Control of Mastitis in the Dairy Herd by Hygiene and Management

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Abstract

An examination has been made of the value of hygiene systems in the control of mastitis and how this control can be improved by changes in hygiene and milking machines and by better use of therapy.

A comprehensive hygiene scheme for controlling mastitis has two objectives: prevention of intramammary infection during milking and prevention of infection between one milking and the next. Indirect evidence suggests that the latter objective is the more important. However, the complete prevention of the transfer of mastitis pathogens from cow to cow has not been found possible, even with a comprehensive hygiene system.

Nevertheless, hygiene systems designed to prevent the transfer of pathogens and more particularly to eliminate residual contamination at the completion of milking have been shown to reduce the number of new infections by about half. The combination of such hygiene systems with effective antibiotic therapy, which reduces the duration of infection, generally resulted in a decrease of more than 50% in the incidence of infection within a year.

It is probable that further reduction in the incidence of infection can be made by improving management techniques. But it is more likely that this will be achieved by improved methods of mechanical milking designed to prevent infection occurring during milking and by the use of better teat dips than by the development of more comprehensive hygiene systems.

It has been generally assumed after the classical studies of Minett, Stableforth, and Edwards (14) in building up herds free of Streptococcus agalactiae, that if hygienic methods are to reduce new udder infection they must prevent or largely prevent the transfer of the principal mastitis pathogens from cow to cow.

In England about 90% of new udder infections, including both clinical cases of mastitis and subclinical intramammary infections, are caused by streptococci and Staphylococcus aureus (Table 1), and 50% of the subclinical infections cause clinical symptoms within a year. Although information on the habitat of these organisms outside the udder of the dairy cow is incomplete, the major source of S. agalactiae and S. aureus in a dairy herd is infected milk (3, 7), and in the absence of an effective hygiene system they are transmitted during milking procedures to the teat skin of successive cows (25). Teat blemishes are also an important source of both streptococci and staphylococci and at any one time about 70% of teat blemishes are infected or contaminated with S. aureus.

Prevention of this spread of pathogens from cow to cow implies that the teats must be kept free of pathogens. To this end methods have been investigated including the use of disinfectants, paper towels, or boiled cloths for washing each individual udder, the wearing of rubber gloves by the milker, and the pasteurization of teat cup clusters before each cow is milked, together with post-milking disinfectant teat dips aimed at destroying any pathogens remaining on the teats after milking. A routine combining all these procedures is referred to as full hygiene (4, 9, 18).

It has been shown that useful hygiene studies can be made within cows using a half-udder milking machine (Table 2) and exposing...
TABLE 2. Effect on the new infection rate of exposing two teats of a cow to pathogens.  

<table>
<thead>
<tr>
<th>Infection characteristics</th>
<th>Teats on right side</th>
<th>Teats on left side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dipped in bacterial suspension</td>
<td>not dipped in bacterial suspension</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number</th>
<th>Cows infected</th>
<th>Quarters infected</th>
<th>Infections</th>
<th>Cases of clinical mastitis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td>12</td>
<td>17</td>
<td>18</td>
</tr>
</tbody>
</table>

Subclinical and clinical mastitis.  

The experimental comparison was made between quarters within cows using a half udder machine. Ten cows, initially free of udder and teat infection, were used for four months. Before milking, each udder was washed with sodium hypochlorite (1,000 ppm available chlorine), teat cups were pasteurized at 85°C for 5 sec, and two teats dipped in a mixed suspension of *S. aureus* and *S. agalactiae* in skim milk.  

Five quarters had two infections in the four months.  

See Report (26).

two teats of each cow to pathogens by dipping them before milking in a suspension of bacteria (26). This method was used to compare the value of chemical and heat disinfection of teat cups and of a post-milking disinfectant teat dip (Table 3) (27). Udder infection was prevented if teat cups were disinfected by heating, but when chemical disinfection was used, preceded by a water rinse, some infection occurred in the absence of a teat dip.  

