Infectious Diseases

Dr. Jenks Britt, *Presiding*

Epidemiologic Diagnosis of Neonatal Diarrhea in Dairy Calves

Dale Hancock, *DVM, MS*
Department of Veterinary Science,
Ohio Agricultural Research and Development Center
Wooster, Ohio

Diagnosis, to some, means the categorization or naming of a particular disease state. Others take a more extended view, holding that diagnosis must include delineation of the nature and origins of the disease state at hand with particular effort toward those areas in which a potential solution is available. This has been called epidemiologic diagnosis (1).

For infectious diseases, categorization diagnosis consists of simply naming the disease and the agent involved. The agent is often improperly spoken of as the "cause" or "etiology" (from Gr *aita* meaning cause). For simple diseases (one agent only) where the association between infection and disease is strong, this sort of diagnosis may be adequate.

With most agents of bovine disease, however, infection may occur with the animal remaining healthy; that is, infection is much more widespread than disease. This fact argues strongly against the assumption of a singular cause. To extend this concept to a herd basis, it must be recognized that the mere presence of a pathogen on a farm does not condemn the farm to a high disease rate. Indeed, *farms which have an excellent record of performance in all health parameters will inevitably be found to harbor a veritable community of pathogens.* In truth, all but a few bovine pathogens are essentially opportunists.

The underlying assumption of epidemiologic diagnosis is that only certain interactions of host, agent and environmental factors lead to disease. Other interactions, even some including agents, fail to lead to disease. No single factor (i.e., the agent) should be spoken of as the "cause" or "etiology" of a disease state. Thus, according to this view, differences in disease rates between herds must be explicable by differences in host, agent, and/or environmental factors.

Adherents of the diagnosis-by-agent-identification hypothesis, on the other hand, assume that differences in disease rates are due to agent factors - that is, microbiologic differences between farms. In light of considerable evidence that many bovine agents are widespread (even ubiquitous) and are known to exist on farms without disease problems, the disease-because-agent hypothesis would seem an extremist position in the absence of considerable proof. For the known agents associated with diarrhea in neonatal dairy calves, either infection is known to be widespread in both high and low morbidity herds, or there is currently no clear data on the herd distribution. Thus, under the constraints of current knowledge, most of the diagnostic efforts must be aimed toward host and environmental factors. Agent identification may be an adjunct to diagnosis.

Mortality Estimates

A wide variety of dairy calf mortality rate estimates have been reported (Table 1). Diarrhea has been noted as the leading cause of calf mortality. (3,7) While there is lack of agreement on mortality rate, there is wide agreement that mortality rate varies greatly between farms and that it tends to be repeatable within a herd from year to year. This has led many to suspect that something other than chance dictates the risk experienced by calves in a given herd.

A number of studies have examined management variable alleged to have an effect on neonatal dairy calf mortality. This article reviews some of them. It is worth noting that all candidate management variables do not have diagnostic significance. For example, herd size (2,3) and the person feeding the calves (4) (owner or employee) have been shown to significantly influence calf mortality rate. Yet a diagnosis of "too large a herd" is likely to meet with no more client acceptance than a recommendation of "fire the hired hand." In NE Ohio, there are numerous examples of large herds where employees feed the calves which have a calf mortality rate under 5%. Only those variables under direct management control are discussed here.

Passive Immunity

A number of studies have compared passive immunoglobulin (Ig) levels during the first few days of life with subsequent mortality risk. Most of these (but not all [8]) have shown that calves with very low Ig levels are at increased risk.(9-14) Several studies have also indicated an

TABLE 1 Mortality estimates of dairy calves.

Reference	Location	Max. age (days)	Mortality Rate with stillbirths	Mortality Rate without stillbirths	Year
Speicher[2]	Mich.	Weaning	13.5	7.2	1966
Oxender[3]	Mich.	60	17.7	11.3	1972
Martin[4]	Calif.	90	—	20.0	1967-73
Hird[5]	Minn.	90	—	11.0-13.5*	1976-79
Hancock[6]	Ohio	30	—	5.2	1980
Hancock[7]	Ohio	42	—	7.5	1982

* Rates computed for each year separately.

effect of passive Ig levels on diarrhea morbidity risk(12-18) and on the case fatality rate associated with diarrhea. (10,13,19) In sum, these studies lead one to the conclusion that management's efficiency of insuring passive immune transfer to neonates is one of the major determinants of herd calf mortality rate. Factors affecting passive Ig transfer and the evaluation of management in this area are discussed below. Calves are born virtually devoid of passive Ig and colostrum provides them with their sole, natural source. Maternal Ig is transferred from the intestinal lumen to the circulation by the apical tubular system in intestinal absorptive cells for a limited time after birth.(20) Maximum transfer is achieved by feeding at least 2 liters of colostrum within 4 hours of birth.(21) Feeding calves less or delaying the time of colostrum feeding, each cause a roughly linear decline in amount of Ig transferred.(21) Thus, "closure" (or cessation of Ig absorption) is progressive as opposed to an all-or-none phenomenon. One study, employing a large number of calves, indicated that all 86 calves bottle fed colostrum at 0, 4, or 8 hours after birth achieved a measurable transfer of all Ig classes.(22) Absorption failures at 12, 16, 20, and 24 hours represented 3%, 17%, 30%, and 57% of the calves, respectively.

