Mastitis is the most costly disease in dairy herds when adequate control procedures are not used. A single quarter infected for one lactation may reduce milk production of that cow 10 to 12% in that lactation (25). Additional costs of discarded milk, antibiotics, and culling increase the cost in an average herd to the dollar equivalent of approximately 700 kg of milk per cow per year (23). A nationwide survey of researchers in 1976 suggested annual losses in the United States of approximately 1.3 billion dollars (1). An exact estimate is difficult because data are unavailable to indicate the actual degree of infection in our dairy herds. However, any of the estimates on cost of the disease illustrate the need for continued work in controlling mastitis.

In the previous jubilee issue, mastitis was covered as a section under "other diseases" and the author, Pounden, devoted approximately one page to the subject to summarize the state of the art at that time (36). Major advances had been in identification of organisms through bacteriological procedures. The etiology of Streptococcus agalactiae was fairly well understood, and the new wonder drug, penicillin, was effective in eliminating the organism from herds. While improved sanitation and milking practices were being encouraged, control was being left to the use of antibiotics. Most recommendations on proper control procedures were based on observations, leading to a wide discrepancy in suggested approaches.

A more complete summary of the disease, published in the same volume of the Journal of Dairy Science, was entitled "Mastitis — The Struggle for Understanding" by James Murphy (21). He suggested that mastitis was the most costly dairy cattle disease, and although research had been conducted, sharp differences remained in interpretation of results. Therefore, Murphy outlined a series of what he considered fundamental points necessary for understanding the disease:

1. Organisms should be classified according to four general groups: Strep. agalactiae, other streptococci, staph mastitis, and bacillary mastitis. In addition, he suggested three degrees of severity — negative, mild clinical, and severe clinical — and that each organism type could be present in each of the three stages of severity.
2. One cannot distinguish the various organisms without laboratory testing.
3. The three clinical stages do not occur with the same frequency for each of the four groups of organisms.
4. Clinically, the severity of the disease varies from time to time and from herd to herd.
5. The different organisms have different shedding characteristics.
6. Strep. agalactiae is different from the other organisms in that its only habitat is the udder; all other organisms involved with mastitis exist in the environment.
7. Relatively few cows have clinical mastitis, but many cows are in the nonclinical state.

He narrowed his conclusions to the following:

The shifting between the clinical stages is the result of a battle going on between the infection in the udder and the cow. Thus, two things must be considered: the ability of the infecting bacteria to injure the udder and the udder's ability to withstand injury. Naturally, many things happen as a result of management and environment that might upset the balance between the infection and the cow. Treatment is known to be able to tip the balance in favor of the cow, even when the causative infection is not cured. Often deliberate changes in management and the environment aimed at mastitis control are followed by a reduction in the incidence of mild-clinical mastitis and
severe-clinical mastitis; the disease, reduced at least temporarily, to the non-clinical stage. So far, however, there is little or no evidence from controlled experiment to support or reject any of the dozen or more factors, and they must be considered on a trial-and-error basis.

Murphy also suggested three lines of action for control. First was to develop proper standardized laboratory procedures for culturing of milk samples. Second was the eradication of Strep. agalactiae, which he felt was the only scientifically based mastitis control action within reach at that time. Third, he suggested an increase in the field of research and concluded that even though little was known about non-Strep. agalactiae mastitis it was virtually certain that specific control measures could be devised for each species. Murphy emphasized the need to study all forms of mastitis by scientific methods, regardless of the costs and difficulties involved.

Neave, in 1959, wrote a comprehensive review of environmental factors affecting mastitis (26). Information available and reviewed in each of the three summaries was obtained primarily through field observations and short trials with small numbers of animals. Thus, many of the reports seemed to present conflicting evidence, and recommendations were based primarily on conjecture rather than scientific evidence.

A considerable amount of research since has been undertaken by a large group of conscientious scientists to answer some of the challenges presented by Pounden, Murphy, and Neave. The research has expanded our understanding of the disease and, in a few cases, exposed errors in the earlier thinking. Some of this work is outlined briefly here.

