The Five-Point Mastitis Control Plan - A Revisory Tutorial!

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Summary

The history, intricacy and some intrigue involved in creating the Five-point Mastitis Control Plan have mostly been discovered some 46 years after its launch. Application of the plan remains essential for good udder health in dairy cows. The story is about great thinking by imaginative scientists, technical innovation by researchers and industry, good applied science to test and trial in the real dairy farming world, and creativity in selling and engaging. All ākonga of mastitis and milk quality need to know their whakapapa to have sufficient mana. Hopefully, most of the story of this upoko is captured here and will help the plan remain tapu.

ākonga – disciples or students, *whakapapa* – genealogy, *upoko* – chapter, *tapu* – sacrosanct

Early Times

The mastitis and milk quality community is (certainly should be) totally familiar with the National Mastitis Council (NMC) 10-point plan, all sorts of newer technologies including internal teat sealants, and now international moves to reduce the quantity, and some types, of antibiotics used in food animals. Entwined in these, and for many farmers, researchers and veterinarians the basis of nearly 50 years of improvement in udder health, has been the teaching and practice of the Five-point mastitis control plan. This has been done to huge effect, some arguing to the point of virtual irrelevance as the etiology and prevalence of intramammary infections have changed so significantly in response to hygienic milk production. It is up to you to judge from this review.

This paper will explain where the plan, and name, came from; suggest why it has five points; revise its basis in theory and practice; and describe some of the novel methods used in extension of the plan. If you do not understand the fundamental aspects and drivers you cannot deliver mastitis control effectively.

The semi-autobiographical stories of the Yorkshire veterinarian, James Herriot, working pre-World War 2, tell how farmers used to find mastitis (commonly termed felon in older days) by flakes in milk, by the different sound as milk from an infected udder hit the metal pail or by the salty taste of the milk. Intramammary infection was very common then; up to 60% of cows were considered to have one or more quarters infected with, most commonly, *Streptococcus agalactiae* or *Staphylococcus aureus*; the herd cell count rarely fell below 1 000 000 cells/mL; and, yet, the severity of clinical mastitis was maybe not too bad. Thankfully, most cows recovered udder health, if never eliminating the pathogen, by response to (very) frequent stripping of the quarter and hosing with cold water. The first effective antibiotics, penicillins, ignoring the sulfa drugs of 15 years earlier, were not available until the mid-1940s. Even then no obvious progress in general herd prevalence of infection or incidence of disease was made quickly, although 'blitz' therapy could eliminate *Str. agalactiae*, at least for a time (Stableforth et al., 1949). Generally, understanding of the majority of issues around mastitis, except maybe classification of pathogens, was confused, muddled and contradictory. Fortunately, Murphy (1956) developed some key thinking on how to deal with mastitis problems as dairy farming evolved in intensity, with fewer but much larger farms, in major dairying nations. However, mastitis remained a 'normal', and mostly uncontrolled, way of life on all dairy farms.

Early Thinking

Once upon a time, mastitis research workers met very infrequently and were only able to communicate over intervals of about four weeks because no affordable air travel was available on science budgets and that was the time it took for a letter exchange by sea mail. However, good relationships developed from about 1960 onwards between individuals and laboratories, often forged through the International Dairy Federation (IDF) and NMC. It became clear that quite separate approaches to manage mastitis, driven by milk quality issues and the need to grow supply, were developing according to regional philosophies. The US was struggling with contradictory concepts between states and a lack of formal control programs (see Murphy, 1956). The Nordic countries, with a comprehensive state veterinary system, went for strict veterinary control. The key German group in Kiel were the main proponents of managing milk cell count and the recognition of the four states of udder health: clinical mastitis, latent mastitis, sub clinical mastitis and healthy. In the UK, from 1955 the group at the National Institute for Research in Dairying (NIRD) focused on reducing the impact of the infected animals by developing hygienic milking practices. The findings of this group, led by Frank Dodd and Frank Neave, with Roger Kingwill, created the basics of mastitis control that many, including NMC, swiftly adopted, promoted and further improved.

The NIRD Philosophy

The NIRD work developed from about 15 years of previous research by Dodd and Neave, such that in 1962 they started their series of three Mastitis Field Experiments (MFE). Their thinking began from the point that, after 40 years of international effort and despite the availability of penicillin antibiotics for therapy of clinical mastitis, the incidence of the disease and the prevalence of infection had changed little, with an average of two quarters infected in at least 50% of all cows. This is also captured in the first edition of the NMC Current Concepts of Bovine Mastitis published in 1963. The NIRD group went on to emphasize the Murphy argument that what is needed is good management, if we knew what that was. Dodd et al. (1964) developed the thinking further (when Frank Dodd was on sabbatical at Ithaca) in a presentation to the American Dairy Science Association. That conference paper contains, probably for the first time, their diagram of the possible sequence of events in the development of infection and mastitis (Figure 1, original copied from paper). Epidemiologists will quickly recognize this as a classical Susceptible-Infected-Resistant/Recovered (SIR) model (Kermack & McKendrick, 1927) for infectious diseases. Strangely, no reference to the SIR framework ever appears (apparently) in the writings of the NIRD team. This first diagram was usually simplified in later publications.

Various states and stages of infection are described from the model by Dodd et al. (1964). It has to be noted that the philosophy was almost all around new infections and elimination of infections. The studies and the outcomes were focused on I and little on S or R.

1. The noninfected gland may or may not be susceptible when exposed to pathogens.
2. The infected gland can only be determined with certainty by bacteriology of a milk sample.
3. The infection may be removed by
a. Spontaneous recovery or
b. Therapy
The gland then returns to the uninfected state, with or without a change to susceptibility.
4. The infection may develop to disease which may be resolved by
a. Spontaneous recovery or
b. Therapy or
c. Death

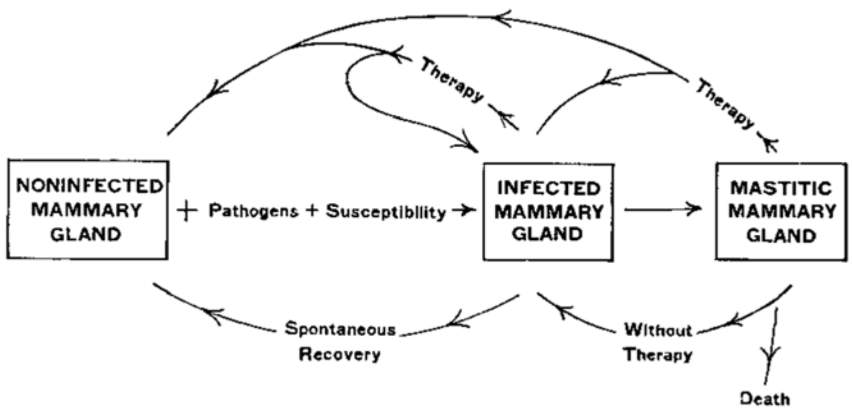

FIG. 1. Possible sequence of events in development of infection and mastitis.

From this, they proposed that a control scheme must be based on preventing new infections, the best method, and also on reducing the duration of infections, preferably thru cure rather than leaving a subclinically infected cow. The potential effect of reducing the duration of infections is shown in Figure 2. The discussion is about preventing and removing infections not simply the disease, clinical mastitis.

Both herds have 10 infected cows but all infections in herd B are shorter in duration. After MFE1, their first field trial, it was better described as

A		B		C
Prevalence of infection	=	Total cows infected during period	X	Average proportion of the period that cows are infected

For 700 cows in 14 herds, if A was 60% and B 80%, C was 75%. Three-quarters of all cows were infected for 75% of their lactation. Cutting either A or B by 50% would reduce A by 50% but cutting both by 50% would reduce A by 75%.

The original philosophy was based on quarters and not the whole udder, but that was over-simplistic because quarters are not independent. In practice, reducing the number of infected quarters by say 50% does not reduce the number of infected cows by 50%.

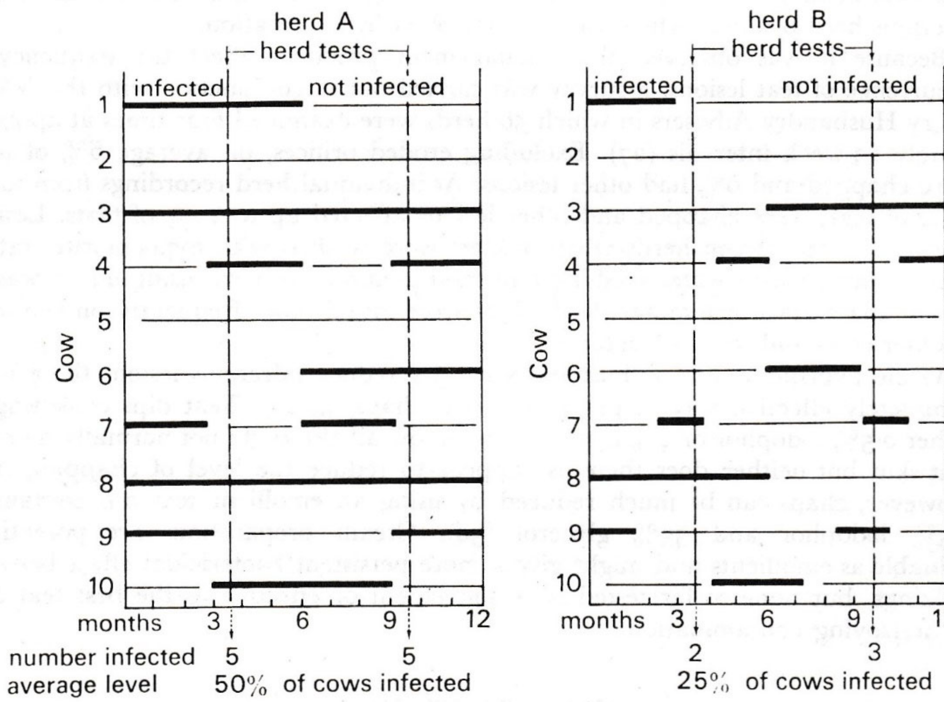

Figure 2. The effect of the duration of infection on the prevalence. The two herds each have eight cows infected but the average duration is twice as long in herd A; therefore, the prevalence is twice as high (Dodd & Neave, 1970, Figure 5).

The methods of control suggested by these models (Dodd et al., 1964) are:

- Eradication of all forms of infection, possible for *Str. agalactiae,* but too little was known about most pathogens
- Prevent infection by immunization (!)
- Widespread antibiotic therapy – an adjunct but already known to have limited effectiveness against *Staphylococcus aureus* and possibly cost-benefit prohibited
- Breeding for resistance

None of the four suggestions were possible at that time and some not even now; the one method of practical control was proposed to be appropriate management of cattle, as Murphy (1956) had argued, if only the weak areas could be identified. This was immediately recognized as being limited by the need to train farmers and staff, and ensure that these thousands of people conform to defined work patterns that eliminate greater susceptibility or reduce exposure, by hygienic milking processes.

It is assumed in SIR models that in any herd an equilibrium exists for any level or prevalence such that the number of infections removed equals the number of new infections created. For the infection level to be sustained (assuming all individuals are more or less susceptible) $R_0>1$ is required (rate of new cases produced X average period of infection has to exceed 1). One interesting feature to debate is whether, when a mastitis is cured, individuals become susceptible again or they have some immunity?

To reduce the prevalence of infection, i.e. get $R_o<1$, it is necessary to reduce the rate of new infection and/or reduce the length of infection.

- Reduce the rate of new infections: prevent infections by lowering exposure (no. infected herd mates, hygiene), including by increasing the cure rate, and improve 'conditions' predisposing to infection (poor teat condition, machine factors)
- Reduce the length of infections: cure in lactation, dry period cure, remove (cull)

NOTE: To date, the susceptibility to infection has not been effectively reduced by breeding or immune modulation.

<u>The Mastitis Field Experiments (MFE) and Dry Period (DP) Trials</u>

From 1959, in the first five years of their concentrated efforts on mastitis control, the NIRD team focused on hygienic methods of milking (MFE 1 and 2) and the elimination of infections in the dry period (DP1 and 2). Then the results were tested in a major field trial (MFE3) as a prototype integrated management control program. The results for the whole period are available in peer reviewed journals but the fullest description is given by Dodd & Neave (1970).

Preventing new infections

The key objective of hygienic milking practices was to reduce exposure of the cows' teats to pathogenic bacteria by reducing the sources and limiting transfer between cows, mostly by destroying pathogens on teat skin. At that time, the main sites of pathogens on teats were infected lesions. Various small-scale experiments suggested udder washing, teat disinfection and cluster pasteurization combined might be effective

The first field trial, MFE1, showed a 53% reduction in new infections using a full hygiene system of all three versus none but there was a large variation between herds. The teat disinfectants did not heal teats well, e.g. they did not reduce the occurrence of teat chapping.

Teat disinfection had been known since the work of Moak (1916) but was limited by low sophistication of disinfectants and lack of emollients (skin conditioners). Of many disinfectants tested in small scale trials none was ideal, although hypochlorite solutions and 0.5% iodophor were best. The most effective disinfectant was 1-4% sodium hypochlorite (bleach), still used widely today with some farmers diluting supermarket bleach (e.g. Chloros).

Real progress started to be made when various manufacturers developed better iodine technologies and use of chlorhexidine to replace chlorines. These new products allowed the inclusion of emollients (skin conditioners) such as lanolin or glycerin that contributed to healing damaged skin. Skin lesions were common at the time of the trials, often caused by damage from machine milking and any of several viral infections, e.g. herpes mammallitis and pseudo-cowpox. The lesions were often secondarily infected with any of *Staphylococcus. aureus, Streptococcus dysgalactiae,* occasionally *Trueperella pyogenes,* and *Streptococcus agalactiae.*

The new products became available for MFE2 which tested the same full hygiene, with rubber gloves for milkers added, against no hygienic methods and a third group of the hygienic methods without cluster pasteurization. Pasteurization was omitted because it was expensive and had limited practicality in commercial herds. Partial and full hygiene gave the same results (Neave et al., 1969). A key result was the massive reduction in lesions, especially chaps, so limiting reservoirs of pathogens on teats, hence reducing exposure and new infections (Figure 3). Thus, a practical method for limiting the rate of new infections on commercial farms was proven by trial. However, this had no effect on the duration of infections and so the effect on reducing the prevalence of infection was slow, about 14% per year.

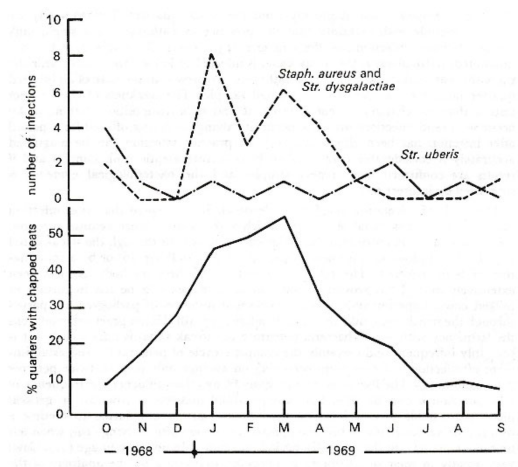

Figure 4. The relationship between teat chaps and new infections (Dodd & Neave, 1970, Figure 3. Data actually from MFE3).

Eliminating infections

The data from MFE1 suggested that 20% of all infections disappeared spontaneously and 29% were removed by antibiotic therapy for clinical mastitis. Therapy had limited efficacy for all infections as the milkers only found 40% of all infections, 843 of 2114 confirmed by laboratory culture of regular milk samples. However, 72% of treated infections were removed by antibiotic treatment, twice as many streptococcal as staphylococcal infections. At drying off, infected cows were treated using the same antibiotic products, but only 7% of infections were removed. These products were mostly short-acting penicillins, however some penicillins in a slower release base suggested better efficacy against staphylococci. These newer short-acting products were still not effective in preventing new dry period infections. Effective prevention, and cure, of infections in the dry period was generally not possible.

Beecham Research Laboratories in the UK developed a novel formulation of benzathine cloxacillin in a slow-release base for intramammary infusion. NIRD studies (DP, dry period, trials 1 and 2) showed that, at the correct dose, it remained effective for up to five weeks providing useful rates of cure (especially of *Staphylococcus aureus*) and prevention of most new dry period infections (Smith et al., 1967). This allowed targeting of a significant period when new, and persisting, infections occurred. Neave et al. (1950) had shown that a new infection occurred in about half of the dry cows examined, with 40% previously uninfected cows becoming infected and 75% already infected cows suffering another infection. DP 1 and 2, using the correct amount of the persistent formulation, reduced staphylococcal infections at calving by 75% and streptococcal infections by 89%, compared with untreated controls, and achieved a reduction in clinical mastitis of 85% post calving (Smith et al., 1967). This new technology, infusing each quarter of the udder with an antibiotic preparation at drying off, was highly effective on both elimination of existing infections and prevention of new infections.

Culling
Culling infected cows is the ultimate method of eliminating infections. Interestingly, the MFE experiments did not test the effect of culling on the rate of elimination. Dodd & Neave (1970) simply state that cows with eight or more cases of clinical mastitis in the same lactation were culled. The various later trials used a clinical rate of 5-8 cases per cow per lactation as the threshold for culling. This was irrespective of how good the cow was otherwise. Culling cows having suffered three of more cases of clinical mastitis in a single lactation has become more common in commercial fairy farming.

Milking machine
The Fell (1964) review concluded that evidence for machine milking affecting mastitis was conflicting, except when the milking action, e.g. excessive vacuum or inadequate pulsation, caused teat damage that pathogens could colonize, and that the milking cluster was a mechanical vector for bacterial transfer from infected cows (quarters) to uninfected animals. This was agreed by Dodd & Neave (1968) when machine milking was the subject of a symposium at NIRD. Evidence otherwise was limited. This symposium promised much but was marred by the tragic loss of three young Irish researchers who died in a plane crash (Aer Lingus 712, 24th March 1968) on their way to the meeting. In their papers presented in their honor, John Nyhan and Michael Cowdig (along with Tom Dwane) first opened the vital subject of how vacuum fluctuations affect the rate of new intramammary infections (Cowdig, 1968; Nyhan, 1968). This was too late for the mastitis control plan being developed. However, the meeting's enduring success was to stimulate the International Dairy Federation, and subsequently the International Standards Organization, to work with researchers and manufacturers to rationalize many individual national technical requirements into a robust standard. First, there was agreement on terminology (ISO 3918, 1978), with several later updates, and then separate national standards were restructured to create international standards (e.g. BS5545, later ISO5707). With regards to mastitis, its control has been much improved by the requirement for a stable (and lower) vacuum; a larger claw volume with a larger air bleed; wider short milk tubes; adoption of alternate pulsation; and greater effective vacuum reserve, at least. These technical advances far exceed in effect the simple benefits of testing and fixing of the milking machine, as maintenance is no substitute for poor design, manufacture and operation.

By the mid-1960s the key tools to reduce exposure to pathogens and eliminate existing infections had been developed. Their effect in commercial herds was tested in MFE3 from 1966-69, subsequently in associated trials, initially in the USA by the Cornel group (Natzke et al., 1972) and later in many countries by many different groups.

Mastitis Control Plans Post MFE3

NIRD/CVL Mastitis Control Plan
The mastitis control plan, based on the extensive studies of the NIRD group and the field trial jointly with the Central Veterinary Laboratory (MFE3), was initially outlined in June 1970 (Kingwill et al., 1970) and then launched to UK dairy farmers in a pamphlet later in 1970 (NIRD/MAFF, 1970) and to the broad industry, especially veterinarians, advisors and farmers, on January 5-6, 1971 at Reading University, in a joint meeting of the British Cattle Veterinary Association and the government Agricultural Development Association (the advisors).

The strategy for effective mastitis control required the components:

- disinfecting every teat of every cow promptly after every milking,
- treating every clinical case of mastitis with appropriate therapy, and recording the case,
- application of dry period antibiotics to all quarters of all animals to return to the herd,
- culling all cows that suffered too many cases of clinical mastitis in the previous lactation and
- ensuring the milking machine was tested annually and maintained to operate according to its design requirements

The trials to prove the outcomes possible and those responsible for the thinking and the practice are clear. The origins of the term Five-point plan, who invented it, where and when, have appeared less clear.

Actually, the NIRD/MAFF (1970) leaflet describes only three main points with two sub-points: dipping all teats in disinfectant, treating infections at dry off and clinical cases, and culling non-curing cows. It makes no mention of milking machine testing or maintenance. Other descriptions of MFE3 (e.g. Kingwill et al., 1970) say the machine was tested and maintained regularly on all 30 test farms and so this aspect was not trialled for effect; perhaps explained by the earlier thoughts of Dodd & Neave (1968) that the machine influence was principally on damaging teats and hence was covered by all machines operating similarly and teat disinfection 'healing' teat trauma.

The Dodd & Neave (1970) and Kingwill et al. (1970) descriptions of MFE3, from which the plan was developed, also describe three points but these are teat disinfection and wearing gloves, drying off and lactational therapy, and machine testing and maintenance, but not culling. Dodd consistently reported a three-point plan thru to at least 1983 (e.g. Dodd 1983). Wilson & Kingwill (1975) also describe a three-point plan from the NIRD/CVL studies, of Prevention, Elimination at dry off and by culling, and Machine testing/maintenance but no mention of therapy for cases in lactation even though MFE3 started with a test of blitz therapy of identified infections (the effect did not persist beyond the first year).

The plan from NIRD/CVL was only ever described as three (+2) points until, in 1985, Dodd & Hoare wrote that the so-called five-point plan is now generally accepted, referring to a term originating in an Australian report (Blood, 1966) pre-dating MFE3 and the availability of modern sanitizers and persisting dry period antibiotics. However, this early Australian plan was only a suggestion. It comprised 1. Correct adjustment and proper use of milking machines (✓), 2. Removal of the source of infection….by suitable treatment and culling (✓✓), 3. Use of clean running water for cluster back-flushing (pasteurization suggested by MFE2 to be of little benefit) and udder washing (X), 4. Post-milking teat disinfection (✓) and 5. 'Efficient treatment' (repetition of 2). This original Australian proposal never seems to have been implemented or evidence in support developed by research or testing, certainly at that time.

Beechams Research Laboratories

Blacks Veterinary Dictionary (15th edition) in 1973 included a Six-point plan, and still does so today (21st edition). This is accredited to Beecham Laboratories Ltd who, apparently, after their involvement in the 1971 UK launch made their own adaptation for extension to veterinarians of six points. Beechams, and the disinfectant industry, had some ownership in the plan as developers of dry cow antibiotics, and much better teat disinfectants. They also had a better route to veterinarians whose role has always been important.

The Milk Marketing Board of England & Wales
Despite all this confusion, practical application of a national mastitis plan in the UK, post the 1970/1 launch, quickly evolved the plan into the well-known five points. As a *five-point plan* it was first rolled out to farmers through the Veterinary Research Unit (led by James Booth) of the Milk Marketing Board of England & Wales (MMB) in two large trials comprising 250 herds each with 140 control herds, from November 1971 to April 1974, one trial in the north and one in the south of England; in a limited way by veterinarians of the Southern Counties Veterinary Society (SCVS) wanting to test under 'field conditions'; and doubtless by other pioneers. The five points were later wrapped in an overriding aim of 'better management' that constitutes the occasional sixth point.

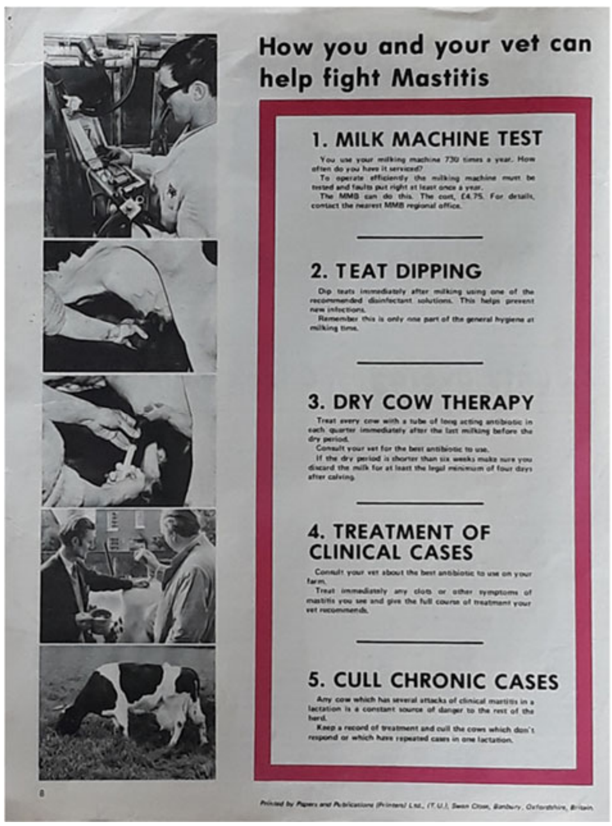

Figure 5. The first publication of the Five-point plan, from the summer 1970 MMB Better Management, page 8.

The progress made by the SCVS was reported by Thornton (1972). Simply, after adopting the NIRD/CVL plan, the trial herds lowered cell count by 51% and clinical cases by 20% within one year. This persisted over a second year. But the trial, on 30 farms initially, was not supervised, only encouraged by the veterinarians. The lack of supervision led to a noticeable loss of enthusiasm by the farmers and their staff and increasing variability in application and results, despite clear financial benefits to the farms.

From the very beginning, i.e. November 1971, the practical advice from MMB to the farmers was condensed into the Five Points, as now recognised, because an unwieldy number of points was being discussed at NMC, numbers considered far too many for farmers to adopt easily. The plan of the trials was first available in the 1971 summer edition of the magazine, a mastitis focus, 'MMB Better Management' (Figure 5). The magazine contained a useful center-page poster of cartoons and section to plot monthly cell counts.

This appears to be the definitive origin of the Five-Point Mastitis control plan.

Booth (1975a) presented the results from the MMB trials, in some detail, to NMC. Essentially, cell counts reduced from 511,000 to 429,000 cells/mL (-17.8%), average milk yield increased >3%, clinical cases declined markedly but variably, and financial performance improved, all despite the trials running in a period of significant depression in dairy farming.

In 1971 the MMB introduced its system of herd milk cell counting. It proved to be hugely valuable to farms and advisors in assessing progress in the control scheme trial and its later adoption.

The various trials were considered sufficiently encouraging that UK advice was promoted from 1973 by a UK National Mastitis Awareness Scheme (later Campaign, NMAC) and the MMB Mastitis Control Service, thus becoming widely adopted throughout the veterinary, advisory and dairy farming communities. However, the NMAC plan was first promoted as a six-point plan: good stock management, preventing infection, treating disease, culling, monitoring cell counts and efficient milking. This was an amalgamation of the NIRD/CVL advice, the new cell count service, looked like the Beecham's advice, and remained somewhat inconsistent until the Five-point plan became recognized for its simplicity and applicability. The Five-point Plan has never excluded any supplementary services.

Waikato, New Zealand

The southern MMB trial in the UK was led by Graham Duirs, a Kiwi spending three years working with James Booth. He returned to New Zealand in 1974, to join the Waikato Dairy Laboratory at Ruakura, joining a team led by Alan Twomey and including John Milne.

In 1974 the New Zealand Ministry of Agriculture & Fisheries produced a Milking Management leaflet (MAF, 1974) that launched a New Zealand five-point plan devised by Twomey, Milne and Duirs. Whilst the cover has the five points (Figure 6), the inside has ten listed points. No mention was made of the origins or any testing of the components of their proposal but the influence of the UK science and the MMB program is obvious. The New Zealand efforts involved highly imaginative and innovative marketing/extension techniques.

A 1975 leaflet (MAF, 1975). featuring cartoons by a well-known artist, particularly engaged farmers with easy and clear messages. The advisory team travelled widely to various farmer meetings. On their travels, the more musically inclined created various lyrics set to traditional tunes to while away the time. These were gathered, recorded by the Waikato Dairy Lab singers and published by the Ministry of Agriculture & Fisheries as 'Mastitis Melodies' becoming hugely popular and even getting radio airtime. The New Zealand extension program became a classic demonstration of how to engage with farmers.

Figure 6. New Zealand leaflet (MAF, 1974)

The New Zealand program produced further important learnings. It was initially based in the Waikato and did not involve dairy companies, their technical support and management in most other areas. Perhaps that is why veterinarians working for Rangitaiki Plains Dairy Company, which had its own plan for mastitis control, claimed (Anderson & Blackshaw, 1977) that of course New Zealand dairy farmers already managed mastitis control properly. However, their letter really destroys their own argument as their company sales records showed only 47% of farms bought any disinfectant and the letter claims antimicrobial therapy is not cost efficient (but 47% of farms spent nothing on dry period antibiotics). The chairman of the company even complained to the government creating a (temporary) fuss and call for Alan Twomey to attend senior officials in the capital. It was necessary to get buy-in dairy company (cooperative) by company.

Elsewhere

Cornell University had a stake in the game. This started with Dodd's sabbatical in 1964 and continued thru their parallel field trial in the late 1960s. Their field study was a little different, using only hypochlorite as the disinfectant and a large dose of penicillin/dihydrostreptomycin, not cloxacillin, for dry cows. Complementary results were obtained with a 75% reduction in infection prevalence, and 7.8% more milk (Natzke, 1972).

In summary, the plan came from innovative British research; it followed a loose term originated in Australia; the evolution of the plan into five points was by the MMB for practical application to farmers in the UK; the Kiwis launched a bold and imaginative extension project; and successful adoption has been enjoyed for nearly 40 years by British, New Zealand, Australian and US dairy farmers (and later many others), and their cows.

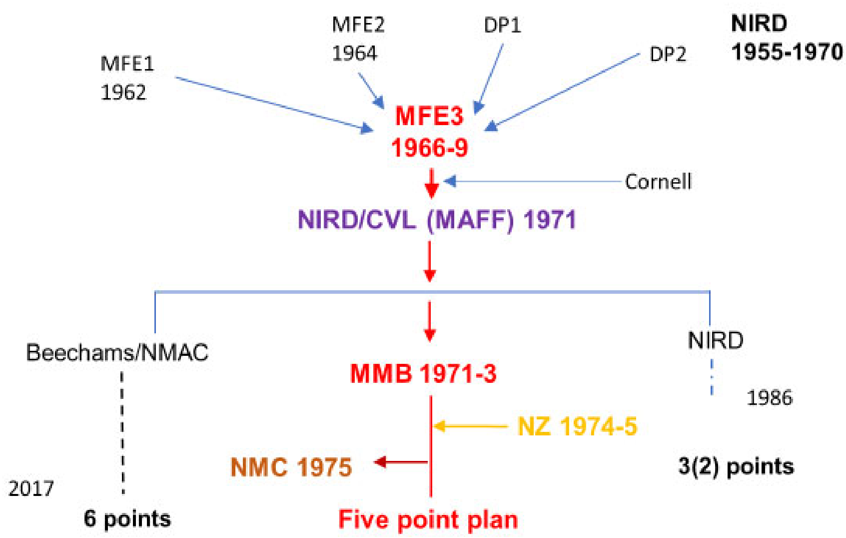

Figure 7. A Timeline of the plan development

<u>The Outcome and Learnings</u>

Application of the results from MFE3 in subsequent trials revealed the difficulties in applying the mastitis control plan in real-time and on relatively uncontrolled and unsupervised farms where there were few obvious and short-term incentives. Neither veterinarians nor advisors ever have enough time on farm to supervise, therefore farmers have to be properly and continuously motivated to adhere to the mastitis control plan being adopted.

Milking machine MFE3 did not test the role of the milking machine but set minimum operating requirements, now far exceeded by today's standards. The trials with UK farmers required that proper operation of the milking machine was the starting point to remove any risk from the milking process and because this positive improvement made farmers more receptive of further advice. Thus, the first point is proper machine testing and maintenance. The order of the other points is logical. In the 1970s only 29% of farms reported having their machine checked annually (Booth, 1975b). It is regrettable that despite much better milking machines today, dairy farmers still fail to remedy machine defects identified by testing with 60% of machines not meeting operational requirements (Berry et al., 2016).

Teat disinfection Disinfecting every teat of every cow after every milking is one of the two core requirements but is the most variable in means and quality of application, and requires use of a quality product. Consistent use is often affected by operator stress and farm economics. In the 1970s only 35% farms teat dipped after milking and 30% of those withdrawing from the MMB trial did so because teat dipping was too difficult (Booth, 1975b). The New Zealand attempt at the program initially did little better despite their supposed saving of staff time by spraying the disinfectant.

Lactation therapy This depends on detection and appropriate treatment, according to the likely pathogen. Initially getting buy-in from veterinarians and veterinary authorities was not easy. The role of the farm veterinarians was crucial and remains so as they are the source of proper advice and all prescription medicines.

Dry period protection. The need for dry period therapeutic elimination has always been the second most crucial component but is now less so. The need to prevent new infections in the dry period remains mandatory but does not necessarily require antibiotic use.

Culling The need to get rid of the persistently mastitic cow persists. In many cases there is now more opportunity to cull on udder health as fewer cows need to be removed for other health reasons.

All findings show that it is important the plan is applied in this order and no other.

Many studies and reports have shown the effectiveness of the Five-point plan. Whilst it is applied at herd level the benefits are most obvious at national levels. Two examples are considered: first, the improvement in udder health of dairy cows in the UK (where the NMAC was pursued with some vigor, particularly by cattle veterinarians) as measured by national cell count (Figure 8) and then the rate of clinical mastitis in an individual herd paying very close attention to following the plan (Figure 9). The annual average cell counts for the MMB of England & Wales (until its demise) show that the plan significantly influenced the prevalence of infection in the national herd with the average cell count halving over 20 years (Figure 8). The variation in effect was also influenced by the motivation to apply the plan better especially culling mastitic cows, the poor economic health of the dairy industry in 1975-6, the bacterial content payment scheme starting in 1983 and the cell count payment scheme in 1990.

The impact remains real and the applicability can be demonstrated repeatedly. When NIRD closed in 1985, the successor group moved to (what became) the Institute for Animal Health at Compton and inherited a research herd with less than perfect mastitis management. Good application of the Five-point plan led to the elimination of *Staphylococcus aureus* infections and minimal clinical mastitis by contagious pathogens (Hillerton et al., 1995), despite the best attempts of various scientists to create infection by experiments in pathology, immunology and milking machine investigations, and trials including testing teat disinfections.

All examples available show how well the Five-point plan works, and all also show that the effects are incremental over time. MFE3 showed with rigorous supervision the level infection could be halved in two years but the full effects took some time longer (Kingwill et al., 1970). The national benefits only became obvious after about ten years of accumulative adoption as determined by clinical incidence (Figure 8) and national cell count (Figure 9) although many other factors contributed., requiring accumulative adoption. Persistence with mastitis management is essential.

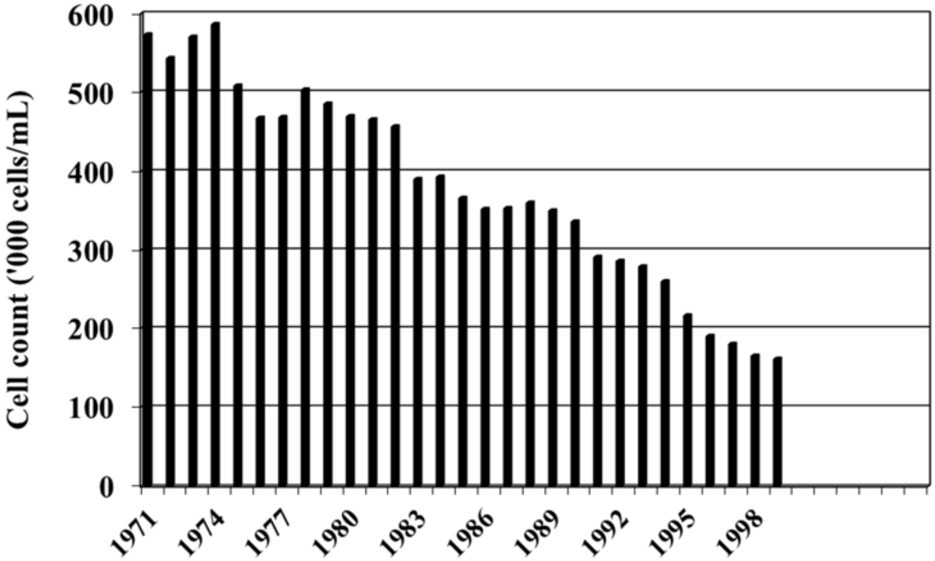

Figure 8. National cell count data for England & Wales showing improvement from start of Five-point plan.