The ineffectiveness of using a teat dip only (Table 3) was possibly due to the very high numbers of pathogens applied to the teats and the relatively low concentration of the teat dip used. Later experiments showed that when more concentrated teat dips are used on naturally contaminated teats, the teat dips alone are usually quite effective in keeping healthy teats free of pathogens between one milking and the next (32, 33).

These and other studies using both artificial and natural methods of exposure to the pathogens showed that even with full hygiene it was not possible entirely to prevent their spread from cow to cow. Nevertheless, the success obtained in preventing both staphylococcal and streptococcal mastitis suggested that even under practical conditions hygiene routines, particularly full hygiene, would significantly reduce the new infection rate.

**Field Trials**

To measure the effect of practical hygiene systems under commercial herd conditions it is important to be able to distinguish between the effect of hygiene and the effect of therapy. This distinction could not be made if subclinical mastitis were treated. Large-scale experiments are necessary because of the relatively low new infection rate and to measure the value of the methods under a variety of conditions.

In a field experiment lasting 12 months with 700 cows the results from farms using full hygiene were compared with those from control farms using no hygiene other than washing the udders with water and a common cloth. The condensed results for each of the 14 herds are shown in Fig. 1. In a further experiment lasting 18 months with a larger number of cows in 15 herds a third comparison, partial hygiene, was introduced which differed from full hygiene only in the omission of the pasteurization of teat cups (9, 18, 30, 31). All three experimental treatments were applied in successive periods in each herd using a Latin-
Fig. 1. Results of the first field experiment (MFE1) with seven herds on a full hygiene routine and seven control herds in which the only hygiene was washing the udders with water. For each herd is shown the total number of udder infections and S. aureus infections found at the start of the experiment, the number of new infections occurring in the next 12 months, and the number of infections found at the end of 12 months; all adjusted to a herd of 50 cows. See Table 4 and text for explanation. After Reports (28, 29, 30) and Dodd et al. (5).

Square design. The provisional results are shown in Fig. 2. In each column, in Fig. 1 and 2 the difference between the total infections and S. aureus infections comprises mainly streptococcal infections.

Both experiments showed that full hygiene resulted in a significant reduction in new udder infection (Table 4); 45% in the first and 58% in the second experiment when compared with the control herds practicing no hygiene. However, in the second experiment the partial hygiene in which there was no teat cup disinfection gave a 44% reduction in new infection. These results are unexpected. The latter large reduction (44%) in new infection was achieved without pasteurization of teat cups before milking each animal, but when this pasteurization was included the further reduction in the second experiment when compared with the control herds practicing no hygiene.

Table 4. The proportionate reductions in new infection rate with three hygiene systems.*

<table>
<thead>
<tr>
<th>Trial</th>
<th>Hygiene comparison</th>
<th>Decrease in new infections</th>
<th>Decrease in new S. aureus infections</th>
<th>Decrease in new streptococcal infections</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFE1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Full V. control</td>
<td>45&lt;sup&gt;d&lt;/sup&gt;</td>
<td>33&lt;sup&gt;d&lt;/sup&gt;</td>
<td>60&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>MFE2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Full V. control</td>
<td>58</td>
<td>62</td>
<td>70</td>
</tr>
<tr>
<td>MFE3&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Partial V. control</td>
<td>44</td>
<td>55</td>
<td>63</td>
</tr>
<tr>
<td>MFE4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Full V. partial</td>
<td>25</td>
<td>17</td>
<td>19</td>
</tr>
</tbody>
</table>

* Full hygiene: teat cups pasteurized, disinfectant with separate udder cloths or towels, and teat dip. Partial hygiene: teat cups not disinfected. Disinfectant with separate udder cloths or towels, and teat dip. Control: teat cups not disinfected, udders washed with water and common cloth, no teat dip.

<sup>b</sup> First field experiment, using 14 herds for 12 months (4, 29).
<sup>c</sup> Second field experiment, using 15 herds for 18 months (9, 18, 31).