Identification of Irritation and Infection

Standardized bacteriological testing procedures were developed, and a bulletin describing the more common ones was published by the National Mastitis Council in 1969 (3). Several studies have described the etiology of some of the less common mastitis-causing organisms such as mycoplasma and coliform (2, 10, 11, 45).

Somatic cell counting and mastitis screening tests received extensive research attention in the late 1950's. The California Mastitis Test (CMT) was developed, and this was followed by several other chemical tests as described in a Health, Education, and Welfare (HEW) publication (14) and more recently in Standard Methods for the Examination of Dairy Products (41).

In the last 10 yr electronic counting procedures, with their increased speed and accuracy, gradually have been replacing the screening tests (11). In response to these developments, Dairy Herd Improvement laboratories began providing a cell counting service for dairymen on composite cow milk samples (43). This service has been of value in making dairymen aware of the mastitis problem in their herds.

In addition, bulk milk cell counts currently are being used to monitor herd mastitis. Herds with consistently high cell counts, which market their milk through an interstate milk shippers' rated milk plant, have their milk rejected. The high degree of unexplained daily variation and the small relationship between bulk cell count and percent quarters infected ($r = .50$) are of some concern; however, cell counts remain the most reliable monitoring procedure available today (44).

Natural Defense

Some natural defense mechanisms such as phagocytic activity of leukocytes and effects of lactoferrin on organism growth aid the animal in resisting infection (33, 37, 40). However, if these mechanisms are to be of value in reducing infection further, some means of enhancing their activities need to be identified.

Vaccination by various routes and different adjuvants are being studied. While some preliminary results are encouraging, no definitive field data are available (17, 18, 30).

Teat canal keratin contains bacteriostatic substances that provide assistance in repelling organisms; however, methods of increasing quantities or improving bacteriostatic activity have not been identified (20).

Mastitis Control Procedures

Prior to 1960 many trials tested the value of individual hygienic practices in reducing bacterial populations (8, 16). These practices included the use of sanitizers in wash water, individual towels, flushing of liners, and germicides on

Journal of Dairy Science Vol. 64, No. 6, 1981
teats. Each of these procedures reduced numbers of bacteria, but their effectiveness in reducing new mastitis infections remained unknown; therefore, their value in mastitis control only could be speculated.

The major breakthrough in mastitis control occurred when Neave, Dodd, and coworkers from the National Institute for Research in Dairying (NIRD) combined and tested the value of these hygiene practices in a series of well-controlled field studies (7). The first of these (MFE1 and MFE2) used commercial dairy herds to compare the effectiveness of various hygiene routines in reducing mastitis infection.

In MFE1, two hygiene levels were compared: 1) a complete hygiene system that consisted of wearing rubber gloves dipped in sanitizing solution before touching the next cow, pasteurizing teat cup clusters between cows, washing udders with single service towels dipped in sanitizer solution, and dipping teats in a germicidal solution after milking, and 2) a system of no hygiene. In MFE2, a third group of herds was added that used the complete hygiene system minus pasteurization of teat cups (partial hygiene) (27). These initial trials allowed for a complete study of the dynamics of the disease. As an example, they showed that in the absence of hygiene an average of two new infections occurred per cow per year and that with complete hygiene during lactation this could be reduced to one new infection per cow per year. However, even with the 50% reduction in the new infection rate, little progress was made in reducing the percentage of quarters infected. If all new infections had been prevented, infection in herds would decrease only by one-third in a year. Thus, while each of the hygiene procedures reduced the number of organisms, their combined value in controlling herd infection was limited. The results also demonstrated that while pasteurization of teat cups drastically could reduce organism transfer, it had minimal beneficial effect over teat dipping in reducing new infection.

