The smart position on teat condition

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Summary

- The primary machine factors that affect teat condition are (in order of priority):
  - Liner dimensions compared to teat dimensions, or the fit of the liner to the teats.
  - Type of liner including shape, material and venting.
  - Milking vacuum level, in both the peak and low flow periods of milking.
  - Degree of over-milking.
  - Pulsation settings.
- All of these factors are interactive, e.g. the effect of liner/teat dimension will be different for different types of liners, milking vacuum level and pulsation settings have different effects for different liner types and the effects of over-milking will be influenced by the milking vacuum level and liner type.
- Liner dimensions play a critical role in determining the range of teat sizes that can be effectively massaged. The most important of these dimensions is the depth of the mouthpiece followed by the liner bore.
- Choosing a liner and the appropriate vacuum level and pulsation settings is an exercise in balancing the fundamental goals of milking quickly, gently and completely.
- Overpressure (OP) is a practical and biologically relevant measure of liner compression (LC). OP and LC increase with milking vacuum level for each individual liner. Increased OP will result in increased teat end hyperkeratosis and increased peak milk flow rates.
- Liners and pulsation settings that maximize milking speed (especially peak flow rates) will also increase the risk of teat congestion and teat-end hyperkeratosis.
- Maximising the gentleness of milking will generally result in a modest reduction (about 10%) in milking speed (cups-on time). This modest increase in cups-on time will have a smaller effect on the number of cows milked per hour, especially if automatic cup removers are used and a maximum milking time is used.

Introduction

Machine milking is a compromise between milking gently, quickly, and completely. Milking gently means maintaining several categories of teat condition:
- Maintaining optimal keratin turnover in the teat canal,
- Maintaining the health and integrity of teat skin,
- Minimising rough teat-ends or hyperkeratosis,
- Minimising congestion in teat tissues to improve teat closure after milking.

Milking speed can be characterised in many ways but the most practical of these for farm managers is the number of cows milked per hour. Average milk flow rates provide a measure of the cups-on time for cows but are not particularly useful in predicting the number of cows milked per hour in a milking parlour because the limiting factor is the slowest milking cow on one side of a herringbone or on the platform of a rotary. Peak milk flow rates
are even less useful in predicting parlour performance because they provide information on only a very short window during the peak flow period and do not take into account what happens during the low flow period. Undue obsession with high peak or average flow rates will result in poorer teat condition.

Other papers in this proceedings present information on the effects of increasing flow thresholds and setting maximum milking times for automatic cup removers. These effects have far greater influence on the number of cows milked per hour than do changes in the milking machine to increase average or peak milk flow rates. Earlier removal of milking units will result in less complete milking, but gentler milking.

Smart SAMM Technote 9 'Manage teat sores and cracks' (DairyNZ 2012) presents an outstanding summary of research on the causes and cures for poor teat condition as well as practical advice on implementing this knowledge. This paper will provide additional insights into specific machine related effects on teat condition and the trade-offs between the three fundamental goals of milking.

**Characterising liners**

The combination of the choice of the liner and the vacuum level at which it is used has the most profound machine-induced effect on teat condition. The fit of the liner to teats is one of the most important aspects of choosing a liner. The most recent version of the ISO milking machine standard (ISO 5707:2007) requires manufacturers to provide sufficient data to be able to choose the liner for a herd; such data may include teat size, liner type or dimensions.

![Diagram of ISO liner specifications, from ISO 5707:2007](image)

There are a number of 'static' liner dimensions specified in ISO that are taken when the liner is in its open position while mounted in the shell. The liner dimensions of most importance to teat condition are (numbers refer to Figure 1):

- 1. Diameter of mouthpiece lip.
- 6. Diameter of the barrel, measured 75mm from the mouthpiece.

Additional dimensions are specified when the liner is fully collapsed at a vacuum level of 40kPa. The most important of these to teat condition are:

- 17+18. Effective length of liner.

In addition to these dimensions there are other ways to classify liners such as: shape (round, oval, triangular, square, tri-circle), material, and venting (none, in the short milk tube or in the liner mouthpiece). The ISO standard also asks the manufacturer to provide information on the desired average liner vacuum and/or the desired average liner vacuum during phase b and phase d of the pulsation chamber vacuum.
Liner compression (LC) is the mean compressive pressure (expressed in kPa above atmospheric pressure) applied to the tissues of the teat apex by the liner during the d-phase of pulsation. Although the concept is simple, the details of measuring liner compression are quite complex and a standardised methodology has not been developed.