<sup>d</sup> After adjustment for the mean number of infected quarters at the start.
Table 5. Frequency of recovering *Staphylococcus aureus* from teat swabs in the second field experiment (MFE)*a, b*

<table>
<thead>
<tr>
<th>Type of hygiene</th>
<th>Reduction from Teat</th>
<th>Reduction from Teat</th>
<th>Reduction from Teat</th>
<th>Reduction from Teat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Partial</td>
<td>Full</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(% )</td>
<td>(%)</td>
<td>(%)</td>
<td>(%)</td>
</tr>
<tr>
<td>Control</td>
<td>37 61</td>
<td>84 85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Partial</td>
<td>17 18 70</td>
<td>63 42 51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full</td>
<td>5 6 90</td>
<td>25 24 72</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

See Report (31) for more detail.

* Seven hundred and fifty swabs were taken from mastitis-free udders (before milking, after washing udders lightly with a boiled cloth and water containing 100 ppm available iodine) at intervals throughout the six-month periods that each of the 15 farms practiced no hygiene, partial hygiene, and full hygiene.

* See Table 4 for explanation.

(25%) was not sufficiently large to be statistically significant in an experiment of this size.

Results of the swabs of teat lesions and teat apexes were better for the full hygiene than for the partial hygiene [Table 5; (31)], but the improvement, due to pasteurization of teat cup clusters, is relatively small and apparently not sufficient to give a significant reduction in new infection.

It is concluded from these results that the main reason for the failure to obtain a better control of new infection was the inability to keep teats free of the common pathogens all the time.

**Weaknesses in the Full Hygiene Routine**

In a cow already infected in one or more quarters or having infected teat lesions, the routine does not prevent the transfer of bacteria from one teat to another of the cow during milking. This could be prevented only by using an individual quarter milking machine.

Even when an udder is washed with a sterile cloth wet with disinfectant, pathogens are distributed over the surface of the udder and teats from infected teat lesions or orifices or from infected milk. Omitting udder washing would prevent this, but there would still be some transfer of bacteria by tail and leg movement and by flies.

Even after pasteurization of teat cups with hot water at 55°C circulated for 5 to 7 sec

*S. aureus* can be recovered, although in only small numbers from about 5% of pasteurized teat cups. The treatment could be made more effective by addition of a disinfectant, improving the surfaces of the inflation (liner), and by prolonging duration of heat treatment.

Dipping hands in the disinfectant used for udder washing, before using the foremilk cup, before udder washing, and before machine stripping is not sufficient to prevent completely the transfer of pathogens from one udder to another. This applies even to gloved hands. Contamination from hands could be reduced by improving the disinfectant but more effectively by omitting the following procedures: use of the foremilk cup, udder washing (except when the teats are dirty), and handling the udder and teats when attaching the teat cups to the teats and when machine stripping. However, because the use of the foremilk cup and palpation of the udder while machine stripping are the main methods the farmer has of detecting clinical mastitis, substitutes for these techniques would have to be used, such as in-line strainers or other indirect tests for abnormal milk.

Teat dips used in the first two field trials were not completely effective in preventing or removing infection of teat lesions and teat canals (30, 31). The sodium hypochlorite (4%) now being used as a teat dip appears to be more efficient in this respect, but even though it persists on the teat from one milking to the next it can destroy only light contamination from milk, dung, or mud acquired after milking.

From these observations and subsequent tests it seems that with full hygiene, cross contamination from one cow to another during the milking routine was mainly from incompletely disinfected hands, because disinfection of teat cups was relatively much more efficient and separate towels were used for udder washing, while contamination within cows was mainly from hands, paper towels, and teat cups. Contamination from other sources than infected milk and teat lesions, while known to occur, is considered to be of secondary importance, if there are still infected cows in the herd. This is true for *S. agalactiae* (7, 25) and *S. aureus* (3), but may be less true for *Streptococcus uberis*, because this organism is apparently more widely distributed on the exterior of the cow (1). This distribution of *S. uberis* probably explains why the full hygiene routine gave less control of infection with this organism compared with *S. agalactiae* and *Streptococcus dysgalactiae* (Table 6) and why new infec-
TABLE 6. Total clinical mastitis and new udder infections in lactating cows in 15 herds during six-month periods when no hygiene was used (control), when partial hygiene was used, and when full hygiene was used.²

