Making Antibiotic Treatment Decisions for Clinical Mastitis

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KEYWORDS

• Mastitis • Antibiotics • Udder health • Treatment • Milk quality

KEY POINTS

- Mastitis is diagnosed based on detection of inflammation, but inflammation does not always indicate continued presence of active bacterial infection.
- Only about one-third of cases of nonsevere clinical mastitis occurring on many modern dairy farms will benefit from use of antibiotics.
- Antibiotic therapy is indicated when the spontaneous cure is significantly less than the expected treatment cure rate and the case is caused by a pathogen that is susceptible to approved intramammary antibiotics.
- The medical history of the cow should be assessed before giving antibiotics to determine if the cow is a good candidate for antibiotic therapy.
- It is not possible for farmers or veterinarians to determine the short-term efficacy of antibiotic treatments based on clinical outcomes.

INTRODUCTION

Mastitis is an infectious disease that is diagnosed based on observation of an inflammatory response that occurs after an intramammary infection (IMI). Most cases are caused by bacteria and vary in presentation depending on the characteristics of the pathogen and the ability of the cow to mount a rapid and effective immune response. When inflammation results in visible abnormalities of milk, the mammary gland, or the cow, the infection is usually considered to be a case of clinical mastitis (CM) and the abnormal milk must be discarded. On most farms, greater than 85% of cases of CM present with only mild (abnormal milk) or moderate (local signs, such as swollen udder) signs and are classified as nonsevere.[1] Although severe cases (with generalized signs, such as fever, anorexia, distress, and so forth) are medical emergencies and should immediately be treated using protocols developed with veterinary input, in North America most treatments of nonsevere CM are performed by farm workers without

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veterinary supervision. Nonsevere CM is a common disease, and treatment of this condition is the most common reason that antibiotics[a] are given to mature dairy cows.[2,3]

Use of antimicrobials to treat farm animals is increasingly scrutinized and must be justified as necessary to maintain animal well-being.[4] Appropriate use of antibiotics for the treatment of nonsevere CM is based on understanding the etiology, review of the cow's medical history and application of well-recognized therapeutic principles to select among approved antibiotics.[5,6] Increased involvement of veterinarians in development of mastitis treatment protocols is needed to ensure appropriate usage. On many farms, almost all mastitis is treated using antibiotics[1] but not all cases of nonsevere CM will benefit from antimicrobial therapy and protocols used to treat these cases should include alternatives strategies for managing those cases.[6] The purpose of this article is to review use of antimicrobials for treatment of nonsevere CM to help veterinarians develop protocols that ensure responsible usage.

HISTORICAL DEVELOPMENT OF TREATMENT PROTOCOLS

In 1947, Murphy[7] confirmed that mastitis was a result of invasion of an organism followed by establishment of IMI and development of inflammation. In those years, almost all bovine mastitis was caused by *Streptococcus agalactiae* and *Staphylococcus aureus* and most treatment protocols were originally developed to combat those pathogens. The high prevalence and desire to eradicate *S agalactiae* was a significant historical factor that established routine use of intramammary antibiotics for treatment of CM and for treatment of dry cows.[8] As these organisms were controlled in the 1980s, researchers recognized that CM caused by coliform bacteria was becoming more prevalent (even in herds with a low somatic cell count [SCC]) and recognized that many of these cases spontaneously resolved without use of antimicrobials.[9–12] The continued emphasis on treatment of pathogens that are no longer common on many dairy farms is apparent when reviewing label claims of intramammary antibiotics sold in the United States and Canada. Of intramammary antibiotics sold in these countries, efficacy against *S aureus* and *S agalactiae* is the primary efficacy claim for 7 of the 8 approved products. As causes of CM have changed it is imperative for veterinarians to reexamine recommendations for management of nonsevere CM. Continued use of treatment protocols that were developed in an era that had different distributions of pathogens is difficult to justify.