The liner touch point (TP) pressure difference is the pressure difference across the liner at which the opposing walls of a round liner just touch (Figure 1b). This measurement was developed for round liners, which exhibit ‘buckling’ behavior when they collapse. The measurement is easy to make and quite repeatable for round liners. The ‘touch point’ of the adjacent walls of triangular or square liners is much more subjective (because the opposing walls of a triangular or square liner never touch), and therefore less repeatable. One method that has been used to estimate the relative LC of different liners, or individual liners used at different milking vacuum levels, is the Residual Vacuum available for Massage (RVM). This value is obtained by subtracting the vacuum required to collapse the liner (i.e. the liner ‘Touch Point’) from the average claw vacuum level. For a given claw vacuum, therefore, RVM is assumed to decline in direct proportion to any increase in the vacuum required to collapse the liner.

One component of LC has been defined as Over-Pressure (OP) (Mein et al. 2003). This is the mean compressive pressure, above that required to just start or stop milk flow from the teat, which is applied to the tissues of the teat apex by the liner during the d-phase. The method used to measure OP suspends pulsation by disconnecting the short pulse tube from one teat cup. Vacuum is then slowly applied in the pulsation chamber until milk flow is observed. This provides a very long d phase of pulsation followed by a slow removal of LC as PCV is increased.

A new method has been developed that makes the measurement easier and provides better accuracy. Dynamic over-pressure (DOP) is measured with continuous operation of the pulsator while the pulsation chamber vacuum is increased in steps of 2kPa until milk flow is observed (Gomez 2010). This method allows observation of all four teats on an individual cow and for several cows to be observed simultaneously. Half-udder or quarter udder comparisons can also be made for two or four liners on the same cow, thus reducing the variability across cows. The DOP method produces values about 66% of the OP method. This must be taken into account when referring to previous recommendations for OP made with the DOP method. Although OP and DOP are not true measures of LC, they can be used as a relative scale for LC.

While DOP and OP are weakly correlated with RVM, there are substantial differences between these two estimates of LC, especially for certain liner types. The mechanics of triangular or other liner shapes are quite different to those of round liners and TP, and RVM, cannot be used to compare LC across liner shapes. We have used OP and DOP as more biologically relevant methods for comparing LC across many different types of liners.

Teat congestion

The vacuum applied to teat tissue during milking is the driving force in producing teat congestion during milking by reducing or eliminating the circulation of blood and other fluids in teat tissues. Congestion is an accumulation of fluids in their normal flow path. If congestion is severe enough and persistent enough, oedema will occur. Oedema is the accumulation of fluids outside of their normal flow path i.e. in the interstitial spaces. The recovery of oedema is a much longer process than the recovery of congestion.

Liner collapse and massage helps to reduce congestion in teat-end tissues by forcing fluids out of the teat end and into the tissues in the teat barrel. These fluids can then be circulated and replaced, provided that circulation is effective in teat-barrel tissues. The liner applies little or no compression to the teat barrel. There is no way to reduce teat barrel congestion during milking. Teat barrel congestion is related to the vacuum in the mouthpiece of the liner, while teat end congestion is related to the vacuum at the teat end (milking vacuum).

Congestion of teat ends will result in a decrease in the effective diameter of the teat canal and reduced milking speed. Congestion of teat barrels will reduce the ability to manage teat end congestion and will result in less complete milk harvesting if the connection between the teat sinus and udder cistern becomes occluded. Both teat-end and teat-barrel congestion, and particularly oedema, can cause discomfort during milking and may also result in reduced patency of the teat end after milking, increasing the risk of bacterial penetration of the teat canal.

Methods for assessing teat congestion are outlined in Technote 9 by observing changes in the colour of teat skin after milking (Normal, Red, and Blue). In addition to noting these changes, it is useful to take note of the location of the colour change; does it occur at the teat-end, the teat-barrel or both. TN9 also recommends...
assessing the firmness of the teat end as another indication of the severity of congestion in teat-end tissues. Firmness is probably a more advanced stage of congestion than colour change at the teat end. Also note the size of the teats most affected. Short teats do not penetrate the liner as deeply and receive less liner compression. Slender and short teats result in higher mouthpiece (MP) vacuum and hence are at higher risk for congestion and oedema.

The location of the congestion is a helpful diagnostic in assessing the cause and the cure for congestion. If congestion is occurring only at teat ends, or teat ends are hard after milking the problem lies in the balance between the milking vacuum level and the degree of liner compression. Reducing milking vacuum will always reduce teat-end congestion as milking vacuum level is the driving force in developing it. Choosing a liner with higher compression will reduce teat end congestion, although most liners in the commercial market apply more compression than is necessary to manage teat-end congestion.