Calves allowed to suckle voluntarily or force fed. A high rate of absorption failure (42.2%) has been reported in dairy calves left with their dams for 12 to 26 hours and allowed to suckle at will.(23) Bottle feeding after removal from dams resulted in Ig transfer in most of these calves leading to the conclusion that the observed high rate of non-absorption was due to the failure of many calves to suckle.

The effect of dam's parity on nursing behavior of dairy calves has been studied.(24) A much smaller percent of calves with older dams nursed within the first 6 hours than did calves of heifers or low parity cows. Presumably, size and shape of udders accounted for the difference.

Force feeding through use of a nipple bottle(22) or a stomach tube(25) results in satisfactory transfer of passive Ig.

Mothering effect. Calves which suckled their dams voluntarily were shown to achieve higher levels of Ig than calves fed a similar amount of colostrum from a stored pool.(26) Mothering effect was largely discounted as the cause of the increased rate of Ig absorption since only limited maternal contact was allowed. The presence of a highly labile chemical in colostrum which enhances pinocytic activity was hypothesized.

Colostrum quality. Several factors affect the Ig concentration of colostrum. The most dramatic effect is due to time postpartum that the sample is taken. Colostrum Ig concentration begins to decline rapidly soon after calving such that 3rd milking colostrum has only 20-30% of the Ig of that taken immediately after calving. (8,27,28) By day 4 postpartum, the Ig concentration is only 2 to 3% of the immediate postpartum level.(27) A similar decline occurs even in unmilked quarters.(8)

Breed differences(29,30) and differences between heifers and older cows(29) in colostrum Ig concentration have been reported. Wide inter-cow differences have been shown within a breed.(27,29,31) The level for a given cow is highly repeatable from one lactation to the next.(29,31) Colostral Ig concentration has been shown to be heritable to a degree.(31) It does not seem to be greatly influenced by either pre-parturient nutrition(8,31) or dry period length.(8) Ig concentration in the lacteal secretion following abortion is much less than that following a normal parturition.(32)

While between-cow variation in colostral Ig concentration probably accounts for some between-calf variation in passive Ig levels, it is doubtful that such differences account for much inter-herd variation in proportion of calves that are hypogammaglobulinemic. The total mass of Ig consumed is much more important than the Ig concentration in determining passive immune levels achieved.(8,21) Thus, one would expect a small rate of hypogammaglobulinemia in herds where large amounts of colostrum are fed even if factors such as low average parity dictates a relatively low average colostral Ig concentration. Use of colostrum beyond the first milking postpartum, however, would be expected to result in a markedly decreased level of Ig transfer and a higher rate of hypogammaglobulinemia if it is provided as the initial feeding (28).

Duration of colostrum feeding. While little benefit, in terms of circulating Ig, is derived from feeding colostrum beyond 24 hours of age, there is clear evidence that colostral Ig can provide local immunity, within the gastrointestinal tract, against enteropathogens.(33-36) Most of the protective effect seems to be contained in the IgG fraction.(34) Maternal vaccination schemes for the prevention of neonatal diarrhea depend on the presence of agent specific antibody in the gut lumen during the time of exposure to the agent.(36,37)

Evaluation of colostrum feeding policies. The following questions are pertinent to the assessment of management's ability to assure adequate passive immune transfer to calves: Are all calves force fed? How much colostrum is fed in the first meal? On the average, what is the interval between birth and force-feeding? What is the longest possible interval between birth and force feeding? Is something other than first milking colostrum used for the first feeding?

Although management changes can often be recommended based on answers to these questions, stated policy and execution are often quite different. Laboratory testing of calf sera for Ig levels must be performed for a definitive assessment of management in this area.

Procedures available for determining the Ig concentration of sera include radial immunodiffusion (RID), refractometry, and the zinc sulfate turbidity test (ZST). RID and the ZST have approximately equal precision while that of refractometry is less. (38) The ZST is far cheaper than RID and is very adaptable to large scale use such as that in diagnostic laboratories.

Traditional thought suggests that only calves under 7 days of age may be sampled to determine the level of passive immune transfer. However, the correlation between first week (2 to 7 days of age) and second week (7 to 14 days of age) ZST values was found to be 0.97. (39) Thus, samples taken at either time contain virtually the same information vis-a-vis the efficiency of passive immune transfer within a herd. The correlation with initial values was found to decline with increasing age; but even in the fifth week of life, most of the between-calf variation in ZST level was found to be due to that in first week of life. A safe conclusion is that calves may be sampled to at least 14 days of age in order to assess management's efficiency in assuring adequate passive immune transfer. Although a high attrition rate in calves prior to 14 days of age will cause a bias in interpretation, a "positive" herd-test for hypogammaglobulinemia is still accurate.