ETIOLOGY OF CLINICAL MASTITIS ON MODERN DAIRY FARMS

As dairy farms have enlarged and become more intensively managed, the distribution of pathogens recovered from cases of CM has become more diverse and on most farms is dominated by opportunistic environmental organisms (**Fig. 1**). Based on herd surveys conducted in many countries,[1,13–18] the most common outcome of culturing milk collected from cases of CM is usually no microbial growth (about 30%), followed by either coliforms (about 30% in intensively managed cows) or environmental streptococci (up to 45% in extensively managed cows in New Zealand). The proportion of cases caused by *S aureus* is highly variable, ranging from 3% in large

[a] The terms *antimicrobial* and *antibiotic* are used interchangeably in this article but are not synonymous. In technical terms, *antibiotics* refers only to substances of microbial origin (such as penicillin) that are active against other microbes, whereas *antimicrobial* refers to any substance (including synthetic compounds) that destroys microbes.

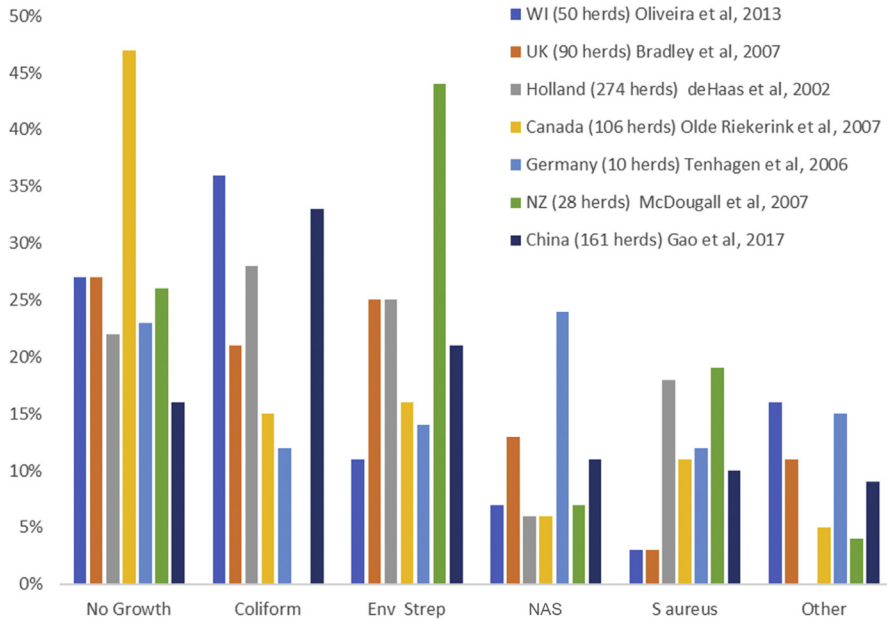

Fig. 1. Results of studies that describe the distribution of bacteria recovered from milk of cows with CM in modern-dairy herds in selected countries. NAS, non-aureus staphylcocci; Env Strep, environmental streptococci.

herds in Wisconsin[1] to 11% in a Canadian national survey[8,19] and 19% in New Zealand,[20] but is usually more prevalent in studies that include smaller herds, extensive management systems, or emerging dairy regions. Overall, about 5% and 7% of cases of CM were caused by other pathogens or the non-aureus staphylococci (NAS), respectively. When data from these studies (see **Fig. 1**) are combined, the weighted average distribution of causes for CM are no growth (26%), environmental streptococci (22%), coliform bacteria (26%), *S aureus* (12%), non-aureus staphylococci (NAS) (8%), and other pathogens (6%). Recognition of the diversity of agents and the proportion of culture-negative results is important to ensure responsible use of antibiotics. On individual farms, the cost-effectiveness of antimicrobial therapy for the treatment of nonsevere CM depends highly on the use of antimicrobials that effectively target predominant etiologic agents. The unnecesary cost of giving intramammary (IMM) antibiotics to patients that are not expected to benefit can be substantial (**Fig. 2**). The scenario in **Fig. 2** is based on nonspecific treatment of 400 patients with CM using a very-low-cost, short-duration treatment (2 tubes of intramammary antibiotics that cost $3.25 each). Of approximately $3000 in annual costs of product, less than $1000 can be expected to result in a bacteriologic cure in excess of an expected spontaneous cure and failure to cure (due to intrinsic resistance). Veterinarians are encouraged to work with dairy producers to increase the use of selective treatment protocols, as symptomatic treatment of nonsevere CM without knowledge of etiology results in overuse and economically nonsustainable use of antibiotics.