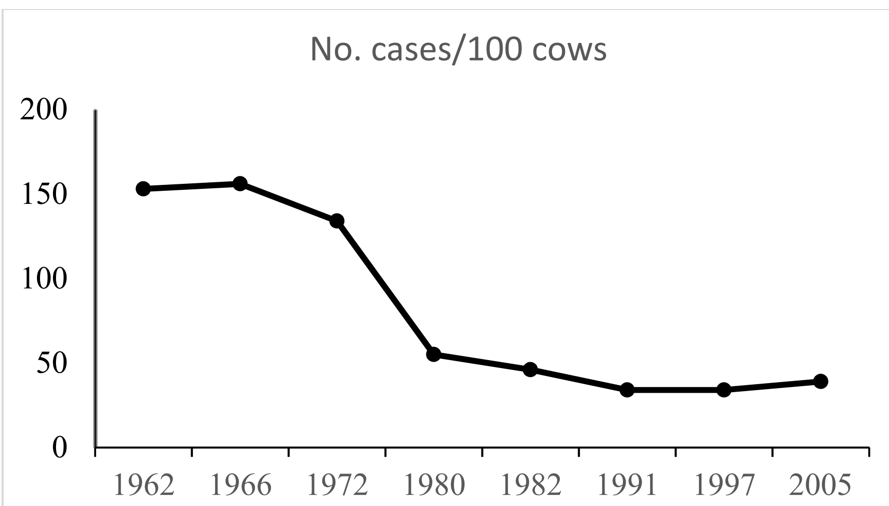

Figure 9. Clinical cases at Institute for Animal Health Chesridge herd showing effect of applying the Five-point plan.

Farmers and staff must want to manage mastitis risk in their herd. To maximize adoption there must be understanding of the issues, education in the aims and outcomes of the components of the plan, and full realization that benefits do not accrue in days or weeks but in years. The farmer needs training, motivation and above all patience.

The mastitis control strategy comes with pre-identified shortcomings:

1. All mastitis probably cannot be eradicated although any herd can certainly be made free of *Streptococcus agalactiae*.
2. It applies best to contagious mastitis with very good evidence for *Staphylococcus aureus, Streptococcus agalactiae* and *Streptococcus dysgalactiae,* and some evidence for

Corynebacterium ulcerans and various other pathogens. It is often claimed the plan is not effective against environmental bacteria, but mastitis caused by *Streptococcus uberis* was halved in MFE3, and now we know hygienic teat preparation can be effective against most organisms.

Most importantly the control methods in the plans were directed at contagious mastitis which was more than 80% of the problem on farms at that time. The plans were developed for the 1960s dairy farm and many evolutions in farm system since then have changed many aspects of dairy farming.

Next

Our inheritance will always contain the thinking on applying simple and cost-effective methods usable on farm. The Five-point plan will always be the basis of mastitis control, however much we augment it to deal with farm system evolution, better immune systems and modulation in the cow, and selection for genetic resistance. However, it will be (is being) challenged as we must minimize use of antimicrobials, especially dry cow products. Notwithstanding, hygienic milking to prevent new infections and minimizing the duration of existing infections are the dairy farmers' holy grail for control of mastitis. But that still requires us to fill the gap of sufficient education on what to do and motivation do it properly and continually.

Many mastitis researchers have been regularly teased that after many decades of research on mastitis, nearly 60 years of NMC, 70 years of penicillin and approaching 50 years of the Five-point plan, new projects arise and we still need to meet the challenge of reducing the burden on the cow. As Wilson (1952) said 'Mastitis is similar to the poor, we shall always have it with us' because farm systems evolve and people change.

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Appendix

The People

Frank Dodd – An eclectic animal scientist who joined NIRD in the mid1940s, later to become head of Dairy Husbandry. He published widely on milking systems, udder health and mammary gland physiology. Frank was a leader in the IDF Group of Experts on Mastitis (A2) activities and became a facilitator melding the disparate international views on mastitis and milking systems.

Frank Neave – A microbiologist who joined NIRD in the early 1940s. He started his research in cleaning of milking systems; first papers found in 1943. He was prodigious in his research but less so in his journal publishing. He came to be particularly astute in understanding teat condition. Much of his knowledge underpinned development of teat disinfectants and the understanding of teat condition that became the focus of the Teat Club International.
Roger Kingwill – A key member of the NIRD mastitis team, jointly made up of microbiologists, milking machine specialists and husbandry scientists.

CD Wilson – A state veterinarian at the Central Veterinary Laboratory. He led the CVL team, essential in the farm components of MFE3 and later extension and education.

James Booth – A veterinarian who led the Veterinary Research Unit of the MMB and first simplified the control plan into five points easily understood by farmers. He recalls doing this in a pub in London but not which of the more than 300 he has visited! James was a career-long member of NMC.

Dairy Customers and Consumers are Asking 'What?!?' About Udder Health?

Jamie Jonker
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Introduction

Dairy customers and consumers are asking more questions with increasing requirements about how milk is produced on the farm for the dairy products they produce and consume. Many questions and requirements focus on milk quality and antimicrobial use – which is really "udder health." While many factors have shaped these questions and requirements, the underlying driving force is antimicrobial resistance and the obligation of judicious and responsible use by all users of antibiotics to ensure their effectiveness now and in the future.

The concern over antimicrobial resistance is not new, indeed resistance to sulfonamides was first reported in the late 1930s (Davies and Davies 2010). In 1998, the World Health Assembly of the World Health Organizations (WHO) adopted a resolution (WHA 51.17) to support countries in their efforts to control antimicrobial resistance. In 2003, the World Organization for Animal Health (OIE) convened an *ad hoc* Group on Antimicrobial Resistance recognizing the importance of the issue. In 2013, the U.S. Centers for Disease Control and Prevention (CDC) provided a first-ever snapshot of the burden and threats posed by the antibiotic-resistant germs estimating "*that in the United States, more than two million people are sickened every year with antibiotic-resistant infections, with at least 23,000 dying as a result*" (CDC 2013).

The dairy industry has also recognized the concern over antimicrobial resistance with most research focusing on mastitis-causing organisms. Beginning in 2005, the International Dairy Federation (IDF) has conducted an annual review of scientific literature to examine the potential emergence of antimicrobial resistance in mastitis pathogens. More than four decades of use for mastitis *"has not resulted in the apparent emergence or progression of resistance in bacteria causing the disease"* (Hogan 2017).

With antimicrobial resistance as the underlying concern, how are customer and consumer questions about antibiotic use shaped and how do they impact antibiotic use decisions on-farm? The first part is government regulation – what are the minimum rules on antibiotic use. A second part is the influence of Intergovernmental Organizations (IGOs) and Nongovernmental Organizations (NGOs) – what should be done above the minimum rules established by individual country regulations. These help to inform public opinion and consumer attitudes that influence customer expectations. Pulled all together, these impact the use of antibiotics at the farm level having implications for udder health.

U.S. Antibiotic Use Regulations

The Federal Food, Drug, and Cosmetic Act gives the U.S. Food and Drug Administration (FDA) the legal authority to approve and regulate drugs including antibiotics for both people and animals. Any antibiotic used to treat, control, or prevent disease in dairy cattle in the United States must be approved by FDA. The process to approve and regulate animal drugs through

FDA's Center for Veterinary Medicine (CVM) is well defined (FDA CVM 2017). FDA also issues *Guidance for Industry* to help industry satisfy the requirements of statutes and regulations. FDA has issued a several interrelated *Guidance for Industry* and updated regulations which influence how and when antibiotics may be used in animals. Additionally, several states have enacted regulations antibiotic use specific to livestock production.

FDA Guidance for Industry #144
"Pre-Approval Information for Registration of New Veterinary Medicinal Products for Food-Producing Animals with Respect to Antimicrobial Resistance" is a harmonized technical guidance (FDA CVM 2004) for the United States, the European Union, and Japan for registration of antimicrobial veterinary medicinal products for use in food-producing animals to characterize the potential to select for resistant bacteria of human health concern.

FDA Guidance for Industry #152
"Evaluating the Safety of Antimicrobial New Animal Drugs with Regard to Their Microbiological Effects on Bacteria of Human Health Concern" guidance (FDA CVM 2003) outlines a risk assessment approach for evaluating the antimicrobial resistance resulting from the use of antimicrobial drug in food-producing animals. It also ranks classes of antimicrobials as to whether they are critically important, highly important, or important to human medical therapy.

Guidance for Industry #209
"The Judicious Use of Medically Important Antimicrobial Drugs in Food-Producing Animals" guidance (FDA CVM 2012) has two principles to minimize the development of antimicrobial resistance from the use of medically important antimicrobial drugs in animal agriculture:

- Principle 1: The use of medically important antimicrobial drugs in food-producing animals should be limited to those uses that are considered necessary for assuring animal health.
- Principle 2: The use of medically important antimicrobial drugs in food-producing animals should be limited to those uses that include veterinary oversight or consultation.

Guidance for Industry #213
"New Animal Drugs and New Animal Drug Combination Products Administered in or on Medicated Feed or Drinking Water of Food-Producing Animals: Recommendations for Drug Sponsors for Voluntarily Aligning Product Use Conditions with GFI #209" guidance (FDA CVM 2013) requested and all pharmaceutical manufacturers agreed to voluntarily withdraw "weight gain" and improved feed efficiency" claims for medically important antimicrobials by December 31, 2016. Additionally, the guidance recommended revision to the conditions of use of medically important antimicrobials administered in feed from over-the counter to a Veterinary Feed Directive and in water from over-the-counter to prescription.

Veterinary feed directive
In 2015, FDA CVM finalized changes to the Veterinary Feed Directive (VFD; FDA 2015), the process for authorizing use of animal drugs intended for use in or on animal feed that require the supervision of a licensed veterinarian. The VFD changes also provided veterinarians with a

framework for authorizing the use of medically important antimicrobials in feed when needed for specific animal health purposes.

State regulations
Since January 1, 2018, California has required all medically important antibiotics used in livestock production to be prescribed by a veterinarian through an established veterinarian-client-patient-relationship, including intra-mammary use (CDFA 2018). California has also restricted the "regular pattern" use of antibiotics for disease prevention. Maryland has also enacted similar legislation beginning in 2018, although it has an exemption for farms selling less than 200 cattle, 200 swine, or 60,000 birds per year (Everhart 2017).

<u>Intergovernmental Organizations</u>
IGOs have an increasing influence on the use of antimicrobials at the farm level due to increasing importance of international trade – 14.2 percent of United States milk solids were exported in 2016 (USDEC 2017). Some IGOs (such as OIE and Codex Alimentarius) establish international food safety and animal health standards which can be enforced through trade agreements while others (such as FAO and WHO) exert influence due to their international intergovernmental standing.

World Health Organization
In May 2015, WHO adopted a "Global Action Plan to Combat Antimicrobial Resistance" (WHO 2015) with the goal to ensure, for as long as possible, continuity of successful treatment and prevention of infectious diseases with effective and safe medicines that are quality-assured, used in a responsible way, and accessible to all who need them. To achieve this goal, WHO set forth five strategic objectives:

- Improve awareness and understanding of antimicrobial resistance through effective communication, education and training;
- Strengthen the knowledge and evidence base through surveillance and research;
- Reduce the incidence of infection through effective sanitation, hygiene and infection prevention measures;
- Optimize the use of antimicrobial medicines in human and animal health; and
- Develop the economic case for sustainable investment that takes account of the needs of all countries and to increase investment in new medicines, diagnostic tools, vaccines and other interventions.

In November 2017, WHO issued new guidelines on use of medically important antimicrobials in food-producing animals, recommending that farmers and the food industry stop using antibiotics routinely to promote growth and prevent disease in healthy animals (WHO 2017). The overarching recommendations included:

- An overall reduction in use of all classes of medically important antimicrobials in food-producing animals;
- Complete restriction of use of all classes of medically important antimicrobials in food-producing animals for growth promotion;
- Complete restriction of use of all classes of medically important antimicrobials in food-producing animals for prevention of infectious disease that have not yet been clinically diagnosed; and

- Antimicrobials classified as critically important for human medicine should not be used for control of the dissemination of a clinically diagnosed infectious disease identified within a group of food-producing animals.

Food and Agriculture Organization
In 2016, the Food and Agriculture Organization of the United Nations (FAO) released "The FAO Action Plan on Antimicrobial Resistance 2016-2020" (FAO 2016). FAO plays a key role in developing countries to support governments, producers, traders and other stakeholders to move towards the responsible use of antimicrobials in agriculture. The FAO Action Plan addressed four major focus Areas:

- Improve awareness on AMR and related threats;
- Develop capacity for surveillance and monitoring of AMR and AMU (antimicrobial use) in food and agriculture;
- Strengthen governance related to AMU and AMR in food and agriculture; and
- Promote good practices in food and agricultural systems and the prudent use of antimicrobials.

World Organization for Animal Health
In 2007 (and most recently updated in 2015), OIE adopted a list of "Critically Important Antimicrobials for Veterinary Use" (OIE 2015) with respect to their importance in the treatment of specific animal diseases. The list complements the five relevant chapters of the "Terrestrial Animal Health Code" (OIE 2017) which establish international standards for minimizing antimicrobial resistance from their use in animals. The OIE considers that ensuring appropriate access to effective antimicrobial agents to treat animal diseases is vital, but stresses the necessity to control access through the intervention of veterinarians. The OIE engages in preventing antimicrobial resistance worldwide through:

- Promotion of responsible and prudent use of antimicrobial agents in veterinary medicine;
- Reinforcement of good governance of Veterinary Services;
- Better knowledge and monitoring of the quantities of antimicrobials used in animal husbandry;
- Harmonization of national antimicrobial resistance surveillance and monitoring programs, and implementation of international coordination programs; and
- Implementation of risk assessment measures.

United Nations
In 2016, the United Nations adopted a "Political Declaration on Antimicrobial Resistance" (UN 2016) affirming commitment for the development of national action plans based on the 2015 WHO "Global Action Plan on Antimicrobial Resistance" including coordination with the FAO and OIE. The political declaration recognized that the key to tackling antimicrobial resistance lies with prevention and control of infections in humans and animals and calls for:

- Innovative research and development;
- Affordable and accessible antimicrobial medicines and vaccines;
- Improved surveillance and monitoring of antimicrobial resistance; and
- Increased international cooperation to control and prevent antimicrobial resistance.

Codex Alimentarius

In 2000, a discussion paper on “Antimicrobial Resistance and the Use of Antimicrobials in Animal Production” was discussed by the Codex Committee on Residues of Veterinary Drugs in Foods (CCRVDF 2000). Based on this discussion paper, CCRVDF undertook work which in 2005 resulted in the Codex Alimentarius Commission (CAC) adopting a standard on “Code of Practice to Minimize and Contain Antimicrobial Resistance” (CAC 2005). The Code included recommendations to prevent or reduce the selection of antimicrobial resistant microorganisms in animals and humans in order to:

- Protect consumer health by ensuring the safety of food of animal origin intended for human consumption.
- Prevent or reduce as far as possible the direct and indirect transfer of resistant microorganisms or resistance determinants within animal populations and from food-producing animals to humans.
- Prevent the contamination of animal derived food with antimicrobial residues which exceed the established MRL.
- Comply with the ethical obligation and economic need to maintain animal health.

In 2007, an *Ad hoc* Codex Intergovernmental Task Force on Antimicrobial Resistance (TFAMR) was formed to develop guidance on risk assessments and risk management options to minimize antimicrobial resistance for antimicrobials used in human and veterinary medicine. This work resulted in CAC adoption of “Guidelines for Risk Analysis of Foodborne Antimicrobial Resistance” (CAC 2011).

In July 2016, the Codex re-established TFAMR to develop science-based guidance on the management of foodborne antimicrobial resistance, taking full account of the WHO “Global Action Plan on Antimicrobial Resistance” (WHO 2015). The Task Force work includes revising the “Code of Practice to Minimize and Contain Antimicrobial Resistance” (TFAMR 2017a) and new guidelines on “Integrated Surveillance of Antimicrobial Resistance” (TFAMR 2017b). The Task Force work is anticipated to be completed in 2020.

<u>Nongovernmental Organizations</u>

NGOs have an influence on the use of antimicrobials at the farm level in a variety of ways. Some NGOs (such as IDF and the World Veterinary Association) represent differing parts of the production chain have policies on prudent use of antimicrobials to minimize resistance which are adopted and adapted by production systems. Other NGOs focus their priorities on prudent use of antimicrobials to minimize resistance to exert influence on regulations and corporate polices.

International Dairy Federation

In 2013, the International Dairy Federation published a “Guide to the Prudent Use of Antimicrobial Agents in Dairy Production” (IDF 2013) to provide a generic framework to support the responsible use of antimicrobial agents on dairy farms. The guide recognized that the whole of supply chain must be involved to manage the food safety risks associated antimicrobial use with specific roles for partners in the chain:

- Dairy farmers in managing animal health and husbandry practices to minimize the occurrence and spread of disease;

- Veterinarians providing expert advice to ensure that the most appropriate treatments are used correctly;
- Food (dairy and meat) processing companies in setting clear specifications for the raw products they source and in verifying and monitoring farmer compliance;
- Pharmaceutical companies in ensuring that antimicrobial agents are properly manufactured, assessed, labelled and then only sold through regulated distribution channels; and
- Competent authorities in effectively controlling the manufacture, registration, supply and use of antimicrobial agents, and in having effective systems in place to monitor for potential problems such as antimicrobial resistance.

World Veterinary Association
In 2016, the World Veterinary Association (WVA) released a "Policy on Responsible Use of Antimicrobials" (WVA 2016) because the use of antimicrobials in animals may contribute to development of antimicrobial resistance. The Global Basic Principles of Antimicrobial Use include the following recommendations:

- Decisions regarding limitation or control of antimicrobial use should be based on risk:benefit analysis;
- Antimicrobials that are important in human medicine should only be used in animals under veterinary care within a valid veterinarian-client-patient relationship;
- Antimicrobial susceptibility testing is an important element of responsible antimicrobial use including testing of individual cases with regional monitoring and reporting; and
- Effective alternatives to antimicrobials are needed and innovation in this area is encouraged.

Consumers International
In 2016, Consumers International released "Antibiotics Off the Menu" report as part of a campaign urging fast food companies to adopt corporate food sourcing strategies about antimicrobial use on food-producing animals (Consumers International 2016). Consumers International called for a commitment from multinational fast food companies that would include:

- Defining a global, time-bound action plan to phase out the routine use of antibiotics used in human medicine across all meat and poultry supply chains; and
- Adopting third-party auditing of their antibiotic use policies and benchmarking results showing progress in meeting the goal.

<u>Consumer Attitudes</u>
A recent consumer attitudes survey (IFIC 2017) found that nearly 25 percent of adults consider use of antibiotics in food-producing animals as one of the three most important food safety issues today. These consumers are more likely to be parents, have higher income, and be in better self-reported health (IFIC 2015). The top sources of information for those consumers who ranked antibiotic use is the top food safety concern are news articles/headlines (18 percent) and friends/family (18 percent).

Consumers do recognize animal get sick and 74 percent support the use of antibiotics to treat a sick food-producing animal (IFIC 2016). Three in five adults would be more confident that veterinarians and farms are using antibiotics responsibly if the FDA requires veterinary oversight for all uses of antibiotics.

Many consumers perceive the use of antibiotics on dairy farms as having a disproportionate link to the real human health issue of antibiotic resistance. Specifically, 35 percent of adults agree that antibiotics in milk contribute to antibiotic resistance in adults, and 34 percent of adults report hearing someone or some group talking about antibiotics in milk contributing to antibiotic resistance (DMI 2016a). Social media analysis reports that consumers voice concern about the threat to health posed by antibiotics in animals raised as food, and the growing threat of antibiotic resistance to human threat (DMI 2016b).

Consumers have negative views about the use of antibiotics on the farm. Consumer data suggests that some consumers choose organic dairy products due to concerns over the presence of antibiotics in milk (DMI 2016a). Similarly, some data suggests that consumers are choosing non-dairy alternatives due to concerns related to perceptions of antibiotic use on dairy farms. About one-third of consumers report buying food labeled "raised without antibiotics" (IFIC 2017).

Customer Expectations

Most consumer facing brands whether retail, food service, fast food, or restaurant, have made public statements and sourcing commitments related to antibiotic use in food-producing animals. Some corporate commitments are general potentially applying to all food sourced from animals, while others are specific to an individual livestock sector such as poultry. An emerging trend in sourcing animal products is "No Antibiotics Ever", that is antibiotics are not used even to treat disease in an animal. What is currently rare, is an antibiotic use policy specific to dairy production. Below are a few samples of current antibiotic use policies from a variety of dairy customers.

Chick-fil-A

"In partnership with our suppliers, we're working to establish a stable, sustainable, supply chain that can deliver on our promise of no antibiotics. Ever. This means that by the end of 2019, every customer, at every restaurant across the country will be served chicken without antibiotics every day (except Sundays, of course!)" (Chick-fil-A 2018)

McDonalds

"Seven criteria have been outlined to guide our work and will serve as goals for System Suppliers:

I. Antibiotics can only be used in conjunction with a veterinary-developed animal health care program.
II. Source raw material (meat) from Food Animals (beef, chicken, pork, dairy cows and laying hens) that are not treated with HPCIA.
III. Antibiotics identified as High Priority Critically Important, Critically Important, Highly Important and Important for human medicine and currently approved for veterinary use, should not be used as first line treatment, and only be used after susceptibility testing of the diseased animals has shown other classes of Antibiotics to be ineffective as determined by the attending veterinarian.

IV. Source raw material (meat) (beef, chicken, pork, dairy cows and laying hens) from Food Animals that are not treated with Antibiotics used solely for Growth Promotion. V. Routine Prevention use of Antibiotics is not permitted. For clarity, however, System Suppliers may continue to use Ionophores subject to applicable laws and regulations.

V. Utilize animal production practices that reduce, and where possible eliminate, the need for Antibiotic therapies in Food Animals and adopt existing best practices and/or new practices that would result in subsequent reductions of Antibiotic use.

VI. Benchmarking and measurement of Antibiotic usage is required to track performance. Successful strategies resulting in antibiotic use reductions will be shared broadly within the McDonald's System" (McDonald's 2017).

Subway

"Our goal is to reduce and eliminate the use of antibiotics in the food we serve globally. Elimination of antibiotics use in our supply chain will take time, but we are working diligently with our suppliers to find quality solutions that also ensure our high quality and food safety standards are upheld and not compromised in any way. Our plan is to eliminate the use of antibiotics in phases with the initial focus on the poultry products that we serve in the U.S. The transition to chicken products made from chicken raised without antibiotics was completed in 2016. The transition to turkey products made from turkey raised without antibiotics was started in 2016 and is expected to take 2-3 years. Supply of pork and beef products from animals raised without antibiotics in the U.S. is extremely limited. We expect our transition to take place by 2025. That said, we recognize that antibiotics are critical tools for keeping animals healthy and that they should be used responsibly to preserve their effectiveness in veterinary and human medicine. Our policy is that antibiotics can be used to treat, control and prevent disease, but not for growth promotion of farm animals. Accordingly, we are asking our suppliers to do the following:

- Adopt, implement and comply with the U.S. Food and Drug Administration's ("FDA's") guidance for industry 209 and 213, which requires that medically important antibiotics not be used for growth promotion.
- Assure that all antibiotics use is overseen, pre-approved and authorized by a licensed veterinarian before they are administered to any animal.
- Keep accurate and complete records to track use of all antibiotics.
- Adhere at all times to all legal requirements governing antibiotic withdrawal times. This assures that antibiotics have been eliminated from the animals' systems at the time of slaughter.
- Actively encourage, support and participate in research efforts focused on improving animal health while reducing antibiotics use" (Subway 2018).

Target

"We believe sick animals must be treated appropriately to end or reduce suffering. When antibiotics or antimicrobials are administered by a registered veterinarian, using them judiciously for therapeutic purposes, they play a critical role in the overall well-being of an animal.

However, we do not support the use of routine, non-therapeutic antimicrobials to promote growth. We expect our suppliers and the producers they work with to phase out this practice and only use antimicrobials when medically necessary.

There is greater risk to human health when antimicrobial-resistant bacteria develop due to overuse and misuse of certain medically-important antimicrobials. In response to this risk, we ask our suppliers to minimize and eventually remove the use of those deemed critical for human health by the World Health Organization (WHO) in its 2014 Antimicrobial Resistance Global Report and listed in FDA Guidance #209.

If animals are put into situations during their lives that increase their risk of disease or illness, that's a concern. That's why we have developed our food animal welfare policy that details the expectations we have of our suppliers and partners throughout the supply chain" (Target 2018).

Walmart

"Walmart believes that antibiotics should be used responsibly in farm animals, and with that in mind, the company is asking suppliers to:

- Adopt and implement the Judicious Use Principles of Antimicrobial Use from the American Veterinary Medical Association (AVMA) including accurate record-keeping, veterinary oversight, and limiting antimicrobial treatment to animals that are ill or at risk.
- Adopt and implement Voluntary Guidance for Industry #209 from the Food and Drug Administration in their own operations and their industry producer programs, including eliminating growth promotion uses of medically important antibiotics
- Promote transparency by providing a report on antibiotics management to Walmart and publicly report antibiotic use on an annual basis" (Walmart 2015).

Wendy's

"Our long-term goal is to find ways to phase out the routine use of medically important antibiotics on the farms that our suppliers source from. We have made great progress over the past year as we joined our key suppliers, farmers and ranchers in investigating environments, therapies and treatments that will reduce the need for preventive antibiotics" (Wendy's 2018)

Implications for Udder Health

While none of the regulations, policy positions, consumer sentiments, or corporate sourcing requirements explored above specifically mention "udder health" or use of antibiotics to treat, control, or prevent mastitis, combined they present a roadmap for "udder health" in the future. The destination at the end is reduced antibiotic use while maintaining and enhancing animal health, food safety, and milk quality. There will be multiple routes to the destination in the United States.

Regulatory oversight

There will be an ever-increasing regulatory oversight on the use of antibiotics in food-producing animals. The days of over-the-counter (OTC) availability of antibiotics are limited with more states likely to follow California and eventually a national restriction on OTC availability of antibiotics. This will include the current OTC lactating and dry cow mastitis treatments moving to prescription only.

Veterinary involvement

The role of the veterinarian will increase. As OTC availability disappears, prescriptions will be required in the context of a veterinarian-client-patient-relationship. Protocols for the prevention, treatment, and control of mastitis (as part of the larger herd health plan) will become common place written together with and approved by the veterinarian including any use of antibiotics during lactation and the dry period.

Selective dry cow therapy
Blanket dry-cow treatment will give way to selective dry cow treatment. Researchers, veterinarians, and dairy farmers are already experimenting with best management plans to implement selective dry cow therapy. With additional refinement, implementation experience, and new tools (see below), selective dry cow therapy will become the norm.

New tools
New and improved tools will be necessary for dairy farmers to maintain and improve "udder health" while reducing the need for antibiotic intervention. Such tools may include:

- Animal only antibiotics to avoid use of antibiotics deemed important for human medicine;
- Real-time diagnostics to improve decision-making on treatment including whether to use an antibiotic;
- Non-antibiotic interventions such as immunomodulators which may boost the cow's immune response to infection;
- Improved vaccine efficacy; and
- Genetic selection for mastitis resistance including gene editing.

Marketplace choice
The marketplace will continue providing consumers who have concerns about antibiotic use differentiated options in the dairy aisle to meet their needs. This may include products using a "No Antibiotics Ever" claim, which will come from dairy farms that will meet this demand. However, the dairy industry must remain vigilant to ensure the honest, responsible marketing of any differentiated product, given that farmers have already suffered from misleading claims made by brands purporting to be "hormone-free" or "GMO-free."

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The History of the National Dairy Quality Awards Program and Its Impact on Milk Quality

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The National Dairy Quality Awards (NDQA) program celebrates its "Silver Anniversary" (25 years) in 2018. The original idea for the National Dairy Quality Awards program came from the Upjohn Company. Upjohn had an NDQA program in the United Kingdom and wanted to bring a similar effort to the United States to promote and recognize herds with exceptional milk quality. The company partnered with Dairy Today magazine, which recruited entries, facilitated judging and promoted winners through the magazine. An annual recognition dinner was held in Madison, Wis., the week of World Dairy Expo. Winners received an all-expense paid trip for the banquet and to attend World Dairy Expo.

In 2000, to expand and broaden the effort, NMC assumed management of the NDQA program. Hoard's Dairyman became a key partner in publicizing the program, providing financial support and recognizing "the best of the best" when in comes to producing high-quality milk. Dairy farms are nominated for the award by dairy industry professionals, such as dairy plant field representatives, veterinarians, Dairy Herd Information (DHI) supervisors and extension personnel.

In the early years, winners were named by region and herd size. The "top dairy" was named the national winner. In 2003, the regional and herd size categories were dropped. Today, all types of dairies – from automatic milking systems to traditional tie-stall barns to dry lot dairies to organic management systems – "compete" against one another. Size and location also vary. For example, this year's Platinum winners range from 87 cows to 3,364 cows, and New York (eastern United States) to Idaho (western United States).

Whether it was 1994, when this program started, or today, the NDQA program has set the bar high by honoring the nation's top milk quality herds. By recognizing these leading dairy herds, milk quality becomes top of mind and collectively dairy farmers produce higher quality milk each year.

Here's some proof. In 2000, the average somatic cell count (SCC) in the United States was 322,000 cells/mL. DHI testing reported average SCC of 296,000 cells/mL, 288,000 cells/mL, 276,000 cells/mL, 262,000 cells/mL, 233,000 cells/mL, 228,000 cells/mL and 217,000 cells/mL, for 2005, 2006, 2007, 2008, 2009, 2010 and 2011, respectively. In recent years, the U.S. average SCC has dropped further – hovering around the 200,000 cells/mL mark.

The NDQA cycle starts each summer when individuals (not dairy producers) nominate outstanding milk quality herds. Evaluators look at two primary categories (and a couple others) – SCC and standard plate count (SPC) – when determining if nominees should become NDQA finalists. Besides looking at annual SCC and SPC averages, evaluators also consider the high month numbers for SCC and SPC when sorting through the nominations. NDQA finalists must consistently (every month of the year) market milk with low SCC and SPC levels. Some years, NMC receives more than 200 nominations. Being named a finalist is truly an honor.

The final application is quite detailed. Finalists and their nominators complete the application form, which is used for final judging. Dairy producers are asked about:

- Milk testing services
- Rolling herd average
- Culling numbers and reasons
- Cow deaths and reasons
- Milking team
- Milking procedures
- Milking and cattle housing facilities
- Heifer mastitis management
- Mastitis vaccines
- Fresh cow protocols
- Subclinical mastitis
- Clinical mastitis
- Milk culturing
- Mastitis pathogens
- Treatments and protocols for Grade 1, Grade 2 and Grade 3 mastitis
- Three-quartered cows
- Quarter milkers
- Extra-label drug use
- Cow identification
- Record keeping
- References

Each fall, a team of milk quality experts discusses aspects to evaluate and assigns scores to each aspect that is evaluated. The team meets face to face and reviews and scores all final applications. In 2017, the team evaluated more than 50 applications. Some the aspects that receive points include: milk quality measurements, systems of monitoring udder health, milking routine, protocols for detection and treatment of clinical and subclinical cases, prevention and treatment protocols, cow comfort, adherence to drug use, record keeping and strategies for overall herd health and welfare. SCC and SPC numbers are minor factors in finalists' total scores.

Dairies with the highest scores earn Platinum, followed by Gold and Silver. Typically, about six dairies receive Platinum distinction. If a dairy receives Platinum for two consecutive years, it must "sit out" for two years before being nominated again for the NDQA program.

Platinum award winners receive complimentary registration and lodging for the NMC annual meeting from NMC. Hoard's Dairyman provides a stipend to help offset travel expenses.

What does an NDQA Platinum dairy look like? It's all over the board. In nearly a quarter century, we've recognized quite a variety – organic, robotic milkers, elite genetics, tie-stall barns, waterbeds, seasonal, thousands of cows, only family labor, sole proprietors, multi-generational, drylots and Jerseys. There's no "true type" dairy when it comes to consistently producing top-quality milk. The common thread is "attention to details." Other common threads include: clean environment, excellent cow comfort, record analysis, employee training, milk culturing, NMC milking procedures, veterinarian-client-patient relationship, machine maintenance and monitoring, animal health monitoring and keen animal husbandry skills.

To give you a glimpse of what it takes to reach the Platinum level, let's peek at this year's Platinum winners.

<u>Bailey's Cherry Valley Dairy LLC, Tomah, Wisconsin</u>
Remove manure and wet sand from freestalls twice daily
Add sand from freestalls weekly
Adjust curtains according to weather
Culture high SCC cows to determine pathogen and give treatment based on culture results

<u>Butterwerth Dairy, Alpena, Michigan</u>
Massage teats as part of the udder prep process to ensure adequate stimulation time
Purchase fresh 2-year-old cows and request SCC data; cows with high SCC are not purchased
After receiving culture results, they consult their veterinarian for treatment recommendations
Notify milking team members via text message regarding treated cows

<u>Country Aire Farms LLC – Fox Ridge Site, Kaukauna, Wisconsin</u>
Rolling Herd Average: 32,390 pounds (14,692 kg) of milk, 1,192 pounds (541 kg) of fat, 972 pounds (441 kg) of protein
After forestripping, teats are foamed with a pre-dip and then dried with a cloth towel
Tunnel-ventilated freestall barn with waterbeds

<u>Folts Farms, North Collins, New York</u>
Milking cows for <2 years
2 robotic milkers
Groom sand-bedded stalls twice daily
Remove manure with alley scrapers that cycle every 2 hours

<u>SunRidge Dairy, Nampa, Idaho</u>
3,364 cows
Rolling Herd Average: 27,407 pounds (12,432 kg) of milk, 999 pounds (453 kg) of fat and 845 pounds (383 kg) of protein
20 different people milk the cows

<u>Tollgate Holsteins, Ancramdale, New York</u>
Average SCC: 44,000 cells/mL
High SCC: 46,000 cells/mL
Incorporate kiln-dried pine sawdust and hydrated lime into each stall daily

To learn more about the NDQA winners since 2000, visit: www.nmconline.org/ndqa.

Practices that Enhance Udder Health

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Introduction

Several years ago, I was participating in a meeting with a large dairy producer, his herd manager, his herdsman, representatives of the milking equipment dealership, the district sales representative from the milking equipment company and myself. The purpose of the meeting was to review the milk quality program of this very successful dairy. The dairy had instituted several mechanical and management practices to improve milk quality, but clinical mastitis was still an issue.

We went over all the recommendations that had been made and the progress of implementing each of them, so the owner was up to speed with exactly what was happening on the dairy. He then asked me what was the major issue with the continuing level of mastitis, when I paused for a few seconds before beginning to answer his question, he smiled, looked directly at me and his herd manger and stated: *"I guess it is just the little things that we need to do better every day to get this mastitis thing under control."* For most dairies it is the little things not one single issue that is causing a high somatic cell count or a high clinical mastitis level.

The new infection rate for mastitis is directly related to the number of bacteria on teats when units are attached. Herds with excellent milk quality typically are milking clean, dry, stimulated teats at most milkings.

Key Factor for Milk Quality

Whether a herd has 50 lactating cows or 5000, the key factor for achieving excellent udder health is the attitude of the owner towards producing milk quality. Obviously, this is much easier in small dairies where the owner is also responsible for a majority the labor. In larger operations, the attitude for milk quality must move through the organization by reinforcing the commitment to milk quality on an almost daily basis. Often larger dairies select various indicators for milk quality but, monitoring the key performance data selected by the dairy has to be very important to both management and employees if the goal of high quality milk shipped from the dairy is to be achieved. The goal is to allow employees to know how they did today! High quality milk production is best maintained when excellent training programs are in place for employees and employees are coached on a regular basis. Employees must understand the "why" behind the recommendations and protocols.

Common Management Practices for Milk Quality

A high percentage of the herds that are recognized at this meeting every year, see the benefit of paying for DHI services so they can monitor individual cows somatic cell counts on a monthly basis. These herds use the data to determine the new infection rate, the cure rate, the level of chronic cows in the herd, to evaluate the effectiveness of their dry cow program, and to know who the problem cows are in the herd on a monthly basis. Most herds also utilize cow side testing, such as the CMT test, to identify problem quarters for bacterial culture and possible treatment. Setting up a protocol of testing every fresh cow and heifer shortly after calving with a CMT paddle allows early intervention for culture and treatment assessment options.