<table>
<thead>
<tr>
<th>Type of hygiene</th>
<th>Number cows examined</th>
<th>Number clinical cases</th>
<th>New infections (total)²</th>
<th>Types of new infection Numbers infected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>104</td>
<td>476</td>
<td>830</td>
<td>S. aureus 404 104 139</td>
</tr>
<tr>
<td>Partial</td>
<td>123</td>
<td>335</td>
<td>450</td>
<td>Streptococcus: 322 123 95</td>
</tr>
<tr>
<td>Full</td>
<td>14</td>
<td>276</td>
<td>324</td>
<td>agalactiae 17 14 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>dysgalactiae 205 46 24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>iberis 110 63 69</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Other organisms 28 36 31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>clinical mastitis, no pathogens found² 66 104 59</td>
</tr>
</tbody>
</table>

²From Report (31) and Neave et al. (18). ¹Includes also clinical mastitis in which no pathogens were found. ²Includes a few other aesculin-splitting streptococci. ³Clear clinical symptoms of mastitis, but either no organisms found, a very mixed flora, micrococci only, or Corynebacterium bovis. ⁴Sixty-two of these cases occurred in only two of the 15 herds.

Infection During Milking and in the Intervals Between Milking

Strictly speaking, infection of the udder is recognized only after multiplication of the organism in the gland, with the consequential changes in the secretion. However, this is preceded several hours or days (20) by penetration of the streak canal and entry into the teat cistern, which may occur as a single step, in stages, or by continuous growth of the organism through the canal. In the following discussion this sequence is implied when referring to the start or initiation of infection.

Infection can start either during the short time that the teat cups are on the cow or during the much longer intervals between milkings. The need for and the effect of the new infection rate of each part of a hygiene system will depend on the relative frequencies of infection during these two periods, but this has not yet been satisfactorily determined.

Direct evidence of the passage of bacteria with S. iberis in the dry cows are relatively common.

TABLE 7. New infections in milked and unmilked udders exposed equally to infection. Comparison made between cows and between quarters within cows.

<table>
<thead>
<tr>
<th>Time of infection</th>
<th>Unmilked Cows (%)</th>
<th>Quarters (%)</th>
<th>Milked Cows (%)</th>
<th>Quarters (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within one week</td>
<td>13/16</td>
<td>19/37</td>
<td>51</td>
<td>1/22² 5</td>
</tr>
<tr>
<td>Within two weeks</td>
<td>15/16</td>
<td>25/37</td>
<td>68</td>
<td>1/22 5</td>
</tr>
</tbody>
</table>

²Uncertain if infection occurred within one or two weeks.

After Neave et al. (19) and unpublished data from Thomas and Higgs (41).

through the streak canal during milking has been provided experimentally by McEwen and Samuel (13). Thiel's (10) results with endotoxin provide supporting evidence, but both experiments were made under somewhat abnormal conditions. Indirect supporting evidence comes from the experiments relating milking machine conditions and infection. Provided the change in milking machine properties that brings about an increase in new infection does not increase the exposure to bacteria, as would occur indirectly with an increase in orifice erosion, then it appears reasonable to assume that the infections originate with bacteria which penetrate, at least partially, through the streak canal during milking.