Over time, the number of milk samples collected from cases of CM that are culture negative has increased.[21] Reasons that milk samples from mastitis cases are culture negative varies based on etiology and case presentation. Cows with chronic

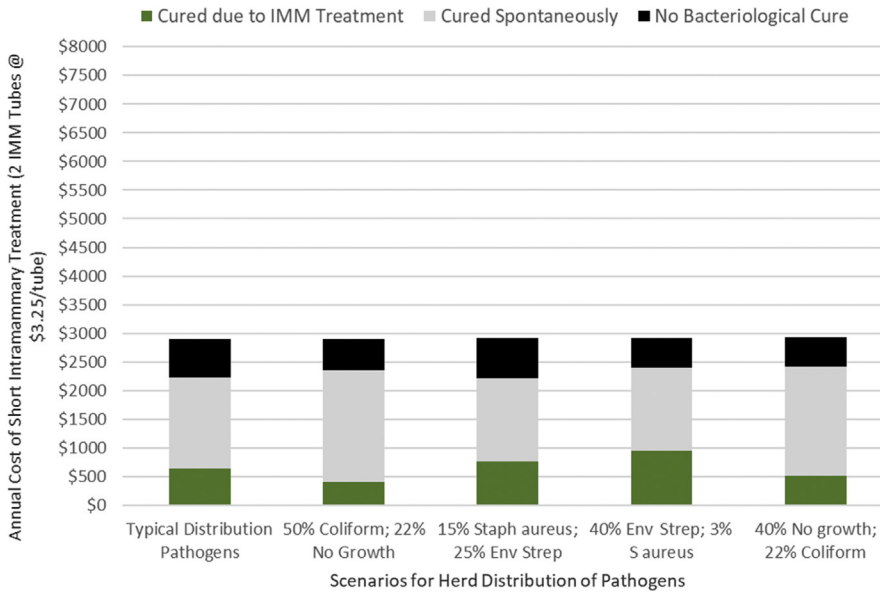

Fig. 2. Distribution of annual intramammary antibiotic costs for a herd treating 400 cases of CM per year using 2 intramammary antibiotic tubes at $3.25 per tube for all cases of CM, regardless of etiology. Env Strep, environmental streptococci.

subclinical mastitis (defined as normal-appearing milk but a long history of high SCC) have strong evidence of on-going failed inflammation that is, most likely the result of persistent IMI. These cases are often false negatives because the large inflammatory response has successfully reduced the number of organisms to less than the normal detection limit (about 100 colony-forming units per milliliter in most mastitis laboratories). Repeated culturing of quarter-milk samples may help arrive at a diagnosis for some of these cases. In contrast, many mild and moderate cases of CM are caused by opportunistic pathogens that have been successfully eliminated by a localized immune response before detection of inflammation. The clinical signs of abnormal milk are detected after the initial immune response, and about 75% to 85% of these cases may be spontaneously cured before detection. Unfortunately, the only way to determine if the clinical signs of nonsevere CM are accompanied by active infection (and thus will benefit from antimicrobial therapy) is to perform microbiological analysis. In some regions, increasingly diverse causes recovered from cases of CM have stimulated the use of selective treatment protocols that limit antibiotic usage to those caused by pathogens that require antimicrobial therapy to improve bacterial clearance.[22,23] Although these are good steps forward, additional cost-effective and easily implemented diagnostic tools are needed to further enhance implementation of these strategies.

ASSESSING PROGNOSIS

Mastitis is caused by a diverse group of bacteria that vary among farms and the probability of achieving a successful outcome is highly influenced by the characteristics of individual pathogens. Depending on virulence factors, organisms infect different sites within the mammary gland, have differing abilities to cause systemic signs, and vary in

expected duration of subclinical phases of infection and expectations for spontaneous bacteriologic cure. Estimates of bacteriologic cure after treatment of CM caused by gram-positive pathogens have ranged from 25% (*S aureus*) to about 65% to 70% (environmental streptococci species and NAS).[24] In contrast, bacteriologic cure of mastitis caused by *Escherichia coli* often exceed 75%.[25] On most farms, about 25% to 40% of clinical cases are microbiologically negative when detected; clinical outcomes of these cases are usually positive.[24,26]