Culturing the clinical cases of mastitis was done in a high percentage of the herds; they knew what bacteria are the primary causes of mastitis in their herds. Many herds delayed treatment until they had preliminary culture results, especially for mild and moderate mastitis cases. Many of the winning herds also had routine bulk tank cultures being performed on a regular basis. Quantitative bulk tank cultures not only can assess the presence of contagious bacteria but in many well-managed herds they give a very good indication for the sanitation of teats when units are attached. When environmental bacteria are in the typical low ranges printed on the forms, teats were clean bacteriologically when units were attached.

Having written protocols for the udder preparation process was another common finding. Protocols must be specific. It's not enough to tell employees to strip cows. The protocol must define which teats are stripped first, the number of streams of milk taken from each teat and that careful observation of the milk must be made to determine any abnormal milk. Udder drying is also a very important aspect of the udder preparation process. Dry cloth towels should be used in a circular motion on the teats followed by flipping the towel and aggressively pinching each teat end. Some farms have elected to use paper towels, which can work well when used in a similar manner, although extra towels may be necessary for some cows. The order of udder preparation is also quite important. The protocol for most herds indicated that the drying step was the last step before units were attached to the cows. Maximum oxytocin letdown requires 10 to 12 seconds of actual teat contact time. Teat contact time is either stripping, rubbing or drying teats. Units should be attached 90 to 150 seconds after the teats are first touched or manipulated during the udder preparation process. Protocols must also be very specific for maintaining proper sanitation in the barn or parlor. Tie stall barns should have technicians removing contaminated bedding under cows before beginning the udder preparation process and scraping barns on a regular basis to remove any manure/urine contamination on platforms. Parlor operations should specify how often the deck should be washed or scraped during milking, how often units should be washed, and how often entry and return alleyways should be cleaned during milking. The washing processes must completely define where the hoses are stored and what is the process used by the technicians to properly clean the deck and units without impacting cow movement into the parlor or creating contamination of teats and udders during the washing process. "Thinking clean" by all milk harvest technicians is important to maximize milk quality. This means clean gloves, clean milking equipment, clean platforms under the cows, clean cows and visibly clean teats when units are attached. Protocols should also be implemented for proper cow handling on the way to the parlor or barn and in the parlor or barn.

Some of the herds have implemented double predipping as part of the udder preparation procedures. Teats are brushed to remove any dry organic material or sand residue and then dipped or foamed with predip. Teats are then immediately stripped and teat ends rubbed to allow effective washing of the teats. As soon as these steps are completed on all 4 teats, all teats are then re-dipped or re-foamed. Field experience has shown this method that originally came out of the University of Minnesota many years ago for tie stall barns, really does make a difference in milk quality, especially in organic bedded herds; either tie stall or parlors.

All of the recent winners have treatment protocols for mild, moderate, and severe clinical mastitis cases. It's interesting to note that some of the winners have typically not treated severe mastitis cases in the previous 12 months. Treatment records are maintained on some type of permanent record, so evaluations can be made and protocols modified as needed.

Many of the contest herds have less than 5% of the cows called for mastitis, and rates of clinical mastitis cases, defined as the number of cases divided by the number of lactating cows, of less than .5%.

Conclusions

Milk quality is never an accident. Herds with low somatic cell count scores and low clinical mastitis levels are paying attention to the details and doing many little things right on most days. Consistency is a key factor to maximize milk quality; consistent udder preparation, consistent cow movement, and stockmanship protocols result in relatively clean, relaxed cows in the milking parlor or barn. The major goals are then to milk clean, dry, stimulated teats. These are easy statements to make, but prove difficult to implement on many dairies. However, the estimated SCC number for U.S. produced milk is now very close to a national average of 200,000, which means many producers are taking steps to produce excellent quality milk and progress is being made.

The Processor's Role in Milk Quality

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The dairy industry has a long history of providing safe, high quality products to the consumer. Interestingly, we have been able to accomplish this even though, historically, the "line of sight" from farm to consumer has not necessarily been that clear. While this is not that unique when compared to other sectors of food production the desire of the consumer to know something about where their food comes from and how it's produced coupled with structural changes within the supply chain such as food safety monitoring capabilities requires that we are much better informed and able to answer with integrity.

It is interesting to see how the definition of quality at the processors level has changed. Traditionally, milk quality has been driven through our regulatory food safety system. Beyond this, processors tended to define quality from an operational perspective. For example, there is a well-established relationship between SCC and cheese yield that motivated many processors to engage their milk suppliers in improving their milk quality because of the impact on efficiency of cheese yield.

Today, quality potentially takes on a much broader definition than basic food safety or processing efficiency. Product quality in terms of taste and consistency, broader perceptions of production practices both at the processing level as well as on-farm all influence how our customers and consumers perceive the dairy products they consume.

<u>Processors Play a Critical Role in Setting Clear and Compelling On-farm Quality Expectations</u>

Processors form the link between on-farm milk supply and the rest of the dairy supply chain. As such they have an opportunity to directly influence on- farm practices.

Specific to improving quality of milk shipped processors can and do have influence by impacting regulatory expectations, providing direct economic incentives, and by effectively communicating the positive on-farm economic impacts of improved milk quality.

Some processors will offer financial incentives based on levels of milk quality attained however many resist incentives based strategies due to the perceived inability to extract this addition cost out of the market. This frequently creates friction between processor and supplier based on the perception that achieving higher quality milk on-farm raises the producers cost of production. This does not have to be the case and processors can and should be effective advocates for improved on-farm milk quality simply because it results in positive farm-level economic contribution in and of itself.

As the dairy supply chain becomes more transparent the definition of "quality" is potentially expanding beyond product attributes to include how and where product is produced.

Processors should play a critical role in educating and setting expectations for our customers and consumers. This can be challenging given the widespread misconceptions regarding how milk is produced however the processor should be an active advocate for on-farm practices that we know are best management practices. The processor stands at the intersection of consumer and customer expectation and the reality of on-farm practices. Too often, the producer feels that this is a one-way process that imposes constraints at farm level without proper understanding of the consequences and too often processors have neither the knowledge or the verification activities in place that allow for effective advocacy.

Producers Need Timely Accurate Information in Order to Manage

Producers rely on the processor for basic information on the quality of the milk they produce. It is one thing for the processor to set expectations for the quality of milk delivered however effective feedback is necessary if a producer is to respond consistently.

Information needs to be accurate, timely, and linked to on-farm management strategies in a way that allows for focused attention when needed.

If the accuracy of information is questioned or feedback is delayed due to frequency of testing, then at the least we have delayed corrective action. If the information is inaccurate or not delivered in a timely fashion we run the risk of directing resources to problems that don't exist. Finally, if the information provided does not assist in focusing corrective action on root causes then we risk wasting resources and delaying problem resolution.

Historically, analytics provided by processors have focused on information such as components and milk quality measures. Today we have the capabilities to provide additional information through milk samples that can provide insights into a herd's overall health and nutrition. These capabilities will continue to develop and provide the processor with additional opportunities to provide valuable information that can be used to better manage farm level decisions (Barbano).

Processors Need to be Technically Capable of Supporting On-farm Milk Quality Activities

As stated above processors need to be effective advocates for the food safety and quality activities both at the processing and farm level. In addition, they should be seen as a knowledgeable milk quality resource by the producer when problems arise.

Additional capabilities may be required if processors are actively representing their milk supply's farm-level practices such as animal welfare, environmental, labor practices, or antibiotic usage. If we are to meaningfully embrace a higher level of transparency around on-farm practices then processors need to be capable of verifying practices through on-farm assessment based activities. This requires that they be able to select assessment frameworks that provide the necessary level of verification without being overly invasive. That they be able to engage with the producer in a meaningful way and that they organize and present the information effectively. These activities should be seen as having multiple purposes. First, they serve as basic measures of compliance with required on-farm policies. Additionally, they form a basis for our ability to effectively advocate and build trust with our customers and consumers.

Proactive vs. Reactive Thinking

Significant effort is currently being expended at the processing level to create quality management systems that are proactive and foster continuous improvement. This is being driven not only by regulatory changes such as FSMA but also by more sophisticated analytic techniques as well as customer expectations. Simply put, the risks and consequences associated with quality or food safety issues in the market place today is huge. Processors are in a position to extend what they are learning at the processing level to assist the producer in understanding and developing more proactive approaches to on-farm management. While monitoring outcomes is necessary it is no longer sufficient. Building monitoring and compliance systems that are process vs outcome oriented and that seek to actively engage those involved provide opportunities to add significant value (Mann).

Processors can and should play a vital role in communicating consumer and customer expectations to the producer. They also are in a position to educate the customer on the realities of what it takes to successfully produce milk. Both of these roles imply a much closer relationship between processor and producer.

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Producing and Marketing High-quality Milk

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Tollgate Farm in Ancramdale, New York, USA, is owned by Jim and Karen Davenport. Our farm is leased and consists of a 64-stall, tie-stall barn with large, foam-mattress-based, stalls bedded with kiln-dried pine sawdust. We place hydrated lime in the back two-thirds of each stall daily. We are currently milking two times a day, averaging 82 pounds of 4.0% fat, 3.1% protein milk, with an average somatic cell count (SCC) of 43,000 cells/mL. We are striving to maximize milk production from homegrown forage.

We are currently feeding a ration, including top dress grain, that is 67% forage on a dry matter basis. Jim and herdsman Art Downs do about 85% of the milkings, with capable part-time relief milkers and family doing the balance. Karen helps around the farm with landscape work, but being a Connecticut agri-science and technology teacher and department chair, her days are quite full.

Our daughter Kristen is at Colorado State University where she received her doctorate degree in pathobiology and has three semesters left for her doctor of veterinary medicine degree. Our daughter Laura is a graduate of the USC Annenburg School for Communication and Journalism with a master's degree in strategic communications. She is currently working for Ketchum in Washington, D.C., focused on food and agricultural issues. When they are home, both girls help at the barn to keep in touch with their roots.

High-quality Milk – Why?

When I first started shipping milk in 1986, the notion of producing high-quality milk was ingrained into my being as a product of a great land grant university – The University of Connecticut. I was taught that to maximize production, a dairy cow had to be free of unnecessary stress – most importantly, infection pressure on her udder. I learned about the correlation between elevated SCC and lost production. To this day, I believe this is reason enough to strive for low cell counts. Now with the marketing of our Hudson Valley Fresh brand solely on taste and shelf life, there is additional economic incentive beyond our Agrimark $0.60/hundredweight (45 kg) top-quality premium.

Our Milking Procedure

In 1987, I attended a University of Connecticut-sponsored New England Dairy Conference meeting on milk quality. We watched a video produced by the University of Minnesota on proper milking procedure using pre-dipping. We have been following these recommendations ever since.

We have many different people milking our cows and some just a few times a year. Our family members, employees and relief milkers have one thing in common: they are dedicated to our milking routine. Everyone wears nitrile milking gloves and follows the same milkhouse setup and shutdown procedures.

When milking, we begin by forestripping, unless there is a wet or dirty teat, then we dry wipe the teats with a paper towel. For dried-on manure, we dip and re-wipe the teat until it is clean and continue to forestrip. We pre-dip using a non-return dipper. After 60 seconds, plus or minus 15 seconds, we dry the teats with a white, single-service paper towel. A quick glance at the teats to be sure the entire teat was covered is important as bacteria don't die by empathy for their iodine-covered brethren. We attach the machine to the teats with minimal or no air intake. We take a moment to properly position the machine for even milkout. When the cow is milked out evenly and completely, the vacuum is shut off and the machine is allowed to drop into our hand. The teats are now post-dipped.

A word about the maintenance of our non-return dipper and strip cup. After each milking, the dipper and strip cup are dumped out, taken apart and cleaned with a chlorinated manual cleaner and 110° degrees Fahrenheit (43° C.) water. They are then rinsed in 90° Fahrenheit (32° C.) water with a similar acid concentration used on the pipeline. The strip cup and dipper are then allowed to drip dry. Teat dip solution is never dumped back into the original container; it is discarded. Unlike Cabot cheese, fine wine and all of us, teat dip does not get better with age. Teat dip should be kept from excessive heat, not allowed to freeze and not on inventory for too long.

The act of forestripping allows for two types of observation. The first is tactile. Any inflammation can actually be felt. If it is new inflammation, it is usually one of two things – a response to a new infection or swelling from physical contact.

The second type of observation is to look at the milk in the strip cup. The plan of attack depends on the type of garget (clots) in the strip cup.

Here are some of the ways we handle different scenarios:
Inflammation and watery milk: Take a milk sample for culturing from the bad quarter, then milk into the can and discard the milk. Treat cow with fluid therapy and use an NSAID IV and supplemental oxytocin at each milking or hand stripping. No IQ antibiotics are used.

Inflammation and thick, or ropy or clotty milk: Take a sample for culturing, CMT (California Mastitis Test) the other three quarters. If they are clear, quarter milk the bad one and wait until next milking and then recheck. If worse, treat with OTC IQ remedy that has activity on both Gram-positive and Gram-negative organisms. Once the culture results are obtained, adjust treatment to the results.

Inflammation and no strip cup signs: CMT the cow. If the inflamed quarter is positive (milk and CMT soap gels), take a culture and use the quarter milker. Decide at the next milking whether or not to treat or wait for a self-cure.

No Inflammation, flakes in strip cup: Use the CMT. If the quarter with flakes is negative, milk the cow up the line, observe any changes and test again the next milking. The milk filter will catch the artifacts – be they sloughed off cells or clumps of old somatic cells.

No inflammation, flakes in strip cup: Use the CMT. If gelling occurs, use the quarter milker to segregate the inferior milk, then take a milk sample for culturing from the bad quarter. Sanitize the cluster before moving on to the next cow. Wait for the results of the culture. Often, if the culture shows no growth, we use the quarter milker until the CMT is negative.

If you are going to push the high-quality envelope, you MUST know each individual cow's SCC. Even with sharp milkers and forestripping, you can get caught with a surprise 1,000,000 SCC cow.

When we get a surprise cow, we CMT her to find the guilty quarter. It is rare to have more than one quarter causing the elevated count. We use the quarter milker, culture a sample of the milk and treat according to the culture results.

<u>Observations of a Humble Dairy Farmer</u>
The following is my anecdotal evidence, which corroborates with commonly accepted industry knowledge that was produced by genuine, scientific research by actual dairy and agricultural engineering scientists. I really have no peer-related papers to back up my theories, but I know they exist. NMC has a multitude of publications on milking system function, cleaning and troubleshooting that can answer anyone's queries. I believe that high-quality milk from udder to tank to truck boils down to the following statement (my apologies to John F. Kennedy). Ask not what your sanitizer can do for you; ask what you can do for your sanitizer.

Milk is an extremely nutritious product, to which any mature mammal that was once a newborn can attest. Milk contains all of the essential nutrients for growth and maintenance. Unfortunately, if not handled properly, milk is also able to grow bacteria that will limit its shelf life, ruin its flavor and cause consumers to flock to unhealthy alternatives. A healthy, stress-free cow gives us nature's most perfect food. After that, it is our job not to ruin it! Milk contact surfaces must not be allowed to inoculate this food with quality-damaging microbes. These surfaces must be sanitary. We predip teats to sanitize them and we wash everything from liners to the bulk tank outlet to sanitize them.

<u>The Teat</u>
The only external milk contact surface of the cow is the teat. NMC has provided a vast list of approved teat dips. Each and every one will do an infinitely better job killing bacteria, measured in microns of thickness, on clean skin than on environmental and contagious bacteria hiding in organic filth measured now in millimeters on a dirty teat. The problem with the teat is that it is attached to the cow. So, to help your sanitizer (dip), you must milk clean cows. Look for a dip with the ability to kill bacteria on contact. Do not look for a "miracle dip" that can correct poor stall design, overcrowded bedding packs or unscraped litter alleys. Clean Cows make Clean Milk!

The Milking System

All modern milking systems have one thing in common – they cost a pile of money. Once again, they should meet industry standards for sizing, slope and vacuum reserve. NMC has handbooks with the most current data on this. Using a capable, experienced installer is critical to the milking system properly handling the milking and washing requirements of today's dairy farmer. I believe that the former requirement is achieved more often than the latter one. I've seen Taj Mahal parlors that milk cows like crazy with sections of 4-inch (10 cm) stainless with a buildup reduced ID (inner diameter) of 2.5 inches (6.35 cm). I'm not an agricultural engineer and I've never even played one on TV. However, I am convinced that the mechanical action of a large, fast-moving wash water slug is the key to properly cleaning a pipeline.

Our barn has more than 400 feet (122 m) of 2.5-inch stainless, ten 90-degree elbows and two 2.5-inch splitters. In 1993, we began milking cows in our barn and found that we had serious pipeline washing issues due to the barn having two different length loops. Our longer length loop's water slug would fall when the other slug hit the splitter, leaving the footage in the longer loop beyond the length of the short loop with a stalactite buildup by the inlets. This would periodically leave us with unacceptable bacteria counts. One solution was more stainless steel, two different air flows and slugs to time the wash water slug's arrival at the return splitter at the same instant. My experienced dealer, not the dealer who installed the system, said "I think I can get this to wash, let's play with the air injector," He gradually increased the slug volume and the air behind it until my digital slug detector (the smallest digit on my left hand) placed in the last inlet, felt a full slug blow by and into the splitter! So, for the last 19 years the pipeline has washed very well with "bottom of the line" (i.e. "cheap") soap and acid. The slugs hit the receiver jar with enough force to visibly shake it.

We rinse with 125° Fahrenheit (52° C.) water, just below the 130° (54° C.) Fahrenheit temperature that will set the fat. The water must be this warm, especially in the winter to heat the stainless steel enough to remove the butterfat. The first rinse discharge looks quite milky; the last two look virtually clear. I sent five samples of rinseate to our Agrimark milk lab. The results are as follows: first rinse discharge through fifth, with tap water as a control.

Sample ID	Product	Fat	Protein	Lactose	Other solids	Solids not fat
1	SKIM	0.73	0.25	0.42	1.53	1.33
2	SKIM	0.18	0.04	0.16	1.27	0.83
3	SKIM	0.10	0.01	0.13	1.24	0.77
4	SKIM	0.10	0.01	0.12	1.23	0.76
5	SKIM	0.09	0.00	0.12	1.23	0.75
Tap water	SKIM	0.08	0.00	0.11	1.22	0.74

One can see that virtually all of the organic matter "milk" has been removed by the rinse. All of the soap and acid have to do is sanitize the stainless steel surface, not scrub out the milk first. The same holds true of the bulk tank. Our tank is pre-rinsed with 140° Fahrenheit (60° C.) water.

Our Agrimark milk truck drivers do a great job using our cold water (and I am sure, Pseudomonas-infected) rubber garden hose to cold-water rinse the tank until the discharge is clear. When the first 140° F pre-rinse happens, there is no chance to set the fat to the stainless steel. In conclusion, removing as much milk with pre-rinsing is the help your soap needs to do its job.

We have won the Agrimark Top Quality Producer Award seven times. The results:

Year	Raw	Pasteurized	SCC	Farm Inspection
2002	2043	19	94,000	100
2004	1667	12	83,000	100
2008	1500	18	60,091	98
2009	1565	11	47,174	99
2010	1357	18	50,429	97
2011	1364	15	48,318	97
2012	1286	13	47,000	98
2014	1516	12	46,548	99

Marketing High-quality Milk: The Hudson Valley Fresh Story

Hudson Valley Fresh (HVF) was conceptualized by our State Assemblyman Pat Manning. He wanted to keep local farms viable by capturing more of the local consumers' money. At about the same time, Dr. Sam Simon, the son of a dairyman from southern New York State, retired from his orthopedic surgery practice and bought a farm from a retired Holstein breeder. Sam was shocked to see that his herd earned milk selling for the same amount it sold for when he was in medical school.

Pat Manning and Sam Simon got together at a local diner and Sam proposed marketing high-quality fluid milk. The "high quality" would be defined with industry-accepted standards.
Sam began this adventure by going to local grocery stores, restaurants and other food purveyors to who quality and, therefore, taste were important. An important customer to this day was the Culinary Institute of America. Once they tried our products they fell in love with them. Every six weeks a new class of aspiring chefs start their education with a single-serve, HVF, whole fat white and chocolate milk. These graduates know us as the must use "dairy" in their recipes!

We have been working with a small, family-owned dairy processor in Kingston, New York, called Boice Brothers Dairy. They were on the verge of folding because Dean Foods et al were able to underprice them. HVF was looking for a processing plant that shared the same goals and objectives as our dairy farmers. Richie Boice, the plant manager, runs the plant like clockwork and is a perfectionist, with no tolerance for sloppiness. The result is perfect finished product testing results. At the time Sam Simon was negotiating with them, Boice Brothers had eight of their own producers. The processor only bought co-op milk to balance their needs. After reaching an agreement, Richie asked what he was to do with his farmers.

Sam replied that if they were <200,000 SCC, we would give them a spot in HVF. Sam gathered their quality reports, which were all >400,000 SCC and some as high as 600,000 SCC. Now, their milk goes to our competitors. HVF farms produce enough milk for all of our needs and Boice's, too.

As is typical of most fluid processors, Richie Boice thought that “milk is milk.” But, now that his sales have increased significantly, customer complaints have ceased, his well-run plant is turning out top-notch products with our top-notch milk!

How We Promote Our Quality and Keep Our Customers

We use no-nonsense, industry-accepted parameters for quality. Raw counts and lab pasteurized counts must be kept at Agrimark’s midrange quality premium levels. The raw count must be <10,000; the pasteurized count <50. “HTST” (high temperature, short time) pasteurization renders these low bacteria counts moot, so all of the focus shifts to the raw count SCC. The SCC limit on raw milk accepted into HVF is 200,000 cells/mL. This puts us at an immediate advantage over much of our competition. HVF’s determination of this SCC level was logical and was in line with recommendations going back to 1987 by Senyk, Barbano and Shipe.

A huge amount of research has gone into the pasteurization-stable enzymes in somatic cells and their deleterious effect on shelf life and flavor. Much of the supporting research comes from the food science department at Cornell University. HVF sends finished product samples biweekly to their lab to monitor our milk plant’s performance. There is a multitude of research to show the decided advantage that low SCC milk has in satisfying the consumer. The reference section at the end of the paper contains a list of pertinent research articles and papers. I feel that the reason our customers are loyal to our brand boils down to one important consideration – our taste buds are smarter than our brains. Madison Avenue ad men can sell a person anything once, but when it comes down to repeat sales of food products, taste buds reign supreme. It really doesn’t matter how much promotion a food product receives; if it tastes bad, it will never be purchased again.

In conclusion, HVF has more than 300 customers in New York City, New York’s Hudson Valley and adjacent Connecticut, Massachusetts and New Jersey. Our superb quality and flavor keep our customers coming back for more. Also, the notion that all of the profits are returned to the dairy farmers who tend the cows, practice high-quality control protocols and produce nutritious, delicious milk makes our future to the dairy industry bright.

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Country Aire Farms, LLC, Dedicated to Milk Quality

Tom Gerrits
Country Aire Farms
Greenleaf, Wisconsin, USA

Here's a little history about our dairy. Country Aire Farms began in the 1930s with my grandfather Edward starting out with nine cows and working his way up to 60 by the early 1960s. My father Budd Gerrits purchased the farm in 1969 after returning from Ag Short Course at the University of Wisconsin-Madison. As my mom, Ione, and dad continued to grow the farm to 200 cows, my brother Mike and I became very interested in taking over the family dairy farm after high school. Mike and I knew the future would be to milk more cows and proceeded to form our own L.L.C. in 1996, in which we bought our first 380 cows with the help of our dad. In 1998, the first stage of expansion began with a green site across the road from the old farm with a new BouMatic 40-stall rotary parlor and 700-foot (213 meters) milking barn, which allowed us to milk more than 800 cows. We further evolved by adding one milking barn in 2006 and a special needs barn in 2008 to help us focus on better management of cows in their most critical time. Then, we decided to add another barn for dry cows and steam-up heifers in 2012. In 2011, two farmers approached us about the possibility of buying their farm that came with 540 cows close to our main dairy and nice land base, so we decided to pull the trigger on it. Today, we have four sons who are in business with us. They specialize in areas of the dairy, including finance, herd management, maintenance and cropping. Currently with both dairies, we milk 3,500 cows and harvest of 6,000 acres (2,428 hectares) of alfalfa, corn and wheat. Our rolling herd average is 33,297 pounds (15,103 kilograms) of milk, 1,292 pounds (586 kilograms) of fat and 995 pounds (451 kilograms) of protein. Our somatic cell count (SCC) at the home dairy averages 107,000 and the standard plate count (SPC) averages 2,000. At the Fox Ridge farm, which took home Platinum in the National Dairy Quality Awards program in 2016 and 2017, the SCC averaged 66,000 and the SPC averaged 1,000 over the last year.

All our calves are born at the dairy and sent to Dalhart, Texas, to be raised for up to 4.5 months. Then, they are sent to Oshkosh Heifer Development, Oshkosh, Nebraska, in which we partnered with six other Wisconsin dairymen. There, they are bred and sent back to the dairies at around 23 months old or 250 days with calf.

The Fox Ridge dairy has a 425-foot-long (130 meters), tunnel-ventilated freestall barn and is scraped with timed alley scrapers to the center of the alley, with gravity flow to the lagoon. We have 46-inch (117 centimeters) stalls with DCC Dual Chamber ISO waterbeds that are bedded twice a week with kiln-dried sawdust.

We are proud to say we have been able to have a great relationship with our cheese plant Satori since May of 2011. Their emphasis on milk quality is the main reason we stuck by their side. One of the quotes from the CEO of Sartori Foods, Jim Satori, during their annual patron meeting was, "We can make bad cheese from great milk, but we cannot make great cheese from bad milk."

Some of the steps we take to achieve high quality milk:
1. Have a set of outside eyes come to our dairy and do an assessment of the dairy.
2. Proper and consistent milking procedure.
3. Parlor Maintenance: Inflations changed every 10 days, pulsator graphs every 2 weeks, milk hoses replaced every 4 months, and meter kits once per year.
4. Stalls are bedded twice a week. Properly fasten and follow the desired measurement with brisket boards, neck rail, and stall width.
5. Mastitis treatments: Minnesota Bi-plate testing and deciding whether to treat or not to treat each individual animal.
6. Vaccination protocols: J-5, J-Vac.
7. Using DHIA testing and DairyComp: Management tools to find those chronic cows and to make decisions to cull or not. Most importantly, we track records to see what percent of the herd is clean or not infected, and we monitor linear score.
8. Udder health: It's more than somatic cell count.
9. Cleanliness: Every six weeks, we remove hair off udders and cut switches off tails.

On Country Aire Farms, we are dedicated to providing consumers with safe, high-quality milk. This commitment to quality also means caring for our employees, our animals and the land. Creating a positive image of ourselves requires us to communicate with the public on the key issues that concern them: animal care, environment and food safety. Working with our processing plant (Satori), veterinarian, consultants and nutritionist has helped us be on the forefront of these topics.

Country Aire Mastitis Management Protocols

Mastitis Treatment Protocol

Grade 1 Mastitis (abnormal milk with no quarter edema/inflammation)

1. Identify Grade #1 mastitis cases and move to hospital pen
2. Sterile sample collected and plated on Minnesota Bi-plate system and remaining sample frozen
3. No antibiotic therapy pending culture results
4. Culture results: If "No Growth," return to home pen
5. Record identification as mastitis event with remark: "No Growth"
6. Those samples showing Gram-positive growth treated with Spectramast LC IMM per protocol for 3 to 5 treatments. If no clinical response, treat with Pirsue IMM per protocol for 3 additional treatments. Samples showing Gram-negative growth and still exhibiting clinical mastitis treated with Spectramast LC IMM per protocol. Record as mastitis event with appropriate treatment protocol(s).

Grade 2 Mastitis (abnormal milk with noted quarter edema/inflammation)

1. Identify Grade #2 mastitis cases and move to hospital pen
2. Sterile sample collected and plated on Minnesota Bi-plate system and remaining sample frozen
3. No antibiotic therapy pending culture results
4. Administer 2cc/100# Flunixamine (Banamine) IV (may repeat in 24 hours) and place red band.
5. Culture results: If "No Growth," remove red band and return to home pen when milk withhold is satisfied
6. Record identification as mastitis event with remark: "No Growth/Banamine IV"
7. Those samples showing Gram-positive growth treat with Spectramast LC IMM per protocol for 3-5 days. If no clinical response, treat with Pirsue IMM per protocol for 3 additional treatments. Samples showing Gram-negative growth and still exhibiting clinical mastitis treat with Spectramast LC IMM per protocol.
8. Record as mastitis event with appropriate protocol(s)

Grade 3 Mastitis (abnormal milk and systemically sick cow)

1. Treat per protocols with systemic antibiotic (Polyflex IM or Oxytetracycline IV), fluid support (Hypersaline 2000 ml IV) and Flunixamine/Banamine IV
2. Record as mastitis event with appropriate protocol

Note: Prior to culturing or treating any clinical mastitis, herdsman evaluates/reviews treatment records and SCC history for chronicity/treatment success prognosis.

<u>Management of Subclinical Mastitis</u>

Following monthly DHIA testing, test day results are evaluated for new subclinical cases. Selection criteria include individuals with test day SCC >300,000 with no previous tests >200,000. Preference given to first or second lactation individuals. Cows are moved to pen 15 and cultures collected for on-farm culture. If culture provides Gram-negative or Gram-positive growth, red bands are applied, individuals are moved to Hospital pen and Grade 1 Mastitis protocol is followed.

<u>Dry Cow Protocol</u>

At 230-236 days carried calf, all cows are dried off with Spectramast DC and internal teat sealant Orbeseal is administered.

My Approach to Milk Quality

Donald Van Hofwegen
D&I Holsteins
Stanfield, Arizona, USA

Having grown up on a family dairy farm in Arizona, I've been in the dairy industry in some way for over 40 years. At D&I Holsteins, my partner and I currently milk over 3200 cows. I've seen many changes in the dairy industry since I purchased my first 10 cows when I was 20 years old, but one thing that has consistently driven me is the pursuit of producing the highest quality milk possible.

At D&I Holsteins, we have an advisory group, consisting of ownership, veterinarians, nutritionist, and the dairy manager, that meets quarterly. With this group, we set annual goals for the dairy and develop the protocols to follow to achieve them. We also monitor our progress and re-evaluate our plan and goals at least annually. One of my main goals is to achieve the 'quality producer of the year' award for our local cooperative. This goal is not set to receive recognition, but rather to set an expectation of the standards of milk quality we want to achieve.

Milk quality is a sign of a healthy cow and starts with the basics on the dairy. Ultimately, I want to produce a product of which I am proud and that consumers will want to purchase. In our facility and system, we have identified three primary drivers of milk quality: parlor maintenance, employees, and environment. Of course, many other factors feed into milk quality, including nutrition and health status of the herd. These shouldn't be overlooked but for us are consistent areas of management.

Parlor maintenance is key to providing our parlor team the resources they need to be successful. We use our local cooperative and company service departments to perform preventative maintenance and call for repairs when something breaks. Our manager is responsible for ensuring that repairs are reported quickly and then are completed in a timely manner. Maintaining a clean, calm and quiet parlor is as important to employee safety and comfort as it is to cow comfort and udder health.

Employees, specifically the parlor crew, are an integral part of milk quality. We depend on the parlor crew to help maintain parlor equipment, to follow the milking routine and procedures, and to help observe the cows daily. Our goal is that the parlor experience is the same for every cow every time she enters the parlor, regardless of the shift or the day of the week. We focus on training and interaction with our parlor crew to help prevent drift from our established protocols. We can't expect them to follow a protocol if we've never taken the time to tell them our expectations or train them on the routine and procedures. Our manager takes the time to check in with the parlor crew multiple times a day. We've found this face time to be a huge help in retaining parlor workers and maintaining our procedures. The parlor crew is encouraged to pull any cow with abnormal milk to the hospital for further examination and to report any and all issues they may observe with the cows.

The environment has a huge impact on milk quality in our system, as our cows are housed in outdoor lots with bedded shades. This impact is not only on udder health but also udder cleanliness as cows enter the parlor. We manage our corrals differently in the winter, when we have more rain and corrals don't dry out as quickly, and in the summer, when our use of round-the-clock cooling adds water to the environment and decreased loafing space for the cows as all the cows spend their time under the shade. We focus on providing clean, dry, soft bedding for the cows every day. Our manager works closely with the corral scraper to ensure he understands the importance of his job, how to effectively scrape the pen, and to bring in dry bedding when it's needed. This requires daily attention to corral conditions and extra labor at time to move bedding, but we have seen improved udder cleanliness and cow comfort when we take these extra steps.

We also monitor our SCC performance with milk test data, our quality results (including SPC and PI, among others) daily from the cooperative, and clinical mastitis rates and culture results. With our advisors, we have developed protocols to assess SCC data after each milk test. With this data to flag cows, we can then assess each cow based on her past performance and current status to determine her future on the dairy. This may include culling her, sampling her milk and treating based on culture results, or re-evaluating her after the next milk test. We encourage the parlor crew to pull cows for abnormal milk, and then empower the hospital crew to evaluate her and follow our treatment protocols. All cows with mastitis have a milk sample submitted to help direct treatment and to monitor infection trends on the dairy as a whole. We review our treatment protocols with our veterinarians and ensure that they are followed.

With our system of reviewing our goals annually, we can monitor our performance and identify areas of improvement or maintenance. In the future, we may continue to set higher quality bars to meet. But with each goal we set, we will identify the potential benefits and costs required to attain the goal and determine if it makes sense for the business to achieve that goal before we move forward. By using objective data where possible and identifying ways to monitor our progress, we are much more effective in reaching our goals. In the meantime, we will continue to focus on our three primary drivers of milk quality (parlor maintenance, employees, and environment) to ensure we maintain the gains we have made and have the consistency to adapt and make more improvements. We will continue to strive to produce the highest quality milk we can because ultimately, we all depend on consumers to purchase our products to maintain our livelihood.

Make the Cows the Consultants with 'Good' Clinical Mastitis Recording and Analysis

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Introduction

Five, 10 or 7, no matter how many points there are to a Mastitis Control Plan "Good record keeping" should be a part of it. Who better to ask how the udder health management program on a dairy is working than the cows? "Good" clinical mastitis (CM) records allow an objective assessment, based on the cow's experience, of the effectiveness of udder health management on a dairy. Few would argue the value of "Good" CM records to udder health management. However, to make the "Cows the Consultants" efficient, timely summary and analysis of CM records is necessary. Given that on farm records systems are largely defined by the user, it is critical that those wanting to evaluate CM records on a population level take the time to develop protocols to ensure accurate and consistent recording of data that is "computer friendly." Unfortunately, even when dairies have "Good" CM records it can be challenging to calculate and routinely monitor the commonly recommended Key Performance Indicators (KPI) of udder health. To address that need, as part of a USDA funded project, we developed HEALTHSUM® to facilitate the efficient, routine summary, integration and analysis of on farm records. The purpose of this paper is to discuss considerations for keeping and using "Good" CM records.

What Makes Clinical Mastitis Records "Good"

Accurate and consistent are two obvious characteristics of any "Good" records. However, their intended function on the dairy must also be considered and impacts the definitions of what are considered accurate and consistent records. Clinical mastitis records in the most commonly used dairy management software are user-defined and dairy personnel typically define those records based on daily needs for managing individual cows. Allied industry professionals and researchers often want to summarize and analyze the records for the herd and different risk groups therein. The former typically involves visual inspection of an individual cow's record or lists of cows whereas the latter generally relies on a computer to efficiently handle all the cows' records. If record keeping is focused on knowing which individual cows received an antibiotic, only recording those treated could be considered accurate. One can look at a cow's record, if she doesn't have an event recorded, she wasn't treated. If she had 3 treatments with "Treatment X" recorded differently each time (e.g. TreatX, TreatmentX and TxX) that could be considered consistent enough for those on the dairy to read her record. However, if the focus is on summary and analysis of disease, failure to record all disease episodes, would lead to an inaccurate record of disease on the dairy. Most computer programs would handle "Treatment X" recorded 3 different ways as 3 unique treatments. They would be considered inconsistent and require manual grouping reducing efficiency of summary and analysis at the herd level. Thus records must be "computer friendly." Both cow and herd level functions are important for the effective management of udder health on the dairy. Given the more stringent requirements for the herd level functions the **focus of record keeping should be on recording disease events and how they were managed not simply treatment events**. Furthermore, complete records are needed to avoid residues in milk and meat. So…

To be considered "Good" clinical mastitis records must support 3 critical functions:

- **Individual Cow-level Health Management**
  - Know which cows were treated, when and with what
  - Cow removal and disease management decision making
- **Herd-level Health Process Management**
  - Protocol compliance oversight
  - Preventive and therapeutic plan outcomes assessment
- **Residue Avoidance/Regulatory Compliance**
  - Complete recording of all treatments
  - Observation of milk and meat withdrawal times

How are "Good" Clinical Mastitis Records Achieved?