The procedure employed by the author is to sample every calf on the premises, regardless of disease status, from 2 to 14 days of age. Each sample is tested by the ZST and assigned a unit value in relation to a pooled adult bovine standard which is arbitrarily given the value of 100 units. The results may, therefore, be interpreted as percent of adult bovine level. Frequency distribution of values obtained is plotted on a diagnostic form.

A study of 5 low mortality farms indicated a high percent of calves with marginal ZST levels (20 - 40 units) but only a small percent with very low ZST levels (less than 20 units). (40) Almost a third of calves in 5 high mortality herds, on the other hand, had less than 20 ZST units. Thus 20 units would seem to be a good division between adequate and inadequate passive immune transfer. It would be reasonable to assume that management's failure to insure adequate passive immune transfer contributes substantially to the excess mortality rate under investigation if more than a rare calf is found to have less than this level.

Housing

Calf housing affects two factors which influence mortality and morbidity rates: (1) the exposure dose of agents and (2) the level of stress of calves. Several aspects of housing are discussed.

Cold, naturally ventilated or warm, artificially ventilated. Neonatal dairy calf housing in the midwest and other northern regions of the United States has traditionally been enclosed and heated (artificially, or by the body heat of older animals). However, results of a 1981 questionnaire survey of NE Ohio dairy farmers conducted by the author would suggest a strong trend toward cold, naturally ventilated housing. Cold housing was described in the questionnaire as follows: "no supplemental heat provided, natural ventilation, temperature fluctuates with that outside and can go below 45° F (includes hutches and cold barns." Fully 75% of the respondents indicated that they used cold housing for calves in the winter months. Nineteen of the farms have been closely monitored for calf mortality during 1982. Several farms using exclusively cold housing (hutches in some cases) experienced no deaths among neonatal heifers born between January 1, 1982 and the end of October. Several others experienced a very low mortality rate. This is in spite of two exceptionally cold weekends in January when temperatures dipped below minus 20° F and winds were in excess of 30 mph. A 1980 survey of 10 dairies in the same region indicated a significantly higher mortality rate among warm housed calves than among those in cold housing. These data, in addition to those from studies in Ontario(41), South Dakota(42), and Scotland(43) suggest that the recommendation of a temperature range of 10-13 C for optimum health of neonatal calves(44) is unwarranted.

Several disadvantages of cold housing have been mentioned. At least one study has indicated a higher labor requirement for hutches as compared to conventional housing(41), but another study found just the opposite to be the case.(42) Discomfort of the calf feeder has also been widely touted as a disadvantage of cold housing; however, considering the large number of NE Ohio dairy farms which currently use cold housing, operator discomfort would not seem a major deterrent.

Farms with high diarrhea morbidity and mortality rates due to poorly designed and managed warm housing will almost certainly benefit from a change to cold housing. Indeed, among NE Ohio dairymen, disease problems experienced by calves in warm housing is the most commonly mentioned reason for the change to cold housing. In contrast, the author is aware of no cases where those using cold housing have changed to warm in an effort to alleviate disease losses.

Ventilation. Poor ventilation in enclosed structures can elicit stress in calves via excess humidity and toxic fumes and will also result in an increased concentration of pathogens in the air.(44,45) While these factors are well known to increase losses due to respiratory disease(44-47) they can have an effect on the rate of diarrhea as well.

A detailed discussion regarding the analysis of ventilation systems is available.(44) Included in the analysis should be examination of the insulation, number of air changes per hour (determined by size of facility, fan capacity, and negative pressure against which the fan is working), whether ventilation is continuous or interrupted (e.g., by a thermostat), and fresh air intake. Details may be obtained from the article cited above.

Group or individual pens. Two broad scale surveys indicated no difference in mortality rates between herds using individual and group housing for neonatal calves.(2,5) Nevertheless, individual pens are often recommended for the control of diarrhea(48) and the epidemiology of certain diarrheal agents argues in favor of such a position. Exposure to, and infection with, some (perhaps all) of the agents are virtually inevitable during the first 4 weeks of life. The exposure dose, however, is important in determining the risk and severity of disease. One would expect that calves in group housing would be exposed to larger numbers of pathogens than those in individual pens. The author is aware of no controlled studies to support this view, however.

Continuous or interrupted use of rearing quarters. A number of reports indicate that periodic interruptions in use of rearing quarters will break the "infection cycle" and result in a lower disease rate.(48-50) Examples of this phenomenon have been seen in several NE Ohio herds where depopulating rearing facilities had a dramatic effect both on morbidity rate and on the epidemiology selected enteropathogens.

Separation of neonates from older animals. It is a widely held tenet that older animals are a major source of enteropathogen infection for neonatal calves. The author is aware of no evidence to support this claim. With rotavirus, infectious particles are shed in large numbers by virtually every calf during the neonatal period(51); while, at least in one study, the virus was not detected in fecal samples from adults.(52) Other agents share a similar epidemiologic pattern with rotavirus-shed in high numbers by neonates but rarely if ever detected in adults.(49) The decline in morbidity associated with an interruption in use of calf quarters would lead one to suspect that the major source of infection is the calf's immediate environment, and that it is contaminated principally by the calves themselves.