On larger US farms, *E coli* is a common cause of mastitis; about two-thirds of cases caused by this organism present with symptoms that are localized to the udder.[1] The rate of spontaneous cure for these mild infections is quite high because the point of infection within the udder is generally superficial mucosal surfaces of the mammary gland cisterns and ducts. On other farms, mastitis is frequently caused by environmental streptococci species, and spontaneous bacteriologic cure rates of these organisms vary among species with some researchers reporting higher rates for *Streptococcus dysgalactiae* as compared with *Streptococcus uberis*.[27] Environmental streptococci species often respond well to intramammary (IMM) antimicrobial therapy but have a low spontaneous cure rate and high rate of recurrence when antimicrobials are not administered. Determination of the etiology of IMI through the use of rapid farm or veterinary clinic-based culturing programs can considerably reduce unnecessary antimicrobial usage while still resulting in satisfactory treatment outcomes.

ASSESSING OUTCOMES

Based on assessment of clinical signs, it is extremely difficult for farm workers or veterinary practitioners to determine if antimicrobial therapy has been effective. The inability of clinical signs to predict bacterial clearance was first noted in 1938 when a researcher administered massive doses of sulfanilamide but failed to achieve therapeutic concentrations in either blood or milk. The researcher noted that "treatment with sulfanilamide was successful in restoring normal flow and normal appearance of milk…but it did not eliminate the streptococci from the udder, nor prevent later acute attacks."[28] This comment is the first indication that clinical impressions are often misleading in determining the efficacy of antimicrobial compounds and also illustrate the difficulty of separating the occurrence of inflammation from active IMI.

Judgements about efficacy of mastitis treatments are generally based on perceptions of how the products performed in the past and are rarely based on objective evaluation of appropriate data.[29] Occurrence of abnormal milk is the most obvious sign of CM, and many farmers assess treatments based on the number of days that milk is discarded. However, this outcome has little variation[24] and is greatly influenced by factors other than treatment (especially etiology; FUENZALIDA ADSA 2017).[30] On some dairy farms, the duration of treatment or choice of drug is based on the appearance of abnormal milk. An abnormal appearance of milk is a nonspecific sign of inflammation that is not always associated with continued IMI and is not predictive of the etiology.

Most approved IMM drugs are active against organisms that are rapidly dividing, and there is no evidence that changing among drugs with similar spectrums of activity or extending duration based on continued appearance of abnormal milk will result in improved clinical or bacteriologic outcomes. Neither duration of treatment nor choice of drug should be based solely on appearance of milk or on indirect indicators, such as California Mastitis Test or quarter-level SCC values. With or without treatment or bacterial clearance, about 85% of cows affected with nonsevere CM caused by coliform bacteria will have normal appearing milk by day 7 (Fuenzalida and Ruegg, personal

communication, 2018). Regardless of etiology, after initial therapy, if milk remains abnormal for more than 6 or 7 days, before administration of another antibiotic, every attempt should be made to determine the etiology of the infection as it is unlikely that switching among drugs with similar spectrums will improve clinical outcomes.

The purpose of antibiotic treatment is to enhance clearance of bacterial pathogens, and efficacy of products is usually initially evaluated based on estimates of the rate of bacteriologic cure. Bacteriologic cure is assessed by comparison of recovery of bacteria from milk samples collected at detection of the cases and subsequently at various intervals after treatment is completed. However, bacteriologic cure also occurs spontaneously and expected rates of spontaneous bacteriologic cure vary widely among pathogens (**Table 1**). The greatest contrast is between expectations of spontaneous bacteriologic cure of IMI caused by *S aureus* (close to zero) and CM caused by *E coli* (about 90%[25].) Additionally, limited efficacy of antibiotic therapy is well documented for IMI caused by *S aureus*[31,32]; some pathogens (such as yeast, *Prototheca zopfii*, *Mycoplasma* spp, and others) are intrinsically resistant to all approved antimicrobial drugs. It is important to note that even with highly efficacious drugs, the benefit of antimicrobial therapy is only for cases that are not expected to achieve spontaneous bacteriological cure; thus, the value of antibiotic therapy decreases for cases caused by *E coli* or other pathogens with high rates of spontaneous cure.