Clinical mastitis records "Good" enough to perform those 3 critical functions can be achieved by following the …

Three Simple Rules of "Good" Recording

1. **Record ALL Disease Episodes** (not just those treated)
2. **Use a SINGLE, SPECIFIC Event for Each Disease**
3. **Record CONSISTENT Event Remarks**
   - **Same INFO** (e.g. Treatment, quarter, severity, pen, culture result) **in the**
   - **Same ORDER using the**
   - **Same ABBREVIATIONS** (including number of characters) **every time**

Though these 3 rules are simple, their application to achieve accurate and consistent CM records on a dairy is not as easy as it seems (or should be). This is because of the primarily user-defined rather than system-defined nature of health data recording in most dairy management software and the tendency to record CM at the cow level. Therefore health data management protocols need to be implemented to achieve accurate and consistent CM records. Like any protocol, compliance is dependent on active, immediate feedback to those involved through the obvious use of those data and identification of errors in data entry that compromise record accuracy and consistency. Consideration of each of these rules follows with example 'event' names commonly used in Dairy Comp 305, however, the concepts apply broadly to any dairy record management system.

Record all disease episodes

This is where a focus on recording disease events and their management is critical. When the focus is on only recording treatments, then it is logical that CM cases that don't get treated don't get recorded. However, this makes CM incidence calculations inaccurate and those cases that didn't get treated are lost to follow-up. These are the most common reason a CM case doesn't get recorded:

- No antibiotic treatment is given as a therapeutic management decision on a cow with the intent of keeping her.

- No treatments are given because she is going to be sold or she dies. The cow may have a sold or died event with a remark indicating mastitis as the reason, however, she still needs to have an event recording the CM case indicating she was not treated.
- The cow will be dried and receive dry cow antibiotic therapy. Again, she still needs to have the CM case recorded for accurate incidence calculations.

Use a single, specific 'event' for each disease
A single event (e.g. MAST) should be used to record CM cases, and ONLY CM cases for accurate calculation of incidence. These are the most common practices that lead to inaccurate CM records:

- Recording cows treated for high SCC or with a positive fresh cow milk culture. To avoid inflation of CM incidence calculation these treatments should be recorded using a different event than the one used to record CM cases (e.g. HISCC and FMAST). Improper recording of cows treated for a positive fresh milk culture with the CM case event can be identified as a high number of records in the first 7 DIM with all four quarters recorded. Suspicion of HISCC being recorded using the CM case event should be raised when a spike in the number of records with the same date shortly after test day are seen.
- Recording CM cases using different events based on etiology (e.g. ECOLI, AUREUS, MYCO) or treatment (e.g. SPECT, AMOXI, HETK). While these could be combined when calculating incidence, this practice strays from the focus of recording a disease event and its management. The disease is mastitis, the etiology, if known, and the treatment of that disease should be noted in the record of that CM case.
- Recording cows with blood in otherwise normal milk. Generally blood in the milk is not associated with a CM case. They should be recorded as a different event (e.g. BLOOD).

Recording multiple mastitis events on the same day for the same CM episode usually to capture supportive care treatments that won't fit in the remark of a single event. This is most common for cows with severe CM in herds that want all treatments recorded. A suggested best practice is to record intramammary antibiotic treatments (or lack thereof) and quarter in the mastitis event and record other treatments in a separate event (e.g. MASTX). An exception would be a cow with CM in multiple quarters identified on the same day. Each quarter should be recorded as a separate mastitis event to get accurate and consistent CM records. This is discussed in more detail in the section "Why Clinical Mastitis Should be Recorded at the Quarter Level."

- Recording daily treatments using the mastitis event. Some herds want to have a record of each day a cow is treated. The first day should be recorded using the mastitis event and subsequent days using another event (e.g. MASTX or DLYMST).
- Recording retreatments using the mastitis event. If a cow has completed a treatment protocol and it is determined that she needs continued treatment, the start of the "retreatment" should be recorded using a different event (e.g. REMAST).

Record consistent event remarks
Consistency is critical for "computer friendly" records. This means the information can be parsed out from the remark and summarized by a software application such as Microsoft Excel® or HEALTHSUM®. Protocols for CM records should be specify the information that will be recorded for all CM cases. At a minimum the quarter and treatment should be recorded to

evaluate outcomes. Consistent abbreviations should be used. Two character abbreviations are recommended as they are the easiest to interpret while maximizing the information recorded when space is limited. Finally each record should have the information in the same order so it can parsed out into separate columns of data manually using the “Text to column” function in Excel® or by a specific software application. An example would be: Treatment as two characters (TX), followed by quarter as two characters (QQ) (e.g. TXQQ). If the character number of abbreviations is variable then that information should come at the end of the remark (see Figure 5) as it will not disrupt the expected order of the information. The following are common issues leading to inconsistent records:

- When a CM case is not treated, the mastitis event is recorded but quarter and or treatment is not. The quarter should always be recorded so the outcome of the CM case in that quarter can be evaluated. There are two common reasons not to treat a quarter. One is a therapeutic decision not to use intramammary antibiotics (e.g. for a case with a no growth or Gram-negative culture result). Such cases should have an abbreviation like ‘NT’ recorded in the treatment space. The other is a decision not to treat because a cow will be culled. In these cases, no treatment should be recorded with a different abbreviation (e.g. BF – Beef). This allows an accurate evaluation of removal associated with the CM case where the therapeutic decision was not to treat with the intent of keeping the cow. This measure will be inflated if cows not treated because they were going to be removed are included. If the first piece of information in a record is missing that will change the order and the data will end up in the wrong column when that records is parsed out. For example if the protocol is TXQQ but TX is missing then QQ data will end up in the TX column for the parsed dataset.
- Recording the pen a cow was in when CM was detected using a variable number of digits. If pen numbers exceed one digit, then single digit pen numbers should be recorded with a leading zero (e.g. 02 not 2).

What Specific Information Should be Recorded?

What should be recorded? It depends on the questions you want to answer. While there may be variation in the questions asked by different dairy udder health management teams, CM data should be recorded so that “Key questions” can be answered. As described above most of those question require treatment and quarter at a minimum. The records should allow routine monitoring of the consistency and efficacy of udder health management on the dairy and be able to answer the following questions:

- Is the prevention/control plan consistently effective?
- Is the management of clinical mastitis cases consistently effective?
- Are treatment protocols consistently applied?
- What is the impact of clinical mastitis on this dairy?

Recommended KPI that answer these questions, their calculation and suggested goals have been described previously by Kelton et al., 1998; Wenz, 2004 and Ruegg, 2011 among many others. What follows are common on-farm CM data recording issues that could impact CM record quality thus the calculation and interpretation of KPI.

Is the Prevention/Control Plan Consistently Effective?
The incidence rate of CM is the KPI monitored to answer this question. Kelton et al., 1998 recommended calculating a "true incidence rate, expressed as cases per 100 cow-days at risk." Cow-days at risk isn't easy to get from most DMS, however, some estimate of the number of milking cows at risk on the dairy can be obtained to use as a denominator as suggested by Ruegg, 2011. **Thus the cases per 100 cows per month can be more easily obtained and expressed as a percentage of milking cows.** This is a value to which most producers and vets can relate. The best assessment of prevention/control would be to include only "New" CM cases from the cows' current lactation in the numerator. Which leads to a needed discussion of CM case definitions.

The definition of a "case" of CM can be challenging if one gets bogged down in the variation that can and does exist between dairies in cases that are detected as an estimate of the number of cows with a minimum criteria of abnormal milk. Suggestions for definitions of detected and recorded CM cases is described below in the context of assessing the outcomes of CM case management. **Establishing common disease case definitions (detection sensitivity for CM) across dairies is a challenge. However, lack thereof does not and should not preclude the accurate and consistent recording of CM as defined on each dairy.** When monitoring trends of the "incidence rate" of CM on a dairy it is wise to consider the potential for changes in the sensitivity of detection that could explain variation in the KPI. Substantial changes in personnel, cow numbers/parlor throughput, milking procedures should be noted. Differences in detection sensitivity can be most problematic when comparing across dairies or to a suggested industry goal. Again, awareness of substantial differences in potential detection sensitivity is warranted when making such comparisons. In a cohort of 30 herds (mean herd size 3969 milking cows) with "Good" CM recording the median % milking cows with "New" CM per month was 3.0% (mean 3.4%) over a 23 month period. Fifty percent of the monthly values were between 1.7 and 4.5%, the minimum observed was 0.2% and the maximum 24%. These are all herds that have successfully controlled contagious pathogens. Such a cohort analysis accurately identifies herds consistently above the cohort average that have documented udder health management challenges and those below the cohort average. Peer group comparisons have been useful to "nudge" some "above average" herds to make needed changes to improve udder health. The data from the 30 herd cohort described above represent CM cases recorded at the quarter level. There is an obvious mismatch between the unit of risk in the numerator and denominator, however, this has been of little consequence in the interpretation of the KPI. Ruegg, 2011 suggests monitoring the proportion of cows with >1 quarter [assumed concurrently] affected with a goal of <20%. Recording and reporting CM cases at the quarter level accounts for multiple quarter CM episodes and will obviously result in a higher CM incidence than if recorded at the cow level. See the section below "Why Clinical Mastitis Should be Recorded at the Quarter Level."

Is the management of clinical mastitis cases consistently effective?
Answering this question requires the ability to efficiently evaluate the outcomes of CM cases ideally recorded at the quarter level. The ability to drill down by milk culture result, treatment, parity and DIM group allows identification of risk factors and better directs actions whether intervention or further investigation. Was the case retreated, was there a recurrent CM case in the same quarter, was the quarter lost, did the cow DIE or was she SOLD due to CM? When the

same mastitis event is used to record all CM cases (ie. retreatments aren't recorded as a different event) the days between two mastitis events in the same quarter can be used to define a retreatment event. Fourteen days is commonly used to define separate CM cases. This cut point is based on the average duration of CM caused by environmental mastitis pathogens reported by Smith et al., 1985. This can be used to label mastitis events as follows based on the days between events recorded in the same quarter: If ≤ 14 days = Retreatment, if >14 days = Recurrence (RECUR) and allows calculation and monitoring of the following KPI:

- Retreatment (RTXD) – The proportion of quarter level CM cases in a month that were retreated represents therapeutic failures when the initial intramammary treatment is changed before the duration of a protocol is completed or further treatment is deemed necessary following the completion of a protocol (whether the first treatment choice was no treatment or an intramammary antibiotic). When the days to retreatment is less than the prescribed days on the first treatment protocol, the retreatment can be defined as a "switch" but still included in the count of RTXD. Typically, a switch represents lack of protocol compliance if it is a change of intramammary treatment with no indication of a change in severity (e.g. administration of parenteral antibiotics for severe CM cases). Herds doing culture-based treatment may have a high percentage of switch cases if they record a no treatment followed by a treatment once culture results are available, typically 1-2 days later. This does not represent a treatment failure and these cases should not be counted as a switch RTXD. A goal of <20% RTXD has been suggested with a CM case defined at the cow level (Ruegg 2011). In the 30 herd cohort described above (CM case defined at the quarter level) the median RTXD was 11% (mean 13%). Fifty percent of the monthly values were between 7.0 and 17%, the minimum observed was 0.2% and the maximum 39%. The factors influencing RTXD need to be better understood to allow better recommendations for interpretation and suggested goals. Plausible factors currently being investigated include cow factors such as immune status, etiology, antibiotic used, farm protocols and people factors (decision criteria, perceptions and motivations).
- Recurrence (RCRD) – The proportion of quarter level CM cases in a month that recurred (subsequent mastitis event recorded in the same quarter >14 days later). These cases likely represent a combination of therapeutic failures (persistent infection) (Wenz et al., 2005; Pinzón-Sánchez and Ruegg, 2011) and prevention failures (new infections). Recurrent cases occurring sooner are more likely preventions failures and having a defined risk period (commonly 60 days) allows routine monitoring of the KPI with a known (2 month) lag from the current date. A goal of <20% RCRD has been suggested with a CM case defined at the cow level occurring >14 days post treatment (Ruegg, 2011). In the 30-herd cohort described above (CM case defined at the quarter level), approximately 56% of all quarter level RCRD cases were within 60 days. With RCRD defined as a subsequent case in the same quarter 15-60 days later the median was 15% (mean 16%). Fifty percent of the monthly values were between 12 and 21%, the minimum observed was 0% and the maximum 36%. Work is ongoing to better define RCRD as a therapeutic failure in the absence of data on the etiology (culture or DNA based) since only about 45% of U.S. dairy operations (56% with 500+ cows) reported performing individual cow milk cultures (USDA, 2016). Meantime reporting RCRD in 15-day intervals up to 60 days can help with interpretation.

- Removals (SOLD and DIED) – The proportion of CM cases at the cow level in a month that were removed within a specified number of days from the date of the case. The numerator in this calculation includes all cows removed during the specified time interval and is not limited to those with a removal event record specifying mastitis as the reason. Obviously the closer a removal event to a mastitis event the more likely that removal was directly associated with the CM case. Whether a disease episode is the direct, immediate cause for removal or a contributing factor can be difficult to discern based solely on time between events. However, routine monitoring of cows that died within 14 days and those sold within 14 and 30 days of a CM case can be used to identify trends and substantial changes in removals likely associated with mastitis. Many cows treated with intramammary antibiotics will likely remain on farm for at least 5-7 days. Monitoring the relative proportion of cows sold by 14 and 30 days of the CM case can provide an indication of cows sold as a direct result of mastitis versus those possibly sold later due to low production (Figure 1).

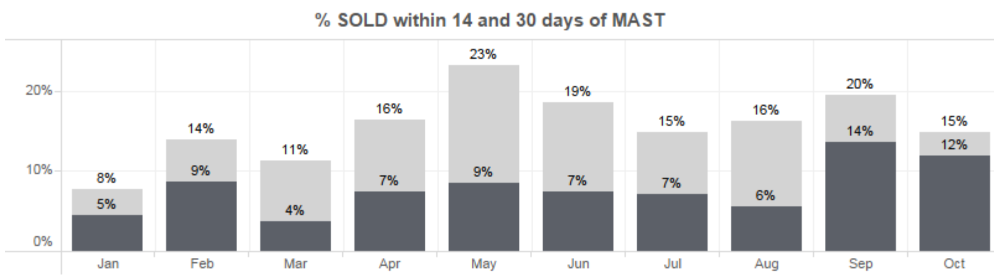


Figure 1. Example of a graph used to monitor the proportion of cows that were sold within 14 and 30 days mastitis. The proportion sold by 14 days nearly doubled in the last two months and warrants investigation.

Dairy producers and veterinarians often want to compare treatment protocols for CM using these KPI. Head-to-head comparisons of different treatments is not valid unless a well-designed clinical trial has been implemented. This is usually not the situation and case selection bias precludes such comparison. A common recommendation is to compare each treatment to acceptable performance benchmarks. For example if a specific treatment has an average monthly RTXD >20% perhaps an alternative treatment should be considered. Consideration of selection bias still needs to be considered (e.g. case severity, previous CM history). Studies are ongoing to explore metrics that could be used to compare performance of an individual treatment as applied on farm. One possibility is evaluation of the days to RTXD patterns (Figure 2).

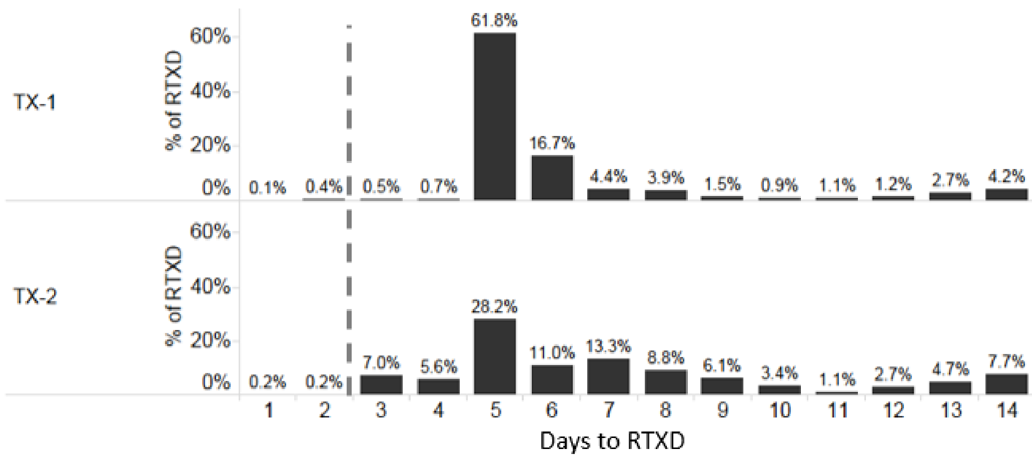


Figure 2. Distribution of days to retreatment (RTXD) of quarter level clinical mastitis cases for two treatments (TX-1, N=1672); TX-2, N=444) on a single dairy. Vertical gray dashed line represents the end of 3 days of intramammary treatment. Cows were scheduled for re-evaluation on day 5.

Both treatments were given for 3 days and cows were scheduled for re-evaluation on day 5. Changing treatment (switch) only occurred in a couple of cases suggesting excellent protocol compliance. There was a substantial difference in the distribution of RTXD from day 3 to 5. For TX-2 12.6% of cases had RTXD on days 3 to 4 compared with only 1.2% of TX-1 cases. However, the percentage RTXD for TX-1 (62%) on the scheduled day 5 re-evaluation was 2.2 times higher than TX-2 (28%). How to interpret these data is still not completely clear. More information about what prompts RTXD and differences in cases given each treatment are needed. Treatment protocols vary but are typically based on udder health history, milk culture result and status of the cow (e.g. DIM, days carried calf and milk production). The CM records should allow efficient, routine comparison of treatments expected, acceptable outcomes based on case characteristics.

Are treatment protocols consistently applied?
Treatment protocol compliance is best accomplished through routine monitoring and active immediate feedback (Figure 3). As described above (Figure 2) days to retreatment can be used to monitor protocol non-compliance such as switching antibiotics before a protocol is completed. The distribution of retreatments for an initial treatment and treatments used for recurrent cases can also be used to monitor protocol compliance.

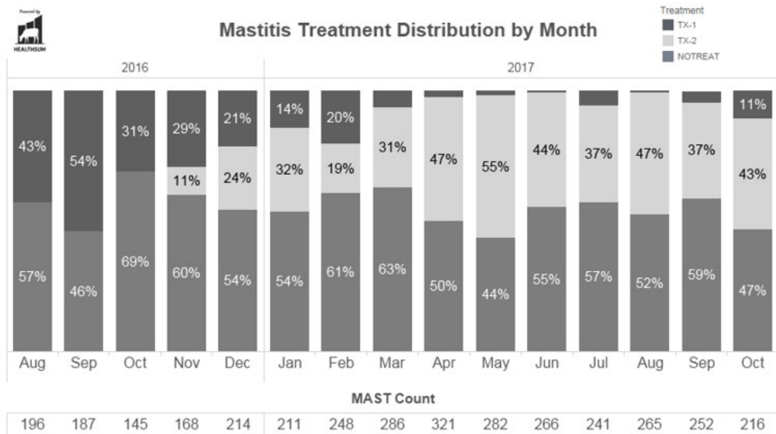
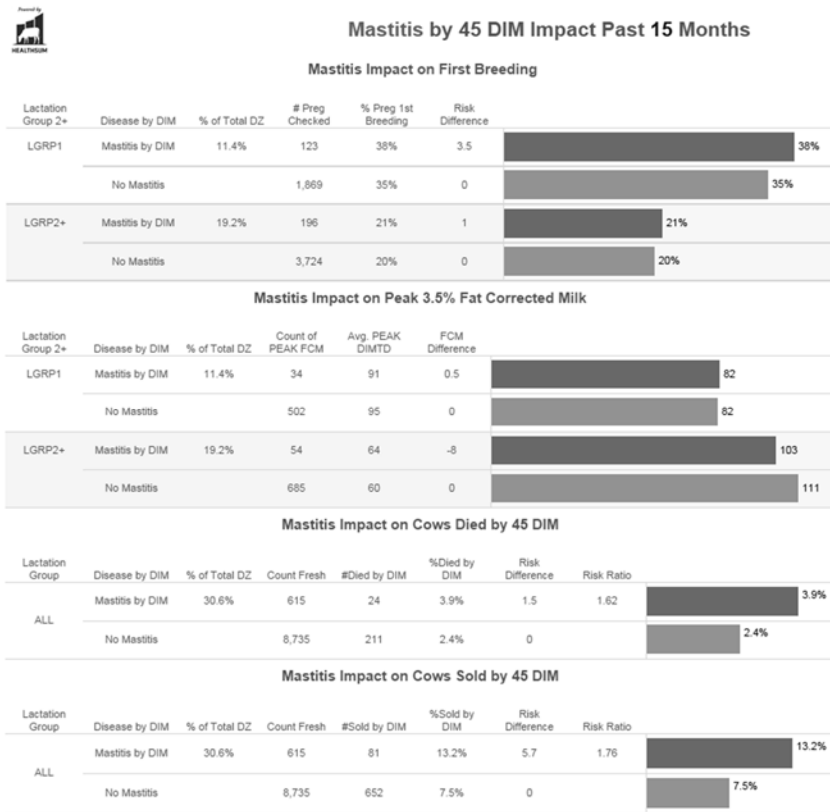


Figure 3. Example of routine monitoring of protocol compliance. The graph shows the distribution of CM cases by treatment each month. It shows a shift over time from TX-1 to TX-2. The increase in TX-1 in the last month shown could be an indication of protocol drift that warrants investigation.

What is the impact of clinical mastitis on <u>this</u> dairy?

Using estimates of the cost of CM cases derived from the literature is appropriate in the absence of better information. Large dairy herds (1000+ cows) with “Good” records and the tools to efficiently integrate CM, reproduction and milk production records are empowered to determine the cost of CM on their dairy (Figure 4). Herd-specific costs of CM are more relevant and allow more accurate cost-benefit analyses of management practices and proposed interventions.



Mastitis by 45 DIM Impact Past 15 Months

Mastitis Impact on First Breeding

Lactation Group 2+	Disease by DIM	% of Total DZ	# Preg Checked	% Preg 1st Breeding	Risk Difference	
LGRP1	Mastitis by DIM	11.4%	123	38%	3.5	38%
	No Mastitis		1,869	35%	0	35%
LGRP2+	Mastitis by DIM	19.2%	196	21%	1	21%
	No Mastitis		3,724	20%	0	20%

Mastitis Impact on Peak 3.5% Fat Corrected Milk

Lactation Group 2+	Disease by DIM	% of Total DZ	Count of PEAK FCM	Avg. PEAK DIMTD	FCM Difference	
LGRP1	Mastitis by DIM	11.4%	34	91	0.5	82
	No Mastitis		502	95	0	82
LGRP2+	Mastitis by DIM	19.2%	54	64	-8	103
	No Mastitis		685	60	0	111

Mastitis Impact on Cows Died by 45 DIM

Lactation Group	Disease by DIM	% of Total DZ	Count Fresh	#Died by DIM	%Died by DIM	Risk Difference	Risk Ratio	
ALL	Mastitis by DIM	30.6%	615	24	3.9%	1.5	1.62	3.9%
	No Mastitis		8,735	211	2.4%	0		2.4%

Mastitis Impact on Cows Sold by 45 DIM

Lactation Group	Disease by DIM	% of Total DZ	Count Fresh	#Sold by DIM	%Sold by DIM	Risk Difference	Risk Ratio	
ALL	Mastitis by DIM	30.6%	615	81	13.2%	5.7	1.76	13.2%
	No Mastitis		8,735	652	7.5%	0		7.5%

Figure 4. Example report of the impact of clinical mastitis on first breeding, peak milk and removals on a 6,000-cow dairy. Such information can be used to calculate the herd-specific cost of clinical mastitis.

<u>Why Clinical Mastitis Should be Recorded at the Quarter Level</u>

1) **Many herds already record quarter and it's not hard to do.** A study of 50 large herds using Dairy Comp 305 found that of the 42 recording CM, 86% recorded the quarter affected while only 67% recorded treatment (Wenz and Giebel 2012).

2) **Cow level recording compromises the accuracy and consistency of CM records.** Management of CM is most commonly performed at the quarter level, ideally guided by milk culture results. For example, consider a cow with 2 quarters affected (LF and RR), one that yields no growth (NG) and the other an environmental strep (EN). The mastitis treatment protocol for the <u>first</u> CM episode of a lactation is no treatment (NT) of NG and an intramammary (IM) antibiotic of EN. Second CM episodes of NG get IM and of EN the same IM as the first. It is clear from this example that a separate record of the affected quarters is necessary to accurately capture all the information about CM case management. Even if culture results are not available outcomes should be evaluated at the quarter level as described below. Attempting to record a multiple quarter CM episode as a single event in most DMS is where problems occur. For example Dairy Comp 305 event remarks are limited to 8 characters and it is not possible to record the above example following the 3 Simple Rules of "Good" Records when recording as a single event at the cow level. To have the same information in the same order using the same abbreviations for all CM records you need to record 2 separate events at the quarter level.

The information to be recorded is treatment, culture result and quarter: NTNGLF and IMENRR. When recorded at the cow level information about the episode is lost and typically what is omitted is that which didn't result in drug administration (the no treatment of the no growth in the LF). The CM record is then not accurate and outcomes of the omitted no growth quarter episode cannot be assessed. When there is pushback on recording each quarter as a separate event, accuracy of the records will be lost but consistency can be preserved in one of 3 ways. The first is to record quarter information last if the abbreviations will be variable in length (e.g. LF and LFRF, 2 and 4 characters). That way the data can still be parsed out by a computer (e.g. a Spreadsheet program) (Figure 4A). The second is to use a delimiter such as a period (.) or slash (/) to separate the data (Figure 4B). This would allow a computer to parse out a variable length abbreviation (like quarter in this example), then parse the remaining data by character number. The third way is to record all possible quarter combinations with a 2 character abbreviation (Table 1).

3) **Accurate assessment of the outcomes of CM cases requires quarter level recording.** Retreatment obviously needs to be evaluated at the quarter level. Currently most herds record initial and retreatments using the same mastitis event. Determination of retreatments therefore is typically based on the days between two mastitis events as described above. For this to be done accurate CM cases need to be recorded at the quarter level. As discussed previously recurrence can be used to evaluate treatment efficacy as a high proportion of recurrent cases in the same quarter are likely associated with persistent infections. By contrast a subsequent case in the same cow in a different quarter represents a prevention failure. When milk culture data are available quarter level CM case recording allows etiology specific assessment of outcomes. It wouldn't be appropriate to compare etiology of 2 CM cases in different quarters.

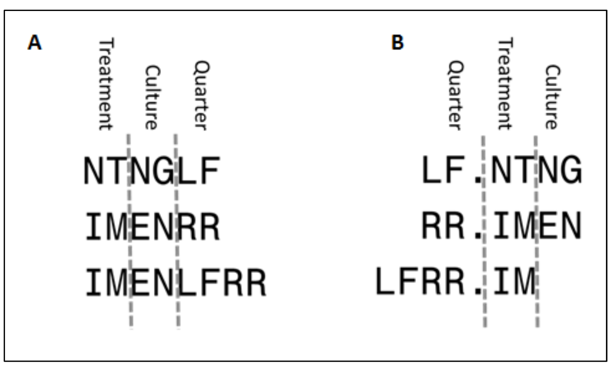


Figure 5. Alternative ways to record multiple quarters and maintain consistency that allows data parsing by computer. A) Quarter with variable character number at end B) Use of delimiter (.) to separate variable and consistent character number abbreviations. Dashed vertical lines denote where the data will be parsed. In A, "fixed width" parsing can be accomplished when the variable character information comes at the end.

Table 1. Two-character abbreviations for all possible multiple quarter combinations. Abbreviations LS or RS indicate Left or Right Side.

Quarters	Abbreviation
LF LR RF RR	AL
LF LR	BL or LS
RF RR	BR or RS
LF RF	BF
LR RR	BH
LF RR	LX
RF LR	RX
3 Quarters	Reverse letters of unaffected quarter using HR for RR

Summary

A focus on recording disease and its management rather than simply recording treatments is needed for continuous improvement in CM record quality. "Good" CM records are accurate and consistent, but more importantly the must support both day-to-day individual cow-level activities and herd-level summary and evaluation of the outcomes of udder health management. Records adequate for those functions typically meet the requirements for residue avoidance/regulatory compliance on the dairy. Health data management protocols based on the 3 simple rules of "Good" recording will ensure records are accurate and consistent and fulfill these critical functions on the dairy. Most important is consistency in the information, order and abbreviations used in CM records allowing efficient summary and analysis using computer applications.

At a minimum quarter and treatment should be recorded for all CM cases. Cases not treated should have that fact recorded. The abbreviations used to denote lack of treatment should be different for cows not treated with the intent of keeping versus those not treated because they will be culled. This allows accurate evaluation of removal as an outcome of a no treat therapeutic decision.

Record CM cases at the quarter level. Many herd already record quarter and it takes little effort but provides substantial benefits. Cow level recording compromises the consistency of CM records and accuracy of case outcomes assessment.

Finally, large herds with quality CM records and the proper tools can determine a herd-specific cost of CM rather than rely on estimates from the literature.

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Lessons Learned About Milking Time Hygiene with Automated Milking Systems

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<u>Introduction</u>

Since the first automatic milking systems (AMS) were installed in Europe in the early 1990s, this groundbreaking technology has spread quickly across the dairy world. The first system was installed in Canada in 1999. It is estimated that there are currently about 1,300 Canadian dairy farms milking with AMS. This accounts for about 12% of the 10,900 farms in Canada in 2017. The size of farms utilizing AMS technology ranges from one unit up to 25 boxes on a single farm with an average size of slightly under two boxes per farm.

As was the case in Europe, the incentive to install AMS was mainly in the goal to reduce labor and provide an improved lifestyle through greater work flexibility. An increase in milk production per cow was also expected, as most herds in Canada moved from two times per day milking to multiple times per day milking with AMS.

This paper will review what has been learned by working through milk quality challenges faced by dairy producers who have adopted AMS as it pertains to the NMC Five-Point Plan.

<u>Milk Quality</u>

The experience in Europe regarding milk quality showed that there would be differences as opposed to conventional systems. For somatic cell count (SCC), one study (Rasmussen 2008) found about a 10% higher SCC with AMS. Approximately half the AMS farms in Canada are on official milk recording. Results of a June 2017 review of Canadian herd numbers by region indicate very little difference in average SCC between conventional milking systems and AMS installations across the country (Valacta 2017).

A Canadian national survey (Tse and Pajor, 2017) asked farmers about their transition to AMS. The perceptions of the dairy producers surveyed was that the adoption of this technology was successful and that they would recommend it to other dairy producers. Additionally, they were optimistic of the profitability of the system, and that the lives of both the producer and the cows had improved. Regarding milk quality, they felt there was little change from the previous conventional system.

The experience in Ontario is different (Dairy Farmers of Ontario, 2017). Concerns of the quality of milk being produced on AMS farms has triggered a review. No difference was seen in SCC between milking systems. However, there has been a significant number of high bacteria counts on AMS farms, as well as elevated freezing point and a slightly higher number of inhibitor infractions. These issues have forced the province of Ontario to examine more closely the quality of milk produced on AMS farms. The survey will also review the levels free fatty acids in milk from AMS farms.

The province of New Brunswick was a late adopter of AMS technology, with the first installation in September 2010. Today, there are 31 AMS farms (16%) of the 193 farms. As with Ontario, average SCCs are similar between AMS and conventional herds (Maritime Milk Quality – Test Results 2017). However, when we examine bacteria counts, we start to see some differences. For the period between January 1 and September 30, 2017, there were 30 milk quality penalties assessed in the province. Of the 30 penalties, 13 were from AMS farms (43%), of which 12 were for bacteria count infractions, standard plate counts (SPC) and laboratory pasteurization counts (LPC); only one for SCC. SPC are generally higher on AMS herds and with more variability. Looking at SPC, of the 10 AMS farms with new barns as opposed to the 15 AMS farms that were retrofitted into old barns, a significant difference is obvious. SPC in the 10 new barns is typically at or below the provincial average of all farms. LPC shows similar trends. The reasons for the differences between new and retrofitted barns have not been closely examined, but it is reasonable to assume that new barns were built based on the most up-to-date recommendations for ventilation, stall sizing, bedding and other criteria.

Equipment Function

The 5-Point Plan states, "Maintain the milking machine properly." For conventional milking machines, we can say today that we have standard testing procedures with terminology based on an industry-wide consensus. The NMC machine milking committee worked for many years to achieve this. Today, the committee is working to achieve the same tools with AMS. The milking time tests of the NMC test procedure still apply, but the dry tests of pulsator function and airflow are yet to be developed.

The concerns we see in the field include: poor teat condition, uneven milk-outs, delayed take off activation and inconsistent vacuum stability. While these issues are not extreme, they are seen at higher rates than with conventional milking systems. Bulk tanks also cannot be overlooked regarding washing function, loading rate, milk freezing, drainage after washing, over agitation, etc.

Udder Preparation

In conventional milking systems, the dirty cow is handled differently at milking time. Udder preparation changes so that the cow's teats are properly cleaned and dried. This is usually accomplished using multiple cleanings, multiple towels or whatever is necessary to produce a visibly clean teat. On a herd basis, this is also true. Producers adopt milking routines to get the results they want. Some producers are happy with just dry wiping teats, whereas most have adopted a full udder preparation routine that utilizes predipping, forestripping, and cloth towels for drying. With the installation of AMS, many udder preparation paradigms have been toppled. The idea of washing teats without drying is something most milk quality consultants, such as myself, have condemned for years. Now, we see this is the standard practice. While the results are mixed, many AMS farms are producing excellent quality milk. Certainly, it is time for a review to see what is most important and what we must emphasize.

Regarding milking time hygiene, Hovinen et. al. (2005) compared teat cleaning using brushes versus wash cups. It was found that there was little difference between the two systems when dealing with clean cows. The wash cup system did show an advantage with dirty cows. A second part of the study indicated that the wash cup system did a better job cleaning teat ends. But clearly the take-home message is: **We need clean cows!** While this is true for all types of milking systems, it is especially critical for AMS herds.

Another part of the udder preparation routine that seems to be forgotten is the importance of prep lag time. The work that was done to understand and emphasize the importance of this factor has too commonly been forgotten. In fact, the old idea of getting the units on as quick as we can seems to have comeback on too many AMS farms. The importance of throughput perhaps was not as much of an issue in Canada as in the United States. There were very few parlors in Canada that were maxed out timewise. Now, with AMS, the urges are to minimize udder prep routines, skip one wash cycle and other perceived time-saving steps, which are all counterproductive to milk quality and udder health.

A survey conducted by Penn State Extension (2017, Parts 1-3) on nine AMS herds examined several factors around the production of quality milk. The study examined the importance of cow cleanliness and measured the ability of these systems to clean teats. The technical success of the cleaning was found to be greater than 90% on most farms. Two farms that had low success rates saw improvements after a dealer service visit. This emphasizes the importance of regular service and constant monitoring of the function of these units. Another part of the study looked at the ability to clean dirty teats. And although all AMS units were able to improve teat cleanliness, many teats were still found to have some residual material on the teat ends at attachment. Again, the importance of cow cleanliness must be emphasized.

Teat Dipping

Teat dipping is a cornerstone of any mastitis control program. Its effectiveness in reducing new infections has been proven again and again. And when we talk about what constitutes proper teat dipping, the discussion usually centers on using an effective germicide that is formulated to be gentle on teat skin. Recommendations for the percentage of the teat to be covered have varied over the years, but today most will ask for a majority of the teat to be covered. The teat orifice is obviously most important. But getting skin conditioning dip high up on the barrel of the teat where the mouth piece of the inflation sits just prior to removal is a goal that most would recommend today.

Based on these recommendations for coverage, many in the industry have expressed concern and frustration with the coverage of teats commonly seen with AMS units. And yet the average SCCs of herds on milk recording in Canada do not vary significantly from the SCC average of all herds on milk recording. Of course, there are many factors that influence SCCs, but the industry, and myself included, has always emphasized that the correct application of teat dip is a critical mastitis control parameter.