TABLE 8. New streptococcal infection when milk ing with and without post-milking teat dip.² ³ ⁴

<table>
<thead>
<tr>
<th>With teat dip²</th>
<th>No teat dip³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Cows infected</td>
<td>2  13</td>
</tr>
<tr>
<td>Quarters infected</td>
<td>3  21</td>
</tr>
<tr>
<td>Infections</td>
<td>3  22²</td>
</tr>
<tr>
<td>Clinical mastitis cases</td>
<td>3  22</td>
</tr>
</tbody>
</table>

²S. agalactiae and S. dysgalactiae. ³Two of 119 swabs of teat apexes yielded streptococci 10 min after the teat dip was used. ⁴All teat apex swabs were positive when taken 10 min after milking. ²One quarter had two infections in nine weeks.
Evidence has been provided by Nyhan and Cowhig (22), Nyhan (21), Wilson (44), and Klastrup (10). Nyhan (21) and Wilson (45), in particular, demonstrated more than twofold increases in new infection by changing the physical properties of the milking machine. The principles involved have not been established, but the least amount of new infection is apparently associated with a relatively large vacuum reserve and air bleeds in the claw-piece, i.e., factors likely to reduce both wet milking, irregular and cyclic vacuum fluctuation.

There is no conclusive direct evidence that infection can start during the intervals between milking, but the new infection rate can be high during the dry period, when milking is completely suspended (17). When a direct comparison is made between milked and unmilked quarters of the same cow which have been equally exposed to bacteria, the new infection rate is at least ten times greater in the unmilked quarters, as shown in Table 7 (19, 41). That infection can occur frequently in the absence of milking implies that infection may often be initiated during intervals between milkings, even though these are of relatively short duration. The evidence that infections do originate during these intervals is provided indirectly by the value of a post-milking teat dip in decreasing the rate of infection.

A within cow comparison (26) showed that a post-milking teat dip reduced new streptococcal infections sevenfold (Table 8). In this experiment, when a teat dip was used, little infection could have occurred during the time the milking machine was on the udder. The three new infections may not have resulted from pathogens entering the teat canal during milking, as the teat dip was not completely efficient. In quarters not receiving a teat dip, 22 new infections occurred.

The main purpose of a teat dip is to destroy contaminating pathogens at the teat apex and thus prevent infection of the teat canal. It is known that teat canal infections can persist for long periods without giving rise to intramammary infection and in such cases the multiplication of the organism is confined to the external opening of the canal. This is assumed because the infection can be removed by efficient teat dips. In the case of quarters with infected teat canals, the canal infections are probably the chief source of pathogens to which the quarter is exposed. This exposure occurs both during and between milkings and, therefore, a teat dip lowers the possibility of contracting intramammary infection both during and between milkings. Therefore, it cannot be assumed that the effect of a teat dip is to reduce new infections occurring only in the intervals between milking. Further experimentation is necessary to establish when infection is most often initiated.

Results of the field experiments provide information concerning infection during and between milkings. In the second field trial (Table 4) pasteurization of clusters, which prevents the major transfer of pathogens from cow to cow during milking, did not have a significantly better effect on the new infection rate when a teat dip was used. Therefore, it seems logical to believe that other less effective methods, common to both full and partial hygiene, of preventing transfer of pathogens, i.e., paper towels, disinfectant wash, and hand

### Table 9. Total new infections and possible cross infections occurring in 12 months (1962-63) in cows in the first field experiment (MFE).\(^{a, b, c}\)

<table>
<thead>
<tr>
<th>Hygiene</th>
<th>Type of infection</th>
<th>Cows Infected at start (^d)</th>
<th>Infections at start (^d)</th>
<th>Total new infections</th>
<th>Clinical cases</th>
<th>Possible cross infections</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(% )</td>
<td>(no.)</td>
<td>(no.)</td>
<td>(no.)</td>
<td>(% )</td>
</tr>
<tr>
<td>Full</td>
<td>All</td>
<td>65</td>
<td>419</td>
<td>363</td>
<td>182</td>
<td>50</td>
</tr>
<tr>
<td>Control</td>
<td>All</td>
<td>60</td>
<td>340</td>
<td>630</td>
<td>309</td>
<td>49</td>
</tr>
<tr>
<td>Full</td>
<td>S. aureus</td>
<td>57</td>
<td>286</td>
<td>189</td>
<td>68</td>
<td>36</td>
</tr>
<tr>
<td>Control</td>
<td>S. aureus</td>
<td>45</td>
<td>201</td>
<td>255</td>
<td>104</td>
<td>41</td>
</tr>
<tr>
<td>Full</td>
<td>Streptococci</td>
<td>17</td>
<td>130</td>
<td>115</td>
<td>63</td>
<td>55</td>
</tr>
<tr>
<td>Control</td>
<td>Streptococci</td>
<td>20</td>
<td>134</td>
<td>310</td>
<td>155</td>
<td>50</td>
</tr>
</tbody>
</table>