GUIDELINES FOR APPROPRIATE USE OF ANTIBIOTICS

Guidelines for appropriate use of antibiotics have been developed[33] and should be applied to mastitis treatments. The most significant guidelines are that *antibiotic usage should involve veterinary guidance and extralabel use should be avoided when on-label use is a possibility*. Veterinarians and producers in the United States should be aware of label indications and claims of efficacy and recognize that extralabel treatments occur when systemic antibiotics are administered or when the dosing regimen of intramammary products is altered from that described on the label. Deviations from label guidelines are common for mastitis treatment and may be justifiable for some drugs but must be done under veterinary supervision. Extralabel use of parenteral antibiotics to treat mastitis is not unusual[3,24,34,35] but should be restricted to justifiable cases, such as cows affected with severe mastitis.

Table 1
Estimated rate of spontaneous bacteriologic cure by pathogen from selected studies

Cause	Spontaneous Bacteriologic Cure (%)	Sources
S aureus	0–11	Oliver et al,[37] 2004; Deluyker et al,[48] 1999; Gillespie et al,[49] 2002
Env streptococci species	28–30	Deluyker et al,[48] 1999; Hoe & Ruegg,[50] 2005; Morin and Constable,[51] 1998
Non-aureus staphylococci (NAS)	44–66	Oliver et al,[37] 2004; Deluyker et al,[48] 1999; Apparao et al,[52] 2009
E coli	80–95	Fuenzalida & Ruegg, personal communication; Lago et al,[22] 2011; Suojala et al,[53] 2010
Klebsiella spp	25–60	Lago et al,[22] 2011; Fuenzalida & Ruegg, personal communication, 2018
No growth	75–85	Fuenzalida & Ruegg, personal communication, 2018

Appropriate usage guidelines[33] also specify that *antibiotics should only be used when there is a reasonable likelihood that a bacterial infection that is sensitive to the proposed antibiotic is present.* Given that 20% to 40% of CM cases are culture negative, this criterion is often not achieved; alternative ways to manage these case should be considered. Antibiotics should not be used for cows that are unlikely to benefit and selective treatment based on on-farm or veterinary clinic laboratories is advised. Practitioners should also ensure that antimicrobials are not given to cows affected with nonsevere CM caused by a refractory pathogen, such as *Mycoplasma bovis*, *S aureus*, *Prototheca*, and *Serratia*. When antibiotics are not likely to be effective, abnormal milk should be discarded until it returns to normal (usually about 4–6 days); frequent observation of the cow's behavior and symptoms (watchful waiting) is recommended to detect the rare instances when severity progresses.

Depending on intrinsic bacterial susceptibility, antibiotics are classified as either narrow or broad spectrum. Narrow-spectrum drugs are usually active against either gram-positive or gram-negative bacteria, whereas broad-spectrum drugs have activity against both types of organisms. The World Health Organization has classified antibiotics based on their importance for treating human illnesses,[36] and responsible usage guidelines suggest that n*arrow spectrum antibiotics that are less critical for treating human illnesses should be used as a first choice.*[33] Most IMM products available in the United States are not high-priority drugs for treatment of human illnesses and only ceftiofur (a third-generation cephalosporin) is listed as both high priority and critically important for human use.[36] Most approved IMM products are considered narrow spectrum, and the use of the broader-spectrum IMM drugs should be reserved for cases that will benefit.

Responsible usage guidelines propose that *antibiotics should be used for as short a duration as possible*. The appropriate duration of antibiotic treatment of CM is not well defined and varies depending on the etiology. Some pathogens preferentially infect superficial mucosal surfaces, whereas other pathogens have the ability to deeply infiltrate mammary gland secretory tissue. There is limited evidence that extended-duration antibiotic therapy increases the bacterial cure of invasive pathogens (such as *S aureus* and some environmental streptococci species).[37,38] However, no research has indicated that extended-duration therapy improves clinical outcomes of mastitis caused by noninvasive pathogens (such as NAS or most *E coli*). The use of extended-duration therapy to treat these types of pathogens significantly increases costs without improving economic outcomes.[39] It is important to note that when extended IMM therapy is considered, veterinarians need to assess the ability of farm workers to perform aseptic infusions, as extended IMM treatment is associated with an increased risk of infection from opportunistic pathogens.