Cow Cleanliness

As has been mentioned previously, the cleanliness of cows entering the AMS is critical to the quality of milk produced. We have the knowledge and experience to provide housing for dairy cattle that will keep them clean. We also have the experience in choosing bedding options, stall sizes, bedding frequency, etc. to do the job effectively. Although based on a small number of herds, I firmly believe that sand bedding is still the gold standard. It is still critical to maintain the stalls so that they are clean and dry, and this presents a few new challenges. The delivery of bedding will be more difficult as we try to disturb the herd as little as possible. Alley scrapers are the preferred method to remove the manure, but there are other options and more to come in the future. The goal remains the same: minimize the depth of the manure cows must walk through. The three-word phrase, “Clean, Dry and Comfortable,” is just as true today with AMS herds as it is with all herds.

The clipping or singeing of udders is not a new practice, but with AMS milking it is more common and important than ever. Not only does it improve teat cleaning, but it also helps in the identification and location of teats for cleaning and unit attachment. Generally, most herds will singe at freshening and again as needed. In colder climates, this may be as common as every two months. Some farms choose to do it at herd health when cows are secured in headlocks; therefore, all cows can be singed. Also, the long hair on the tail switch needs to be removed as this also can become caught in the brushes during cleaning.

Tools

The tools that are needed to investigate and solve milk quality issues with AMS herds are practically the same as with conventionally milked dairy herds. We will use individual cow milk samples to identify mastitis bacteria, bedding cultures, bulk tank cultures and other tests. We can score cow cleanliness, teat end condition and other herd data to help make informed decisions.

Take home messages

- Cows must be clean; the margin for error is small.
- Milking equipment: maintenance and analysis are critical.
- Utilize existing milk quality tools.

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Culling Cows with Mastitis: An Economic Perspective

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Introduction

Mastitis is considered to be the most costly disease for dairy cattle herds in the developed countries (Halasa et al., 2007). It is also a major cause of impaired animal welfare (Broom et al., 1991). In addition, the majority of antibiotics used in dairy herds are used to treat or prevent mastitis (cited from Gussmann et al., 2017). Although large efforts have been made to manage mastitis, it remains a major problem in dairy herds. This is driven by several factors including the increasing herd size (Jørgensen et al., 2016), application of AMS milking systems (Hovinen and Pyörälä, 2011), increased milk production and emergence/reemergence of new strains causing mastitis (Lyhs et al., 2016). Therefore, farmers should continuously be looking for improved management to control mastitis. Naturally, the cost-effectiveness of improved management should be taken into account.

The classic 5-points plan to manage mastitis (Neave et al., 1969) does focus on the key issues with regard to dairy cow management in relation to udder health: hygiene, milking machine maintenance, dry cow therapy, lactational treatment and culling of chronic mastitis cows. In published research in the last decades, most of these management measures have gained much attention and are thoroughly studied. However, although an important management factor in dairy farming, the effect of culling chronic mastitis cows on the overall farm mastitis situation and on the farm profitability is less well established and because of the complexity of culling decisions less well understood.

Models for the culling process in dairy cattle herds have been developed already in the 1960s (Robertson, 1966). More recently, two main approaches have been used to study the economic impact of culling of cows with mastitis. These are: 1) the dynamic programming and optimization approach (e.g. Van Arendonk et al., 1986; Kristensen et al.,1987; Houben et al., 1994; Gröhn et al., 2003; Heikkilä et al., 2012; Cha et al., 2011; Cha et al., 2014), and 2) the stochastic Monte Carlo simulation approach in a bio-economic framework (e.g. van den Borne et al., 2010a; Halasa, 2012). These studies provided useful tools to aid in providing economic sound culling and replacement decisions of dairy cows with mastitis. However, a general framework for the assessment of the economic impacts of culling cows with mastitis is lacking and therefore the interpretation of results of the known modelling studies is difficult.
This paper describes the economic reasoning behind culling decisions of cows with mastitis and presents a general framework to the factors that should be considered when assessing the economic impact of culling cows with mastitis, with special focus on mastitis caused by contagious pathogens.

Culling: Definition and Effects of Udder Health Disorders

Fetrow et al. (2006) defined culling as the departure of a cow from the herd due to sale, slaughter, salvage or death. In most cases, the culled cow will be replaced by another cow and hence the word "replacement" is frequently used as a synonym for culling. Traditionally culling can be categorized as voluntary or involuntary (Fetrow et al., 2006). Voluntary culling is carried out normally due to economic incentives such as poor production, in which the farmer has influence on the culling decision. Involuntary culling is carried out normally due to diseases (e.g. mastitis, and lameness), poor reproduction or death, and the farmer has less influence on the decision. This traditional classification hides the fact that a decision to cull a diseased cow is often also voluntary, since prolonged or more intensive (and thus more expensive) treatment might still cure the cow. Although hardly studied, repeated or more intensive treatments are often seen as not cost-effective and hence cows with chronic or non-cured mastitis are replaced by a fresh heifer. Based on this, Fetrow et al. (2006) challenged the traditional distinction of culling and suggested culling to be defined as either economical or biological motivated. Biological culls are related to culling decisions that are forced or could not be avoided due to for instance death, while economical culls include cows that a decision to replace them by other cows has been deemed to be economically smarter (Fetrow et al., 2006). Economical culls actually comprise the vast majority of the culled cows, including culled cows due to diseases such as mastitis. This classification "Biological vs. economical culling" in our opinion is a better reflection of reality.

Udder health can be associated with culling in two ways. A first mechanism is that by implementing measures to prevent mastitis, the udder health of a farm would be better, and therefore fewer cows would be culled. This would lead to a lower overall culling rate on the farm; culling as a negative effect of mastitis. The second mechanism is the other way around. By culling (chronic) mastitis cows, the udder health on a farm will improve; culling as preventive measure (this is the way culling is described in the 5-point plan).

Several studies have been conducted to identify reasons for culling cows. The probability for a cow to be culled was influenced by cow factors, including among others, health disorders, (Millan-Suazo et al., 1988; Gröhn et al., 1998; Hadley et al., 2006; Schneider et al., 2007; Piepers et al., 2009). Among health disorders, udder health disorders ranked number two after reproductive disorders in the reasons for culling. Millan-Suazo et al. (1988) showed that 4% of the cows are culled due to udder health problems with odds up to 2.7 for being culled compared to cows in lactations without udder health problems (clinical mastitis and teat problems). Bascom and Young (1998) showed that 15% of the cows are culled due to mastitis. Gröhn et al. (1998) estimated that 14.5% of the cows are culled due to mastitis, while Seegers et al. (1998) estimated that 12.4% of the cows are culled due to udder health related disorders. Piepers et al. (2009) estimated that 10% of heifers are pre-maturely culled due to udder health disorders. In none of these studies, it was identified whether the culling due to mastitis was a negative side effect of mastitis or was preventive.

Several studies have also identified cow-factors that affect culling decisions (Millan-Suazo et al., 1988; Neerhof et al.; 2000; Hadley et al., 2006; Schneider et al., 2007). Generally, milk production, reproduction, breed, lactation stage, and parity have effects on the longevity of the cow. Specifically, in relation to mastitis, these factors also affected the culling decisions, but mastitis related factors had also an effect. For instance, Reksen et al. (2006) estimated that cows with bacteriologically positive culture sample for *Staphylococcus* (S.) *aureus* or *Streptococcus* spp. had significantly higher hazard ratios of being culled compared to cows with bacteriological negative samples, while this was not the case for cows with CNS positive samples. In addition, the risk of culling was higher for cows with samples of rich positive cultures compared to those with sparse culture. This perhaps indicates that the severity of the case may affect the culling decisions. Bar et al. (2008a) indicated that clinical mastitis significantly increased the risk of a cow being culled in all parities and after the third clinical mastitis case, the odds of culling the cow were more than 4 times as high as the odds of a cow without clinical mastitis.

Clearly, the above studies investigated the risk of culling of individual cows in relation to other cows in the same herd. Studies investigating the relation between culling of cows due to mastitis and the overall mastitis situation of the herd are scarce. Mohd Nor et al. (2014) investigated culling rates of 1,903 Dutch dairy herds and found that herds with a higher rate of culling had a higher average cow SCC and a higher level of cows with a new high SCC. So also at the herd level, it could be seen that a better udder health situation was associated with lower levels of culling. This might be an indication that most of the culling due to mastitis can be seen as a negative side effect of the occurrence of mastitis rather than as prevention of mastitis.

<u>The Economics of Culling</u>

Economically, the optimal culling moment of a cow is the moment that the future production value of that cow is lower than the future production value of a replacement cow, considering the costs of rearing or buying that replacement cow. This is referred to as the retention pay-off (RPO) value of a cow, which represents the economic value of keeping the cow in the herd for an extra defined time period compared to replacing it. Once the RPO value of a cow is below 0, then it is beneficial to replace the cow.

Although in theory RPO is the most rational approach toward culling decisions, many other factors complicate the decision to cull a cow at the economically optimal moment. These factors are:

1. The determination of the future value of a cow. Since every cow is a unique creature, the future production of each individual cow differs. The prediction of the future production of a cow can be based on past production performance and disease events. It is clear that the expected future value of a cow decreases instantly when a cow is diseased. Treatments do decrease the future value as costs, but expected lower yields and expected higher risk of disease does also lower the future value. As described beneath, models have been developed to optimize culling decisions based on the RPO method, taking into account multiple complications including among other problems mastitis (e.g. Grohn et al., 2003). As a result, the models can become tremendous large and complex, while still not being complete, impeding their use as a decision support tool on daily bases.

2. Farmers' behavior, perception and preference. Farmers do not necessary behave rationally. Some prefer to treat young animals with mastitis as they are the future potential of the herd while they cull older cows (Gussmann et al., 2017). Others prefer to treat high producing cows, while they prefer to cull low producing cows regardless their age (Gussmann et al., 2017). Thus, cow factors do as well affect the decision to treat or cull a cow with mastitis, and the importance of

these factors varies from one farmer to another (Gussmann et al., 2017). This subjective appreciation of certain cows can also exist because of a lack of proper economic calculations with regard to those aspects. In addition, sociological factors may also influence the culling decisions (Beaudeau et al., 1996).

3. The farming system: RPO models assume the availability of replacement heifers at the moment of culling. The farming system affects the availability of replacement cows/heifers, which affects the culling decisions. In open systems, farmers can buy new animals, making it easier to replace cows, but they are more affected by price fluctuations and the market. In closed systems, farmers do decide on a culling rate by the decision to keep a newborn calf for rearing (Mohd Nor et al., 2014). In such a system, farmers would usually cull a cow once a replacement cow is available. Early culling gives an understocking, while late culling gives an overstocking. Therefore, in a closed farming system, farmers usually rank the cows for culling based on culling criteria founded mostly using the farmer's own perceptions and preferences. Once replacement animal(s) are available, the cow(s) on the top of the list are culled. This in fact may delay the culling of a cow with mastitis caused by a contagious pathogen, leading to the infection of healthy herdmates. On the other hand, it also may result in premature culling as some animals are removed prematurely due to space restrictions. In both situations, the culling is definitely not economically optimal from an RPO perspective, but it maybe optimal within the farm system.

4. Herd size and production level: Herd size may be a proxy for the economic orientation of the farmer. Small herds are more often managed based on personal preferences of the farmer, where the drive behind having the animals is less economically motivated. Culling in such herds is more often not based on economic optimality; cows may be kept because of personal feelings. In contrary, management in large herds is more rational and merely motivated by economics and hence culling is expected to be economically motivated. Large and/or high producing herds have higher culling rates than small and/or low producing herds (Hadley et al., 2006; Schneider et al., 2007).

5. Herd health management and genetic improvement: These factors may also influence the culling decisions (Hadley et al., 2006; Beaudeau et al., 1996). If a farmer is involved in an eradication program of a specific disease, the farmer may prioritize to cull cows diagnosed with that specific disease, regardless of the economic effects of the decision. Also, genetic progress (newer generations of cows being better) is an often herd argument for high culling rates.

6. Regional or country related factors (Hadley et al., 2006; Schneider et al., 2007): Prices of milk, meat and feed may vary between regions and countries, affecting the optimal culling moment. In addition, treatment costs (e.g. in case of clinical mastitis) and regulations in term of antimicrobial use may vary between regions and countries, affecting the optimal culling moment, as well. Moreover, other regulations in terms of payments of subsidies to farmers may affect the culling decisions. For instance, in Norway farmers are subsidized twice a year based on, among other factors, the number of animals and the region (Anonymous, 2017). Therefore, farmers may delay the culling until they are paid, leading to suboptimal culling decisions. In the Netherlands, there is public debate about the longevity of cattle and the dairy industry is stimulating farmers to reduce culling rates and to increase cow longevity.

The Economics of Culling Cows with Mastitis

Mastitis is a multifactorial disease, in which pathogen, cow and herd factors affect its occurrence, persistence and elimination. The cow's risk of (re)infection, and cure probability following treatment, as well as the causative pathogen of a mastitis case are important factors that must be considered when determining the optimal culling decision of a cow with mastitis.

Pathogens causing mastitis vary largely in their clinical presentation, effects on production, persistence, spontaneous elimination or elimination following treatment of the case and in spread patterns between cows. Mastitis cases caused by contagious pathogens such as *S. aureus* and *S. agalactiae* are important to eliminate as an infected cow may infect healthy herdmates. The economic losses (failure costs) due to mastitis caused by contagious pathogens are not only due to the case itself, but also due to infection of herdmates. Contrarily, the economic losses due to mastitis cases caused by environmental pathogens are only due to the effects on the case itself. Recently, Jørgensen et al. (2016) argued that *S. agalactiae* could possess environmental spread pattern besides the known contagious behavior of the pathogen. This suggests some kind of an opportunistic spread behavior combining both environmental and contagious spread. The economic effects of culling cows infected with pathogens that have this opportunistic behavior is unknown and could be different than those for cows infected with purely contagious or environmental pathogens. Thus, the transmission dynamics of the causative pathogen should be considered when assessing the economic effects of culling cows with mastitis.

Another important pathogen characteristic than its pattern of transmission is the recovery probability. Recovery following treatment of a mastitis case caused by a certain pathogen could be higher or lower than that for a case caused by another pathogen. For instance, recovery from clinical mastitis caused by *S. uberis* is higher than that for a case caused by *S. aureus* (Zadoks et al., 2001a; Sol et al., 2000). Thus, treating the clinical case caused by *S. aureus* may be economically unjustifiable in certain situations, as it may persist as a chronic subclinical case infecting healthy herdmates, because *S. aureus* is a contagious pathogen. This can also be taken in consideration given the societal concerns regarding prudent use of antimicrobials, in order to limit antimicrobial resistance. Thus, economic effects of culling a cow with mastitis caused by a certain pathogen may be different than that for a cow with mastitis caused by another pathogen. Therefore, culling decisions should be pathogen-specific, considering differences between pathogens in both transmission and recovery.

Few studies have shown that strains of the same pathogen species may behave differently in spread patterns. For instance, Zadoks et al. (2001b) showed that *S. uberis* could possess a contagious spread pattern. Evidence has also been shown that certain strain of *Klebsiella* may also spread in a contagious pattern (Munoz et al., 2007). Strain differences have also been shown regarding the recovery probability of mastitis cases caused by *S. aureus* (Borne et al., 2010b; Barlow et al., 2013). This suggests that culling decisions should also be strain-specific. Nevertheless, the high costs of strain typing and the long time it takes to provide the results limit its current use as a regular diagnostic tool for treatment and culling decisions from a practical standpoint.

Generally, cows vary in, among other factors, their productivity and reproduction potential, as described above. In relation to mastitis, they also vary in susceptibility (Zadoks et al., 2001a), and recovery following treatment (Steeneveld et al., 2011). Thus, decisions to cull cows should be cow-specific considering cow-factors including the susceptibility of the cow to mastitis, the chance of recovery following treatment and the future potential in terms of among others productivity and reproduction potential of the cow.

Approaches and Assessments of the Economics of Culling Cows with Mastitis

During the 1980s, considerable work has been conducted identifying optimal culling and replacement strategies for dairy cows using dynamic programming and Markovian processes (e.g. Kristensen et al.,1987; Van Aarendonk et al., 1988). This work was further developed to include diseases such as mastitis (Stott and Kennedy, 1993; Houben et al., 1994; Gröhn et al., 2003; Cha et al., 2011; Heikkilä et al., 2012) availing useful tools for cow-specific replacement or treatment decisions to control mastitis. Nevertheless, in a review by Lehenbauer et al. (1998), the authors stated “although culling strategies that have increased emphasis on mastitis control provide reduced incidence and prevalence of mastitis, these policies do not achieve maximum financial gain and do not appear to be justified economically compared with policies emphasizing production. However, culling policies based on objective criteria that include increased risks and costs associated with mastitis in addition to milk production potential may be economically viable”. The studies that are indicated by Lehenbauer et al. (1998) used mainly the dynamic programming approach (e.g. Stott and Kennedy, 1993; Houben et al., 1994). Later studies also came up with similar conclusions. For instance, Gröhn et al. (2003) used the dynamic programming approach and indicated that culling was recommended for low producing cows, while it was beneficial for high producing cows only late in the lactation. A similar observation was obtained by Bar et al. (2008b) who found that replacement of these cases are beneficial for open cows (not pregnant) late in the lactation from around day 234 after calving, but could be as early as day 152 after calving for low producing cows. Cha et al. (2011) used as well dynamic programming and found that in most cases, the treatment was more profitable than culling the cow. Heikkilä et al. (2012) concluded that regardless of the high costs of clinical mastitis and by the parities increasing risk of it, it is almost always profitable to treat clinical mastitis and keep the diseased cow in the herd. More recently, Cha et al. (2014) concluded that the optimal recommended time for replacement a cow with clinical mastitis was in general up to 5 months sooner than that for a cow without clinical mastitis.

The dynamic programming approach allows the estimation of the RPO value of a cow considering the cow characteristics and hence allows optimal and cow-specific decision making for operational reasons. However, studies used the dynamic programming approach focused on modelling the occurrence of clinical mastitis and ignore subclinical mastitis. In addition, the transmission dynamics of the pathogen were not considered in the published studies, perhaps due to the challenges of this approach to model population dynamics, possibly due to its demands for high computational power, because the number of the modelled states would grow exponentially with the number of modelled factors (Nielsen et al., 2010). The lack of modeling the spread dynamics of the contagious mastitis causative pathogens may underestimate the positive impact of control strategies (antibiotic treatment/culling), because curing or removing an infected cow would reduce the risk of infection of healthy herdmates; as explained above.

Another approach that is also used to assess economic impacts of management and control of mastitis, and in few cases, including culling is using stochastic Monte Carlo simulation in bio-economic modeling. Few bio-economic models were published such as Allore et al. (1998), Østergaard et al. (2005) and Halasa et al. (2009). The models simulated multiple pathogens simultaneously, were herd-specific, and the first 2 models included the cow characteristics in modeling the risk of infection. The model by Halasa et al. (2009) simulated the spread of both contagious and environmental mastitis causing pathogens and was then used to assess the economic impact of strategies to control contagious subclinical and clinical mastitis pathogens including the impact of culling these cases (van den Borne et al. 2010a; Halasa, 2012). These were the first and only studies that studied and quantified the economic impacts of culling contagious mastitis cases. Van den Borne et al. (2010a) estimated that culling of uncured subclinical contagious mastitis cases following antibiotics treatment can save on average 57€ per cow per year, regardless the lactation stage or the parity of the cow. But this could vary between 4€ and 112€ per cow per year depending on the extent of the problem (prevalence) in the herd. Halasa (2012) used the same model to assess the economic consequences of treatment and culling of clinical contagious mastitis cases. The author estimated that culling of uncured clinical mastitis cases following 5 days treatment with antimicrobials vary; from a loss of about 2€ per cow per year to savings of about 8€ per cow per year depending on the extent of the problems with contagious mastitis in the herd. In both studies, the authors recommended that herds with high transmission would first implement measures that reduce the transmission rate, such as hygiene measures, rather than culling, as culling may exaggerate the losses. In this respect, it is important to mention that this model focuses on herds with large problem with *S. aureus* and assumes that somatic cell count is almost a prefect parameter to select cows for testing and subsequent treatment against subclinical mastitis.

The simulation modelling approach allows testing strategic decisions and is useful to represent herd-specific situations, which is important as herds vary largely due to herd and farmer related factors as explained above. In addition, the developed bio-economic models simulated several pathogens simultaneously permitting pathogen-specific assessments of measures to prevent and control mastitis, and one (Halasa et al., 2009) included the transmission dynamics of the contagious and environmental mastitis causative pathogens. Nevertheless, this modeling approach has a limitation in providing optimal cow-specific decisions, as it depends on setting up specific criteria for decision making, reflecting groups of cows that fit the criteria rather than individual cows.

The approaches used to examine the economic effects of culling cows with mastitis in general are with no doubt useful despite of the different limitations of each approach. Still the ultimate approach would be to provide a tool that allows strain- cow- and herd-specific decisions for treatment or culling of cows with clinical or subclinical mastitis. The ultimate way would be to estimate the RPO value of a cow within a Monte Carlo simulation model providing both operational and strategic decisions. But to our knowledge such a system is unrealistic to run with current available computational capacity.

Recently, Steeneveld et al. (2011) proposed an interesting approach to examine the cost effectiveness of cow-specific treatment of clinical mastitis. Although the proposed approach still functions in the same way as other Monte Carlo simulation models (by setting up criteria for selecting cows), detailed cow characteristics were modelled to estimate the probability of recovery following treatment. Allore et al. (1998) and Østergaard et al. (2005) included algorithms for cow-specific risk of infection. Græsbøll et al. (2017) proposed an interesting approach to predict the future potential of a cow, allowing the ranking of cows for culling based on their future potential. This could be a good substitute for the RPO value given the limitations (Græsbøll et al., 2017). Combining these elements in a bio-economic Monte Carlo simulation model, and considering the transmission dynamics of mastitis causative pathogens would allow provide a tool for pathogen-, cow- and herd-specific decision making on treatment or culling mastitis cases. It is important to mention that many scenarios must be run to identify the potentially effective scenarios considering the many modelled processes and elements. In addition, exact optimal decisions may not be reached, but decisions based on exact valuation are really taken in dairy herds, as the decision process is influenced by many factors.

Conclusions

Culling is an important aspect of mastitis management, either to limit the negative effects of mastitis occurrence or to prevent new mastitis cases. Studies in relation to mastitis and culling were either risk factors studies or purely based on modeling to assess the economic consequences of culling cows with mastitis. No intervention studies were found. Only two modelling studies considered investigating these effects by including the transmission dynamics of contagious mastitis pathogens in a bio-economic simulation model focusing on treatment decisions. Furthermore, no studies were found estimating the economic effects of culling cows specifically with chronic mastitis.

The economic effects of culling cows with mastitis are dependent on herd, cow and pathogen factors. This means that the benefits of culling a cow with mastitis caused by a specific pathogen can be different from one herd to another depending on herd factors including the extent of the mastitis problem within the herd. In addition, the benefits of culling a cow with mastitis within a herd can be different than culling another cow with mastitis within the same herd depending on the cow-factors and the causative pathogen.

There is a need for a comprehensive assessment of the economic effects of culling cows with mastitis, including culling cows with chronic and contagious mastitis. The assessment should consider pathogen, cow, herd, region/country characteristics, in order to provide herd health managers with reliable tools for cost-effective culling decisions in relation to mastitis prevention and control.

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Machine Milking and Mastitis Risk: Looking Ahead, with the Benefit of Hindsight

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The first successful commercial milking machine was produced in 1889 by a Scottish plumber, William Murchland. Other commercial machines were developed in the following years by an assortment of plumbers, tinsmiths, inventor-farmers, doctors and engineers (Dodd and Hall, 1992). For the next 60 years or so, the main basis for further development and commercialization of milking machines seemed to have been the 'suck it and see' approach. The first real scientific contributions to understanding the possible links between milking machines, milking management and mastitis were conducted in Iowa and in Ireland in the 1960s. This review charts some of the diversions, dead-ends and significant leaps forward since those early days, and offers some recommendations for the path ahead.

State of Knowledge 60 Years Ago

By the end of the1950s, most dairy farmers in western Europe and North America had switched from hand-milking to machine milking, a transition that was accelerated by acute shortages of farm labour throughout Europe post-World War II and the electrification of farms in the United States. A key conclusion at that time was that: 'in general, there has been more infection and mastitis in machine-milked cows compared with hand-milked cows.' (Anon, 1959).

Machines that used single-chambered teatcups had been replaced well before then because: 'in the hands of most users, they caused congestion of the teat and discomfort to the cow and were therefore inefficient milkers.' Thus, it appears that the rapid transition to use of double-chambered teatcups occurred primarily because they milked more rapidly (Anon, 1959).

Only two milking-related mastitis risks were identified with any confidence in the extensive review cited here as 'Anon (1959)'. The likely authors (probably Frank Neave and Frank Dodd) were young pioneers in mastitis research at that time. The two main risks identified in that review were:

- Excessive vacuum. The prevailing wisdom was that milking vacuum should not exceed 14-15 inHg (47-51 kPa) because 'the higher the vacuum and the longer the teatcups are left on the udder, the greater is the probability of injury. One obvious sign of this is erosion of the teat sphincter which has been shown under certain conditions to be associated with an increase of staphylococcus infection and mastitis'.
- Type of teatcup liner. A slack moulded liner was found to cause more mastitis than a stretched moulded liner of smaller bore. Another study showed that one type of moulded liner caused more mastitis than a type of extruded liner.

Advances in Knowledge During the 1960s

At least one 'Five-point Mastitis Control Program' emerged in the 1960s. The first point in that rudimentary 'Five-point Control Program' for Australian dairy farmers was:

1. 'Correct adjustment and proper use of the milking machine'.

The basis for this cryptic recommendation was a brief chapter by Blood and Mein in an Expert Panel Report on Bovine Mastitis (Anon, 1966). Subsequently, the sole surviving member of that Panel (G Mein) spent much of his professional career trying to clarify and quantify this ambiguous recommendation.

Two years later, Dodd and Neave (1968) introduced another major review with a paragraph that has continued to echo through the next 60 years:

> 'In considering the relationship between machine milking and mastitis, we are faced with a paradox. Most farmers and field observers, and many research workers accept that the milking machine, either intrinsically or because of the way it is used, is a major factor influencing the incidence of udder disease in commercial dairy herds and the specific cause of a very high incidence in particular herds. As a result, authoritative statements on how mastitis should be controlled lay stress on the design, maintenance and use of the milking machine. Yet research has so far failed to provide convincing evidence of the general relationship between levels of infection in herds and the methods of machine milking' (Dodd and Neave, 1968).

In a related reference to the widespread belief that over-milking was the most important fault, these reviewers noted that:

> 'Over-milking occurs in all herds and averages several minutes per cow in most, and is always longer with front quarters compared with hind, yet there is normally about 50% more infections in hind quarters'.

Based on the evidence they reviewed at the time, Dodd and Neave listed five known or likely risks:

- The milking machine acts as a vector in transmitting pathogens from an infected quarter to non-infected quarters. The source of pathogens can be either milk or an infected lesion, and the transmission can be between cows or from an infected quarter to an uninfected quarter between cows.
- Evidence of damage resulting from machine milking is clear from examination of the teats of most herds. Teat orifices are often everted and eroded, there may be small haemorrhagic areas near the tip of the teat and teat chaps are usually most serious near the 'pressure ring' at the base of the teat where the teatcup mouthpiece makes a seal. In the absence of good hygiene these lesions are likely to be infected, shedding very large numbers of pathogens and therefore increasing the spread on milking equipment. Further evidence from Iowa (Witzel and McDonald, 1964) showed that, at or near the end of milking, vacuum levels within the teat sinus were similar to those within the pulsation chambers of the teatcup and that damage induced by high vacuum is caused to the inner membranes of the teat.

- Recently, 'vacuum fluctuations' have become widely accepted as an important pre-disposing cause of udder disease [although the results to date] are interesting but inconclusive.
- The complete absence of pulsation may lead to increased udder disease [but there are] no good data on the effect of variation in pulsation within normal limits.
- Specific types of liner may cause an increase in clinical mastitis (but no evidence on the effects of variation in liner dimensions, shape or properties of the liner).

Two Irish researchers were the first to show that inadequate vacuum pump capacity was associated with higher bulk milk cell counts (Nyhan and Cowhig, 1967). They followed up this field study with the first research herd evidence to show that unstable vacuum was linked to an increase in new mastitis infection rate. Tragically, these Irish scientists died in an air crash while travelling to the UK to participate in the 1968 International Symposium on Machine Milking. The outstanding legacy of that ill-fated Irish research team was their demonstration that a single milking machine factor could have a major influence on udder disease. The immediate outcome of their work was to stimulate subsequent research (in the UK, Ireland and elsewhere) on the specific ways in which bacterial invasion occurs during machine milking.

<u>Further Advances from the 1970s to 2000</u>

The contributions of science and engineering throughout the 1970s, 80s and 90s produced significant advances in our knowledge and understanding of what was meant by that cryptic advice, in1966, on the 'correct adjustment and proper use of the milking machine'.

Vacuum fluctuations and 'impacts'

The pioneering Irish work, which demonstrated that irregular vacuum fluctuations somehow increased intra-mammary infection, was continued at the National Institute for Research in Dairying (NIRD) in the UK and by a new Irish research team led, initially, by Jerry O'Shea and later by Eddie O'Callaghan.

A series of research herd experiments at the NIRD in the early 1970s clearly showed that the new mastitis infection rate could be increased significantly whenever certain types of vacuum fluctuations were applied in combination. The most potent, mastitis-producing combination was found to be high cyclic vacuum fluctuations (generated within the cluster by fast cyclic opening and closing of teatcup liners) together with high, experimentally-induced, "irregular" vacuum fluctuations generated beyond the cluster (Thiel *et al*, 1973; Cousins *et al*, 1973). With the help of high-speed cine filming and the use of a special test rig affectionately known as "Winchester Bessie", scientists at the NIRD proposed a new working hypothesis that they called the "impact mechanism". Impacts were thought to be the main mechanism of new mastitis infections. This term was coined to describe the rapid upward movement of small droplets or slugs of milk from the short milk tube towards the external teat orifice as a consequence of high transient pressure differences generated within the teatcup or cluster.

The numbers of impacts occurring in a 5-min period using the "Winchester Bessie" rig were recorded for a range of high or low liquid flow-rates, two different claw types (one with a 'high' volume claw bowl, the other with a 'low' bowl volume), and a range of different pulsation characteristics. The highest impact frequencies (of up to 260 impacts per 5-min period) were recorded with the small volume claw in combination with alternating pulsation (especially with a pulsator ratio close to 50:50). No impacts were recorded at low liquid flowrates when a claw with an effective bowl volume greater than 150 mL was used in combination either with alternating or with simultaneous pulsation, and a pulsator ratio of 67:33. Very low impact frequencies (less than 9 per 5-min period) were recorded at high liquid flow-rate using the high-volume claw in combination with alternating pulsation (D Akam, pers. comm. to G Mein, 1977).

The new Irish research team struggled initially to repeat the experimental results obtained by Nyhan and Cowhig until a thoughtful suggestion by their herdsman, who had worked with Nyhan, provided the breakthrough. He suggested that the original results had been obtained with a much less stable type of teatcup liner than that used experimentally by the new research team. The rest of this story is well known. O'Shea and O'Callaghan soon became famous for their research herd studies on the effects of liner slips on new mastitis infection rate (O'Shea and O'Callaghan, 1978; O'Shea *et al*, 1987).

The Irish "impact" mechanism was, essentially, the same mechanism as that proposed by the UK researchers but with one key difference. In the Irish studies, impacts were thought to result from "acute" irregular vacuum fluctuations with exceptionally fast rates of pressure change. Such acute fluctuations could be measured only in the adjacent teatcups within an individual cluster when one teatcup slipped. In contrast, impacts in the UK studies were thought to result from high cyclic fluctuations acting together with comparatively slow changes in milking vacuum. With the great benefit of hindsight, however, it should be noted that the extruded liner used in the UK studies was widely regarded as prone to slip frequently. Because liners tend to slip more frequently at lower milking vacuum, it is possible that liner slips contributed to the high new infection rates obtained in the UK experimental treatment groups.

These studies in the UK and Ireland stimulated, either directly or indirectly, six major branches of research or development around the world. Those results are described in detail elsewhere and were reviewed by Mein and Schuring (2003). Their main lessons in relation to our theme of machine milking and mastitis risk were:

- High cyclic vacuum fluctuations are not important, by themselves, as a major cause of new infections;
- New mastitis infections due to the 'impact' mechanism can be greatly reduced (or possibly eliminated entirely) by the use of clusters that combine at least the following essential characteristics:
    - a claw that has an effective bowl volume of at least 150 mL (5 fluid ounces, a little more than ½ cup): Note that most modern claws have a volume of about 450 ml (15 fluid ounces or just short of a pint)
    - short milk tubes that have a minimum bore size of about 10-11 mm (0.4 to 0.48")
    - if alternating pulsation is used in a conventional cluster, then any pulsator ratio that is not close to 50:50.

Teat health, teat canal characteristics and level of exposure to pathogens

In 1987, Dodd published another seminal review and concluded that "the main way milking machines will influence the level of exposure [to infection risk] is likely to be their direct effect on the health of the teat duct and the skin of the teat" (Dodd, 1987). Other research studies in the following years confirmed that the risk of new infections by contagious as well as environmental pathogens such as *Str. uberis* is increased by machine-induced changes in teat-end condition. Such changes may include: increased congestion and oedema in the teat wall which results in slower closure of the teat canal and/or hypoxia in teat tissues; slower rate of removal and regrowth of teat canal keratin; greater degree of openness of the teat canal orifice after milking; increased hyperkeratosis of the teat-end.

An important outcome of these new perspectives was a much greater emphasis on the maintenance of healthy teat skin and teat-ends as a key part of any effective mastitis program. In 1994, IDF published an excellent bulletin on "Teat tissue reactions to milking and new infection risk" written by a group of European scientists (Hamann *et al,* 1994a & b). This European group concluded that changes to teat tissue, the teat-end and teat canal alter the risk of new mastitis infections. Subsequently, Neijenhuis *et al* (2001) showed a significant association between teat-end callosity and incidence of clinical mastitis. At about the same time, simpler methods for quantifying the short- or medium-term effects of milking on teats were proposed by Hillerton *et al* (2000) who noted that many effects of machine milking are easily recognizable immediately after cluster removal. These scientific contributions provided a framework for the establishment of an informal discussion group of researchers and udder health advisors, self-styled as the "Teat Club International" (TCI). The TCI published a series of reviews covering: non-infectious factors and infectious factors affecting short-term or medium-term changes in teats; developed and promoted a simple protocol for systematic evaluation of teats in commercial dairies; published guidelines for interpretation of observations, guidelines for data collection and analysis; produced a teat condition portfolio; and, in addition, conducted numerous short courses on evaluating teat condition and interpreting the data.

In 1993, a Danish study (Rasmussen, 1993) provided the springboard for achieving shorter milking times and better teat condition for high-producing cows, especially in North American herds milked thrice per day. In that Danish study, milking time was reduced by 0.5 min per cow with no loss of milk yield when the end-of-milking setting for automatic cluster removers (ACRs) was raised from 0.2 kg/min to a flow rate threshold of 0.4 kg/min (from 0.45 to 0.9 lb/min). Teat condition improved markedly and significantly fewer cows developed clinical mastitis in the early detachment group of cows.

Rasmussen's research results sparked a 5-year period of cautious field evaluation in the USA. Threshold flowrate settings for ACRs were raised from default settings of about 0.3 kg/min to 0.5 kg/min (0.7 to 1.1 lb/min) for herds milked twice per day, and to levels as high as 0.9 kg (2 lb) per min for some herds milked thrice daily. At the same time, default time-delay settings of 10-20 sec for cluster removal were shortened to 0-5 sec. The net effect was to reduce average milking times per cow by 1 min or more with no reported loss of milk yield, no change in SCC or mastitis levels. In addition to quicker milking, the major benefits have been improved teat condition and calmer cows, especially the fresh cows. Today, almost every manufacturer, installer or user of ACRs around the world has benefited from, or been influenced by, the practical consequences of this research.