See Report (29) for more detail.

\(^{a}\) See footnote to Table 4.

\(^{b}\) Three hundred and seventy cows in seven herds on full hygiene, and 351 cows in seven control herds.

\(^{c}\) See Table 4.

\(^{d}\) Less than 2% of cows infected with organisms other than staphylococci and streptococci.

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disinfection, had an even smaller effect on the new infection rate. Thus, the prevention of infection by both hygiene routines appears to have been due mainly to the post-milking teat dip. For the reasons described above, this prevention of new infection may have occurred both during and between milkings.

If full hygiene, which includes efficient pasteurization of teat cups, was fully effective, infection during milking could in general arise only from pathogens transferred from one quarter to another within the same cow. In the field experiments we have no means of knowing how much infection occurred in this way, because hand disinfection and teat disinfection (by teat dip) were not absolute. However, if with full hygiene we assume that a new infection, in a cow already infected in another quarter with the same type and strain of organism, occurred during milking—a large assumption—then still only 40% of all new lactation infection was in this category, though, as expected, the proportion was higher than in the control herds (Table 9). Thus, in the first field experiment most new infection, even in the hygiene herds, apparently took place through organisms carried from one cow to the next.

From these results it would appear that further improvement in the reduction of new infection by hygiene is likely to come from the development of better teat dips or other methods of eliminating skin contamination at the end of milking. It would be possible to further reduce contamination from hands, or gloved hands by the methods already described. However, with our present state of knowledge it is questionable if much benefit would accrue unless pasteurization of teat cups is practiced also. This is unlikely to be a generally accepted practice, but could be used in large herds where more complex and expensive milking equipment would be acceptable because of its intensive use.

Variation Between Herds in Response to Hygiene

In the field experiments there were extreme variations in the new infection rates between one herd and another, whether or not hygiene routines were being used (Fig. 1 and 2).

In Fig. 1, Herd 3 is seen to have a low new infection rate and Herds 2 and 12 a high rate. Table 10 shows that Herd 2 had a new infection rate over seven times greater than Herd 3. The difference in the new infection rate in these herds could be due to difference in strains of pathogens, though we believe this is unlikely because, as Table 10 shows, there was in Herd 2 both a high S. aureus and a high streptococ-
Fig. 4. Herd no. 3. Chapped teats and new udder infection. The number of chapped teats was recorded each four months and the number of new infections determined for each period of four months. ○, Total infections at start. ●, Streptococcal infections at start.

eval new infection rate. This was true also for Herd 12 (Fig. 1). It seems more likely that the very high new infection rates in Herds 2 and 12 were due to environment or management factors specific to the herds and that these are probably milking machine differences.

Detailed milking machine measurements were made in most of the herds used for these experiments and wide differences were found in the vacuum reserve, air bleed, pulsation characteristic, milk lift, and inflation design. There was, however, no clear correlation between any of these factors and new infection rate, though Herds 2 and 12 had a high milk lift, back ropes were used to hold the teat cups, and air bleeds in the claw were usually blocked. Further examination of Herds 2 and 3 showed that Herd 3 had a much greater vacuum reserve and air bleed than Herd 2 and wet milking (flooding of the teat cup with milk during the main part of milking) was infrequent, whereas this occurred frequently in Herd 2.