Availability of sufficient calf housing. The number of calf housing units available on most farms is adequate for an average calving rate. Unfortunately the rate of calving is extremely erratic. A monthly heifer birth rate of 3 to 4 times the average rate is not uncommon. Where extra housing capacity is not available one of several things happens: calves are crowded into available space, makeshift housing is used (often group housing), or calves are weaned and moved more quickly than usual to make space for newborns. All of these options would likely increase the risk of diarrhea morbidity and mortality. Herds with disease problems would be well advised to provide at least twice as many units as dictated by average monthly calving rate.

Nutrition

Amount of liquid diet. Many dairymen and veterinarians think that overfeeding milk will result in diarrhea, though there is considerable disagreement on what constitutes overfeeding. Two studies indicated that diarrhea was not observed in calves fed milk *ad lib.* (53,54) Although 10% of body weight per day is a commn recommendation for milk feeding of calves, the maintenance requirements listed in Nutrient Requirements of Dairy Cattle (55) are a function of body weight to the 0.75 power; with smaller calves receiving over 11% of their body weight in milk per day and larger ones just over 9%.

There is ample evidence that calves will achieve acceptable levels of gain if fed milk or a suitable substitute at the daily rate of 8% of body weight provided calf starter is offered free choice. (56) Marked underfeeding has been reported to result in an increased mortality risk in cold housing. (43)

Type of liquid diet. Satisfactory performance can be obtained by feeding milk, colostrum, or properly formulated milk replacer. (56,57) A blanket recommendation against any of these products would seem unwarranted. A study of 77 Michigan dairy herds showed no significant difference in mortality rate between herds feeding whole milk and those feeding milk replacer. (3)

Colostrum may be stored by freezing, refrigeration, fermentation at ambient temperatures or by the addition of chemical preservatives. Freezing results in virtually no loss of nutrients while fermentation or chemical treatment cause physical changes and some nutrient losses.(58) Colostrum has a higher dry matter concentration than milk and thus can be diluted prior to feeding. Dilution rates of 2:1 and 3:1 (fermented colostrum:water) resulted in performance equal to whole milk feeding.(59) Feeding a 1:1 dilution resulted in lower weight gains and more scours. Many herds add large quantities of mastitic milk to the fermentation containers. If this is done the product should probably not be diluted.

The selection of a milk replacer for young calves should take into account the digestive capabilities of the young neonate. Milk protein sources in the form of dried skim milk, whey, or dried buttermilk are acceptable.(56) Non-milk proteins such as fish meal or soybean products may cause poor performance and an increased incidence of diarrhea.(56) Lactose and glucose are the only carbohydrates utilized by the young neonate.(56) Starch should not be included. Milk replacer should consist of 10 to 20% fat to avoid an excess rate of diarrhea (57). Lard and various vegetable fats provide satisfactory sources of fat.(56)

Dry matter concentration of liquid diet. Milk and properly diluted milk replacer contain approximately 12 to 13% dry matter. The best dry matter concentration for prevention of scours was reported to be in the range of 10 to 15 percent (60).

Method of feeding. Feeding in open pails or with a nipple resulted in no significant differences in weight gains, (61,62) rate of diarrhea, (61,62) or mortality rate.(3)

Lactobicillus feeding. Studies regarding Lactobacillus feeding calves for the prevention of diarrhea are less than convincing. The most logical purpose of this practice would be to prevent overgrowth of pathogenic coliform organisms. In two studies no significant differences were seen in gut coliform concentrations between calves fed large numbers of Lactobacillus and control calves.(63,64) The population density of Lactobacillus increased and that of coliforms decreased during the first two weeks of life regardless of treatment.(63)

Selenium status. Soils in large parts of the United States including New England, much of the Midwest, the Southeast, and the Pacific Northwest are deficient in selenium.(65) Selenium deficiency can result in nutritional muscular dystrophy in calves.(55) Adequate selenium has also been shown necessary for optimum performance of certain host defense mechanisms.(66,67) If dams are supplemented with a sufficient level of selenium, calves will not be deficient at birth.(68) However, levels commonly incorporated into dry cow rations in deficient areas are often not sufficient to ensure adequate levels in the neonate. A reasonable policy would be to inject calves with a selenium containing product at birth.

Vitamin A status. Although Vitamin A deficiency will place calves at high risk of morbidity and mortality, it is probably not a common problem.(55,56) Where dry cows are fed poor quality forages or corn silage and a low-carotene concentrate, supplement Vitamin A to calves and/or dams is indicated.(55,56) Colostrum is the newborn calf's principal source of Vitamin A.(69)

Treatment of Diarrhea

A certain amount of diarrhea occurs in every group of dairy calves. Management's ability to recognize signs of diarrhea early, to develop effective criteria regarding when treatment is justified, and to carry out effective and consistent treatment, will undoubtedly have an effect on diarrhea case fatality rate. These factors should, therefore, be evaluated in the problem herd.

