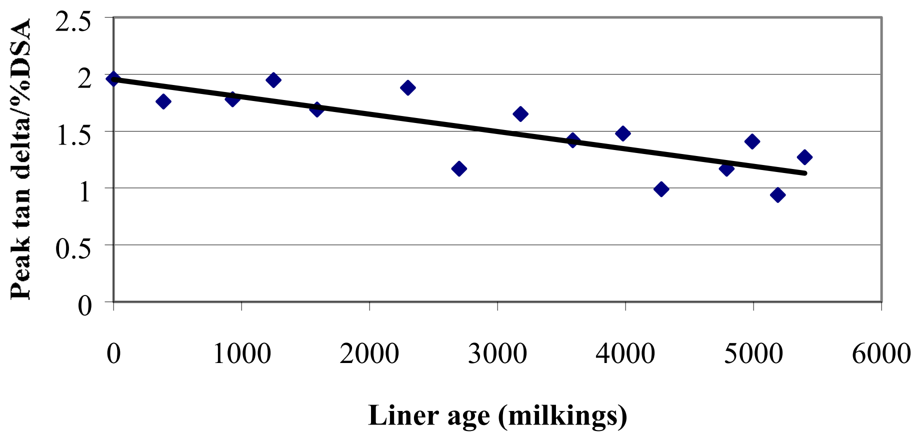
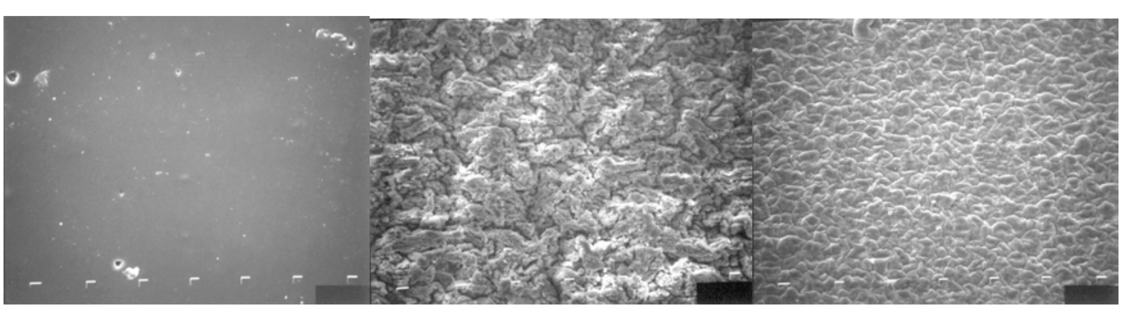


Figure 10 Change in tan delta with strain as liners age.

Bulk composition of the liners, as determined by Thermo Gravimetric Analysis, showed that the carbon content did not change with the number of milkings, suggesting that both the polymer and black content were unaltered. However, additional extractable matter, was shown by gas liquid chromatography of a solvent extract, to be fatty acid esters and /or fatty acids, they have very similar spectra. The scanning electron micrographs show that the new liner has a clean and smooth internal surface (Fig. 11) After approximately 1500-milkings, the inner surface of the liner barrel had a crazed appearance with a layer of finely structured material present. Energy dispersive x-ray spectrometry (EDAX) showed that the inorganic matter was deposition of calcium-phosphate-based material where the liner barrel folded around the teat during liner closure. Little calcium was deposited elsewhere on the liner. There was no systematic variation of the DOP content with age, although the 6PPD anti degradant content (included to protect the rubber from oxidative deterioration) reduced with age.



(a) unused (b) 2500 milkings (c) 4300 milkings

Figure 11 Scanning electron micrographs of liner barrel, point in contact with teat, for different ages of liners, X200.

DISCUSSION

This study used the same group of cows over 7-months for experimental measurements. That is a weakness of this study as the milking performance was always likely to diminish, as shown by the drop in yield (Fig. 1). However, although the peak and average flow rates decreased with time, only relatively small decreases, approximately 0.5 L/min, occurred. The decreases within the supposed life of the liner, 2500-milkings, were not statistically significant drops. The decreases in flow characteristics only became significant after 4000-milkings although the decrease started by 1600-milkings and were reversed by re-tensioning of the liners. The flow rates did not change further after 4000-milkings although only 50% of the yield decrease had occurred by then. This suggests that the yield changes were not the major governing factor of milk flow. Further, the need for re-tensioning liners looks evident and flow starts to be affected permanently by 3000-milkings although the sensitivity of flow rates alone is not high.

The use of the same cows throughout the study is a strength of this study. The only two comparable studies (Davis et al. 2000; Gleeson and O'Callaghan, 1998) used many fewer measurement points and different group of cows for each assessment, although with a control group at each point. Periodic milking of the test group of cows using new liners was undertaken in the middle and the end of this study showing no significant difference in any feature from the new liners tested at the start of the study, and giving confidence in the results reported for ageing of liners. Davis et al. (2000) reported a significant decrease in peak flow rate with increasing liner age but not for average flow rate. However, their middle test point had an increased rate of flow for both groups of cows showing the problems of using different groups of cows. The inflection reported here we attribute to the re-tensioning of the liners, it could not be a cow effect

Gibb and Mein (1976) reported more liner slips with new liners than with aged liners. The studies by Gleeson and O'Callaghan (1998) and Davis et al. (2000) found the opposite. Here, we recorded a considerable increase in visible and audible liner slips with age of the liners. No obvious slips occurred with new liners. Gleeson and O'Callaghan (1998) suggested that the propensity for liner slips varies with liner design and so that may be an influence on the results.