Appropriate usage guidelines infer that the cow is healthy enough to respond, and veterinarians should ensure that treatment protocols include the review of the cow's medical history before making a decision to give antibiotics. The purpose of antibiotic therapy is to assist the immune response, and many characteristics of the cow are known to influence the probability of a successful immune response.[40] Characteristics related to a healthy immune response include age, stage of lactation, negative energy balance, history of previous treatments, and environmental factors (such as heat stress). Older cattle ($\geq$third parity) often have poorer responses to treatment as compared with younger cattle.[14,20,41] A history of chronically increased SCC is also associated with a poorer prognosis after mastitis therapy.[42,43] Cows in the immediate postpartum period are known to be immunosuppressed, and heat stress can reduce the ability of the cow to respond to an IMI.[44] Before administration of antibiotics, the

herd-health manager should assess if the cow has risk factors that indicate antibiotics may be beneficial. For example, short-duration IMM antibiotics may be considered for CM occurring in valuable older cows that have nonsevere gram-negative mastitis in the immediate postpartum period. Conversely, watchful waiting may be considered for CM occurring in older cows that have a long history of repeated nonsevere cases.

DETERMINING THE APPROPRIATE TREATMENT

Surveys of dairy producers indicate that IMM antibiotics are used to treat most cases of mastitis.[3,24,29] In the United States, there are 7 approved IMMs; No systemically administered antibiotics are approved for treatment of mastitis and IMM antibiotics should be used as the first choice for treatment of nonsevere CM. Approved IMM products have pharmacologic characteristics that ensure a sufficient concentration of the drug (or active metabolite) will be present in the udder during the approved dosing interval to kill or restrict growth of the organisms listed on the product label. Almost all approved IMM antibiotics are labeled for treatment of *Streptococci* and *Staphylococci,* and 2 products include label claims for *E coli.* No products have claims for the treatment of mastitis caused by *Klebsiella spp*; but when treatment of mastitis caused by this organism is attempted, extralabel IMM administration of a drug with known gram-negative activity is recommended. Little to no research exists to support the efficacy claims for other organisms, and the lack of efficacy data makes it very difficult to justify the use of antibiotics for the treatment of mastitis caused by many pathogens.

Research has shown that extralabel use of systemic antibiotics (such as injectable ceftiofur) is beneficial for the treatment of septicemia that occurs in many cows affected with severe mastitis.[45,46] However, no benefit has been demonstrated when ceftiofur was administered systemically to cows affected with nonsevere CM.[47] Systemic administration of most antibiotics that are allowed under extralabel guidelines is not likely to result in therapeutic concentrations in the udder, and this use is not recommended for the treatment of nonsevere CM. As most mastitis treatments are administered simply based on observation of inflammation (without knowledge of the pathogen), most systemic treatments are difficult to justify both medically and to consumers.

MAKING TREATMENT DECISIONS FOR NONSEVERE CLINICAL MASTITIS

The decision to use an antibiotic for the treatment of nonsevere CM should be based on a reasonable expectation that an active bacterial infection is occurring in a cow who has a reasonable probability of responding to treatment using an antimicrobial with an appropriate spectrum of activity and that the use of the antibiotic will result in clinical outcomes that exceed expectations if antimicrobials are not administered.

The initial decision for nonsevere cases is to identify cows that may not be responsive to antibiotic therapy and using watchful waiting or other options for managing these cases. Watchful waiting refers to simply monitoring the cow, discarding her milk and waiting for the inflammation to subsist, which usually occurs within about 4 to 6 days.[22,24,26] After the milk returns to normal, the cow can be returned to the milking herd; but segregation in a group of cows with high SCC is often recommended. Permanent dry off of the affected quarter is an option for quarters that have received multiple antibiotic treatments. Culling should be the first choice for cows that are diagnosed with *Mycoplasma bovis* and most cows infected with *S aureus*.

After assessing the cow, determination of etiology is recommended. Based on the typical distribution of pathogens that cause CM (see **Fig. 1**), if antibiotics are

administered to all cases based on clinical signs only, their benefits are reduced. Using reported values for pathogen-specific rates of spontaneous cure (see Table 1) and assumptions about treatment efficacy for various pathogens (Table 2), the overall proportion of cases that can be expected to benefit from nonspecific antibiotic therapy ranges from about 20% to 33% (see Table 2). Thus, approximately two-thirds of antibiotic treatments given by farmers who administer antibiotics to all cases of nonsevere CM (without knowledge of etiology) are of no or limited benefit to the cow. When pathogen-specific treatments are not feasible, only some cows will benefit from antibiotics and even fewer will benefit from extended-duration therapy; in this instance, the best economic decision is to treat for a short duration using an IMM antibiotic.[39] When short-duration therapy is used, it is important to recognize that treatment will usually be completed before milk returns to normal appearance.