If congestion is occurring in the teat barrel the solution lies in reducing the vacuum level in the liner MP. Reducing the milking vacuum level will provide some benefit, but the main factor in MP vacuum is the size of the liner compared to the size of the teat and secondarily by the shape of the liner. Choose a liner with a shallower mouthpiece depth to reduce MP vacuum for short teats. Choose a liner with narrower bore to reduce MP vacuum in slender teats. Triangular liners generally produce higher MP vacuum than do round liners because the seal between the teat barrel and liner barrel is not as good. Another recent technology to reduce MP vacuum is the addition of an air vent in the liner mouthpiece. Reducing the low flow period by eliminating over-milking and increasing detacher flow thresholds will also reduce the degree of congestion in teat barrels as the low flow period is the time in which teat barrel congestion develops most rapidly.

Pulsation settings can affect the degree of teat-end congestion (but have little influence on teat barrel congestion). If the d-phase (or massage phase of pulsation) is less than 150 milliseconds the time required for relief of the teat end congestion will not be sufficient. Excessively long d-phases (greater than 250 milliseconds) will do no harm to the teat but will reduce milking speed as a greater percentage of the pulsation cycle will be in massage rather than milk mode. As the length of the b-phase (or milking phase of pulsation) increases so does the degree of congestion in the teat-end. If high milking vacuum is used it is beneficial to reduce the duration of the b-phase to reduce the congestion developed in the teat-end. Liner performance maps are being developed by our research group for specific guidance on the balance between vacuum level and b-phase duration for specific liners.

Swelling or ringing at the base of the teat

If teats are exposed to high MP vacuum for a single milking, swelling (a sign of teat barrel congestion) will occur. If the exposure to high MP vacuum continues the tissue at the base of the teat responds by forming a thickened ring. This ring formation occurs over a period of 1 to 4 weeks. Rings can also occur on the teat barrel, rather than at the base of large teats if the liner is too small to allow the teat to fully penetrate the liner.

Technote 9 recommends scores of Normal (no ring, little or no swelling, visible MP lip mark) or Swollen (presence of a palpable thickened ring). It is also useful to note the size and shape of teats with palpable rings as an indicator of the fit of the liner to the herd. The same management strategies for teat barrel congestion apply to teat ringing as ringing is a consequence of excessive teat barrel congestion occurring at the base of the teat (in the region of the MP chamber). The primary preventive strategy is to reduce MP vacuum and over-milking. If rings are apparent on large teats, consider the MP and barrel bore of the liner. No one liner can accommodate all teat sizes so there is a balance between taking care of the large teats at the expense of the small teats.

Other teat pathologies

Excessive milking vacuum, high tension liners and high compression liners can lead to openness of the teat orifice after milking. When examined immediately after milking, the external teat orifice may appear to be closed, slightly open or, in extreme cases, with a funnel-shaped opening about the size of a match-head. Vascular damage (petechial haemorrhages, or more extensive haemorrhaging), can occur in the skin and tissues of the teat end as the result of high milking vacuum, especially when combined with prolonged over-milking or absence of massage during the d-phase of pulsation. Both of these conditions indicate a severe stress on teat tissues and should be addressed immediately using observations on teat congestion to aid in identifying the most probable milking machine cause (usually high vacuum and/or pulsation failure).

Teat-end hyperkeratosis or teat-end roughness

Stretching of teat skin when the liner collapses results in hyperplasia including a condition called hyperkeratosis. Hyperkeratosis (HK) means ‘excessive keratin growth.’ It is a normal pathological response to the forces applied
to the teat skin during milking and is a thickening of the skin that surrounds the external teat orifice. The onset and severity of hyperkeratosis is profoundly influenced by climate, seasonal and environmental conditions, milking management, herd milk production level and genetics of individual cows. Scores for teat-end HK as presented in Technote 9 are: No Ring (N), Smooth Ring (S), Rough ring (R), and Very Rough Ring (V).

The onset and severity of teat-end roughness is exacerbated by conditions resulting in drying and hardening of the teat skin produced by harsh environmental conditions or exposure to certain chemicals. Reports of teat-end hyperkeratosis problems are far more prevalent in high-producing herds during colder periods of the year. Teat dips with emollients can reduce the severity of teat-end cracking by keeping skin soft and pliable but do not address the underlying issue. Hyperkeratosis can be reduced by using lower compression liners, reducing milking vacuum level, and adjusting threshold settings of automatic cluster removers to shorten average milking times per cow, thereby milking more gently and more quickly, but not as completely.