Effect of Teat Lesions on New Infection Rates

The frequency of occurrence of chaps on the teat skin and of other teat blemishes may influence the new infection rate. In herds practicing full hygiene a significant relationship has been found between the new infection rate and the number of cows with teat lesions of all types. For example, within Herds 2 and 3 the new infections found per cow in each four months of the year are apparently related to the percentage of chapped teats determined at the same intervals (Fig. 3 and 4). However, when the same two herds are compared it is evident that while Herd 2 had the lower incidence of chapped teats it had a very much higher new infection rate than Herd 3. Presumably, in Herd 2 a much more important factor than teat lesions was operating to increase the rate of new infection. This high infection rate applied to both streptococci and staphylococci and for this reason the cause seems less likely to be due to strain of organisms than to machine characteristics.

Teat chaps and sores, however, are still considered to be one reason more than a 50-60% reduction in the total new infection was not achieved in the field experiments. Table 5
shows that although the proportion of *S. aureus*-contaminated teats was considerably reduced by hygiene, the reduction was much less on teats with chaps and sores.

**Lowering the Incidence of Infection in a Herd**

Hygiene does not, of course, remove existing mastitis from a herd; this is usually present in about 50% of cows (Table 9). To do this, it is necessary to use adequate therapy on all cows with mastitis or on all cows in the herd. The latter has the advantage that it requires no laboratory facilities, but it is expensive if applied during lactation because large amounts of milk must be discarded.

Treatment of mastitis by therapy is part of herd management and also a hygiene procedure in the sense that if successful it reduces the pathogenic flora in a herd or in some cases, as is well known (12, 34, 39), will remove from the herd the main source of a pathogen, i.e., the infected udder. When this occurs the immediate effect is greater than that of any hygiene routine at milking time. However, without adequate hygiene, a single course of therapy given to all infected cows has in our experience been useful only in herds with a low initial incidence of *S. aureus* infection, because of the relatively poor response to therapy of this type of mastitis. Even with few staphylococcal infections, herds have returned to their original state within about two years.

Duration of the effect of a single course of penicillin infused into all infected quarters of a 29-cow herd is shown in Fig. 5. The herd, milked by hand, appeared to reach the original level of infection in about 16 months.

When more than half the cows in a herd are infected, a 50% reduction in the new infection rate by hygiene will lower the level of infection in a herd very slowly. The reasons for this have been fully discussed elsewhere (5). The most economical and effective way of lowering the incidence is by dry period therapy applied to all animals at the end of lactation (8, 11, 36, 38).

**Effect of Hygiene in the Dry Period**

There is evidence that dipping teats in 5% tincture of iodine after the last milking in

<table>
<thead>
<tr>
<th>Time and method of contaminating tip of teat that could give rise to intramammary infection both during and between milkings</th>
<th>Using a post-milking teat dip</th>
<th>Degree of protection against infection</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Just before milking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From use of strip cup and from udder washing, etc.</td>
<td>Degree of protection against infection</td>
<td>During milking</td>
<td>Between milkings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>During milking</td>
<td>None</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>From contaminated teat cup, and from the milk of adjoining infected quarters and from infected teat lesions</td>
<td>Partial</td>
<td>Partial</td>
<td></td>
</tr>
<tr>
<td>Between milkings</td>
<td>From adjoining infected quarters and teat lesions, by direct contact when animal walking, lying down, moving leg or tail. From bedding, flies, etc.</td>
<td>Continuous exposure of quarter with infected teat canal</td>
<td>From pathogens derived from any one of the above sources Good</td>
</tr>
</tbody>
</table>

* These procedures would probably give little benefit unless teat cups were free of contamination.

* The maximum effect of a teat dip occurs when the lesion is freed from infection by the dip.
lacation can reduce new infection in the early part of the dry period (23). However, it has been shown (24) that infusion of an antibiotic at this time is much more effective in this respect and can protect the udder from infection over a long period (37). Nevertheless it is advisable to use a teat dip after the final milking of lactation because there is then less chance of infection if the antibiotic persists for only a few days.