When possible, pathogen-specific treatment programs are preferable. In most selective treatment protocols, no antibiotic treatment is given until the preliminary results of the culture are known (generally 24 hours), whereas in other protocols, treatment is initiated after the milk sample is collected and results of preliminary cultures are used to modify therapy. The concept of culture-based treatment is to administer antibiotics only for cases that have active (culture positive) infections caused by pathogens (usually gram positive) that are likely to be sensitive to approved IMM antibiotics. For cases with no microbial growth or gram-negative growth, milk is simply discarded until it returns to normal or antiinflammatories may be given if indicated (some moderate

Table 2
Proportion of nonsevere cases of clinical mastitis that would be expected to achieve bacteriologic cure from routine IMM antibiotic therapy used without knowledge of etiology

			Assumed Efficacy of IMM Treatment[b]		Proportion of Total Cases Benefiting from Antibiotic Usage[d]	
Actual Cause	A. Proportion of Cases[a] (%)	B. Assumed Rate of Spontaneous Bacterial Cure (%)	C. Scenario 1: Some Benefit of Antibiotic (%)	D. Scenario 2: Highly Efficacious Antibiotic[c] (%)	A × (1 − B) × C Scenario 1 (%)	A × (1 − B) × D Scenario 2 (%)
No growth	26	85	15	50	0.59	1.95
Coliforms	26	75	25	50	1.63	3.25
Env streptococci	22	20	80	95	14.08	16.72
NAS	8	60	40	80	1.28	2.56
S aureus	12	10	25	60	2.70	6.48
Others	6	50	5	20	0.15	0.60
Proportion of cases benefiting from antibiotic usage (%):					20.4	31.6
Proportion of treated cases receiving no benefit from antibiotics (%):					79.6	68.4

Abbreviation: Env, environmental.
[a] Weighted average of studies included in Fig. 1.
[b] Proportion of cases *in excess of spontaneous cures* that would result in bacteriologic cure due to antibiotic therapy.
[c] Assumes reduced rate of spontaneous cure and increased efficacy of antibiotic.
[d] Calculated as proportion of cases × (1−spontaneous cure) × assumed efficacy of IMM treatment.

cases). For more information on the development of culture programs please see Alfonso Lago and Sandra M. Godden's article, "Use of Rapid Culture Systems to Guide Etiology-Based Clinical Mastitis Treatment Decisions," in this issue.

When nonantibiotic treatment strategies are used, we are assuming that the immune response will be effective in clearing the infection. Thus, it is essential for veterinarians to ensure that the medical history of the cow is assessed before withholding antibiotics. When cows have conditions that result in immune suppression, (immediate postpartum period, severe negative energy balance, concurrent disease, and so forth) or if a culture-negative case or gram-negative case is preceded by a long period of increased SCC (indicating that the cow's immune system has not been successful in eliminating the pathogen), short-duration IMM therapy may be considered.

SUMMARY

Appropriate use of antimicrobials on dairy farms contributes to improving animal well-being and dairy farm sustainability but it is important for veterinarians to recognize that many cases of nonsevere CM will not benefit from antimicrobial therapy. Mastitis is caused by a diverse group of bacterial pathogens with differing distributions among farms. In intensively managed herds, many cases of CM are culture-negative when detected or are caused by pathogens with high rates of spontaneous cure. In such herds, when treatments are administered without knowledge of etiology, most antimicrobial treatments are likely to be unnecessary. There is considerable opportunity for veterinarians to improve antimicrobial usage on dairy farms by encouraging farmers to adopt culture-based treatment protocols that limit antimicrobial usage to cases that will benefit. When this option is not feasible, farmers should be encouraged to review the medical history of the cow before treatment and, when antimicrobial use is warranted, initiate therapy using a narrow-spectrum drug for a short duration.

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