**Putting it all together**

**Liner fit**

Teats have some ability to conform to liner dimensions while liners have much less ability to adapt to different teat sizes. Since there will always be a range of teat sizes and shapes in any herd, the best liner is the liner that will perform well over the widest range of teat sizes. For the liner to apply compression to the end of the teat, the teat-end must be positioned in the part of the liner that is able to collapse and provide this compression. Teats stretch about 40% from their resting length to their length when milked with a narrow bore liner. A liner with a mouthpiece depth of 30mm is necessary to apply full compression to the lower 25mm of the teat (minimum teat length = (MPD (mm) + 25mm)/1.4). There has been a general trend toward breeding for short teats, and first lactation cows have the shortest teats in any herd.

In addition to the problems generated by insufficient LC, these short teats will also be milked with a high mouthpiece vacuum, as the teat is not long enough to create a seal in the liner barrel. The result of this will be ‘ringing’ at the base of the teat, and congestion and oedema in the teat, as indicated by intense red or blue colouring of the teat skin.

The relative diameter of the teat compared to the liner barrel also plays a role in the MPC vacuum during milking. Teats stretch in both length and width: they get ‘fatter’ and ‘longer’. The total volume of the teat in the liner is relatively constant so if teats get ‘fatter’ they will not elongate as much. Wide bore liners (liner bore diameter greater than teat diameter) will cause the teat to get fatter and reduce the ability of the teat to elongate into the zone of effective compression. This increases the minimum teat length that can be effectively massaged during milking.

**Liner compression and teat-end hyperkeratosis**

The primary milking machine influence on teat-end hyperkeratosis is LC. Environmental conditions and teat size and shape also have a large influence but are not ‘adjustable’ in commercial herds. LC for any individual liner will also increase with the milking vacuum level at which it is used because the pressure difference across the liner is increased during the d phase of pulsation. OP can be measured in the field without specialised sensors and is a more biologically relevant indicator of LC than RVM. Mein et al. (2003) reported a range of OP from eight to 20kPa for 18 different liners. These OP values are highly correlated with teat end hyperkeratosis in field studies. In a survey of commercial farms in Wisconsin, liners with the highest OP measurements produced in excess of 80% of teats that were roughened and cracked while liners with the lowest OP measurements produced fewer than 20% of teats that were roughened and cracked. Lower OP results in less hyperkeratosis or teat-end roughness. DOP requires more sophisticated measurement equipment but is highly correlated with OP. Measurements of DOP on 42 liners from the US and EU marked produced a range from 2-15kPa, and were about two thirds of the OP values for the same liners. The greatest DOP values are more than six times the lowest values for this range of commercial liners.

**Vacuum level and pulsation settings**

Vacuum level and pulsation settings must be chosen for each liner, taking into account the milking technology and management on each individual farm. Methods have been developed to predict the effect of milking vacuum level and pulsation settings on milking speed and teat-end congestion for a specific liner. An example of the results of one of these liner performance maps is shown in Figure 2 (a 20mm bore triangular liner fitted with a vent in the mouthpiece, OP of 5kPa and mouthpiece depth of 27mm). This information has been previously unavailable to milking managers, and we hope that now these methods will be used to take some of the mystery out of milking.
The liner performance map illustrated in Figure 3 is for one specific liner and the specific milk speed and congestion values do not apply to other liners. This liner has a vent fitted into the MP of the liner, which results in a considerably lower MP vacuum than traditional liners. Research indicates that liners with low MPC vacuum reduce the occurrence of ringing and blue teats after milking. In addition these liners also result in conditions that make unit removal much easier. If teat barrels in the MPC region become congested, the 'rings' at the base of the teat act to hold the liner on the teat even after vacuum is removed from the claw.

Liners with different shapes, materials, venting, OP values and differing relationship between OP and claw vacuum will produce different results. There are some general trends, however, that illustrate some basic principles that likely apply to all liners. The percentage numbers in the body of the chart relate to the relative milking speed, as indicated by average milk flow rates:

- As claw vacuum increases, so does the milking speed.
- As the b phase (milk:rest ratio) increases, so does milking speed until some critical point at each vacuum level at which point milking speed declines with increasing b phase duration due to increasing teat-end congestion.