A concise review of diarrhea treatment is available.(70) Since the principal cause of diarrheic death is dehydration, oral fluid therapy should be a routine part of treatment. Antibiotics probably have merit in the treatment of diarrhea cases during the first few days of life since this is the period when colibacillosis occurs. Diarrhea cases beyond 7 days of age are seldom associated with bacterial pathogens and antibiotic treatment would seem unwarranted. Antibiotic resistance to the commonly used drugs is extremely common among *E. coli* isolates.(71) Neomycin, ampicillin, tetracycline, erythromycin, penicillin, streptomycin, kanamycin, and sulfa drugs should be considered ineffective unless a laboratory sensitivity test indicates otherwise.

Vaccination

Four conditions must be met for a biological product to be of known usefulness:

1. The disease must cause losses which are not readily subject to management control short of immunization.
2. The product must be shown effective in controlled trials.
3. The product must be shown effective in epidemiologically sound field trials.
4. Protection must be cost effective.

The veterinary practitioner who assumes without question that all licensed biologics have met these four conditions has been misled. A close scrutiny of the literature and a certain amount of scepticism are necessary to make a sound judgement on a specific product.

Maternal vaccination with E. coli bacterins. Maternal vaccination with formalin-killed bacterins of enteropathogenic *E. coli* has been shown to give significant protection to calves challenged with the same strain.(72,73) Use of a formalin-filled bacterin containing 3 *E. coli* strains was not effective in a field trial, however.(74)

A surface antigen of *E. coli* termed K99 is strongly associated with enteropathogenicity.(75,76) Considerable evidence indicates that K99 is a virulence factor allowing adhesion of the enteropathogenic *E. coli* strains to the intestinal wall.(73,77,78) One study found protection of calves against fatal diarrhea due to challenge with enteropathogenic *E.coli* to be strongly associated with colostral K99 antibody titer and also demonstrated protection by maternal vaccination with purified K99 antigen.(73) Commercial bacterins containing K99 antigen are available though the amount of antigen required for an optimal immune response has not been delineated.

Althouth the assumption is frequently made that the presence of enteropathogenic *E. coli* on a farm will inevitably lead to a high disease rate, one study found K99+ *E. coli* to be widespread and to exist on a number of farms with low rates of diarrhea morbidity and mortality.(79) In NE Ohio, only a small minority of herds have serious problems with diarrhea morbidity and mortality in the first week of life. Thus, few herds would be expected to derive major benefit from K99 vaccination. These data suggest that colibacillosis is highly subject to management control in the absence of vaccination.

Oral vaccination of calves with modified live rotavirus-coronavirus vaccine. Field trials have indicated a significant reduction in diarrhea morbidity and mortality through oral vaccination of newborn calves with either modified live rotavirus or with both modified live rotavirus and coronavirus.(80,81) Serious questions were raised regarding the epidemiologic soundness of the earlier of these field studies.(82) Other studies have shown neither a reduction in morbidity and mortality,(74,83,84) nor a change in rotavirus shedding patterns (84,85) due to oral vaccination.

Maternal vaccination with modified live rotavirus-coronavirus vaccine. It has been demonstrated that the colostral rotavirus antibody titer can be substantially increased by maternal vaccination with a killed product containing adjuvant (36,86) and that this gives significant protection to calves against rotavirus-associated diarrhea.

(36) However, according to one report, heifers vaccinated with a commercially available modified live rotavirus-coronavirus product had colostral rotavirus and coronavirus titers that were not significantly different from unvaccinated controls. (87)

Rotavirus and coronavirus commonly occur in low morbidity/mortality herds leading one to the conclusion that losses associated with these agents are highly subject to management control.

Conclusion

In most instances of neonatal dairy calf diarrhea, agent identification is not diagnostic from an epidemiologic (solution-oriented) standpoint. The underlying causes may be identified only by a meticulous examination of management practices.