A subjective method of assessing strip yield, under-milking, was used here. There was relatively little strip yield with new liners and then related only to individual cows. Quantity was not measured but was noted to be small volumes with new liners. The proportion of teats under-milked increased significantly as the liners aged, becoming statistically significantly different by 3000-milkings. Davis et al. (2000) also reported an increase in strip yield as liners aged. They regarded this as related to the ageing of the liner barrel in particular because it occurred with an artificially aged barrel and 'new' mouthpiece. Davis et al. (2000) comment on difficulties they experienced in assessing strip yield by hand expression as it may not have overcome proximal congestion of the teat. There was no evidence of such congestion in the current study. Although mouthpiece chamber vacuum was not measured, the evidence from the proportion of teats with proximal congestion, determined as thickened rings at the base of the teat, was for a decline in proximal congestion. The occurrence of the proximal congestion is likely to be exposure to a constant high vacuum in the mouthpiece chamber for the majority of milking. Newman et al. (1991) showed that this varied with design of the liner. Davis et al. (2000) found an increase in mouthpiece chamber vacuum with liner age. This would appear at odds with the increase in the rate of liner slips they report unless their design and composition of mouthpiece became too inflexible with age and the liner did not conform well to the size and shape of the teat. It was found here that teats were thinner after milking with increasing liner age. The effects on performance of liners are highly dependent on design and so should affect the changes with ageing. The hardening of the mouthpiece will be less that for the barrel as the heat history of that part of the liner will be less with age. Softening due to the swelling of the nitrile rubber will offset the hardening.

Discoloration of teats after milking was shown previously to be caused by a number of milking factors including over milking (Hillerton et al., 2000). There was no evidence of over milking in this study. Good milk let down was ensured, cluster take-off was highly efficient and strip yield increased with liner age. The ten-fold increase in the proportion of teats discolored when milked with aged liners suggests some other factor probably related to inadequate liner wall movement and so inadequate pulsation appears likely. The change was gradual with liner age. The poorer teat condition observed indicate that changes are occurring to make the teat more susceptible to damage. The stress imposed on the teat end is a complex compromise between, sometimes, conflicting requirements that warrant further investigation.

The liners tested lengthened with age and so would lose tension. As the liner tension reduces, due to creep in the rubber, then the degree of teat massage will reduce significantly. This may explain the higher proportion of discolored teats with increasing liner age. The apparent increase in liner stiffness and hysteresis with age is likely to have also made the liners less responsive to the pulsation applied.

Examination of the teat barrel surface showed that it deteriorates with age, probably due to the effects of chlorine from the cleaning process. These nitrile liners appeared to absorb some fatty components, probably milk fat, so swelling them on the internal surface. The swelling was concentrated in the areas where the liner contacts the teat end, so it is not uniform. The liners had a deposit of inorganic material, also reported by Gleeson and O'Callaghan (1998). It has been shown here that the deposit contains protein and calcium salts. It can be speculated that protein adheres to the abraded liner surface and that calcium carbonate or chloride is deposited on the protein film. These liners were tested in a hard-water area and so they were continually exposed to high concentrations of calcium salts. This may indicate that liner ageing, or the signs of liner ageing can vary geographically.

This study provided clear evidence that nitrile rubber milking liners age with use and that the effects can be seen on milking performance, teat responses and in the properties of the liner too. These results confirm and extend previous limited observations.

Initial ageing effects can be countered by re-tensioning liners after 1500-milkings as previously recommended. All changes were seen to be gradual, but changes in milking performance were obvious within 3000-milkings of age. The effects on strip yield, teat color and proximal congestion were also highly significant by this age having been progressive from new. It is clear that the mechanical properties of the rubber also deteriorate and its surface changes markedly.

The previous recommendation of using this specification of liner for a maximum of 2500-milkings appears valid. Changes were clearly underway by this age. Any extension of the recommended life would allow no safety margin for milking performance, teat health and possibly milk quality, based on the condition of the liner internal surface. It should be noted that the conditions for liner ageing and testing, albeit using commercial systems, were close to optimum and probably very much better that normal commercial conditions.

There are some differences between the results of this study and those of Davis et al. (2000). The timing of the deterioration is most likely due to the differences in chemical composition of the liner, the effect of heat, mechanical work done and the changes in dimensions but may also indicate that liner shape and design are important. There is no evidence that these extend the life of the liner in any significant way just that they may influence which properties change within the recommended life.

Conclusion

Under what were considered to be optimal conditions of use the UK-type nitrile rubber milking liner showed several significant signs of deterioration of milking performance, deleterious effects on teat condition and composition such that its life cannot be recommended as longer than 2500-milkings. Under other than optimal conditions the life may be shorter.

Acknowledgements

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References

1. Davis, M.A., D.J. Reinemann, and G..A. Mein. 2000 Relationships between physical characteristics and milking characteristics of the aging milking liner. ASAE Paper No. 003014. Milwaukee, Wisc.:ASAE.
2. Gibb, I.McD., and G.A. Mein. 1976. A comparison of the milking characteristics of teatcup liners. *Aust. J. Dairy Technol.* 31:148-153.
3. Gleeson, D.E., and E.J. O'Callaghan. 1998 A note on the effect of ageing on teatcup liner performance. *Ir. J. Agric. Food Res.* 37:93-95.
4. Hillerton, J.E., I. Ohnstad, J.R. Baines, and K.A. Leach. 2000. Changes in cow teat tissue created by two types of milking cluster. *J. Dairy Res.* 67:309-317.
5. Newman, J.A., R.J. Grindal, and M.C. Butler. 1991. Influence of liner design on mouthpiece chamber vacuum during milking. *J. Dairy Res.* 58:21-27.
6. long to include in the body of the article.