The effects of these two machine settings are interactive: e.g. there are a number of combinations of claw vacuum and b phase duration to achieve a relative milking speed of 90% of the maximum for this liner. Which is best? The different shaded areas in the performance map (Figure 2) indicate the degree of teat-end congestion for teats that are longer than about 37mm, or enough to penetrate into the zone of effective compression for this liner i.e. low, medium, high or extreme teat-end congestion. Note that:

- As claw vacuum increases, so does teat-end congestion
- As the b phase (milk:rest ratio) increases, so does teat end congestion

The risk of teat tissue congestion for teats shorter than the minimum length defined by mouthpiece depth is indicated by the pressure in the claw vacuum column because these short teats will not receive the full benefit of LC, as described above and congestion is influenced primarily by claw vacuum level.

As an illustration of the use of the specific liner performance map (Figure 2), consider a milking parlour with operating vacuum of 48kPa and claw vacuum of 42kPa during the peak flow period of milking. Claw vacuum approaches system vacuum as flow rate declines at the end of milking so that the expected claw vacuum in the low flow condition will be about 47kPa. It is useful to measure claw vacuum during both the peak flow and low flow (just before unit removal) periods on a farm to assess congestion risk during all phases of milking. In this example a range of 5kPa in claw vacuum over the range of expected claw vacuum conditions should result.

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<th>Claw Vacuum</th>
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<td>47</td>
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Figure 2. Performance map for triangular liner fitted with mouthpiece vents
The milking speed numbers should be interpreted using the expected claw vacuum during the peak flow period of milking (42kPa in this example), as the peak flow period makes up the largest portion of the total milking, especially if automatic cluster removers are used. The fastest milking condition (91% of the fastest possible condition for this liner) will occur with a b phase setting of 500-550ms, however, the risk of teat-end congestion will be relatively high during the peak flow period (bordering between low and medium). During the low flow period of milking (claw vacuum of 47kPa) this pulsation setting increases the risk of teat-end congestion borders between high and extreme.

If gentleness of milking was the main priority, a system vacuum level of 42kPa (range of claw vacuum from 41kPa during the low flow period to 36kPa during the peak flow period) and b phase duration of 450ms might be chosen. These machine settings for this liner would result in very low teat congestion during the peak flow period and only moderate teat congestion during the low flow period for most cows and would substantially reduce teat-end and teat barrel congestion for cows with short teats. The milking speed for these settings would be 80% of the maximum for this liner, or a reduction of 11% compared to the previous settings. If the average cups-on time were four minutes, the change in the average cups-on time would be an increase of about 26 seconds. The lower vacuum setting would also likely result in more complete milking.

It is possible to estimate the relative HK risk with this liner in these two milking conditions. This (triangular) liner has an OP value of 5kPa and will, therefore, produce less teat-end HK than a liner with an OP value of 10kPa. Liners that are designed to optimise peak milk flow rates tend to have OP values of 10kPa or more. All of the OP measurements presented here were made using a claw vacuum level of 44kPa. Predicting how OP changes with the pressure difference across different liner types is still underway, but a rough estimate is that OP changes by about a quarter of the change in claw vacuum. The OP during the low flow period in our fast milking example would be about 6kPa and about 3kPa in the gentle milking example. Less HK should result in the gentle milking scenario.

![Figure 3. Milking speed as measured by average milk flow rate (AMF) for three different liners on two different farms over a range of system vacuum and pulsation settings](image-url)
A new experiment has just been completed in the UK with three different types of liners, used on two types of milking systems (low-line and mid-line). The relationship between milking vacuum level, pulsation settings and average milk flow rate are shown in Figure 3. Milking speed was primarily affected by milking vacuum level.

Milking speed in the midline system was about 7% lower for the mid-line system than for the low-line system, although the claw vacuum during the peak flow period was similar for both systems. The midline system produced a much higher milking vacuum in the claw and MP vacuum during the low flow period.

This is a good illustration of the problem of using peak milk flow rate as an indicator of milking speed. Liner type had little influence on milking speed in the mid-line system. Liner type did have some influence on milking speed in the low-line system with the triangular liner having the greatest average milk flow rate followed by the round liner (about a 9% reduction from the triangular) and the triangular liner fitted with the MP vent (about a 12 % reduction from the triangular).

While milking speed showed small differences across liner types, visual observation of teat congestion showed bigger differences (Figure 4). The triangular liner with a MP vent appeared to create fewer signs of teat congestion than the other liner types, with the biggest differences occurring at the highest vacuum levels. These differences in teat congestion correspond to differences in the MP vacuum developed by these liners in both the peak and low flow periods.

References and further reading


Mein, GA, DJ Reinemann, E O’Callaghan, and I Ohnstad. Liners and Pulsators: Where the rubber meets the teat and what happens to milking characteristics. Proc. IDF Conference: 100 years with liners and pulsators, Bruges, BE, 2003