References

1. Schwabe, C. W.: The current epidemiological revolution in veterinary medicine. Part I. Prev Vet Med 1:5-15, 1982. - 2. Speicher, VA, Hepp, RE: Factors associated with calf mortality in Michigan dairy herds. JAVMA 162:463-466, 1973. - 3. Oxender, WD, Newman, LE, Morrow, DA: Factors influencing dairy calf mortality in Michigan. JAVMA 162:458-460, 1973. - 4. Martin, SW, Schwabe, CW, Franti, CE: Dairy calf mortality rate: characteristics of calf mortality rates in Tulare County, California. Am J Vet Res 36:1099-1104, 1975. - 5. Hird, DW, Robinson, RA: Dairy farm wells in southeastern Minnesota: the relation of water souce to dairy calf mortality rate. Prev Vet Med 1:53-64, 1982. - 6. Hancock, DD: Mortality rate of liveborn dairy heifers to 30 days of age in 10 Ohio dairy herds, unpublished data. - 7. Hancock, DD: Mortality of heifer calves during the first 6 weeks of life in 19 Ohio dairy farms: distribution by age, season, and presumptive cause. Proc CRWAD 63:45, 1982. - 8. Lomba, F, Fumiere, I, *et al.*: Immunoglobulin transfer to calves and health problems in large bovine units. Ann Rech Vet 9: 353-360, 1978. - 9. Gay, CC, Anderson, N, *et al.*: Gamma globulin levels and neonatal mortality in marked calves. Vet Rec 77:148-149, 1965. - 10. McEwan, AD, Fisher, EW, *et al.*: Observations on the immune globulin levels of neonatal calves, and their relationship to disease. J Comp Path 80:259-265, 1970. - 11. Penhale, WJ, Christie, G, *et al.*: Quantitative studies on bovine immunoglobulins II plasma immunoglobulin levels in market calves and their relationship to neonatal infection. Br Vet J 126:30-36, 1970. - 12. Boyd, JW: The relationship between serum immune globulin deficiency and disease in calves: a farm survey. Vet Rec 90: 645-649, 1972. - 13. Thornton, JR, Willoughby, RA, *et al.*: Studies on diarrhea in neonatal calves: the plasma proteins of normal and diarrheic calves during the first 10 days of age. Can J Comp Med 36:17-25, 1972. - 14. McGuire, TC, Pfeiffer, NE, *et al.*: Failure of colostral immunoglobulin transfer in calves dying from infectious disease. JAVMA 169:713-718, 1976. - 15. Fisher, EW, Martinez, AA, *et al.*: Studies on neonatal calf diarrhea II. Serum and fecal immune globulins in enteric colibacillosis. Br Vet J 131:402-414, 1975. - 16. McNulty, MS: Studies on rotavirus infection and diarrhea in young calves. Vet Rec 99:229, 1976. - 17. Cabello, G, Levieux, D: Comparative absorption of colostral IgG, and IgM in the newborn calf. Effects of thryroxine, cortisol, and environmental factors. Ann Rech Vet 11:1-7, 1980. - 18. Frerking, H, Aeikens, T: About the importance of colostrum for the newborn calf. Ann Rech Vet 9:361-365, 1978. - 19. Fisher, EW, Martinez, AA: The relationship between the zinc sulfate turbidity, serum immune globulins and the susceptibility of calves to diarrhea. Br Vet J 134:231-233, 1978. - 20. Bush, LJ, Staley, TE: Absorption of colostral immunoglobulins in newborn calves: J Dairy Sci 63:672-680, 1980. - 21. Stott, GH, Marx, DB, *et al.*: Colostral immunoglobulin transfer in calves II. The rate of absorption. J Dairy Sci 62:1766-1773, 1979. - 22. Stott, GH, Marx, DB, *et al.*: Colostral immunoglobulin transfer in calves I. Period of absorption. J Dairy Sci 62:1632-1638, 1979. - 23. Bringole, TJ, Stott, GH: Effect of suckling followed by bottle feeding colostrum on immunoglobulin absorption and calf survival. J Dairy Sci 63:451-456, 1980. - 24. Edwards, SA, Broom, DM: The period between birth and first suckling in dairy calves. Res Vet Sci 26:255-256, 1979. - 25. Molla, A: Immunoglobulin levels in calves fed colostrum by stomach tube. Vet Rec 103:377-380, 1978. - 26. Stott, GH, Marx, DB, *et al.*: Colostral immunoglobulin transfer in calves IV. Effect of suckling. J Dairy Sci 62:1908-1913, 1979. - 27. Porter, P: Immunoglobulins in bovine mammary secretions. Quantitative changes in early lactation and absorption in the neonatal calf. Immunology 23:225-238, 1972. - 28. Stott, GH, Fleenor, WA *et al.