Using data from those trials, Dodd summarized the dynamics of the disease in the following equations:

\[
\text{Average infection} = \frac{\text{Total cows infected in the period} \times \text{Duration of infection}}{1}
\]

\[
\text{Total cows infected in the period} = \text{Number infected at the start} + \text{Any cows becoming infected}
\]

The first equation demonstrates the following: if 50% of the cows are infected at some time for 50% of the period, then the average infection in the herd will be 25%. It then follows that decreasing either the duration or the rate of infection by 50% would result in a 50% decrease in percent cows infected in the herd. For maximum gain in mastitis control one must not only reduce the rate of new infection but also the duration of infection (7, 9).

The importance of the dry period with respect to both initiation and duration of new infection was demonstrated in an early study. New infections are frequent in the first 3 wk of the dry period with nearly as many new infections occurring during the dry period as during lactation (Figure 1). In a study concurrently with MFE2, cloxacillin carried by two different vehicles was infused at the time of drying off. A comparison at the next calving revealed that quarters treated with the antibiotic in a long-acting base had fewer persisting infections.
infections and developed fewer new infections than quarters treated with the antibiotic in a quick-release base.

A third field trial (MFE3) combined the effective hygiene practices of MFE2 with routine dry cow treatment in an attempt to couple decreased infection rate with reduced duration of infection (45). The 3-yr study was initiated on 32 commercial herds in England (NIRD) and 27 in New York (Cornell University) (23). The partial hygiene procedure (MFE2) was used in one-half of the herds with a 4% chlorine teat dip as the only hygiene practice in the remaining herds. In addition, all quarters of all cows were infused with antibiotics at the time of drying off. Infection was decreased an average of 75% in the herds in both countries, with all herds having a positive response. Infection in herds using teat dip as the only hygiene practice had as great a reduction as those in which dairymen used the partial hygiene routine. While more organisms apparently were transferred between cows where a teat-dip-only practice was used, the dip was effective in eliminating those organisms which were transferred.

Comparable field studies in Israel and Australia gave similar results (19, 46). These studies have formed the basis for the presently recommended mastitis control procedures of regular use of a teat dip combined with dry cow therapy (TDDCT).

Also included in MFE3 was a study of the effects of blitz therapy in reducing the rate and duration of new infection. Infections detected by bacteriological testing were treated (in a portion of the herds) after initial sampling. Herds in which blitz therapy was used had fewer cows infected soon after treatment and maintained that advantage for the first 80 wk of the study. Since infection in all herds was similar, at the end of the study the researchers concluded that this additional treatment was unwarranted.

Eight of the New York herds were continued on the TDDCT project for an additional 3 yr to monitor the long effects on infection and incidence of coliform mastitis (22). Quarters infected remained between 7 and 8%, and coliform infection (as measured by herd infection based on semiannual herd tests and rate of clinical mastitis associated with coliforms) remained constant. The routine use of antibiotics did not appear to favor development antibiotic-resistant organisms.

**Hygiene**

Coliform mastitis is affected least by teat dipping and dry cow therapy. Additional hygiene practices that reduce the degree of environmental contamination, especially that presented by the stall bedding material, often are recommended to reduce clinical outbreaks (2, 10, 11).

Many compounds have been tested as potential teat dips by laboratory tests and artificial challenge techniques. These procedures are useful in providing a quick, relatively inexpensive method of screening potential compounds (35) but are inappropriate for determining which products should be marketed.

**Milking Machine and Mastitis**

The early review by Neave revealed little research evidence regarding the relationship between the milking machine and mastitis (26). Since that time, numerous studies have concentrated on identifying the role of the milking machine in initiation of new infection. The combination of cyclic and irregular vacuum fluctuation has been associated with increased new infection rates (42). Milking equipment with frequent liner slip also has put quarters at a higher risk of infection than machines without liner slip (32). It has been hypothesized that these operating conditions may enhance the likelihood that liquid droplets containing bacteria will be impacted against the teat end, thereby increasing the risk of infection (42).