Contributions of science and engineering to design and performance of milking systems
The 1996 revision of the International Standards Organization (ISO) Standards on Construction and Performance of Milking Systems, and on Mechanical Testing Procedures, provided another springboard for the application of science and engineering principles to milking technology. Examples of the shift in emphasis, from the traditional dimensional specifications to the new performance-based guidelines and standards, include:

- New guidelines for the diameter, slope and configuration of milklines evolved from the principle that stratified milk flow, rather than slug flow, was the preferred flow condition in dual-purpose milklines. As a direct result of the new ISO guidelines, milkline sizes have tended to increase in Western Europe. At the other end of the range, milklines greater than 100 mm in diameter are seldom installed in new milking systems in the USA today.
- The simple but subtle change to measuring Effective Reserve in or near the receiver, rather than at a position near the regulator, had an astonishing impact on the design of milking systems, the preferred placement of vacuum regulators and the recommended size of vacuum pumps, especially in North America. This change in measurement point enabled the milking equipment industry to understand the problems associated with locating the regulator too far from the receiver, and the use of airline fittings that were often too small for the volume of air flowing through them. These common deficiencies became obvious when new guidelines for evaluating vacuum levels and air flows were developed by the Machine Milking Committee of the National Mastitis Council (NMC), a process that was spear-headed by Johnson *et al* (1996). The NMC guidelines have been widely adopted by the milking equipment industry. The outcome has been marked improvements in vacuum regulation in milking systems across the world.
- New guidelines for determining Effective Reserve and for sizing vacuum pumps evolved from the simple performance guideline that vacuum in the receiver should remain stable within 2 kPa (0.6 inHg) of the intended level. The practical application of these guidelines produced significant electrical power savings on dairy farms across the USA, Canada and Mexico. Concurrently, vacuum regulation was improved on the majority of these farms.

Milking-time observations and milking-time testing
Up until the 1990s, both ISO standards and field tests of the mechanical performance of milking machines usually stopped short of any specific performance guidelines or tests of cluster performance or teatcup action. That omission was surprising because the components of a cluster are the only ones that come into contact with the cows' udders. No other components of a milking system can influence the milking characteristics of a cow or her risk of infection unless they affect either the liner vacuum, liner wall movement or the cyclic pressure applied to the teat, or the cluster weight distribution between udder quarters. Schuiling *et al* (1994) observed that: 'Milking is not going well in some modern milking installations which meet or exceed ISO standards' and suggested that such problems may be due to 'malfunction of the liner'.

Those comments by Schuiling *et al* reflected a growing awareness of the need to develop a series of simple milking-time observations and tests for evaluating the milking performance of a cluster and the effectiveness of teatcup action. This change in emphasis from the 'system' components of a milking system to the cluster components was long-overdue. It resulted in much greater attention to the factors involved in achieving good 'milkability' (Reid, 1996), greater awareness of the effects of vacuum within the mouthpiece chambers of teatcup liners on teat condition and udder health (Rasmussen *et al*, 1998) and a much clearer understanding of what is meant by effective pulsation. One of the best, most accessible and practical summaries of these new perspectives is the New Zealand SammPlan Technote 6 (www.dairynz.co.nz/animal/cow-health/mastitis/tools-and-resources/guidelines-and-technotes).

<u>2000 and Beyond</u>

The automation and information revolution

This century ushered in the information age. The milking machine and its associated components have become the data collection and analytical center of the dairy farm; especially those farms using automatic milking machines. Technical futurist Ray Kurzweil predicts that the exponential increase in technologies like computers, genetics, nanotechnology, robotics and artificial intelligence will result in a 'singularity' in the next 20 years in which machine intelligence will be infinitely more powerful than all human intelligence combined. Anyone who has worked with 2018 milking machine intelligence will attest that we still have a way to go as human intervention is required for virtually all of the management decisions on a dairy farm.

The scientific seeds of automation were sown in The Netherlands with the development of electronic cow identification (ID), and monitoring of cows using physiological variables that could be measured quickly and automatically such as cow activity (as an indicator of oestrus), milk temperature and electrical conductivity of milk (as a screening test for mastitis).

These scientific seedlings began to flower in the 1990s. By then, it had become clear that continuing developments in automation and the application of computers on farms would change the future of dairying in major ways. The world's first commercial voluntary milking system, which was installed in 1992, heralded the possibility that milking might become a background operation on many farms.

In conventional milking parlors, hardware components such as cow ID tags, milk meters, automatic cluster removers and auto-drafting gates were being integrated via a central, on-farm data processing system. These components had the potential to provide an information system for more effective and more profitable herd management. The pioneering work of veterinary specialists such as Stewart *et al* (2001) on large dairy farms with conventional milking systems enabled the milking staff to concentrate on the task of milking while the herd manager got daily management summaries on the milk yields of individual cows, herd health and reproductive activity.

In the coming century, sensing systems will continue to improve and provide better and better management advice for nutrition, reproduction, and animal health including mastitis management. The milking machine will be the nerve center of this artificial intelligence. The role of milking machines and mastitis will shift from the milking machine as a mastitis risk to the milking system as predictor of individual cows' mastitis risk and application of adaptive milk harvesting techniques to reduce this risk as well as a tool for early detection of mastitis and advisor on treatment strategies.

Future trends
It is likely that the quest to milk cows faster will continue for the foreseeable future. The motivations for faster milking are shifting from human labor efficiency to return on the capital investment in automatic milking technology. Milking speed can be characterized in many ways. The most practical measure of milking speed for farm managers is the number of cows milked per hour in a milking parlor or per day per automatic milking system stall. The milk removal process is only part of the milking process; typically accounting for less than half the time required to move cows into position for milking, prepare teats and udders, remove milk from all quarters, apply post-milking dip, and move cows out of the milking area.

The trend of increasing production level of cows shows no sign of stopping in the coming decades. The time required to harvest milk from a quarter is a function of the amount of milk in the quarter (production level + milking interval) and the milk removal rate. There are biological limits to the rate at which milk can be removed. Increasing milking frequency can compromise the defense mechanisms of the teat canal. Increased milking frequency has been associated with a higher percentage of quarters that leak milk between milkings, but as yet has not been associated with increased mastitis risk. The question of how to balance milk production level with milking frequency will be an interesting one in the coming decades.

Quarter milking has eliminated cross-contamination during milking, although has not had a dramatic effect on mastitis risk. Early adopters of automatic quarter milking showed no difference in udder health scores, while later adopters appear to have slightly worse outcomes. This is like due to the overwhelming influence of udder hygiene on mastitis risk. Increased milking frequency reduces mastitis risk. Penry et al (2017) found that in a quarter milked AMS herd there was no association between quarter peak milk flow rates and clinical mastitis risk but did find an association between reduced milking interval and reduced clinical mastitis risk. The plausible hypothesis for the causal mechanism is the powerful cleaning effect of the milk process whereby milk flowing out of the teat canal removes bacteria that may have lodged in the canal. Note that the study cited above was conducted on a herd using an automatic milking machine with complete separation between quarters, thus eliminating the possibility of cross-contamination and the impact mechanism. Most recent studies on the association between peak milk flow rate and infection risk have been conducted with conventional claws. Some, but not all, of these studies claimed an association between peak milk flow rate and udder health. An excellent literature review is presented by Penry et al (2017).

Herd management and milking management practices have much larger effects on mastitis risk than the direct effects of the milking machine. It has been clear for some time that sanitation is the predominant effect on mastitis risk and keeping bacterial numbers low on or near the cows' teat-ends reduces the new infection rate. The overriding effect on the occurrence of mastitis in a herd is the bacteria challenge to teat ends. Attention on reducing mastitis infections has increasingly focused on environmental organisms for herds which have reduced or eliminated the threat of contagious organisms. The focus of reducing mastitis risk during the milk removal process will increasingly focus on ways to maintain or enhance the natural defense mechanisms of the teat. There are several distinctly different physiological aspects to the gentleness of milking and teat canal defenses:

- Maintaining optimal keratin balance in the teat canal,

- Minimizing rough teat-ends or hyperkeratosis,
- Minimizing congestion in teat tissues to improve teat closure after milking
- Maintaining the health and integrity of teat skin.

A more detailed discussion of the milking machine factors affecting these defense mechanisms is presented by Mein (2015) and Reinemann (2017).

The major exposure to environmental organisms occurring in stalls and resting areas although the exact mechanism of bacteria transport through the teat canal and into the teat sinus is unclear. A simple method developed and validated by Schreiner and Ruegg (2003) for scoring udder hygiene has proved an invaluable tool to monitor the effect of the cow environment on udder cleanliness. Cows with more than 10% of their udders covered with manure or other debris were 1.5 times more likely to be infected with a major pathogen than cows with cleaner udders. The tool allows for a quick and easy assessment (usually no more than 20 minutes), and more importantly, provides a quantitative measure of performance that can be used to test the efficacy of different animal management strategies.

Recent research on raising the milk flow threshold setting for ACRs and/or setting a maximum time limit for milking slow cows has opened up new possibilities for milking herds more quickly, with no apparent adverse effects (Reinemann 2017 and forthcoming IDF bulletin on cluster remover settings). These studies provide convincing evidence that early unit removal and the resulting, slightly reduced, completeness of milking does not produce a measurable increase in SCC or mastitis risk. The main benefits of early unit removal are a reduction in cups-on time, greatly reduced teat-barrel congestion and a slight reduction in teat-end hyperkeratosis as a result of the reduction or elimination of the low flow period of milking. The historical association between quarters that are not completely milked and increased probability of developing mastitis symptoms may be due to these quarters being in the early stages of clinical mastitis which causes incomplete drainage of the gland, and clinical symptoms develop shortly thereafter (Dr. Pamela L. Ruegg, personal communication, and D. Reinemann, personal experience). An incompletely milked quarter may therefore be the result of a mastitis infection, not the cause of that infection. A better understanding of the influence of teatcup removal strategies at both the udder and quarter level on milk production rates will be an important research question in the near future.

Teat size, particularly teat length, has been gradually decreasing as milk production levels have increased. Fitting liners to teats is a major challenge now and will likely continue to be an issue in the foreseeable future. This may include development of liners designed to function well on short teats and/or attention to teat length in breeding programs. Nowadays, average teat length on high producing herds in all parts of the world is between 45 and 55 mm. Teats shorter than about 40 mm will not penetrate into the zone of effective liner compression, or form a good teat/liner barrel seal on many commercial liners. One indication of poor teat/liner fit is elevated mouthpiece chamber vacuum during the peak flow period of milking and (Reinemann et al, 2013) and associated congestion of teat barrel tissue (Penry et al, 2017).

<u>Summary of Key Recommendations or Conclusions</u>
The fundamental biomechanics of milking will remain the same into the foreseeable future. However, their relative importance on mastitis risk will continue to evolve as cows are evolved

to better suit future dairy operations. Mastitis risk is reduced by keeping bacterial numbers low on or near the cows' teat-ends, especially if machine settings and/or milking management practices are less than ideal. Herd management and milking management practices probably have over-riding effects compared with the potential contribution from milking machines. New mastitis infection rates are lower during lactation than in the early dry period. This implies that regular milking may have positive benefits in helping to keep teat canals and teat-ends clean. New research during the past 20 years has shown there is no need to leave clusters on cows in an attempt to empty the udder completely at every milking. Furthermore, there are significant practical advantages (e.g., better teat condition, calmer cows, quicker herd milking) to be gained from early removal of clusters. The widespread use of more stable clusters, larger-bore short milk tubes and larger, free-draining claw bowls has probably already reduced the potential gains from eliminating the conventional claw in many milking systems.

Healthy teat ends are critical to the maintenance of low numbers of infected quarters. The major machine factors affecting gentleness of milking (i.e. cow comfort and teat condition) are, in likely order of relative importance:

1. Liner fit, or liner dimensions relative to teat dimensions (affecting liner compression, mouthpiece chamber vacuum);
2. Average claw vacuum level (main effects on teat congestion, hyperkeratosis, comfort);
3. Duration of cups-on time (over-milking is linked with poorer teat-end condition);
4. Liner compression (main effects on teat congestion and hyperkeratosis);
5. Pulsation settings (especially, the b-phase duration and d-phase duration).

The future will bring more sophisticated monitoring and control strategies for milk harvesting and the milking machine and associated equipment and facilities will play a larger role in collecting data and applying intelligent advice and automation for detecting and managing mastitis risk on dairy farms.

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Selective Dry Cow Therapy: What are the Possibilities for North America?

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<u>Introduction</u>

Dry cow intramammary (IMM) antimicrobials were developed in the 1950s; their use was recommended in the 1960s as part of the National Institute for Research into Dairying's 5-point plan (United Kingdom). Blanket dry cow therapy (BDCT), or the treatment of every quarter of every cow with a long-acting antimicrobial at dry-off, was instituted to combat the high rate of clinical mastitis observed within the 2-weeks post-calving (Green et al., 2002) as well as to cure existing infections at dry-off. Research groups have demonstrated that a majority of clinical mastitis cases during this time are contributed by organisms that were present at dry off or newly acquired over the dry period (Todhunter et al., 1991; Bradley and Green, 2000; Green et al., 2002). However, management and control of mastitis pathogens during the dry and lactating periods has been widely successful as indicated by the increase in negative quarter-level culture results at dry-off from 44% in 1985 to between 73% and 95% of quarters within the last decade (du Preez and Greeff, 1985; Pantoja et al., 2009; Rajala-Schultz et al., 2011). The prevalence of contagious pathogens such as *Streptococcus agalactiae* and *Staphylococcus aureus* and reduction of bulk tank somatic cell counts (BTSCC) from 295k cells/mL in 1997 to 193k cells/mL in 2014 also suggests that BDCT is not currently a necessity in all herds (Ekman and Øster□s, 2003; Robert et al., 2006, USDA NAHMS, 2016a). Additionally, only 11.1% of overall test days were greater than 400,000 cells/mL in 2016; this compares to 30.3% of test days in 1998 (Miller and Normal, 1999; Norman et al., 2017).

Regardless of these improvements since the implementation of BDCT, over 90% of cows are treated and 90% of operations use antimicrobial products at dry-off in the USA according to a survey by the National Animal Health Monitoring System in 2014 (USDA NAHMS, 2016b). There are several reasons why a producer/management might elect to not use IMM antibiotics at dry-off: 1) economic returns via decreased labor and dry-tube costs; 2) public or government policy: for example, Nordic countries have adopted restrictions that permit only selective use of antimicrobials, leading to reductions of approximately 80% and 40% for dry-cow and clinical mastitis treatments, respectively (Ekman and Øster□s, 2003); 3) the introduction of an applicator into the teat end is not risk-free (Leelahopongsathon et al., 2016); 4) alternative/adjunct products to antibiotics including teat sealants are reported to have success decreasing the risk of new infections (Godden et al., 2003; Rabiee and Lean, 2013); and 5) consequences related to public health such as accidental residues in the bulk tank or the development of antimicrobial resistance. For these reasons, selective treatment of cows at dry-off is an opportunity that is being considered by producers and veterinarians.

Selective dry cow therapy (SDCT) is the identification and treatment of only cows/quarters having an infection at dry-off or at high risk for acquiring an infection during the dry period. The clinical, health, and microbiological outcomes resulting from the use of specific strategies have been explored by research groups over the past few decades. Most practitioners and researchers wish to address the following question: "Are cows in selective treatment protocols, or cows that are not treated with dry-cow antimicrobials at higher risk for experiencing negative outcomes?" This question has been interrogated using field trials and subsequent statistical models to compare treatment groups when evaluating outcomes such as risk of clinical mastitis, bacteriological cure, new infection risk, early lactation milk production, early lactation SCC/linear score, and risk of culling.

Current Strategies

Identification of the cows or quarters that would benefit from antimicrobial treatment is the cornerstone of SDCT protocols and can be performed in several manners. The diagnostics elected for use can be performed at the quarter or cow level, and treatment decisions in regard to dry cow therapy can be made similarly. Accuracy, costs, labor, and ease of use/implementation should be considered when selecting tools to identify cows/quarters to be treated within SDCT programs. The following paragraphs describe strategies for SDCT and the respective results of field trials. The selected trials considered all mastitis pathogens in their microbiological and statistical analysis; all were published after 1990.

Use of a bulk tank SCC or single composite SCC prior to dry-off

The first studies on decreased IMM antibiotics at dry-off were performed in herds with low bulk tank somatic cell counts (BTSCC). These studies randomly assigned cows or quarters to either blanket-treatment or to no treatment; cows/quarters were not separated based on risk or infection status. This often resulted in an increased incidence rate of clinical mastitis or risk of new intramammary infections (IMIs) in cows/quarters not receiving treatment. For example, Hogan et al. (1995) performed a study on 4 US herds with BTSCC <250,000 cells/mL where cows were randomized into 4 groups: antibiotic dry cow therapy, antibiotic dry cow therapy and *Propionibacterium acnes* injections (PAI), PAI only, or no treatments. A statistically higher percentage of cured quarters and lower percentage of new IMIs were found in cows that received IMM antibiotic versus those that had not (Hogan et al., 1995). However, statistical comparisons between groups that did not receive PAI were not provided. Schukken et al. (1993) performed a study on one Dutch herd with a BTCC of 140,000 cells/ml (50 cows) in which 2 quarters were treated and 2 quarters remained untreated within each cow. This resulted in a 10-fold increased risk of clinical mastitis, or 10 cases of clinical mastitis in uninfused quarters versus 1 case in a quarter that was infused with dry-cow antibiotics (Schukken et al., 1993). In the same trial, no statistical differences were found between groups for new infection risk or bacteriologic cure of major pathogens. Minor pathogens were reduced in quarters that were treated with antimicrobials. When treatment was performed on the cow level in a California herd (233 cows; 240,000 cells/mL) with a low prevalence of contagious mastitis pathogens, no statistical differences were found between groups for culling, clinical mastitis risk, or SCC in the first 120 days of the subsequent lactation, even when cows were stratified into high and low (≤500,000 cells/mL) SCC groups (Berry et al., 1997). Scherpenzeel et al. (2014) used a split udder design and evaluated use of an individual-cow SCC threshold rather than use of a bulk-tank threshold. Primiparous animals with SCC <150,000 cell/mL and multiparous animals with SCC <250,000 cells/mL were included; 1,657 cows had 2 quarters that were treated and 2 that were not. In the trial, the incidence of clinical mastitis was 1.7 times higher in quarters dried without antimicrobials (95% CI: 1.4-2.1). SCC was higher in non-treated quarters and a higher percentage of the quarters were culture positive at calving and at 14 days in milk (DIM).

Culture only method
The current gold standard for diagnosing an IMI is aerobic culture. However, the time, labor, and materials associated with culturing cows can be an added cost, and this diagnostic tool, when used in a SDCT protocol can identify infected cows/quarters, but will not determine cows at higher risk for acquiring infections during the dry period. The effects of culture-driven antibiotic use at dry-off were determined by Browning et al. (1990) in an Australian field trial including 1044 cows from 12 herds. Culture-negative cows were randomly allocated to receive blanket therapy or no treatment while culture-positive cows were randomly allocated to receive blanket therapy or treatment of only infected quarters. No statistical differences were detected in clinical mastitis risks between the groups within the first 5 months of lactation. No differences were found for new infection risk in the cows that were culture-negative at dry-off; however, new infection risk was 4 times higher in selectively treated culture-positive cows versus blanket treated culture-positive cows (Browning et al., 1990). Only cows infected with a major pathogen (n=608) were enrolled in a Norwegian study that assessed the effects of SDCT on culling, mastitis, milk yield and SCC (Øster□s and Sandvik, 1996). Cows were randomly allocated into a placebo group, control group, or one of two IMM antibiotic treatments. Cows within the antibiotic groups only received treatments in quarters experiencing IMIs. It should be noted that quarters known to have an IMI in the placebo and control groups were not treated with antibiotics. There were 21% less cases of mastitis in antibiotic treated quarters ($P = 0.09$). Treated quarters also had lower SCC and a higher lactational milk yield. There was no effect of therapy on culling rate. Patel et al. (2017) used quarter-level treatment of culture-positive quarters in addition to internal teat sealant (1 herd, 56 cows) and described no statistical differences between BDCT and selective quarter treatment when assessing bacteriological cure and new infection risks (Patel et al., 2017).

Cow records only: SCC and/or mastitis events
Though not presented as a SDCT trial, Huxley et al. (2002) evaluated the use of a teat sealant in cows with routine composite SCC below 200,000 cells/mL with no previous cases of mastitis and a projected dry period of >51d. Comparisons were made between cows only receiving internal teat sealant and cows receiving only blanket antibiotic therapy. No statistical differences were found for clinical mastitis cases, new infections with minor pathogens, nor overall bacteriologic cure. While new infection risk for major pathogens was lower in antibiotic-treated cows, bacteriologic cure rates were only higher for the minor pathogens *Corynebacterium* spp. in antibiotic-treated cows (Huxley et al, 2002). Another trial evaluating internal teat sealant in the UK used a split-udder design with the same cow-level criteria. However, in this trial (Bradley et al., 2010) all quarters received the internal teat sealant product, even those treated with antibiotics. No statistical differences were described between groups of quarters for bacteriologic cure and new infection risks and no differences were found in clinical mastitis risk.

In a non-inferiority study comparison, McDougall (2010) assigned cows (~900 cows from 6 New Zealand herds) with SCC ≤ 150,000 and no history of clinical mastitis in the current lactation to no treatment, a novel antibiotic, or a reference antibiotic at dry-off. When analysis was performed on the quarter level, there were fewer IMIs characterized by any pathogen at freshening in antibiotic treated groups; when analysis was performed on the cow level, there was only a difference seen for major pathogens. SCC was lower in treated groups, and there was a lower hazard of clinical mastitis during the dry period and in early lactation for treated groups

(McDougall, 2010). A study performed in the US by Rajala-Schultz et al. (2011) on 4 herds (~400 cows) also used computer records and mastitis events to determine which cows to enroll. Cows had to have a SCC ≤ 200,000 cells/mL over the last 3 tests with no cases of mastitis in the current lactation. If the cow met the criteria but there was 1 case of mastitis, the cow had to maintain a SCC <100,000 cells/mL until dry-off. Cows were then randomly assigned to receive IMM antibiotics or no treatment. No statistical differences were described for new infection risk or early lactation milk production. Overall, there was a lower SCC in the treated cows; however, when evaluated on the herd level, only 1 herd had a statistical difference between groups for this outcome (Rajala-Schultz et al., 2011). Most recently, our group used only on farm data from DHIA tests and on-farm computer record keeping systems, performed/employed by 72.8% and 98% of large dairies, respectively, to guide SDCT. In our study, a computer algorithm identified "low risk" cows as having no more than one clinical mastitis event, a mean of the last 3 test-days ≤ 200,000 cells/mL, a last-test SCC of ≤ 200,000 cells/mL, and a projected dry period of <100d. Low risk cows were randomized to receive dry-cow antibiotics and external teat sealant or external teat sealant only. When comparisons were made between antibiotic-treated and teat-sealant only low risk cows, no statistical differences were found for new infection risks, 1st test milk production, 1st test LS, daily milk production in the first 30 DIM, clinical mastitis risks, and culling risks. Bacteriologic cure was different between groups. Of the 20 quarters that did not cure, 13 were in quarters not treated with antibiotics; 19 were contributed by the minor pathogens CNS (Vasquez et al., 2017).

N-acetyl beta-glucosaminidase (NAGase)
Hassan et al. (1999) used levels of NAGase, a lysosomal enzyme with elevated levels during infection, in a SDCT protocol on 3 dairy farms in Australia (150 cows). Cows were randomized into one of 4 groups: comprehensive treatment (IMM antibiotics in all 4 quarters), selective treatment (IMM antibiotics only in NAGase-positive quarters), or no treatment in all 4 quarters. Milk samples retrieved two and six weeks into the dry period showed that the proportion of infected quarters differed significantly between groups (untreated > selectively treated > comprehensively treated); however, after 6 weeks, at calving, and at 3 weeks into lactation there were no significant differences in infection status between groups. Clinical cases of mastitis occurred only in the untreated and selectively treated groups ($P < 0.01$). Using cultures at dry-off as a reference, NAGase values did not accurately define infections (Hassan et al., 1999).

Cowside tests only
Though no randomized field trials have assessed the performance of only rapid cow-side tests such as California Mastitis Test (CMT) and milk leukocyte differential (MLD) tests in a SDCT protocol, they have been evaluated to determine the infection status of a cow at dry-off. CMT and MLD have fair to good sensitivities and specificities for late lactation animals, but are dependent upon cut-point and interpretation (Poutrel and Rainard, 1981; Hockett et al., 2014; Godden et al., 2017).

Combination of culture and cow-level data
A teat-sealant study on 482 low SCC (<200,000 cells/mL), culture-negative cows was performed using a randomized quarter-level study design and 4 different treatments: control (no treatments), IMM antibiotic, IMM antibiotic and internal teat sealant, and teat sealant only (Woolford et al., 1998). The number of clinical IMIs during the dry period was higher in the control quarters than

the infused quarters, but not different between the teat sealant only and control quarters. The same findings were found for new IMIs at calving.

A BTSCC requirement of <250,000 cells/ml (4 herds) was combined with individual culture data at dry-off to evaluate new infection and clinical mastitis risks (Berry and Hillerton, 2002). The group found a 9% difference in cases of clinical mastitis between the untreated and treated cows ($P = 0.001$). However, cows randomized into treatment groups were those with negative, CNS-positive, or *Corynebacterium*-positive culture results 1 week prior to dry-off. The overall new IMI risk was statistically higher in the untreated versus treated cows; the greatest contribution to this finding was for major pathogens (*S. uberis)* in quarters already infected with minor pathogens. No statistical differences were found in the prevalence of CNS post-calving between treated and untreated groups (Berry and Hillerton, 2002).

Cameron et al. (2013, 2014) used culture in addition to several other screening tools on 16 Canadian herds: cow level inclusion criteria in the study consisted of a dry period between 30 and 90 days, 3 serial SCC <200,000 cell/mL prior to dry-off, no clinical mastitis in the 90 days prior to dry-off, and a CMT score of <2 on the day prior to dry-off. Cows were then randomized to BDCT or SDCT. While cows within the BDCT were all treated with antimicrobials, only culture-positive cows within the SDCT group were treated. All cows also received internal teat sealant. No statistical differences were found for bacteriological cure and new infection risks at calving, ln(SCC) over the first 180d, clinical mastitis risk within 120 d, or test day milk production between SDCT and BDCT cows.

Making sense of discrepant data

In trials that did not use a combination of tools, cows at risk due to historically higher SCC or multiple mastitis events, and currently infected cows (if culture was not used) were among the cows included in the non-treated group. Dissimilarities between findings could also be due to the presence of higher levels of major pathogens on the included dairies, the lack of teat sealant use, or the inclusion of herds with BTSCC >250,000 cells/mL.

In an effort to generate an overall outcome for trials that evaluated treatment protocols at dry-off, two groups performed meta-analysis on previously published research. One analysis by Halasa et al. (2009a) was performed on 4 SDCT trials (SDCT protocol versus BDCT protocol) and 13 BDCT trials (BDCT versus no-treatment). In it, the meta-analytic pooled relative risks for bacteriological cure were 1.76 and 1.78, respectively. For new infection, pooled relative risks of 0.58 and 0.55 were described for BDCT versus SDCT in the 2 meta-analyses (Robert et al., 2006a; Halasa et al., 2009b). While statistical differences in relative risk were seen for protection against new quarter IMI, no statistical differences were calculated when the selection unit was the cow (Halasa et al. 2009b). In the Robert et al. (2006a) meta-analysis, pooled differences in new IMI risk were statistically significant for streptococcal and *Staphylococcus aureus* IMIs and not for IMIs caused by CNS or coliforms. Statistically different findings for BDCT versus SDCT in 15 of the 25 studies could be due to the fact that contributions of streptococcal species and *Staphylococcus aureus* represented more than 35% of IMIs in 50% of the studies included.

Readers will note that the main objective of many of the studies described here was not to compare a selectively treated or untreated group of cows/quarters to a blanket-treated group of cows or quarters, rather the SDCT data comparing these groups could be extracted from the results presented in each manuscript. Overall, there are limited studies that adequately capture the best comparisons in regard to sample size, study design and statistical evaluations. These include Sharpenzeel et al., 2016 (Netherlands), Cameron et al., 2013 and 2014 (Canada), and Rajala-Schultz et al., 2007, Patel et al. 2017 and Vasquez et al. 2017 (US). The differing findings in each of these trials dictate the need for more research on the subject. However, we do know that selection of farms for SDCT should be dependent on pathogen prevalence.

<u>Economics of SDCT</u>

An economic analysis comparing BDCT to no dry-cow therapy of all cows within a herd concluded that dry-cow therapy was advantageous. However, the modeled costs of not using dry cow antibiotics always included lower milk production and higher SCC for these cows, with values retrieved from regression analyses with suboptimal R^2 values (McNab and Meek, 1991). More recently, stochastic modeling was used to evaluate the economics of SDCT by Huijps and Hogeveen (2007). The economic parameters associated with the greatest influence on costs were antibiotics, milk losses, and the hourly rate for labor. The infection parameters that produced the most influence on costs were clinical mastitis, the probability of culling, and infection rate over the dry period. When infection rate and antibiotic costs are low, no DCT might be best, but variation is high; in scenarios where selection criteria has high sensitivity, there will be lower average costs. Default values of the input variables and probabilities in this Dutch model showed that SDCT economically is the best option (Huijps and Hogeveen, 2007). In studies where "economic" outcomes were similar between groups (milk production, infection risk, clinical mastitis risks, and culling risks) partial budget analysis can easily be performed. A net benefit of $2.62 per cow was calculated for the pilot study performed at the University of Minnesota by Patel et al., (2014). This accounted for the cost of labor and supplies to segregate, sample, and culture all cows at the quarter-level (Patel, 2014). As cure and infection risks were similar between groups, the authors did not account for additional cases of mastitis experienced by one group over another. Eliminating the costs of culture by using only computer data, our group found a net benefit of $6.87 per cow when 35% of cows were allocated to the "high risk" group and subsequently treated with dry-cow antibiotics. The economic analysis performed by Scherpenzeel et al. (2016) used computer modeling to predict economic outcomes using 7 different SDCT scenarios. These models assumed higher subclinical and clinical mastitis prevalence and decreasing total antimicrobial usage for each scenario of decreasing sequential SCC thresholds. Two of 7 programs produced an economic advantage of SDCT over BDCT: 1. using 50,000cells/mL for 1^{st} lactation and higher animals and 2. using 150,000cells/mL for first lactation animals and 50,000cells/mL for $>1^{st}$ lactation animals (Sherpenzeel et al., 2016). Subsequent to this analysis, the same group (Sherpenzeel et al., 2018) used mathematical modeling to determine the effect of individual-farm BTSCC and clinical mastitis incidences on economic values (costs associated with clinical mastitis or subclinical mastitis in early lactation). BDCT was compared to a sliding scale of SDCT (100% -0% antibiotic use) on farms with permutations of low, high, and average BTSCC and low, high and average clinical mastitis incidences. The authors concluded that for all evaluated BTSCC levels, SDCT was more economically beneficial than BDCT, with greater profits occurring in herds with lower incidences of clinical mastitis; all types of herds can reduce dry-cow antimicrobial use without negative economic consequences (Sherpenzeel et al., 2018).

Application
According to Ekman and Østerås, 2003; and Cameron et al., 2014 herds with a bulk tank SCC ≤250,000 cells/mL, hygienic dry-off procedures, and very low prevalence of contagious pathogens could be considered for SDCT. Treatments should be on the cow level: some groups have also shown that due to interdependence of quarters, split-udder or quarter-level treatment design might contribute to negative outcomes, and quarters do not act independently when considering infection risk (Robert et al., 2006b; Paixão et al., 2017).

Cow side or record-based tests such as CMT, clinical mastitis history, and DHIA SCC offer the convenience of readily accessible data, but if using microbiological culture as a reference gold-standard, these methods will result in more misclassifications. High sensitivity will minimize the potential risk of not treating a cow that might benefit from treatment. Sensitivity can be increased by using lower SCC thresholds to define "at risk" cows. With a more sensitive test, more cows will be treated. Regardless, lower thresholds will result in more prudent use of antimicrobials than in a BDCT system. Sensitivities and specificities of using monthly SCC and clinical mastitis events as treatment criteria for SDCT range from 58.4% to 69.4% and 62.7% to 71.5%, respectively (Torres et al., 2008; McDougall, 2010; Rajala-Schultz et al., 2011). As described by the referenced field trials, aerobic culture can be used on all cows or a subpopulation of cows (e.g. cows with SCC below a certain threshold) to screen cows or quarters for treatment. This generates additional costs and the need for reliable and conscientious sampling as well as trained personnel or external laboratory staff to define an infected quarter. Additionally, cows need to be segregated for sampling at least 1 day prior to dry-off and again when animals to be treated are identified.

Conclusion
BDCT has been an effective method to reduce new IMI and increase bacteriologic cure in subclinical and clinically infected cows at and during dry-off; however, selective use of IMM antibiotics for those cows that will likely benefit can produce similar results when applied in appropriate herds. Selective antimicrobial use at dry-off creates an opportunity to practice good drug stewardship and in many situations SDCT has been shown to offer economic benefits. Research indicates that success of a SDCT program is farm specific. Veterinarians should remain abreast of current research findings and consider farm management and pathogen presence as they work with producers to develop a best SDCT strategy.

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Blanket Dry Cow Therapy: Still the Recommendation that Should Cover Most, if Not All, Cows

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Introduction

The efficacy of dry cow therapy as an intervention strategy to help control mastitis is well established. Antibiotic dry cow therapy cures existing infections and will help prevent the establishment of new infections. The application of dry cow therapy and other mastitis control procedures have led to dramatic reductions in contagious mastitis and a significant improvement in udder health. In this paper it is acknowledged that the improvement in udder health may warrant the consideration of selective dry cow therapy, but that the vast majority of herds will profit more by selecting dry cow therapy for all their cows; blanket therapy.

Dry cow intramammary antibiotic therapy studies were conducted more than 50 years ago (Smith et al., 1966). Such studies have proven multiple times that this strategy is effective in preventing and curing existing intramammary infections (Eberhart, 1986). Thus, the use of treating cows with antibiotic given intramammarily at dry-off is widely practiced; it is estimated that almost all cows in the US are treated at the end of lactation (NAHMS-2014).

Given the widespread adoption and success of blanket therapy (treating all cows with intramammary antimicrobial drugs) at dry-off, the question has to be raised: Why consider an alternative and what would that alternative look like? One alternative would be the use of selective dry cow therapy where dairy operators treat only those cows and/or mammary quarters that have or are suspected of having an intramammary infection. Why is selective dry cow therapy being considered and should it replace the recommendation of blanket dry cow therapy use? Answering this question will be the major focus of the paper.

The Purpose of Dry Cow Therapy

> The most recent edition of Current Contents of Bovine Mastitis (2016) summarizes the purpose of dry cow quite distinctly:
> "The basic principle of dry cow therapy is twofold:
> 1) Treatment of all quarters to eliminate subclinical infections that are present at drying-off and
> 2) Prevention of new infections during the dry period.

For mammary quarters not infected the first point is not applicable. The uninfected mammary quarters cannot be cured, there is no infectious agent to be eliminated. Under this scenario, not treating the uninfected quarter, selective therapy, makes sense. The obvious problem is: How do you know which cow and/or which quarter(s) are not infected? The second point raised in the Current Contents of Bovine Mastitis (2016) links the prophylactic value of dry cow therapy. Here the uninfected mammary quarter "enjoys" some advantage of having the intramammary instillation of antibiotic ointment into the gland to protect against the establishment of new infections during the dry period.

Cure of Existing Intramammary Infections at Dry-off

Blanket dry cow therapy can be viewed as a method to treat cows with subclinical mastitis. Several reviews attest to the efficacy of such treatment in the cure of intramammary infections (Barlow 2011; Francis 1989; Eberhart ,1986; Philpot, 1979; Neave et al., 1969; Oliver and Murinda, 2012). There are many commercial products commonly used for dry cow therapy (NAHMS 2007) and given their widespread adoption by the majority of dairy operations it can be concluded that dry cow therapy use is accepted as successful. Oliver and Murinda (2012) concluded that most dairy advisors recommend the blanket dry cow therapy program. Dry cow therapy's success relative to lactating therapy is in part a function of the ability to use a greater dose of the antibiotic in a longer acting vehicle. An advantage of dry cow therapy administration is that it will be administered to a non-lactating cow where the constraints of milking and the associated withholding periods, and even possible withdrawal periods, are much less of a concern; and thus, the associated risk of residues in milk with dry cow therapy use is relatively low.