*: Colostral immunoglobulin concentration in two fractions of first milking postpartum and five additional milkings. J Dairy Sci 64:459-465, 1981. - 29. Kruse, V: Yield of colostrum and immunoglobulin in cattle at the first milking postpartum. Anim Prod 12:619-626, 1970. - 30. Muller, LD, Ellinger, DK: Colostral immunoglobulin concentrations among breeds of dairy cattle. J Dairy Sci 64:1727-1730, 1981. - 31. Dardillat, J, Tillat, G, Larvor, P: Colostrum immunoglobulin concentration in cows: relationship with their calf mortality and the colostrum quality of their female offspring. Ann Rech Vet 9:375-384, 1978. - 32. Straub, OC, Matthaus, W: The immunoglobulin composition of colostrum and the persistence of acquired immunoglobulins and specific antibodies in the calf. Ann Rech Vet 9:269-275, 1978. - 33. Logan, EF, Penhale, WJ: Studies on the immunity of the calf to colibacillosis III. The local protective activity of colostrum within the gastrointestinal tract. Vet Rec 89:628-632, 1971. - 34. Logan, EF, *et al.*: The role of colostral immunoglobulins in the intestinal immunity to enteric colibacillosis in the calf. Res Vet Sci 17:290, 1974. - 35. Logan, EF, Pearson, GR: The experimental reproduction of enteric colibacillosis in colostrum fed calves. Vet Rec 101: 443-446, 1977. - 36. Snodgrass, DR, Stewart, J. *et al.*: Diarrhea in dairy cattle reduced by feeding colostrum from cows vaccinated with rotavirus. Res Vet Sci 32:70-73, 1982. - 37. Logan, EF, Penhale, WJ: Studies on the immunity of the calf to colibacillosis III. The local protective acitivity of colostrum within the gastrointestinal tract. Vet Rec 89:628-632, 1971. - 38. Pfeiffer, NE, McGuire, TC, *et al.*: Quantitation of bovine immunoglobulins: comparison of single radial immunodiffusion, zinc sulfate turbidity, serum electrophoresis, and refractometer methods. Am J Vet Res 38:693-698, 1977. - 39. Hancock, DD: Measurement of immunoglobulin levels in serum from calves more than 7 days of age to monitor colostrum feeding practices in dairy herds. Proc CRWAD 63:31, 1982. - 40. Hancock, DD: Use of the ZnSO turbidity test to evaluate adequacy of passive immunoglobulin levels in neonatal calves on a herd basis. Proc CRWAD 62:39, 1981. - 41. McKnight, DR: Performance of newborn dairy calves in hutch housing. Can J Anim Sci 58:517-520, 1978. - 42. Vorgenson, LJ, Jorgenson, NA, Schingoethe, DJ, Owens, MJ: Indoor versus outdoor calf rearing at three weaning ages. J Dairy Sci 53:813-816, 1970. - 43. Williams, PEV, Day D, Rven, AM: The effect of climatic housing and level of nutrition on the performance of calves. Anim Prod 32:133-141, 1981. - 44. Bates, DW, Anderson, JF: Calculation of ventilation needs for confined cattle. JAVMA 174:581-589, 1979. - 45. Anderson, JF, Bates, DW: Influence of improved ventilation on health of confined cattle. JAVMA 174:577-580, 1979. - 46. Pritchard, DG, Carpenter, CA, Marzaria, SP, *et al.*: Effect of air filtration on respiratory disease in intensively housed veal calves. Vet Rec 109:5-9, 1981. - 47. Ishino, S, Oka, M, Terui, S, Ikeda, S: Pathological and microbiological studies on calf pneumonia occurring in mass rearing facilities. Nat Inst Anim Hlth Quart 19:91-103, 1979. - 48. Radostits, OM: Treatment and control of neonatal diarrhea in calves. J Dairy Sci 58:464-470, 1975. - 49. Wray, C, Thomlinson, JR: Factors influencing occurrence of colibacillosis in calves. Vet Rec 96:52-56, 1975. Roy, JHB: Factors affecting susceptibility of calves to disease. J Dairy Sci 63:650-664, 1980. - 50. Hancock, DD, Saif, LJ, Bohl, EH, Redman, DR: Evaluation of response to field use of commercial oral rotavirus-coronavirus vaccine in 10 Ohio dairy herds. Proc CRWAD 62:43, 1981. - 51. Dagenais, L, Pastoret, PP, Schwers, A, *etal.*: Epizootiologic de la diarrhee a rotavirus chez les bovins. Ann Med Vet 124:565-575, 1980.- 52. Mylrea, PJ: Digestion in young calves fed whole milk *ad lib* and its relationship to calf scours. Res Vet Sci 7:407-416, 1966.- 53. Marshall, SP, Smith, KL: Effect of different milks and levels of intake upon growth of young dairy