Reports on the effect of extending milking beyond the end of milk flow have given mixed results; however, if overmilking is deleterious to udder health, its effects are minimal (26). A companion review article by Thompson gives a more detailed discussion of the possible role of milking machine function and mastitis.

**Future Developments**

Major progress in the last 25 yr has been in development of a mastitis control system effective in virtually all herds. The combination of teat dipping, dry cow therapy, and proper milking machine function has reduced infection to less than 8% of quarters. This author's interpretation of the interaction between
occurrence of infection and the proposed control programs is illustrated in Figure 2. The infection process, illustrated in the middle of Figure 2, begins when an uninfected cow susceptible to mastitis encounters a bacterial challenge and becomes infected. This infection can be identified only through sampling and bacteriological analysis. Once infected, approximately 40% of quarters become clinical and require antibiotic therapy (4). A higher percentage of new infections associated with environmental organisms become clinical near the time of occurrence than those associated with Staphylococcus aureus and Strep. agalactiae. Factors influencing the presence of mastitis organisms on the teat and susceptibility to infection are shown at the top of the figure. Bacterial challenge depends upon both a source of organisms, such as an infected quarter or the environment, and a means of transmission. While trauma increases susceptibility to infection, other possible factors require further investigation.

As illustrated in Figure 2, present mastitis control programs function by reducing the rate of new infection through teat dipping and by shortening the duration of infection through culling and therapy, lactation and dry cow. If the natural defense mechanisms could be enhanced, they would aid significantly in control of the disease by decreasing susceptibility and increasing spontaneous recovery. The question remains: in which direction should research move to make the most beneficial advancements in mastitis control? In selecting a research approach, we must follow one of two paths. The first would be to work on improving components of the present system, the major

![Figure 2. The infection process: environmental and management interactions.](image-url)
limitation of which is lack of total control. It is likely, however, that such improvements only could reduce, not eliminate infection.

A second approach would be to use the present system to keep mastitis under control until a new system, such as the enhancement of natural resistance, which offers the possibility for total control, could be developed. Following this route eventually may lead to total control of the disease, but the cost of achieving the goal will be substantial and the risk of failure relatively high. If increasing natural resistance is to be of value either it must control organisms not presently controlled or it must replace the present TDDCT program. Investing large amounts of time and money to develop another technique approximately as effective against the same organisms as the present system must be questioned.

Let us consider these two broad general areas of research: 1) improving the present control system, and 2) decreasing susceptibility and increasing resistance. The present teat-dip-dry-cow-therapy program is effective through its reduction in rate of new infection and in shortening duration of infection.

The effect of rate and duration of new infection is illustrated in Figure 3 for four five-cow herds. Herds 1 and 2 have the same rate of new infection, but the duration in herd 1 is twice that of herd 2; this results in an infection in herd 1 that is twice as high. Herd 3 has a high infection rate, but the relatively short duration of infections results in an overall infection similar to that of herd 1 (with average rate of infection). Herd 4 has a low new infection rate but a long duration of infection.

While infection in herds 1 and 3 are the same, the dairyman’s analysis of the herd situations would be different. Since the number of cases of clinical mastitis is related to the new infection rate, herd 3 would be expected to have approximately twice as many clinical cases as does herd 1 in spite of a similar infection of mastitis.

These herds also would differ as to the method of control that would give the most rapid and noticeable effect on infection. Herds 2 and 3, with their higher infection rates, would derive the greatest benefit from a good hygiene program to reduce the number of bacteria at the teat end. The longer infections of herds 1 and 4 would respond more positively to an effective therapy program.

With this background, one can examine factors affecting rate and duration of infection to determine which of our present mastitis control systems offer the greatest potential for improvement.

**Decreasing Rate of Infection**

All hygienic procedures, including the use of teat dips, have an impact upon the rate of new infection by decreasing the bacterial challenge to the teats. In lactating dairy cows, pathogens may be transferred in varying amounts, and by several vectors including flies, suckling calves, common cloths used in washing udders, wash water, hands of the operator, milking machine, and direct contact with environmental sources (7) (Figure 2).