Most of the early work in dry cow therapy efficacy was conducted when contagious mastitis was the predominant pathogen group. It has been argued that since those primary studies on the efficacy of dry cow therapy that the population of mastitis pathogens has changed. Widespread adoption of the contagious mastitis control strategies has resulted in a shift from contagious to non-contagious mastitis pathogens. Chief amongst the population change over time are the increased prevalence of coliform and the non-ag streptococcal like mastitis pathogens. Eberhart (1986) discusses the dynamics of environmental mastitis pathogens in the dry period. He states a range of 3.8-35.1% of all quarters becoming newly infected during the dry period and indicates that the average rate of new infections in untreated dry cows over the dry period is between 8 and 12%. Smith et al., (1985) indicate that the first 10-15 days and the last 10-15 days of the dry period are the times with the greatest susceptibility to new intramammary infections. Both coliform and the non-ag streptococcal mastitis pathogens appear to affect the gland most at these times. Bradley et al. (2015) found that the coagulase negative staphylococci are more prevalent at dry-off and most prevalent 6 weeks after dry-off, and least prevalent at 2 weeks after dry-off. These data on coagulase negative staphylococcal intramammary infections may reflect the success of dry cow therapy (both curative and prophylactic) seen early but not late in the dry period. The increase in the coagulase negative intramammary infections at the sixth week sample may be due to the failure of the dry cow therapy product to sustain an effective antibiotic dose that would inhibit new infections. Indeed Oliver et al. (2012) state that currently two major shortcomings with present dry cow antibiotic formulations are their limitations in curing coliform infections and their lack of ability to sustain an effective antibiotic dose late into the dry period.

Prevention of New Intramammary Infections

During the dry period there is a need to not only cure the existing intramammary infections but to protect against new ones as well. The national trend in herd bulk tank milk somatic cell count is steadily decreasing over time (Fox, 2017) which would suggest that the number of cows with intramammary infections has been decreasing over time. Thus, the need for blanket dry cow therapy to reduce the number of infections is logically diminishing as well.

Yet, the dry period is arguably the time of a cow's "lactation cycle" when she is most susceptible to intramammary infections (Eberhart, 1986). This would seem counterintuitive because the dry period is the time when the cow is not proceeding through the rigors of milking and therefore less exposed to contagious mastitis pathogens. Additionally, without the untoward effects of machine milking vacuum the teat would be presumably less susceptible to injury and insult during the dry period. Yet the early and late portions of the dry period are the times of heightened susceptibility to new intramammary infections by the non-contagious pathogens (Bradley et al., 2015; and Smith et al., 1985). Presumably, a keratin "plug" should form at the beginning of the dry period and help confer resistance to mastitis. But Dingwell et al. (2003) reported not all mammary quarters appeared to form a keratin plug and as many as one-fourth of all quarters did not appear as closed at 6 weeks into the dry period. The open quarters appeared significantly more susceptible to new intramammary infections than those that closed.

Given the susceptibility of open quarters to new intramammary infections during the dry period, it is not hard to understand the success of teat sealants in the control of intramammary infections. The commercial internal teat sealants generally contain a bismuth subnitrate formulation that are inserted into the streak canal at dry-off. Rabiee and Lean (2013) in their meta-analysis of 18 field studies involving the use of a teat sealant as part of the dry cow program state that the application of internal teat sealants was associated with the significant reduction of new intramammary infections during the dry period and reduced clinical mastitis postpartum. The teat sealants were effective with and without the co-treatment with antibiotic dry cow therapy. Yet the use of teat sealants has been associated with the appearance of black spots in aged cheddar cheese (Anonymous, 2006). It was proposed that some bismuth subnitrate from the teat sealant will end up in the cheese vat and in the presence of hydrogen sulfide in the vat will produce bismuth III sulfide and cause a black precipitate in the forming cheese. For this reason, some milk processors have banned the use of this sealant by dairy producers serving their creameries (Anonymous, 2006).

The Argument for Selective Dry Cow Therapy

Blanket dry cow therapy can fulfill the stated purposes as it has been shown to be effective in curing some existing intramammary infections as cows enter the dry period and prevent additional infections that develop during this time. This fulfillment of purpose would support its long-standing use as a significant component of a mastitis control program. However, the blanket recommendation for such therapy has been called into question. The number of existing intramammary infections is thought to be much reduced in cows as evidenced by the shrinking somatic cell count over time. Some would argue the risk of antibiotic residues in dairy farm milk increases with blanket dry therapy use and thus the blanket therapy should be avoided. Another argument has been made that blanket therapy use will lead to the development of antibiotic resistant strains of mastitis pathogens which will threaten bovine and human health. A third argument could be made that instillation of intramammary products always carries the risk of introducing a new infection into the mammary gland, an iatrogenic infection. But before we challenge these arguments it would be helpful to review studies examining efficacy of selective dry cow therapy.

The principle behind selective dry cow therapy is that it is only administered to cows and their mammary quarters that have mastitis infections. Thus, there is a need to identify which cows/quarters are uninfected. Such identification can be done directly through diagnosis of the agent through culture or nucleic acid based analysis; or it can be done indirectly through a measure inflammation, the reaction to infection, such as measures of somatic cell counts or milk components (enzymes, proteins, lactose, or ions). Clearly there must be more effort applied to determining the infected quarters, more cost in analysis, more effort in assessment and summarization, and in short, more management. With any assessment of infection status of a mammary quarter there will be the risk of misclassification. A false positive will result in treatment of a mammary quarter that was not infected, which happens quite frequently some would argue with blanket dry cow therapy management. So, it is the false negative result that is most "injurious" to the cow and the dairy operator as this mammary quarter should have received antibiotic therapy in the effort to cure the infection when the false negative result suggested that therapy was not necessary. Of course, not all pathogens are susceptible to antibiotics and thus pathogen diagnosis would be helpful in determining which mammary quarters are infected with pathogens likely to be susceptible to dry cow therapy. But regardless of method of selection of the mammary quarter to receive the therapy, the success of selective dry cow therapy is dependent on spontaneous cures of the false negative diagnoses, the lack of need for a prophylactic effect, an overall reduction of clinical mastitis, a reduction of somatic cell count and increased milk production relative to cows receiving blanket or no dry cow therapy.

Selective Dry Cow Therapy Studies

Perhaps the first study examining the utility of complete vs. selective dry cow therapy for mastitis control was done by Rindsig et al., (1978). These coworkers recognized that there were several reviews which discussed the advantages of blanket dry cow therapy. Yet they also recognized that such treatment could be wasted on mammary quarters that were not infected and not destined to become infected during the dry period. They enrolled 232 cows from the University of Illinois dairy herd. They split the herd into 2 groups: those that received complete dry cow therapy (all quarters and all cows) and a selective group. Within the selectives, they split the group into those cows that merited therapy and those that did not. Cows would merit therapy if: 1) they had a composite milk somatic cell count of greater than 500,000 cells/ml during the month before the expected dry date; or 2) the cow had at least one mammary quarter with a milk CMT score greater than 2 just prior to dry-off; or 3) a cow with a history of clinical mastitis at some period during the lactation prior to the dry period. In the selective group there were 64 cows infused with antibiotic in all mammary quarters and 48 cows left untreated. Rindsig et al. (1978) reported that there were significantly fewer mammary quarters infected postpartum in the complete therapy group as compared to those in the select group. Since cures were similar between groups, the infection prevalence advantage seen in the blanket therapy group was a function of the rate of new infections. The blanket, complete, therapy group cows developed significantly fewer new intramammary infections during the dry period relative to the select group. Complete therapy group cows had lower cell counts after the dry period relative to select therapy group cows. The authors concluded: "Complete therapy would be the choice where new infections in dry period are of concern." Of course, it would seem that new infections in the dry period are always a concern.

Since the study by Rindsig et al. (1978), there have been several studies examining the benefits and drawbacks of selective dry cow therapy relative to complete or blanket dry cow therapy strategy. The following discussion is not meant to be a complete review of such studies but an introduction into some of those conducted.

Browning et al. (1994) examined selective dry cow therapy in 12 herds and split selected cows into two groups: 1) cows which received antibiotic therapy in all mammary quarters when at least one quarter was infected and 2) cows where only the infected mammary quarter received therapy. Intramammary infections were detected before dry-off and postpartum. Infection status of cows in Groups 1 and 2 were compared to those cows receiving blanket dry cow therapy. The prevalence of infected mammary quarters did not differ significantly among treatment groups across all three sampling periods (dry-off, calving, mid-lactation). However, there were significantly more new infections found at calving for Group 2 cows. However, the prevalence of intramammary infections at mid-lactation was similar for all groups.

Browning and coworkers (1994) calculated that less antibiotic was required to cure infections and prevent new infections in Group 2 cows (all quarters treated) than for the blanket therapy cows. Moreover, these researchers noted that by mid-lactation the prevalence of infection was similar between all group cows and suggested that there were more mastitis infection risk factors to be controlled outside of the dry cow period. Yet, research by Berry et al. (1997) indicated that cows not treated during the dry period produced significantly less milk than dry cow therapy administered cows. Similarly, Osteras and Sandvik (1998) reported that control cows not treated with antibiotic produced less milk in the subsequent lactation than cows with selectively treated quarters infected at dry-off. Additionally, Osteras and Sandvik (1998) found that non-treated cows had higher milk somatic cell counts and incidences of clinical mastitis post calving.

McDougall (2010) stratified cows with low milk somatic cells (<150,000 cells/ml) into 3 groups. The first group did not receive intramammary treatment at dry-off while groups two and three received different dry cow therapies in all quarters. Cows in the first group, controls, had significantly higher incidence of new intramammary infections and clinical mastitis than treated cows. Rajala Schultz et al. (2011) studied selective dry cow therapy's effect on milk somatic cell count postpartum. In their study they used cows with no clinical mastitis in the last 3 months of lactation and low milk somatic cell counts (<200/0000 cells/ml) during this time. These cows were randomly assigned to receive commercial dry cow therapy or serve as non-treated controls. All other cows, those that did not have the low cell count and no clinical mastitis characteristics, received dry cow therapy. Non-treated cows, again, cows apparently free of mastitis and not treated, had significantly elevated milk somatic cell counts postpartum. However, there appeared to be a significant herd by treatment response on milk somatic cell count suggesting that although in aggregate the selective therapy effects as measured by cell count did not look good, in some herds selective therapy appeared to be equivalent to blanket therapy. In summary, the results of studies examining different forms of selective dry cow therapy using different control groups suggest an advantage to the blanket dry cow therapy strategy. Milk production increases, fewer cases of intramammary infections and clinical mastitis are noted, and lower milk somatic cell counts post calving, have all been associated with blanket dry cow therapy as opposed to selective. Yet as evidenced by Rajala Schultz et al. (2011), and others, there is often a significant herd effect suggesting that in some herds the selective approach may work better than in other herds.

Final Thoughts

One of the major concerns of the use of antibiotics on dairy farms is that therapies will be misused and such misuse will lead to residues entering the milk supply. Interpretation of Figure 1 would suggest that over time less and less milk is leaving the farm with residues. Moreover, the current amount of residue laden bulk tank milk appears to be one hundredth of a percent of all shipments, suggesting herd milk residues are rare. The number of tanker loads with residues is clearly decreasing linearly over time. One would expect that this signifies that producers are improving their abilities to keep antibiotic laden milk out of the market. However, the percentage of milk producers without a residue violation has plateaued (Figure 2) and additionally is perhaps sixfold greater than the number of tanker loads in violation. This signifies that there are proportionally more producers than tanker loads with residue violations. And thus, there are some herds with problems while the vast majority of herds are able to keep residues out of the milk supply. If the later interpretation is correct then the argument that dry cow therapy will lead to more residue violations is not as strong. It appears that the problem of residues lies more with a few, perhaps poorly managed, herds.

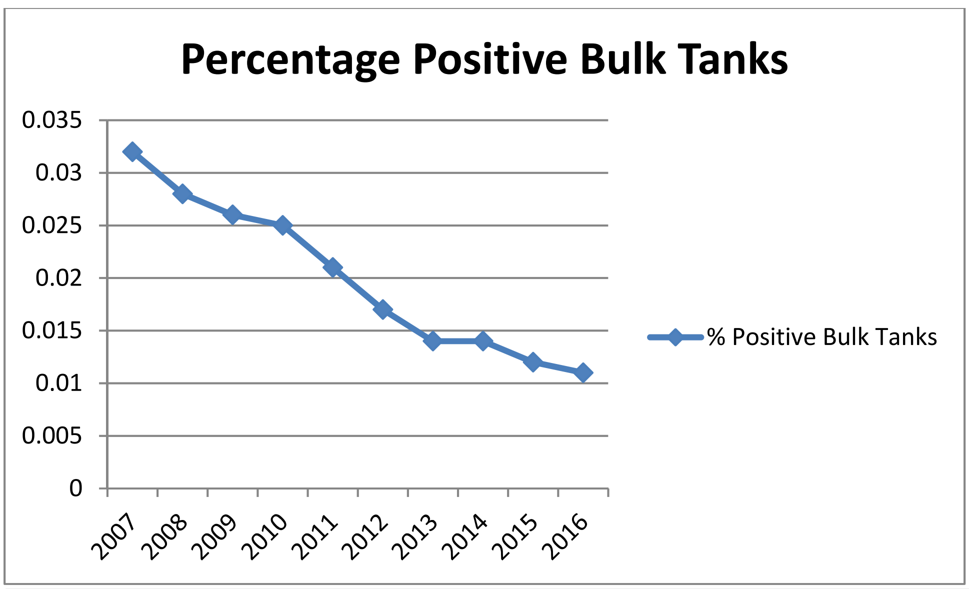

Figure 1. Percentage of bulk tank milk by year that are leaving dairy herds to be processed that had antibiotic residues of note. Data accessed from https://www.kandc-sbcc.com/nmdrd/.

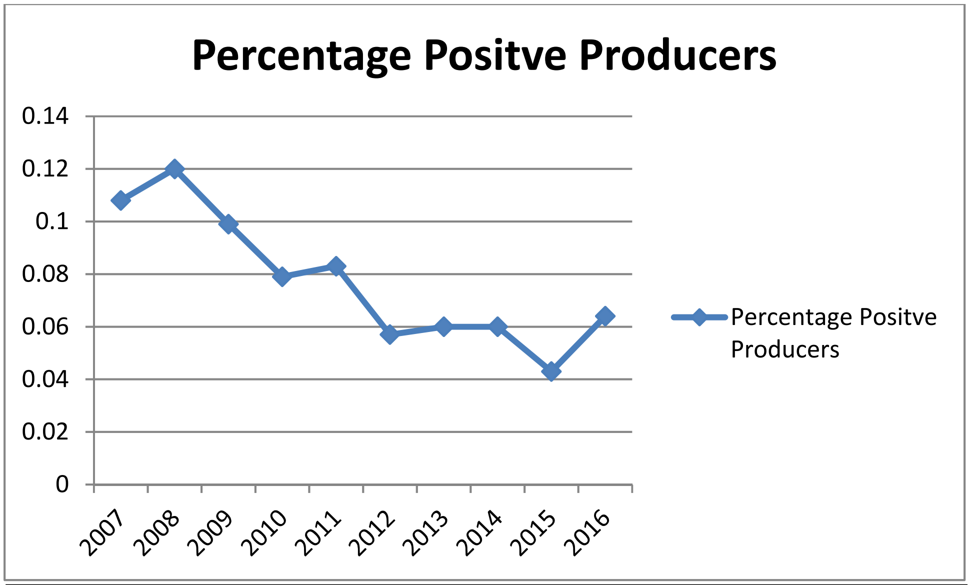

Figure 2. Percentage of dairy producers by year that shipped milk to be processed that had antibiotic residues of note. Data accessed from https://www.kandc-sbcc.com/nmdrd/.

Another major concern of blanket dry cow therapy use espoused by advocates of selective dry cow therapy is the possible selection for drug resistant mastitis pathogens. This is a fear of many when antibiotics are used without cause. But in the case of blanket dry cow therapy the cause is clear: Complete Dry Cow Therapy is to be used to cure existing infections and prevent new infections. Whereas such a strategy is likely not as necessary to cure existing infections as the prevalence of mastitis seems to have decreased dramatically over time, the utility of such a strategy as a prophylactic has been demonstrated. Moreover, there is no evidence to indicate that blanket dry cow therapy has led to the selection of antibiotic resistant mastitis pathogens (Oliver and Murinda, 2012).

A possible negative to the use of blanket dry cow therapy is that teat end of mammary quarters not needing treatment are being exposed and manipulated leading to increased risk of iatrogenic infections. Yet the fact that cows receiving blanket as opposed to selective therapy have fewer new intramammary infections postpartum suggests this is not a great risk. Some arguing against blanket dry cow therapy will suggest that the strategy represents excessive use of antibiotics that runs counter to consumer preference for milk as a wholesome and natural product. Again, reference to Figures 1 and 2 would argue that antibiotic residues should be less of concern over time and that milk quality as measured by the absence of residues on the vast majority of farms is improving.

A potential long-term danger associated with the consistent use of selective dry cow therapy might be evidenced by the increased annual incidence and prevalence of *Streptococcus agalactiae* mastitis in Denmark (Mweu et al., 2012). Keefe (2012) indicates that dry cow therapy is very effective in eliminating *S. agalactiae* intramammary infections and the widespread adoption of the blanket dry cow therapy approach appears to be correlated with the near elimination of *S. agalactiae* from certain countries. In Denmark, only selective dry cow therapy is permitted and the move away from blanket dry cow therapy coincides with an increased incidence and prevalence of *S. agalactiae* mastitis.

Ultimately, the success of selective dry cow therapy depends on spontaneous cures of infections not detected and therefore not treated, immune function and the lack of need for the prophylaxis and prevention of clinical mastitis that the intramammary antibiotic provides, the ability to identify the mammary quarters that are to be selected for treatment and the management where-with-all to make a selective program successful. No doubt, selective dry cow therapy can save money by a reduction in antibiotic purchased and administered. Yet the costs to identify the selected cows and quarters for treatment must be compared. A full-scale study comparing the cost to benefit ratio of selective vs. complete dry cow therapy would be helpful. Some herds with excellent management and excellent mastitis control and employ a program of selective dry cow therapy quite effectively. But it does not appear that at this time there is any compelling reason to recommend that all, most, or even many herds, should choose selective dry cow therapy over blanket dry cow therapy.

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Forced to Selective Dry Cow Treatment by Legislation: Blessing or Curse?

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Introduction

The use of antibiotics in food-producing animals has been a frequently discussed topic the last decade in the Netherlands. Differences in the total use of antimicrobials between human medicine and veterinary medicine led to many discussions. Development of antimicrobial resistance resulting from agricultural use of antimicrobials that could have impact on the treatment of human diseases has become a global public health concern. This finally ended up in the Netherlands in the Task Force Antibiotic Resistance in food producing animals in 2008. Representatives from all parties within the food-production chain (farmers organisations, meat processing industries, feed suppliers), the Royal Dutch Veterinary Association (KNMvD) and the Government were represented in the task force. Per animal production sector (cattle, veal, poultry and pigs) action plans were developed. Main goal of the Task Force was to get more insight in the use of antimicrobials and to focus on a more prudent and restrictive use of antimicrobials. The minister of agriculture stated in 2010 that the total use of antibiotics in food-producing animals should be reduced by 20% in 2011, by 50% in 2013 and 70% in 2015. All these reductions were related to the total antibiotic use in 2009.

In August 2011, a report from the Health Council of the Netherlands was published in which recommendations were made that should result in a reduction in the use of antimicrobials in general and some classes of antibiotics in particular for all food- producing animals. Comparing the use of antimicrobials for the different species of food-producing animals, use of antimicrobials in dairy cows was relatively low, compared to swine and poultry. Therefore, the main focus of prudent antibiotic use in dairy was to decrease the use antibiotic classes or therapeutic groups. Based on the report from the Health Council the use of 3rd and 4th generation cephalosporins and (fluoro)quinolons, the so called “critically important antimicrobials (CIA)” deserved first attention in the approach on dairy herds.

To monitor the use of antimicrobials, a national data base (Medirund) was created in which the antimicrobial usage in dairy farms was uploaded by the veterinary practices. With these data the first figures on the use of antimicrobials could be calculated in 2012. Results showed that more than 65% of the total antimicrobial usage was administered intramammary and the majority of intramammary use (>60%) was used for dry cow treatment.

The next step to achieve a more prudent use of antimicrobials in order to decrease the risk of antimicrobial resistance, was the ban on the preventive use of antimicrobials in Dutch livestock, effective since 2012. This implicated that one goal of the use of antimicrobial dry cow treatment, prevention of new infections in the dry period, was not allowed anymore. Labels of dry cow tubes were adjusted and the claim of prevention of new intra mammary infections during the dry period was omitted. As a result, Dutch dairy farmers were forced to Selective Dry Cow Treatment (SDCT) rather than Blanket Dry Cow Treatment (BDCT). In January 2014, the Royal

Dutch Veterinary Association provided a guideline, ‘The use of antimicrobials at dry-off in dairy cattle’, to support veterinarians in advising dairy farmers in the practice of SDCT (KNMvD, 2014).

The somatic cell count (SCC) thresholds to select cows for SDCT were based on a simulation study by Scherpenzeel et al. (2106) and were assumed to result in an optimal tradeoff between reduced antimicrobial usage associated with udder health versus increased risk of new intra-mammary infection (IMI). It was decided that multiparous cow with a cow SCC > 50.000 cell/ml and first calf heifers with a SCC > 150.000 cells/ml were allowed to dry of with antimicrobials. The interval between last milk recording and drying off should not be longer than 6 weeks.

Legitimate concerns have been raised by farmers and veterinarians about the negative impact of the potential increase in both clinical and subclinical mastitis associated with SDCT and its consequential impact on animal welfare and production. Therefore, the aim of this study was to evaluate the effect of the enforced transition from mainly BDCT to SDCT, as a result of the legislation and guideline on dry cow therapy in the Netherlands, on the antimicrobial usage and on udder health performance at national, practice and cow level.

Material and Methods

Gain of acceptance / Implementation of the guideline

Based on the ban of the preventative use of antimicrobials the delivery conditions of the dairy plants started to prescribe the selective use of antimicrobial DCT. The most important prerequisite for mandatory rules and legislation is to gain acceptance and to win a broad support. Support not only from farmers but from the vets as well.

How do you convince farmers to cease with the routine of blanket DCT, a dry off tool that has been recommended for more than 40 years as part of the five-point mastitis control plan (Dodd et al., 1969). How can you guarantee them that it would not lead to more clinical mastitis or even dead cows? The anxiety for changing the rules was present in both farmers and vets. The strong belief in the efficacy of BDCT, the relatively low price of dry cow tubes and the lower need for optimal hygiene and management made it difficult to move to SDCT.

Most important message to the farmers was that they first had to optimize their dry cow management before they could started with selective DCT. It was explained that cows with a low SCC that were dried of without antimicrobials were free of an IMI. Farmers was thought to improve immune status of the cow and decrease infection pressure in order to keep the cows free of IMI during the dry period.

Antimicrobial Usage Associated with Udder Health

Information on the use of antimicrobials on all Dutch dairy herds is collected in an national database (Medirund). Veterinary practices upload every two weeks all their sales figures from each individual farm into the national data base. Out of this information rolling annual averages are calculated every quarter of the year. Besides the total use of antimicrobials, the different usages are also provided.

Veterinary Practice Level

The University Farm Animal Practice serves around 300 dairy cattle herds, comprising about 27,500 cows in total. All antimicrobial drugs used on these herds were distributed solely by the veterinary practice. A subset of 20 herds with individual cow DCT data available via farm management software (CowVision, AgroVision, Deventer, the Netherlands) were used for the herd level analysis of antimicrobial use associated with udder health.

Effect on udder health performance

We used an elevated SCC as an indicator for the presence of an IMI (Schukken et al., 2003, Vissio et al., 2014). In line with the thresholds for elevated SCC used in Dutch national milk recording, primiparous cows with an SCC of ≥ 150,000 cells/mL and multiparous cows with an SCC of ≥ 250,000 cells/mL were classified as infected (de Haas et al., 2008). In this study, we investigated dry period SCC dynamics using key performance indicators (KPI) provided via milk recording (CRV, Arnhem, the Netherlands). The KPIs used were the mean percentage of cows with a new IMI at the first milk recording following a dry period (% new IMI), and the mean percentage of cows cured of an IMI during the dry period (% cured IMI). A new IMI was defined as a change in SCC from below the threshold of 150.000 cells/ml for primiparous and 250.000 cells/ml for multiparous cows at the last milk recording before calving to an SCC equal to or greater than the threshold at the first milk recording after calving. A cured IMI was defined as a change in SCC from equal to or greater than the threshold (150.000 cells/ ml for primiparous and 250.000 cells/ml for multiparous cows) at the last milk recording before calving to an SCC below the threshold at the first milk recording after calving.

The annual mean % new IMI and the mean % cured IMI from milk recordings (CRV, Arnhem, the Netherlands) were available from 2012 through 2017 for 280 herds served by the University Farm Animal Practice (Harmelen, the Netherlands). For each year, we calculated the annual mean % new IMI and the mean % cured IMI by combining the data from all the 280 herds.

Statistical Analysis

Data were first extracted from the different software programs and exported to MS Excel (Microsoft Office, Redmond, Washington, USA) for initial data handling. Summary statistical analyses were performed using SPSS 24.0.0.1 (IBM, New York, USA).

Results

Antimicrobial Usage Associated with Udder Health

In Figure 1 the usage of antimicrobials of the Dutch dairy herds over the last 6 years is shown. Total usage of antimicrobials decreased from 2.9 Defined Daily Dose Animal Year (DDDA/Y) in 2012 to 2.09 DDDA/Y in 2017, which was a decrease of 28%. Decrease in total antimicrobial use was caused by a decrease of the intramammary antimicrobials for mastitis and by a decrease in intramammary antimicrobials for DCT.

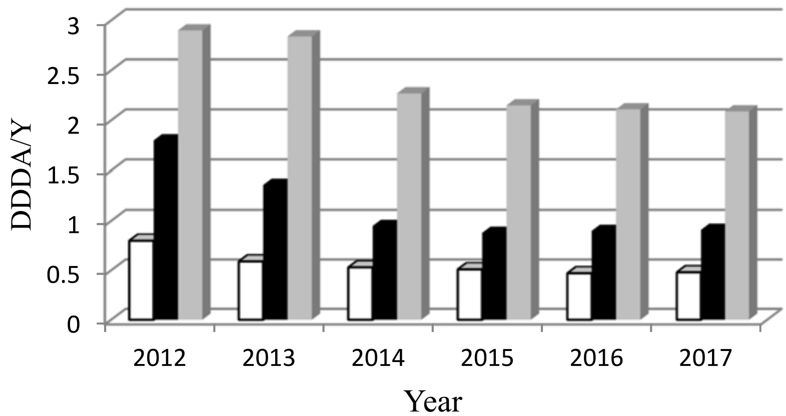


Figure 1. Dutch average of total use of antimicrobials (grey bars), intramammary dry cow tubes (black bars) and intramammary mastitis tubes (white bars) in defined daily dose per animal year (DDDA/Y) (n = approximately 18.000 dairy herds).

Usage of intra mammary antimicrobials (mastitis and dry cow tubes) as percentage of the total use is shown in Table 1. Decrease in use of antimicrobial DCT started already in 2013 and continued in 2014. A kind of steady state was reached at 2016 and 2017. From 2012 through 2017 usage of antimicrobials for DCT decreased by 50%. Usage of antimicrobials for mastitis showed also a decrease of 40% from 2012 until 2017. Use of antimicrobials for intra mammary decreased from 69% to 65% in 2017 and in 2017 antimicrobials for DCT accounted only for 44% of the total use of intra mammary antimicrobials.

Table 1. Total use of antimicrobials and the intra mammary (IMM) use of antimicrobials as Defined Daily Dose Animal Year (DDAY) from 2012 through 2017 in all Dutch dairy herds (n= approximately 18.000 herds)

	Year					
Variable	2012	2013	2014	2015	2016	2017
Total use of antimicrobials (DDDA/Y)	2.90	2.84	2.27	2.15	2.11	2.09
IMM antimicrobials mastitis (DDDA/Y)	0.8	0.59	0.53	0.51	0.47	0.48
IMM antimicrobials DCT (DDDA/Y)	1.8	1.36	0.95	0.88	0.90	0.91
IMM (mastitis + DCT) as % of total use	69%	70%	64%	63%	66%	65%
IMM DCT as % of total IMM use	62%	48%	42%	41%	43%	44%

Effect on udder health performance

An overview of the national BMSCC over the last 11 years is shown in Figure 2. BMSCC shows a decreasing trend and BMSCC dropped below 200.000 cells/ml in 2015. Since the ban on preventive use of antimicrobials in 2012 national BMSCC declined by 30.000 cells/ml.

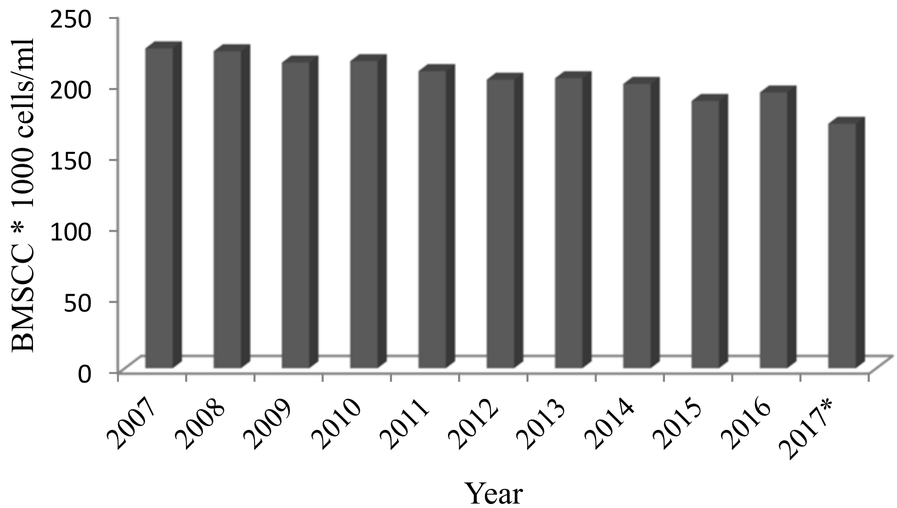


Figure 2. National BMSCC in the Netherlands from 2007 until 2017 (n= approximately 18.000 herds). *Average BMSCC of 2017 is calculated until June 2017.

Results of SCC changes during the dry period at the 280 herds belonging to the University Farm Animal Practice are shown in Table 2. The annual mean % new IMI changed from 16% in 2013 to 18% in 2014 and to 17% in 2016, a slight increase in the number of new infections during the dry period. The annual mean % cured IMI during the dry period was 74% in 2013 and 2014 and 75% in 2017.

Table 2. Somatic cell count dynamics over the dry period from 2013 through 2017 in herds serviced by the University Farm Animal Practice in the Netherlands (n= 280 herds). Thresholds for primiparous cows 150.000 cells/ml and 250.000 cells/ml for multiparous cows

	Year				
Variable	2013	2014	2015	2016	2017*
Mean (SD) % new IMI	16 (9)	18 (10)	17 (9)	17 (10)	15 (8)
Mean (SD) % cured IMI	74 (16)	74 (18)	76 (17)	75 (18)	75 (19)

*Calculations for 2017 are carried out until December 1, 2017.

The results from the 20 dairy herds with individual SCC and DCT data are shown in Table 3. The same thresholds are used: 150.000 cell/ml for primiparous animals and 250.000 cells/ml for multiparous cows. SCC change over the dry period was calculated in relation to DCT with or without antimicrobials. Percentage of animals with new infections during the dry period (L-H) was higher in animals that were dried off without antimicrobials than in animals that were dried of with antimicrobials, 18.1% and 11.1% respectively in 2015. On a cow level cure rates of IMI in the dry period (H-L) were also slight higher in the group of animals that were dried of with antimicrobials compared to the group without antimicrobials.

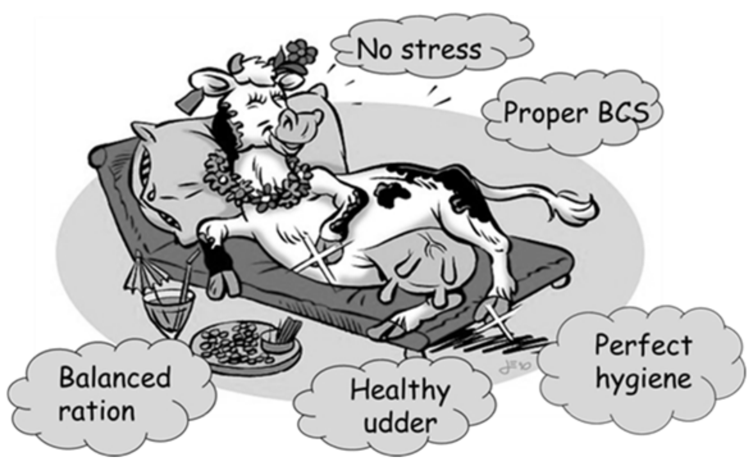
Table 3. Effect of the use of antimicrobials (AM) at drying off on the SCC change over the dry period, with threshold for primiparous cows at 150.000 cells/ml and 250.000 cells/ml for multiparous cows

		# of animals		SCC change over dry period			
DCT	Year	Low (L)	High (H)	L-L (%)	L-H (%)	H-L (%)	H-H (%)
no AM	2012	169	24	82.8	17.2	66.7	33.3
	2013	375	44	84.3	15.7	72.7	27.3
	2014	622	76	78.1	21.9	55.3	44.7
	2015	652	75	81.9	18.1	74.7	25.3
AM	2012	972	361	86.8	13.2	76.7	23.3
	2013	781	328	87.6	12.4	78.4	21.6
	2014	621	344	87.6	12.4	79.9	201
	2015	598	332	88.9	11.1	80.1	19.9

Discussion

The ban on the preventive use of antimicrobials in 2012 lead in the beginning to anxiety and sometimes even to anger. Farmers felt misled since they had been thought for decades to apply BDCT. They complained about all the investments they had made the past decades in order to reach a low and acceptable BMSCC. But not only farmers raised questions by the implementation of the guideline, there were also veterinarians who did not belief in the new approach. On the other hand, data showed that the BDCT was not as blanket as we thought. Only 85% of the farms was using a real BDCT meaning that all the cows were dried of with antimicrobials. Trying to convince farmers and vets to dry off cow without AM was based on the prudent use of AM and the urgent situation of increasing AMR worldwide. Efficacy of dry DCT was not an issue, since protection of BDCT against new IMI in the dry period is in general better than SDCT (Halasa et al., 2009). The challenge was to improve dry cow and transition management in order to minimize the risk of new IMI during the dry period. Farmers explained that the protection of a dry cow tube should be replaced by improved management. To appeal to farmers' imagination, we provided the following cartoon and explained them they should treat their dry cows like a princess.

"Treat your dry cow as a Princess"



Results showed a remarkable reduction in the number of antimicrobials used, both at the national level and at the veterinary practice level. Surprisingly, not only a decrease in the use of intra mammary dry off tubes was seen, but the usage of intra mammary antimicrobials to treat mastitis also showed a sharp decline. A decrease of intra mammary mastitis tubes could be caused by a decreased mastitis incidence, but could also be associated with a more restrained treatment of (sub)clinical mastitis cases. The ongoing attention on prudent us of antimicrobials in the last 8 years changed the mind set of farmers and made them more reluctant to treat their animals with antimicrobials. Treatment of mastitis with other remedies than antimicrobials are becoming more obvious.

The national mean % new IMI and mean % cured IMI during the dry period seemed not to be negatively affected by the decreased use of antimicrobials for intramammary use (DCT and mastitis therapy). As explained before it could be that with the shift from mainly BDCT to SDCT, both dairy farmers and veterinarians adjusted their focus to other management practices, such as hygiene and transition cow management, to ensure optimal udder health in their herds (Green et al., 2007, Scherpenzeel et al., 2016). They were practicing the "Princess-method".

Following a period in which BDCT was an essential part of the of the 5-point mastitis control plan, the results from this study indicate that in the Netherlands a nationwide forced shift to SDCT over a relatively short period of time, was associated with no significant changes to udder health during the dry period and with the decreased use of antimicrobials. The implementation of a national guideline on the use of antimicrobials in dairy cows at dry-off is likely to have helped in the selection of those cows that did not need antimicrobial DCT for a successful dry period, thus contributing to a more prudent use of antimicrobials and lowering the antimicrobial selection pressure.

Conclusion

Reduction in number of antimicrobials was achieved in only two years and was facilitated by the use of the guideline "The use of antimicrobials at dry-off in dairy cattle". The forced transition from mainly BDCT to SDCT in the Netherlands resulted in a reduction in the number of intramammary antimicrobials used on dairy herds without having a deleterious effect on udder health during the dry period. Those big steps would probably not have been made if SDCT was promoted in a voluntary way. Awareness of the importance of the transition period improved management, nutrition and hygiene during the dry period. These management adaptations will not only be beneficial for udder health but for the total performance of the fresh cow, like reproduction, claw health, metabolic performance and milk production. So overall, being forced to SDCT can be seen as a blessing.