calves. J Dairy Sci 53:1622-1626, 1970. - 54. National Research Council: *Nutrient Requirements of Dairy Cattle,* 5th ed, 1978. - 55. Church, DC: Digestive Physiology and Nutrition of Ruminants, Vol 3, Practical Nutrition, 2nd ed., O&B Books, Inc., Corvallis, OR, 1980. - 56. Appleman, RD, Owen, FG: Breeding, housing, and feeding management. J Dairy Sci 58:447-464, 1975. - 57. Foley, JA, Otterby, DE: Availability, storage, treatment, composition, and feeding value of surplus colostrum: a review. J Dairy Sci 61:1022-1060, 1978. - 58. Jenny, BF, Mills, SE, O'Dell, GD: Dilution rates of sour colostrum for dairy calves. J Dairy Sci 60:942-946, 1977. - 59. Jenny, BF, Mills, SE, *et al.*: Effect of fluid intake and dry matter concentration of scours and water intake in calves fed once daily. J Dairy Sci 61:765-770, 1978. - 60. Wise, GH, LaMaster, VP: Responses of calves to open-pail and nipple-pail systems of feeding. J Dairy Sci 51:452-456, 1968. - 61. Morrill, JL, Dayton, AD: Method of feeding milk and access to fiber source for young calves. J Dairy Sci 64:146-148, 1981. - 62. Gilliland, SE, Bruce, BB, *et al.*: Comparison of two strains of *Lactobacillus acidophilus* as dietary adjuncts for young calves. J Dairy Sci 63:964-972, 1980. - 63. Elinger, DK, Muller, LD, Glantz, PJ: Influence of feeding fermented colostrum and *Lactobacillus acidophilus* on fecal flora of dairy calves. J Dairy Sci 63:478-482, 1980. - 64. Mortvedt, *et al.*: *Micronutrients in Agriculture.* Soil Sci Soc ofAm, Madison, WI, 1972. - 65. Boyne, R, Arthur, JR: Alterations of neutrophil function in selenium deficient cattle. J Comp Path 89:151-158. - 66. Peplowski, MA, Mahan, DC, *et al.*: Effect of dietary and injectable Vitamin E and selenium in weanling swine antigenically challenged with sheep red blood cells. J Anim Sci 51:344-351, 1981. - 67. Perry, TW, Peterson, RC, *et al.*: Relationship of blood serum selenium levels of pregnant cows to low dietary intake, and effect on tissue selenium levels of their calves. J Anim Sci 46:562-565, 1978. - 68. Church, DC: *Digestive Physiology and Nutrition of Ruminants Vol 2, Nutrition,* O&B Books, Inc., Corvallis, OR, 1971. - 69. Blood, DC, Henderson, JA, Radostits, OM: *Veterinary Medicine,* Lea & Febriger, Philadelphia, 1979, pp 466-468. - 70. Fairbrother, JM, McDonough, PL, Shin, SJ: A survey of dry resistance in *Escherichia coli* isolated from neonatal calves in New York state from 1976-1978. VIDO Proc 2:515-524, 1978. - 71. Myers, LL, Newman, FS, *et al.*: Passive immunization against experimentally induced enteric colibacillosis by vaccination of dams. Am J Vet Res 34:29-33, 1973. - 72. Acres, SD, iSAACSON, re, *et al.*: Immunization of calves against enterotoxigenic colibacillosis by vaccinating dams with purified K99 antigen and whole cell bacterins. Inf Imm 25:121-126, 1979. - 73. Acres, SD, Radostits, OM: The efficacy of a modified live reo-like virus vaccine and an *E. coli* bacterin for prevention of acute undifferentiated neonatal diarrhea of beef calves. Can Vet J 17:197-209, 1976. - 74. Guinee, P, Jansen, WH, Agterberg, CM: Detection of K99 antigen by means of agglutination and immunoelectrophoresis in *Escherichia coli* isolates from calves and its correlation with entero-toxigenicity. Inf Imm 13:1369-1377, 1976. - 75. Braaten, BA, Myers, LL: Biochemical characteristics of enterotoxigenic and nonenterotoxigenic *Escherichia coli* isolated from calves with diarrhea. Am J Vet Res 38:1989-1991, 1977. - 76. Hadad, JJ, Gyles, CL: The role of K antigen of enteropathogenic *Escherichia coli* in colonization of the small intestine of calves. Can J Comp Med 46:21-26, 1982. - 77. Smith, HW, Linggood, MA: Further observations on *Escherichia coli* enterotoxins with particular regard to those produced by atypical piglet strains and by calf and lamb strains: the transmissible nature of these enterotoxins and of a K antigen possessed by calf and lamb strains. J Med Micro 5:243-250, 1972. - 78. Hancock, DD, Kohler, EM, Lance, SE: Epidemiology of K99+ *E. coli* infection in heifer calves during the first week of life in 20 dairy herds. Proc CRWAD 63:45, 1982. - 79. Mebus, CA, White, RG, *et al.*: Immunity to neonatal calf diarrhea virus. JAVMA 163:880-883, 1973. - 80. Thurber, ET, Bass, EP, Beckenhaur, WH: Field trial evaluation of a reo-coronavirus calf diarrhea vaccine. Can J Comp Med 41:131-136, 1977. - 81. Newman, FS, Myers, LL, *et al.*: Licensing and use of calf scours vaccine. Part II. An analysis of Scourvax-Reo. Proc 77th Ann Mtg US Anim Hlth Assoc, 59-64, 1973. - 82. DeLeeuw, PW, Ellens, DJ, *et al.*: Rotavirus infections in calves: efficacy of oral vaccination in endemically infected herds. Res Vet Sci 29:142-147, 1980. - 83. Hancock, DD, Saif, LJ, *et al.*: Evaluation of response to field use of commercial oral rotavirus-coronavirus vaccine in 10 Ohio diary herds. Proc CRWAD 62:43, 1981. - 84. Theodoridis, A, Prozesky, L, *et al.*: Studies on neonatal calf diarrhea caused by rotavirus: transmission of the disease and attempted vaccination of colostrum deprived calves. Onderstepoort J Vet Res 47:31-34, 1980. - 85. Snodgrass, DR, Fahey, KJ, *et al.*: Passive immunity in calf rotavirus infections: maternal vaccination increases and prolongs immunoglobulin Gl antibody secretion in milk. Inf Imm 28:344-349, 1980. - 86. Myers, LL, Snodgrass, DR: Colostral and milk antibody titers in cows vaccinated with a modified live rotavirus-coronavirus vaccine. JAVMA 181:486-488, 1982.