Two of the vectors easily can be eliminated from any management system — suckling calves and contaminated rags used for washing udders. Flies are suspected of carrying mastitis causing organisms, but this problem should be minimal if proper fly control measures are used. Direct contamination by wash water may be eliminated through addition of sanitizing solution; however, drying of the udder or washing only the teats is encouraged for maintenance of milk quality and for preventing the movement of...
contaminated water from the udder down into the teat cup cluster. Organisms entering the teat cup in such a manner then might be available for backjetting during milking machine malfunction. Such effects may be accentuated through the use of mechanical prewashers, and while there is no documented evidence for increased new infection associated with the prewashers, their potential negative effects must be considered. The hands of the operator are virtually impossible to sanitize. The wearing of rubber gloves dipped in a sanitizing solution greatly reduces the number of organisms transferred. However, field studies in England and at Cornell were unable to demonstrate any added beneficial effect on mastitis control. The milking unit may be involved in transfer of organisms from quarter to quarter or from cow to cow. Data from MFE2 revealed that approximately 40% of all new infections could have been cross infections. A cross infection occurs when an organism from an infected quarter is transferred to a noninfected quarter within the same cow. This transfer could be prevented effectively by eliminating the claw and extending the short milk hoses to the milk transfer line or bucket or, alternatively, by inserting one way valves into the short milk tube. These mechanical changes would be relatively inexpensive, and potential economic benefits are great. Workers at several locations are testing these techniques.

Teat cup transfer of organisms from cow to cow virtually can be eliminated with pasteurization of units between cows or by backflushing (7). Herds on the complete hygiene system (MFE2) that used the pasteurization unit had fewer new infections than those that used the partial hygiene system. Since pasteurization units were expensive to purchase and maintain, added benefits were not worth the added cost. Although backflushers and pasteurization units are effective in reducing the number of organisms transferred at milking, they do nothing to prevent those infections which occur between milkings or those that result from cross contamination (5, 7). In ordinary milking, the number of organisms in the cluster is related to the number of cows milked with the unit and the length of time the unit is contaminated with milk and kept at a temperature conducive to bacterial growth. Thus, backflushers are expected to be of little (not apparent to the dairyman) or no value in the small herd. However, there are potential benefits in large herds and in herds contaminated with organisms (i.e., Mycoplasma) that are spread by the milking unit. Well-controlled studies are needed to assess the relative merits.

Phillips suggested that presquirting of milk from each quarter before udder preparation caused a reduction in new infection. The action presumably removed organisms that had gained entrance to the teat sinus and that would be introduced into the udder sinus if the quarter were massaged first. This technique also might flush organisms from the streak canal (34). While the concept was intriguing, other research has not confirmed these results (28).

The application of an effective teat dip after milking will reduce the organism population on the teats to near zero. The rate of increase in number of organisms on the teat between milkings depends on the residual effect of the teat dip and the cleanliness of the environment with which the udder comes in contact. A possible means of enhancing the ability of existing teat dips to prevent infections would be to increase their residual effect. This work is likely to be counterproductive because of the concern for chemical residues entering the milk through absorption and improper udder washing. The concern for chemical residues may force the testing of lower concentrations in teat dips than are used; however, this is not expected to improve mastitis control per se. Thus, testing new germicidal compounds as possible teat dips offers little potential in mastitis control because the compounds currently available remove approximately 100% of teat end organisms and remain effective for a portion of the period between milkings.

Organism transferred by direct contact with environmental sources can be reduced by proper maintenance of stalls and yards, but there appears to be no practical means of eliminating this mode of transfer (2, 11). The use of clean fresh bedding material and semi-permanent smooth surfaces should reduce the degree of contamination and the potential risk of new infection. For coliform mastitis, the reduction in numbers of organisms is beneficial in curbing clinical outbreaks and is expected to reduce the risk of new infection. More information is needed to develop methods for
reducing the number of organisms which come in contact with the udder from environmental sources.