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Selective Dry Cow Therapy: The New Zealand Perspective

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Introduction

Antimicrobial use in New Zealand animals is relatively low by international standards (Hillerton et al 2017). This is partly due to the extensive, pasture-based systems of production with associated lower incidence of disease. The major indication for antibiotic use in the dairy industry in New Zealand is mastitis related, that is, either treatment of clinical cases or dry cow therapy (DCT; Compton and McDougall 2013). As New Zealand is a major food exporter it needs to meet and exceed international standards. Hence there is a renewed focus on good stewardship of antibiotics, particularly in use of critically important antimicrobials and DCT in the dairy industry.

Selective dry cow therapy (sDCT), that is, not treating every cow at end of lactation with long acting, intramammary antibiotics, has been the recommended approach in New Zealand since the early 1990s. The current national mastitis management plan (SmartSAMM; wwww.dairyNZ.co.nz\mastitis) recommends that every cow be protected over the non-lactation period. This protection may be provided by long acting intramammary antibiotics (DCT) for those cows likely infected, or by infusion of internal test sealants (ITS) in those likely uninfected at dry off.

The process of prescribing by veterinarians is within a framework of a thorough knowledge of a farms milk quality history and mastitis epidemiology. Veterinarians may recommend whole herd DCT where the epidemiology suggests a high prevalence of infection and a high rate of new infection that suggests any cow selection based on most recent herd test SCC data may misclassify too many cows.

Selecting Cows

The current recommendations are that any cow with a maximum SCC at any DHIA test of ≥150,000 cells/ml (≥120,000 for 1st lactation animals) and/or a history of clinical mastitis in the current lactation is treated with DCT (and commonly with ITS as well), while those below these cut-points may be left untreated or infused with an ITS.

Good stewardship of antimicrobials requires identification of likely bacteria and their sensitivity to antimicrobials prior to prescribing. Bacterial culture or polymerase chain reaction (PCR)-based techniques are the gold standard for indicating presence of bacteria or DNA, respectively. On-farm culture techniques have also been evaluated as a way of defining infection without the requirements of an on-farm laboratory (Cameron et al 2014). However, under New Zealand systems with seasonal calving and hence drying off, the logistics of aseptically sampling large numbers of cows before drying off, as well as the time and direct costs, are usually considered prohibitive. Therefore, indirect tests for infection are used. These need to be cheap, easy to implement and have a high sensitivity (Se) and specificity (Sp).

Individual cow SCC
Individual cow somatic cell counts (SCC) are widely used as a proxy for infection status. The Se and Sp for major pathogen infections (i.e. *Staphylococcus aureus*, *Streptococcus* spp., *Escherichia coli*) using a maximum lactational SCC of ≥150,000 cells/mL as a proxy for infection (where the last herd test was <80 days before drying off) has a Se, Sp, positive predictive value (PPV) and negative predictive value (NPV) of 0.85, 0.72, 0.19 and 0.98, respectively (McDougall et al 2017, Table 1).

Modelling of cut-points demonstrates that the Se decreases while Sp increases as the SCC threshold is increased (Table1). Putting that in context, in a group of 500 cow with a 7.5% cow-level prevalence of major pathogens, 4, 6, 7, 8, and 11 cows with a major pathogen infection would be false negatives (i.e. be defined as uninfected) as the cut-point is increased from >125,000 to >225,000 cells/mL in 25,000 steps (Table 1). Conversely 187, 159, 137, 123, and 108 cows would be false positives, that is, truly not infected when the as the cut point is moved from >125,000 to >225,000 cells/mL in 25,000 steps (Table 1). Thus if we assume that those cows below the cut point are treated with an ITS and those above with DCT, we have increasing numbers of cows that should be receiving DCT not getting this treatment, while there are fewer cows not required DCT, getting DCT, as the cut point increases.

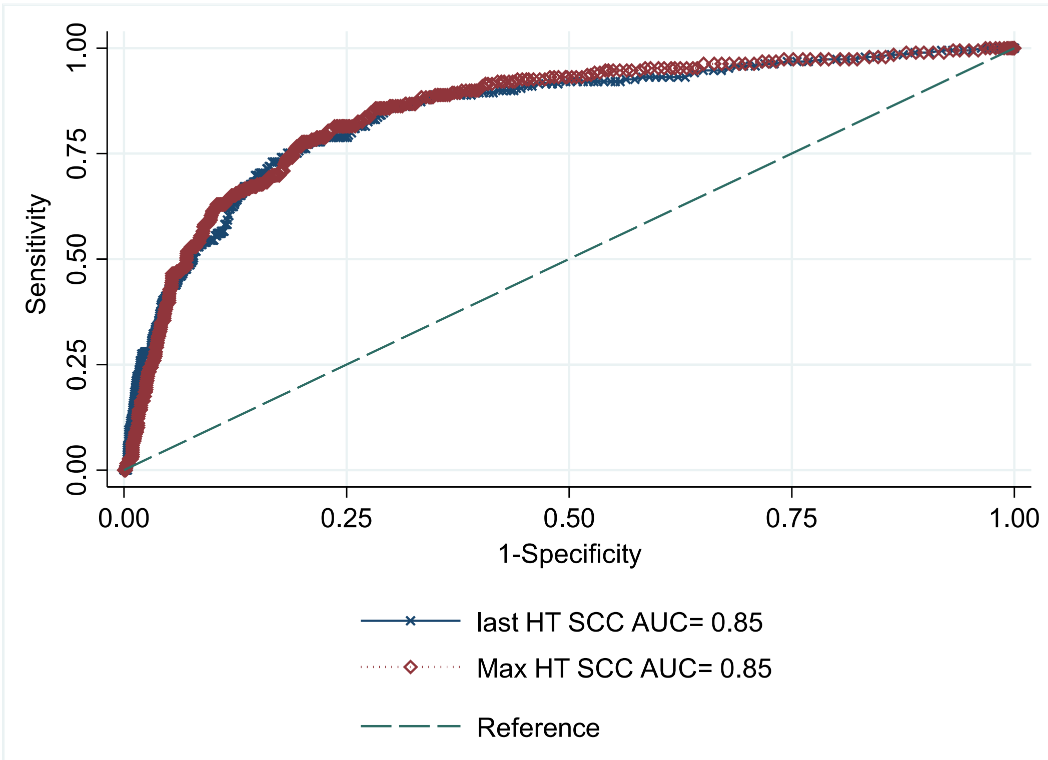
Table 1. Classification of cows (number of cows) using various maximum herd test somatic cell counts (SCC; x 1,000 cells/mL) to define cows as likely to be infected with a major pathogen compared with actual quarter-level culture results where a cow was defined as infected with a major pathogen if one or more glands were milk sample culture-positive for a major pathogen. This table assumes a cow-level prevalence of a major pathogen infection in one or more glands at dry off of 7.5% in a group of 500 cows (McDougall et al 2017).

Cut point:	Infected	Uninfected	total	Se	Sp	PPV[1]	NPV[2]
>125	33	154	187	0.88	0.67	0.17	0.99
≤125	4	308	312				
>150	31	128	159	0.85	0.72	0.19	0.98
≤150	6	333	339				
>175	30	107	137	0.80	0.77	0.21	0.98
≤175	7	354	361				
>200	29	94	123	0.78	0.79	0.23	0.98
≤200	8	367	375				
>225	26	82	108	0.71	0.82	0.24	0.97
≤225	11	380	391				

[1] Positive predictive value
[2] Negative predictive value

There was no difference in the ability of SCC to categorize cows as infected with a major pathogen, irrespective of the interval from the last herd test to drying off, when the last herd test occurred within 80 days of dry off. A single herd test within the last 80 days of lactation provides a Se and Sp for detecting cows with a major pathogen infection equivalent to that provided by using the maximum herd test SCC from three or four herd tests in the lactation, or of the average of each herd test SCC (Figure 1). This suggests that for herds that do not undertake routine DHIA testing, a single test late in lactation would be sufficient to define cows as infected or not.

Figure 1. The receiver operator curves (ROC) to predict the presence of a major intramammary infection in one or more glands in cows based on the last herd test somatic cell count (SCC) or the maximum herd test SCC. (AUC = area under the curve)



Does ITS work?

Where selective DCT is to be used, there needs to be confidence that the alternatives (no treatment, or use of ITS) are effective. Meta-analysis suggests that ITS reduces risk of new intramammary infection over the dry period, and the risk of clinical mastitis in the next lactation relative to DCT alone or no treatment in low SCC cows (Rabiee and Lean 2013). The efficacy of internal teat sealants has been demonstrated under New Zealand circumstances (Woolford et al 1998; Compton et al 2015). ITS has been demonstrated to be effective in reducing prevalence of infection at calving, reducing clinical mastitis incidence and reducing subsequent SCC where ITS is infused precalving into primiparous heifers (Parker et al 2007, 2008). Practically producers commonly use ITS in heifers before using it in cows, with the experience of efficacy in heifers convincing them to try it in cows

Practical Approach

The majority (>90%) of herds in New Zealand calve in spring, and the average herd size is 430 cows. In this highly seasonal system, drying off generally occurs on one to three calendar days, with commonly several hundred cows to be dried off at one time.

Producers generally monitor feed availability of pasture, hence have a general idea as to when drying off will need to occur. Commonly availability of pasture is the limiting factor for length of lactation (not impending parturition). Thus producers monitor pasture availability, pasture quality, body condition score of cows and for those herds with milk quality issues, the bulk milk SCC.

For both logistics and farm management reasons, it is common for producers to dry off cows in groups. Dry off sequence is generally based on BCS, previous SCC data, and in some cases due calving date.

Tactical decisions to dry cows off may occur fairly quickly, for example, if the weather forecast suggests rain is due, decisions may be made to dry cows off before significant weather systems affect pasture and hygiene on farm.

Under New Zealand management systems it remains common to reduce milking frequency from twice to once-a-day within a week of drying off, and to manipulate the ration to reduce protein availability. This is commonly done by introducing pasture or corn silage to substitute for *in situ* grazed pasture. The rationale for such an approach is to reduce milk yield at the point of drying off.

Cow selection
The majority of New Zealand farms have electronic data for cow demographics, and for the approximately 60% of herds that undertake DHIA recording, SCC data.

Prior to drying off, cow level data including SCC, clinical mastitis history, pregnancy status (pregnant versus not pregnant and due date for pregnant animals), other disease history, and the genetic value of the animals are collated.

In New Zealand, antibiotic DCT is only available following prescription by a veterinarian. Under the Veterinary Council of New Zealand (the professional regulatory body) guidelines, veterinarians are mandated to have a full understanding of the epidemiology and microbiology of mastitis on a farm, prior to prescribing. Hence the majority of veterinary businesses undertake what is termed a ‘milk quality review’ or ‘DCT review’ prior to prescribing. This face-to-face meeting between the producer and veterinarian generally takes 45 to 90 minutes and both herd and cow level decisions around culling and DCT prescribing, as well as management changes to improve mastitis diagnosis and control are discussed and documented. This meeting is commonly used to plan logistics of the drying off process including cow selection, cow nutritional management, farm staff training, and post dry off management strategies.

Where multiple treatment types are being used within a farm, for example, with some cows are being treated with antibiotic DCT, and others with an internal teat sealant, producers may choose to dry off animals by treatment type groups. This minimizes the risk of misidentification and missed treatment of individual animals during the drying off process. With availability of electronic identification systems, and automated drafting gates, selection of subsets of cows within the herd is feasible.

The mechanics of drying off
To maintain a sufficiently high level of hygiene, particularly where ITS is being used, the aim is that no more than 20 animals/hour/person should be dried off. Thus to dry off 200 cows requires a total of about 10 hours. The aim is to limit a session of the drying off to <3 hours, thus for 200 cows, three to four people are required.

Staff availability and training
Historically producers and their staff have undertaken infusions at drying off. However, with increasing use of ITS alone or in combination with DCT, drying off is taking longer and requires a higher level of skill to ensure hygiene is maintained.

Thus many veterinary businesses are providing training to producers or staff and/or providing teams of technicians to help producer's dry cows off and infuse ITS in heifers. In common with other dairy industries, New Zealand is struggling to find enough experienced people to manage and milk cows, which places greater pressure on farm labor management around drying off. Veterinary businesses commonly recruit seasonal staff to manage the workloads through the drying off period (i.e. March to June). Training is provided in the processes of drying off, and some businesses will also use quality assurance steps such as ensuring that staff can collect 20 or more milk samples aseptically, with laboratory diagnosis of a contaminated sample resulting in retraining.

Infusion of products into the mammary gland entails some risk to staff, particularly where primiparous animals are being infused prior to 1st calving. Thus safety precautions including the wearing of personal protective equipment such as field hockey shin guards to the forearms, helmets and glasses are used by prudent businesses. Some veterinarians routinely use a low dose (i.e. 10-20 mg) of xylazine in dairy heifers to reduce risk to staff. However, there is a small risk of abortion, hence not all businesses use this approach.

Facilities
Drying of is generally undertaken in the parlor as there are rarely other suitable facilities on farm. The majority of farms in New Zealand milk twice daily, thus there is enough time between milking's to dry off.

Some milking parlors may be risky to undertake infusions in, commonly in the situation where young animals are being handled in rotary parlors where animals can move around and potentially kick those undertaking infusions. In this these cases, purpose built, mobile cattle handling facilities ("teatseal trailers") provided by veterinary businesses may be used to undertake infusions (Figure 1). These trailers will generally hold five or six animals at a time, and allow three or four technicians to work simultaneously. One constraint when using the trailers away from the dairy parlor is availability of clean water to maintain hygiene.

Figure 2. Purpose built cattle handling facility for intramammary infusion where on-farm facilities are not safe enough to infuse. This approach is commonly used for dairy heifers where the main milking parlor is a rotary.

In herringbone sheds, generally one side of the parlor is used, and the breast rail moved in to improve restraint of animals.

Process

The required equipment is assembled prior to farm visits. This can be placed in large sealable plastic bins. Equipment includes disposable gloves, personal protective equipment including milking aprons or waterproof coveralls, forearm and wrist guards, glasses and in some cases helmets, equipment to ensure appropriate teat hygiene and antisepsis (disposable paper towels, teat antiseptics, cotton wool balls moistened with 70% methylated spirits). Internal teat sealants may be very viscous at low temperature, hence it is common to float the containers of ITS in large buckets of warm (35°C) water to reduce viscosity and ease infusion.

To minimize risk of cows infused with antibiotic dry cow therapy or internal teat sealant being inadvertently milked, cows are thoroughly marked with paint and the animal number recorded.

Generally one technician or farm staff member will undertake all of the processes associated with the drying off process in one cow. That is, they will identify and mark the animal, clean the teat appropriately, infuse the product, apply teat antiseptic and record the animal number. Systems where, for example, one person cleans the teats and another infuses introduces too much risk of poor hygiene or missing cows.

There are two strategies which are used for the teat antisepsis and infusion process. For primiparous animals that may be fidgety and have a high likelihood of contaminating a teat end once cleaned, each individual teat is cleaned then infused individually. For cows which are generally quieter, all four teat ends may be cleaned (starting with the front teats) and then all four teat's are infused (starting with the rear teats).

The New Zealand practice is that quarters that appear non-functional ("light quarters") are not infused with an antimicrobial DCT at drying off. This is due to concerns that there is an increased risk of an inhibitory substance grade early in the subsequent lactation. Due to the seasonal nature of both dry off and calving, many cows in milk supply have only recently calved in spring and hence there is an increased risk of inhibitory substances.

Post dry off

Following drying off cows may remain on the farm upon which they were milked, or in some cases are transported to winter grazing. Current best practice is to visually assess cows' health on a daily basis on pasture, and to bring cows to handling facilities or milking parlor at approximately 2, 4 and 6 weeks following drying off. Cows with grossly evident signs of swelling of the mammary gland are palpated and if suspected of having clinical mastitis they are then stripped and treated with a lactating cow antimicrobial.

Post infusion clinical mastitis

Clinical mastitis is diagnosed sporadically following drying off. While this does occur following infusion of antibiotic DCT, it is more common in those animals infused with an ITS alone.

There are no robust incidence estimates of clinical mastitis post dry off under New Zealand conditions. Generally where antimicrobial DCT is used, the incidence of clinical mastitis over the dry period is less than 2%. Where internal teat sealants alone are used there have been sporadic reports of higher incidences of clinical mastitis and occasional mortalities. Investigation of such incidents generally finds a history of poor hygiene at infusion, commonly associated with a history of wet weather and muddy pastures or farm tracks. Environmental mastitis pathogens such as *Escherichia coli*, Klebsiella spp., Pseudomonas spp., or Streptococcus spp. are the common isolates from such cases. While herd owners commonly blame misclassification of cows when allocating cows to internal teat sealant treatment alone, studies where microbiology is available pre dry off and post calving indicate that clinical disease over the dry period, in those cows actually infected at drying off, is rare.

Conclusions

With increasing consumer and regulatory focus on good stewardship of antimicrobials, use of selective dry cow therapy is a logical step for dairy industries internationally. Research studies have demonstrated the efficacy of internal teat sealants alone. In practical terms, good hygiene is required where internal teat sealants alone are used, but with appropriate training of farm and technical staff this is achievable, even where large numbers of animals are being dried off in a relatively short period of time. Good training and planning is required to ensure successful application of internal teat sealants.

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Investigation of the Relationship between Bacteria Counts, Bedding Characteristics and Bedding Management Practices with Udder Health and Milk Quality on Dairy Farms: Preliminary Results

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Introduction

High levels of bacteria in bedding (bedding bacteria counts; BBC) are associated with increased bacteria loads on teat ends (4,5) and, in some reports, with an increased risk for environmental mastitis infections (1,3). However, relatively few studies have investigated the relationship between BBC and udder health (1,2,3,6), and science-based guidelines are lacking to interpret BBC culture results in different bedding materials. Therefore, the primary goal of our study is to conduct a multi-state, multi-herd cross-sectional observational study to describe the relationship between bedding bacteria counts and udder health and to identify goals (cut points) for interpreting BBC test results. A secondary objective is to identify bedding characteristics and bedding management strategies that are associated with lower BBC and improved udder health. In this abstract we will present preliminary results that describe bedding characteristics associated with total bacteria count (TBC) in new and used bedding samples collected from herds using new sand (NS), reclaimed sand (RS), manure solids (MS) or other organic bedding materials (OB).

Materials and Methods

One hundred-eighty-eight herds were enrolled from 17 dairy states with the assistance of herd veterinarians or mastitis researchers. New and used bedding samples, collected from the bedding storage area or from the back of stalls, respectively, where collection was made to obtain a representative sample. Both bedding and bulk tank milk samples were collected twice from each herd during summer and winter of 2016. A herd management questionnaire was used to collect information describing farm characteristics, facilities, bedding management practices, parlor routines and treatment protocols. Bedding samples were cultured to describe TBC, counts of coliform bacteria, non-coliform bacteria, *Klebsiella* spp., *Bacillus* spp., *Streptococcus* spp., and *Staphylococcus* spp. per cc of bedding material, as well as analyzed to measure pH, organic matter (OM, %) and dry matter (DM, %). Herd level DHIA test day data describing udder health measures (e.g. herd avg. SCC, percent of cows with Linear Score > 4.0) will be obtained from the DHIA record processing centers.

For the preliminary analysis, generalized mixed linear regression models were developed using SAS 9.4 (SAS Institute Inc., Cary, NC), both for new and used bedding samples, to evaluate if TBC (dependent variable) was associated with the bedding material type (NS, RS, MS, OB; explanatory variable). After adjusting for multiple contrasts, means were considered to differ when $P \leq 0.008$. Multivariable regression models were developed to evaluate the relationship between TBC and bedding characteristics, including age of bedding sample, pH, DM and OM. All models were controlled for season (summer/winter) and for repeated sampling by herd.

Results

The average herd size was 941 (35 to 9650) cows and average milk production per cow/year was 25,663 (15,715 to 34,500) lbs. Of the 188 herds enrolled, 26.2%, 17.4%, 22.4% and 34% of the herds used NS, RS, MS or OB, respectively. For new bedding samples collected from the bedding storage area, the mean (log10 cfu/ml ± standard error) total bacteria count in MS (5.84 ± 0.16) and RS (5.57 ± 0.18) was greater than for NS (3.20 ± 0.15) or OB (3.25 ± 0.13). In used bedding samples collected from the back of stalls or dry lot area, mean TBC were high for all bedding types, ranging from 6.56 to 6.81.

The results of the multivariable models indicate that bedding characteristics such as the pH, DM% and OM% were generally associated with TBC in the new bedding samples. Specifically, in new bedding samples, DM% had a negative association with TBC in 3 of the 4 bedding types (MS, NS, OB), and OM% had a positive association with TBC in 3 of the 4 bedding types evaluated (MS, RS, OB). In new MS the estimate (standard error) describing the association between BBC and either DM% or OM% was -0.01 (0.005) and 0.01 (0.006), respectively. In used bedding samples, DM% had a negative association with TBC in MS and NS, but had a positive association with TBC in OB. The estimate (standard error) describing the association between BBC and DM% was -0.01(0.003) and 0.07 (0.02) in MS and OB, respectively; pH and OM were not associated with TBC in used bedding.

Conclusions

Preliminary results indicate that TBC in bedding increase after being used in stalls, irrespective of bedding material type. In new bedding samples, a higher DM% was associated with reduced TBC, while higher OM% was generally associated with increased TBC in most bedding types. Relationships between BBC and udder health will be reported when data analysis is complete.

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Associations of the Milk Microbiota with Sampling Method and Bedding

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Introduction

Studies of the bovine milk microbiome have reported the presence of DNA sequences from previously uncultured bacteria in the healthy mammary gland but have used different methods of sample collection (Oikonomou et al., 2012; Kuehn et al., 2013). These studies have not reported the sampled cows' bedding type even though cows housed on different bedding types are exposed to different bacterial species (Rowbotham and Ruegg, 2016). The objective of this study was to determine if the milk microbiota was associated with method of sampling and bedding type.

Materials and Methods

This study was conducted at the Marshfield Agricultural Research Station according to University of Wisconsin-Madison Animal Care and Use Protocol A005753.

Enrolled Cows

The study herd is comprised of primiparous cows (n = 127) housed in a single freestall barn with 4 pens each containing a different type of bedding: manure solids, new sand, recycled sand, or mattresses with sawdust. Cows that were 14-270 days in milk with no history of clinical mastitis, all monthly somatic cell count (SCC) < 150,000 cells/mL and all 4 quarter SCC < 100,000 cells/mL on the day of sampling (n = 67) were eligible for inclusion in the study. Five eligible cows from each of the 4 pens were randomly selected for the study.

Milk Sample Collection

Three milk samples were aseptically collected from each enrolled cow. First, the udder was wiped with a dry cloth towel to remove gross contamination. Next, teats were dipped in 0.5% iodine predip. After 30 s, iodine was wiped off with another dry cloth towel. Teats were then scrubbed with gauze soaked in 70% isopropanol. The isopropanol was allowed to dry and approximately 10 mL milk from each quarter was collected into a sterile sample vial for a composite milk sample (n = 20). One randomly selected teat from each cow was then sampled twice more: once after a second isopropanol scrub (n = 20) and then with a needle inserted directly into the gland cistern for collection of milk into 2 vacuum blood collection tubes with no additive (n = 40; Hiitiö et al., 2016). All milk samples were cultured on trypticase soy agar with 5% sheep blood and on MacConkey agar for 48 h at 37°C.

Microbiota

A modified commercial DNA extraction kit was used to extract DNA from milk samples. Extracted DNA was subjected to 40 cycles of polymerase chain reaction (PCR) using primers for the V4 region of the 16S bacterial rRNA gene. Amplified DNA was then sequenced on an Illumina MiSeq and sequence data were analyzed in mothur.

Results and Conclusions

None of the quarter (n = 20) or cisternal (n = 40) samples had bacterial growth in culture. Four composite samples resulted in non-significant growth, 2 had growth of non-aureus *Staphylococcus* spp., and 1 had growth of *Corynebacterium* spp. Cisternal milk samples were the most likely to have successful PCR amplification ($P = 0.001$). Chao richness was greatest in composite samples ($P = 0.01$) at 636 while quarter and cisternal samples had similar richness of 347 and 356, respectively and did not differ by bedding. Shannon diversity did not differ by sample type or bedding and ranged from 3.88 (quarter) to 4.17 (composite). Canonical discriminant analysis of cisternal samples by bedding type revealed different bacterial community compositions despite the similar richness and diversity (Figure 1). In conclusion, cows' bedding should be a consideration in milk microbiota studies and further investigation is needed into the effects of sample collection method on the success of milk microbiota analysis.

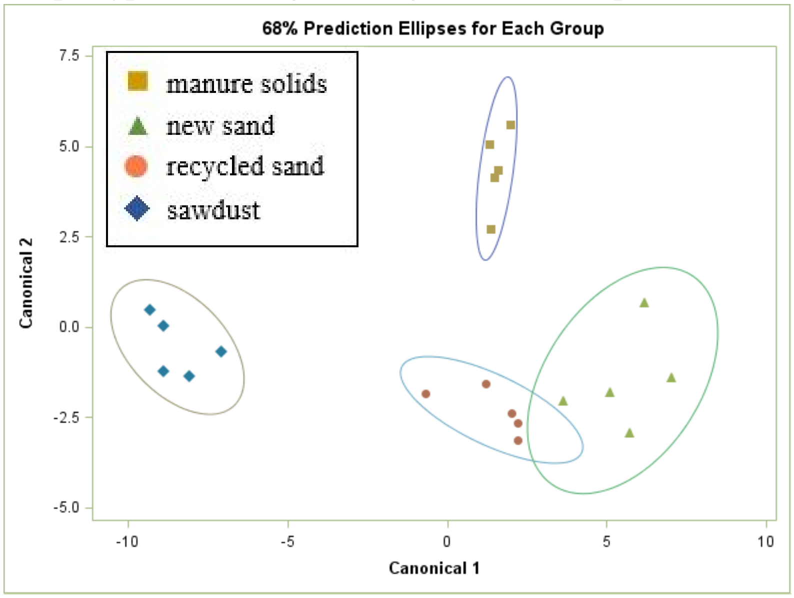

Figure 1. Canonical discriminant analysis of cisternal milk samples by bedding type (n = 5 per group) with 68% prediction ellipses.

Acknowledgements

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A New Method for Obtaining Biopsies from the Teat Canal of Dairy Cows

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Introduction

The teat canal is the cylindrical duct at the lower end of the teat, lined by a stratified cornified squamous epithelium. This cornified keratin lining is an important innate defence mechanism against mastitis, as it acts as a physical and chemical protective barrier. Its thickness and other characteristics of the teat canal have been related to the susceptibility of cows to mastitis (Hillerton and Lacy-Hulbert 1995; Davidov *et al.* 2011). A technique used to evaluate characteristics of the keratin layer was to extract loose desquamating keratin from the teat canal. However, as keratin is a layer of a cornified epithelium, the amount of desquamated keratin is unlikely to represent the total amount of keratin present in the canal. For histological examination of the teat canal, cows were sacrificed. New sampling techniques are needed to better understand the role of keratin in the teat canal in protecting cows' mammary glands from mastitis. The studies presented here aimed to develop a biopsy technique to obtain teat canal epithelium from live cows.

Materials and Methods

Study 1 Ex vivo: Seven udders obtained from recently slaughtered lactating dairy cows were suspended from a frame in a close-to-natural position. Each quarter was randomly assigned to one of five sampling techniques: a) cytobrush (Thermo Fisher Scientific NZ, North Shore City, New Zealand), b) Achieve biopsy needle (Care fusion, Vernon Hills, Illinois, USA), c) tumour extractor (Shoof International Ltd. Cambridge, New Zealand), d) curette (Kruuse, Langeskov, Denmark) and e) punch biopsy (Health link, Jacksonville, Florida, USA). Each udder had every quarter sampled using a different technique. Resulting tissue samples were prepared for histological observation using a Haematoxylin and Eosin stain.

Study 2 In Vivo: Based on results obtained in Study 1, two quarters per cow (n=9) were randomly assigned to either curette or tumour extractor sampling techniques. The remaining two quarters served as non-sampled control teats. On the day of sampling (day 0), cows were sedated and a tourniquet was placed at the base of the teat. Local anaesthetic solution (2% lidocaine) was infused through the streak canal and stripped from the cistern approximately 30 seconds later. Cows were not milked during the study. Anti-inflammatory (Metacam, Boehringer Ingelheim, Ingelheim, Germany) and antibiotic (Penethaject, Bayer Animal Health Ltd., Auckland, New Zealand) treatments were administered at recommended doses intramuscularly after sampling. Behavioural responses during and after sampling and inflammation scores of the healing process were analysed using least square means in R studio. On day 13 of the study, the cows were slaughtered at abattoirs and the udders retrieved for histological inspection of healing after sampling.

Results

Study 1: The techniques were scored according to their ease of use, amount of tissue retrieved and wound left in the teat. Results were analysed using the nlme function in R studio with score as the fixed effect and cow as random effect. There was no significant difference between the three highest scored techniques (Achieve biopsy needle, curette and tumour extractor). Sampling techniques were also classified as “Suitable” or “Non-suitable” according to the structure observed in the photomicrographs (Figure 1) and the repeatability of the technique. The results were as follows. Cytobrush biopsy technique (A): not suitable in any sample. Achieve biopsy needle (B): some histological cuts retrieved only muscular rather than epithelial tissue. Tumour extractor (C): appropriately sized, well-structured biopsy samples, but not repeatable. Curette (D): well preserved in structure and repeatable samples. Punch biopsy (E): some samples had muscular tissue with absent or low numbers of epithelial cells.

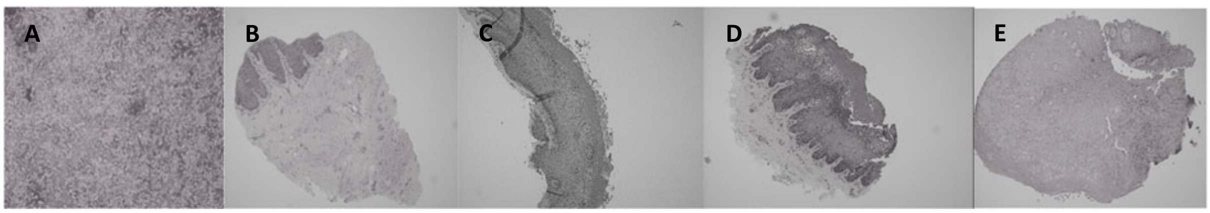

Figure 1. Photomicrographs of the histological sections obtained from the different biopsy instruments. A: Cytobrush (4x) B: Achieve biopsy needle (10x) C: Tumour extractor (10x) D: Curette (10x) E: Punch (10x).

Study 2: There was no statistical difference in the behavioural responses of the cows for the two techniques: tumour extractor and curette, or in the inflammation scores 13 days after sampling (Figure 2).

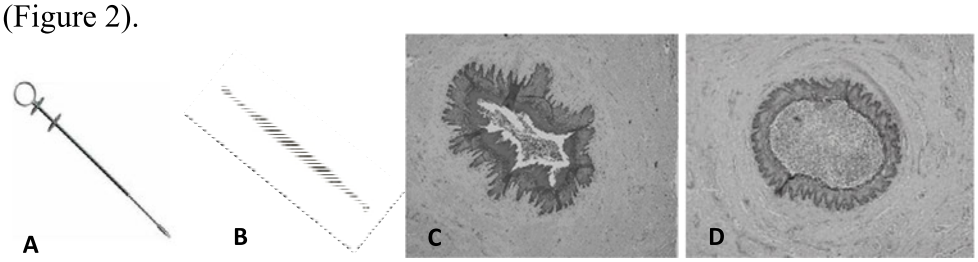

Figure 2. Tumour extractor (A), Curette (B) and the photomicrographs of the midsections of the teat canal sampled with the tumour extractor (C) and curette (D) 13 days after sampling.

Conclusion

A novel technique for obtaining epithelial samples from the teat canal has been developed. The favored technique is the curette, due to the repeatability, practicality, quality of the samples obtained and the low levels of disturbance of the cows during and after sampling.

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Validation of Prediction Algorithms for Early Detection of Clinical Mastitis caused by Gram-positive and Gram-negative Pathogens

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As precision technologies become more available on-farm, an opportunity exists for automated animal health monitoring and the early detection of diseases such as mastitis. Milk components remain relatively stable over time in healthy cows (Forsback et al. 2010), but changes in milk composition and cow activity have been reported prior to clinical mastitis (CM; Tholen, 2012). This time-series change in cow performance and behavior could help to not only identify mastitis but also give an indication of the pathogen type, which could assist with treatment decisions. This is especially important as the use of antimicrobials is coming under increased scrutiny. The objective of this study was to validate algorithms derived from milk and activity measures for the retrospective ability to identify CM caused by Gram-positive and Gram-negative pathogens.

Materials and Methods

Milk yield, electrical conductivity, somatic cell count (SCC) and milk composition (lactose, protein, and fat %) were collected using an in-line milk meter (AfiMilk MPC, Afimilk Ltd., Kibbutz Afikim, Israel) or analyzer (AfiLab) at Virginia Tech (VT) and University of Florida (UF) Dairy between March 2011 and March 2012. Activity measures included daily steps (UF; Afi Pedometer), and rest bouts, total resting time, and rest bout duration (VT; Afi PedometerPlus). A quarter milk sample was collected at CM detection for bacteriological analysis. Milk and activity data were extracted for the 14 d before and 14 d after CM (n = 166) and for control animals (n = 166) matched for breed, parity, and days in milk (DIM).

Algorithms were derived using change in each explanatory variable over a 7-d period. Slopes of the 10 explanatory variables of interest (milk yield, conductivity, SCC, lactose %, protein %, fat %, steps, rest time, rest duration, no. of rest bouts) were estimated using linear regression and were calculated between d 7 and 5, 4, 3, 2 or 1 before infection. All slope ranges were offered into the models for Gram-positive and Gram-negative infection, as well as breed, parity, body weight, and DIM. Backward stepwise elimination mixed effect regression was used to derive models. Infection was treated as a binomial response and farm was included as a random effect. Final models had variables remaining significant ($P < 0.05$) or tending to be significant ($P < 0.1$).

An independent dataset was created using data collected from VT dairy between August 2015 and April 2017 for external model evaluation. Milk and activity data were collected as described earlier, and were combined with cow data including parity, breed, DIM, body weight, and CM history (diagnosis date and bacteria isolated). Algorithms were evaluated by comparing observed infections with predicted infections and calculating sensitivity (Se) and specificity (Sp) for the original dataset (internal validation) and the independent dataset (external validation).

Results
The final model for Gram-negative CM included the change in activity (d -7 to -5), conductivity (d -7 to -4), fat % (d -7 to -2), lactose % (d -7 to -3 and -2), and milk yield (d -7 to -3 and -1; Table 1). Evaluation based on the derivation dataset yielded a Se of 81.8% and Sp of 73.7%. External evaluation indicated 18.1% Se and 66.8% Sp, using the optimal cutoff according to the original dataset. The final model for Gram-positive CM included parity, and change in activity (d -7 to -3), lactose % (d -7 to -1), milk yield (d -7 to -5 and -3), and SCC (d -7 to -1). The Se and Sp, based on internal validation, were 71.4% and 78.2%, respectively. Using the independent dataset, the Se and Sp estimates were 38.5% and 61.3%, respectively.

Table 1. Sensitivity (Se), specificity (Sp) and infection thresholds (CO) for the internal and external evaluation of algorithms flagging Gram-negative and Gram-positive clinical mastitis.

Bacteria type	**Internal evaluation**			**External evaluation**					
				Retrained Cutoff			**Original Cutoff**		
	Se	**Sp**	**CO**	**Se**	**Sp**	**CO**	**Se**	**Sp**	**CO**
Gram-negative	81.8%	73.7%	0.13	0%	96.7%	0.99	18.1%	66.8%	0.13
Gram-positive	71.4%	78.2%	0.13	38.5%	84.5%	0.28	38.5%	61.3%	0.13

Conclusions
Estimated Se and Sp were lower for external validation for both pathogen models. The distribution of the datasets were very different; the original dataset had a 50% CM incidence, 22% of which were Gram-negative and 21% were Gram-positive infections, whereas the test dataset consisted of more than 130,000 records, of which 0.5% related to Gram-negative cases and 1.2% Gram-positive cases. Retraining the threshold for flagging CM reduced Se of the Gram-negative model but improved Sp of both models. Data collected on farm provides a good resource for animal health monitoring; however, management tools constructed from this data need to be based on the distribution of infections seen in practice.

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