Further Progress in Control of Mastitis

As previously discussed, significant reduction in new infection of the udder can be achieved by hygiene alone. Further improvement of hygiene is possible, but no practical system is likely to keep all teats free of the common pathogens all the time. However, the results of the second field trial where partial hygiene reduced the total new infections by almost 45% and streptococcal infections by 60% suggest that full hygiene is not necessary for substantial control of new infection. Future work should be concerned with specific hygiene methods in relation to the time of occurrence of infection. The results (Fig. 2, Tables 3, 6, 8) indicate that an efficient post-milking teat dip is very important and Table 11 shows how, in a simplified form, a post-milking teat dip could prevent intramammary infection. It could also, of course, as stated earlier reduce the possibility of infection during milking, by reducing the number of infected teat canals and the number of pathogens that usually persist on the teats and in teat lesions from one milking to the next.

A good control of _S. agalactiae_ mastitis has been achieved in experimental herds by hygiene alone without a post-milking teat dip (2) and in one of two commercial herds by Wilson (43). However, although much more information is needed, the case for a teat dip is based on the observation of Monk (15), Udall and Johnson (42), Gould (6), and Murmane (16), and on the studies of Schmidt, Merrill and Guthrie (35), our second field trial (15, 30, 31), and Reports (28, 32, 33). (See also Tables 3, 6, and 8.)

There is no doubt that certain machine factors are responsible for an increase in new infection rates. If the main cause of the very marked differences in new infection rates between herds (that applied the hygiene routine correctly) was differences between machines and not strain of pathogen, then a considerable further reduction in the new infection rate should be possible by correcting faults in either machine design or machine operation or both.

The possibility of being able to prevent all or nearly all infection during machine milking and stripping would appear to be quite strong if previous experimental results (Table 8) are confirmed. Assuming this is possible, hygiene for the control of mastitis could be much simplified, reliance being placed mainly on the use of a post-milking teat dip, provided it was effective in destroying or preventing the multiplication of all pathogens on the tip of the teats between milking.

The field experiments were designed to determine if hygiene alone, without treatment of subclinical mastitis, could reduce significantly the new infection rate. Independent trials of dry period therapy made to reduce the incidence of infection in a herd in the most economical way were very promising (33, 36, 38).

To measure the effect of a combination of hygiene and dry period therapy, a third field experiment is in progress with about 2,000 cows in 31 herds (32, 33). Two different hygiene systems are being compared, neither including teat cup cluster pasteurization, and the reduction in the new infection rate in lactation depends mainly on preventing new infections by means of a post-milking teat dip aimed at preventing invasion of the teat canal.

The average reduction in the incidence of infection in the first 12 months was 50% in the 31 herds and further reductions have been shown in the subsequent six months (33). These results are encouraging, particularly as it is now clear that a marked reduction in the incidence of infection follows even moderate reductions in both the new infection rate and the duration of infections (5).

Conclusions

Simple hygiene routines with and without disinfection of teat cups before milking each animal can reduce new infection rates in commercial herds by about 45%. Disinfection of teat cups before milking each cow did not produce a significant improvement over no disinfection of teat cups. Because of this and other indirect evidence there is reason for believing that most infection occurs in the interval between milkings. If this is confirmed, hygiene can be further simplified.

The large variation between herds in their response to hygiene may in the main be caused by machine factors that result in an increase in infection during milking.

Since hygienic measures only influence the rate of new infection their effect on the incidence of infection is slow. Therapy alone is inadequate, in that any success is of a tem-
porary nature. For suitably quick and lasting results, therefore, hygiene and therapy must be combined.

It is considered that further reduction in new infection rates will come mainly from the reduction in the incidence of infection by therapy in both dry and lactating cows, by using improved teat dips aimed mainly at preventing all teat canal infection and the development of milking machines designed to prevent infection during milking. Improvements in control measures should come also from better control of teat lesions, more information on the habitat of *S. dysgalactiae*, and a better understanding of the reasons for the apparent association of *S. aureus* mastitis with machine milking.

Acknowledgments

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References