**Shortening Duration of Infection**

The difference between herds in percentage quarters infected is often from differences in duration of infection rather than differences in new infection rate (Figure 3) (7, 9). Duration of infection can be decreased through several means: spontaneous recovery, culling, lactation therapy, and dry cow therapy. In the Cornell field trial, 18% of infections which were present during a lactation and gone by the following dry period left via spontaneous recovery. Additional reports from controlled dry cow treatment studies have indicated that 10 to 30% of infected quarters spontaneously recover. A portion of the apparently spontaneous recoveries may be attributed to false positive samples on initial sampling and false negative samples at final sampling. However, this route of elimination is potentially an important one, and research directed at enhancing the animal's natural defenses is warranted.

Routine culling not only removes cows with a high percentage of days infected from the herd, but also brings into the herd replacement animals in first lactation that have a low percentage of infected quarters. While culling aids in reducing herd infection, increasing the culling rate as a means of reducing mastitis is not warranted economically (24).

Dry cow therapy is presently the most effective means for eliminating infections in a mastitis control program. Products on the market remove between 70 and 98% of infections, depending upon the formulation and the causative organism. Another value of dry cow therapy is derived from prevention of new infection. Products currently marketed are capable of reducing the new infection rate from approximately 14% to 7% of quarters. Persistence of antibiotics in the gland provides the protection against new infection (4).

Based on data from MFE3, the following projections can be made for a 100-cow herd. If the average infection over the entire lactation is 7% (of quarters), then infection at drying off will increase to approximately 13% of quarters (or a total of 52 infections). A good dry cow therapy product that is 90% effective will eliminate 47 of those 52 existing infections and also should prevent approximately 50% of the new infections that normally would occur (research has shown the new infection rate during the dry period is approximately 14% of quarters or 56 infections in a 100-cow herd).

Since treatment efficacy of products presently available is relatively high, the greatest potential gain could be derived from the development of products that would remain in the udder through the first few milkings of the next lactation and be more effective in preventing new infections. The antibiotic residue would be removed with the colostrum with little risk of contaminating the milk supply.

Although there is no indication of an increase in resistant organisms from routine dry cow therapy, the extensive use of antibiotics in disease prevention is of concern. The development of an effective internal or external teat sealant might provide an alternative to dry cow therapy in herds with few quarters infected. In the Cornell project, 7.1% of quarters were infected at the final herd survey after 3 yr on the program. In that year, 13% quarters were infected at drying off, and this was reduced by dry cow therapy to 5% at the subsequent calving. If dry cow therapy had been replaced with a teat sealant, 70 to 80% of the existing infections would have remained. In a 100-cow herd, this would mean 36 to 42 more quarters infected at the start of the next lactation even if the sealant were 100% effective. If drug resistance does not become a factor, the use of a teat sealant would be of little economic value unless a rapid inexpensive method of identifying infected quarters became available.

The use of selective dry cow therapy to reduce the quantity of antibiotics used has been tested in several studies. In any of the selective schemes some infected quarters are missed, and the rate of new infection is increased, thus reducing the overall effectiveness of the control program.

Lactation therapy often is looked upon unfavorably, not only because its effectiveness is inferior as compared to therapy in the dry period but also because of the economic losses associated with discarded milk. Treatment response of quarters with clinical mastitis is highly variable with the majority of studies reporting positive responses in the 40 to 70% range. The variability is caused by differences in...
susceptibility of various organisms to the drugs, duration of the infection before treatment, age of the animal, degree of tissue involvement, etc. The value of lactation therapy in mastitis control is limited further since only 40% of all new infections that become clinical are being identified and treated. New mastitis screening instruments, such as electronic cell counters and conductivity meters, allow for rapid identification of abnormal milk. These tests could be used to identify new infections before clinical signs appear; however, field studies are needed to determine if they provide sufficient accuracy for routine use.

Nonclinical infections have a higher rate of response to therapy than do clinical infections. Early identification of new infections would allow for early treatment and a more favorable response to antibiotics. This combination may allow the affected quarter to return to normal production in that lactation. An economic study is needed to determine if the costs of early diagnosis, treatment, and discarded milk would be offset by the increase in milk production in that lactation. This approach would be similar to the blitz therapy used by Dodd and Neave in MFE3 (7), which demonstrated an early biological benefit but was not tested economically. If economically feasible, treatment of subclinical mastitis provides the greatest potential for shortening the duration of infection. Table 1 gives the number of infections at various times during 3 yr (4).

Only 702 of the 1770 new infections appearing were clinically identified and treated. In a normal mastitis control program (with teat dipping and dry cow therapy) all remaining infections would remain until the dry period or would be eliminated by culling. The duration of these remaining 1068 infections could be shortened if a system for early detection of infection could be combined with effective lactation therapy. Since most new infections occur in early lactation, the effectiveness of lactation therapy potentially could exceed that of dry cow therapy.

**Decreasing Susceptibility**

This is the route to follow if one wishes to provide a complete or near complete control program and is willing to accept the risk of failure.

The goal of most disease control programs is to increase the number of resistant individuals in the population. This might be accomplished by inducing resistance or by selection of those naturally resistant. Genetic selection can be effective if resistance to the disease is highly heritable. A limiting factor in estimating the heritability of mastitis is lack of an acceptable definition of severity or degree of mastitis. Most studies estimate heritability of mastitis near .10 and find that mastitis is more commonly in high producing dairy cows. Selecting for mastitis resistance, then, would reduce substantially progress in selection for milk production; thus, it is accepted generally that selection should be based on milk production and that mastitis must be controlled by other means (39).

Stimulation of the immune response through vaccination should be the ultimate goal if complete control is considered essential. The large number of different organisms which cause mastitis makes preparation of an effective vaccine a challenging task. In the last decade, studies have provided evidence that the mammary gland can produce an immune response. However, no reliable field data are available to indicate that new infections can be prevented or severity of clinical mastitis reduced (18, 29). Future research is needed to identify the necessary antigens, adjuvants, and routes of administration which would make immunization a viable option in mastitis control. Since *S. aureus* and *Str. agalactiae* are controlled adequately by teat dipping and dry cow therapy, the greatest economic benefits would be obtained through development of vaccines effective against environmental organisms. Although progress in this area has been slow in the past, the recent development of rapid, sensitive tests for measuring immunoglobulins should facilitate the work.

The mammary gland is protected partially against infection by milk components such as leukocytes and lactoferrins (17, 33, 40). Research is underway to enhance the role of each in the prevention of infection.

Schalm demonstrated that quarters with high leukocyte concentrations have a greater resistance to bacterial challenge by *Aerobacter aerogenes* (38). With this in mind, researchers have been testing the ability of plastic coils (inserted into the mammary gland) to increase

Journal of Dairy Science Vol. 64, No. 6, 1981
leukocyte concentrations and thereby increasing resistance to infection (15). However, decreased infection rates remain to be demonstrated. The economic impact of this method of control must be considered since a strong negative relationship exists between milk leukocyte concentrations and milk production.

There are several management and environmental factors related to resistance to infection but usually not considered as control procedures. These include the prevention of teat injury, proper sanitary care of teat cannulae and treatment materials, and reduction of stress. These factors must not be overlooked if maximum benefit is to be gained from control procedures.

**State and National Mastitis Control Schemes**

Prior to 1955, several Northeastern states set up laboratories for bacteriological identification of infection. Veterinarians in charge of the laboratories supervised collection of milk samples and prescribed treatment. The primary emphasis of the program was one of eradication of Str. agalactiae based on its identification and treatment in individual cows. Gradually the emphasis has moved toward total control of all organisms on a herd basis. As we look toward the future, a state and national control program must be considered if we are to derive maximum benefits from our research. The program must be effective enough so that with an educational campaign it will create sufficient incentive for adoption by dairymen; mandatory programs have the wrong emphasis and will not work.

In designing an effective mastitis control program to be used nationally one should begin with the understanding that total eradication is not possible with present technology nor is it necessarily a desirable goal. Since mastitis poses little threat to public health, the selection of control procedures must be justified economically. Mastitis control should be optimized rather than maximized; thus, the availability of tools to reduce infection is not a sufficient reason for using them.

An effective mastitis control program to be recommended nationally should include the following design criteria: 1) the program should provide maximum dollar return to the dairyman; 2) the program must be aimed at all herds, rather than only those herds in which there is a higher incidence of infection. A 10% improvement in all herds (with an average of 25% quarters infected) is more economically significant than a 75% improvement in the worst 5% of herds (with an average of 50% quarters infected) and is cheaper and easier to achieve; 3) the control system must be effective against all pathogens — a system based on the eradication of only one organism cannot be justified economically (8). The TDDCT program, which resulted from MFE3, appears to best fit the design criteria. Although in that study samples were collected routinely for bacterial analysis, dairymen were not provided with the results, and treatment was never administered based on the results. Therefore, when other dairymen adopt TDDCT procedures, they can expect a similar reduction in infection, without the aid of bacteriological testing.

In addition to the primary mastitis control program, bacteriological testing and somatic cell counting also might be considered as supplementary programs. However, the dairyman must be aware that the information gained from these diagnostic measures will be useless unless action is taken based on the results; in addition, the action must be different from that which would have been taken without the results. Bacteriological testing is relatively expensive, and its routine use in mastitis control presently cannot be justified economically. For this reason, the use of bacteriological testing should be limited to increasing research information and working with refractory herds.

If research demonstrates that the cell count is sufficiently accurate in identifying new infections and that early treatment of these infections results in positive economic returns, cell counting could be valuable and might be developed into a supplementary program for mastitis control. Until that information is available, the main value of a cell counting program is in alerting dairymen of the mastitis situation in their herds.

Several computer models that simulate the mastitis infection process have been developed (31). These models are potentially powerful tools for identifying those changes in control procedures offering the greatest economic benefits. Once these changes have been identified, field studies should be performed to test their validity.

Journal of Dairy Science Vol. 64, No. 6, 1981
In summary, substantial progress has been made in mastitis control research during the past 25 yr. The results obtained from large, long-term, well-designed field studies provided the basis for these major advances. The resulting control procedures, which include teat dipping and dry cow therapy, are effective in reducing infection in herds to approximately 7% of quarters. There are two major means by which improvements in the present control program could be made: shortening the duration of infection and reducing the rate of new infection. Shortening the duration of infection could be accomplished through early treatment of new infections in lactation; however, the economic feasibility of that system has yet to be determined. Success is dependent upon an inexpensive, accurate method of early detection of infection. Electrical conductivity testing and somatic cell counting offer some possibilities for success in this area. Improvements in dry cow therapy to eliminate existing infection or culling appear to have little potential benefit, whereas increasing the spontaneous cure rate warrants further study. Reducing the new infection rate also must be considered in the overall picture of mastitis control. Areas warranting study include the use of back-flushing systems (especially for large herds) and redesign of milking equipment to prevent the transfer of organisms within the cluster during milking. Alterations in antibiotic formulations to increase persistence of the drugs throughout the dry period also should be considered.

Stimulation of the immune mechanisms is one alternative to the TDDCT approach and offers perhaps the greatest potential for total control of mastitis. However, progress will be slow, and the risk of failure is relatively high.

ACKNOWLEDGMENTS

The author wishes to acknowledge the efforts of Susan ter Meulen, Martha Doane, and Shelly Masso in the preparation of this manuscript.

REFERENCES


