



Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.

SYMPOSIUM: DISEASE PREVENTION IN CALVES

Factors Affecting Susceptibility of Calves to Disease

J. H. B. ROY

National Institute for Research in Dairying
Shinfield, Reading
Berkshire, United Kingdom

ABSTRACT

Enteric and respiratory disorders are the main hazards to successful calf rearing. The many interrelated factors in the etiology of these disorders are reviewed, and an attempt has been to classify the factors into those of a microbiological, immunological, nutritional, genetic, physical, or psychological nature.

No one would dispute that enteric and respiratory disorders are the two main hazards to calf health, but many would argue about the relative importance of specific pathogens and other predisposing factors in the etiology of these disorders.

Classification of Enteric Disorders

Classification of neonatal diarrhea, i.e., feces of less than 120 g dry matter/kg, has been attempted at least twice. First, it has been classified on the substrate on which the dominant microorganisms thrive. In this scheme diarrhea was classified either as putrefactive, in which the saccharo-proteolytic organisms such as *Escherichia coli*, whose main activity is proteolytic, predominated, or fermentative in which the saccharolytic organisms, such as lactobacilli, prevailed; their activity is associated with the conversion of sugar mainly to lactic acid (186). Second, diarrhea has been classified as nutritional or infectious, the former usually being synonymous with fermentative and the latter with putrefactive diarrhea.

The risks of research workers being at cross-purposes when discussing diarrhea is shown by the early work of Williams Smith. Contrary to the views of most other workers on the subject, he suggested that lactobacilli rather than *E. coli* were associated with calf diarrhea and that high counts of *E. coli* were due to

agonal invasion (157). However, it now seems likely that his studies were confined mainly to calves that had fermentative diarrhea where body weight loss was about 6% compared to a loss of up to 17 or even 24% in the much more severe putrefactive diarrhea (60). Over the years, many attempts have been made to control the growth of *E. coli* in the alimentary tract by including lactobacilli in the feed of calves. Indeed, it has been claimed that administration of enterococci and lactobacilli before the first feed of colostrum and for the next 3 days reduced mortality and incidence of diarrhea (183). The definitions of putrefactive and fermentative diarrhea are not mutually exclusive; damage caused to the villi of the duodenal mucosa by mixed infections of rotavirus and *E. coli* may reduce intestinal enzyme activity, e.g., lactase (22), and this may result in fermentation in the large intestine (54) with production of organic acids of low molecular weight, especially lactic and acetic acids. Thus, a primary putrefactive diarrhea may be associated with a secondary fermentative diarrhea. Moreover, subdivision into infectious or nutritional diarrhea cannot be upheld since nutritional diarrhea from gastric dysfunction may develop into an infectious diarrhea if enteropathogenic strains of *E. coli* become dominant in the environment.

It is sobering to go back some 55 yr to the classical work of Theobald Smith and his colleagues at the Rockefeller Institute for Medical Research at Princeton, who in the period after World War I established the basic knowledge on *E. coli* infection in calves, which has been confirmed at 20 to 25 yr intervals by successive generations of research workers in their attempts to make further progress. Even in 1925, Theobald Smith commented that calf diarrhea had been the subject of extensive investigations, but it was he who indicated that *E. coli* diarrhea in calves resembled cholera in man, and he, therefore, referred to it as calf cholera (160). The similarity with cholera and the dissimilarity from fermentative diarrhea in

Received August 3, 1979.

infants has been reaffirmed recently (184, 185). It was Theobald Smith also who showed that coli adhered to the mucous membrane of the ileum and spread towards the duodenum, and it was he who suggested that *E. coli* became dominant in the alimentary tract as a result of failures in peptic digestion.

However, areas of dispute still exist; most investigators agree that fermentative diarrhea occurs in the large intestine and that the primary site of establishment of *E. coli* is in the ileum, but there is disagreement as to how far the organism spreads towards the duodenum in enteropathogenic diarrhea. Ingram (60) showed that within 5.5 h of birth, coli were restricted mainly to the ileum and large intestine, but by 8.5 h after birth, they were also in the abomasum at 10^3 /ml. In the duodenum the viable *E. coli* reached a peak at 1 to 4 days of age, and in normal healthy calves declined to small numbers at 10 days of age (10 to 10^2 /ml), presumably because of the dominance of lactobacilli. In contrast, calves whose deaths were associated with a localized intestinal infection had viable counts of 10^7 to 10^8 /ml in the duodenum at this latter stage. Similarly, Theobald Smith (160) showed that *E. coli* reached the cecum within 12 h of birth in calves that were not fed, and that even in calves killed and promptly examined, coli were in the duodenum in large numbers. He pointed out that in the last few hours before death, coli spread rapidly throughout the intestine. Although the location of *E. coli* is of interest, it is perhaps irrelevant in relation to its effect since the enterotoxin or a mediator, possibly cyclic AMP, produced at one site results in excessive secretion throughout the rest of the small intestine (20). In addition, although rotavirus appears to damage the mucosa of the duodenum by shortening the villi and replacing the tall columnar epithelium by a short cuboid form, (115, 116), there is disagreement as to how far rotavirus spreads towards the ileum (116, 131).

Because of the complexity of health problems in relation to interactions of the various environments that impinge on the calf, each environment will be considered separately in relation to enteric and respiratory disorders. These two groups of disorders occur at different ages, enteric disorders being limited largely to the first 10 days of life and respiratory infections being most important from 6 to 8 wk

of age onwards. Both conditions are aggravated by domestication of cattle.

Microbiological Environment

In neonatal enteric disease, *E. coli* appears to be the most important pathogen, although in certain situations there is clear evidence of viruses, such as rotavirus and coronavirus, being involved either alone or together with *E. coli* (54). The relative importance of these viruses (104, 194) and enteropathogenic strains of *E. coli* has yet to be elucidated (1, 103, 112, 114), but it appears that in general, although there are exceptions (1), rotavirus becomes established some time before *E. coli* and that rotavirus increases the pathogenicity of *E. coli*. A further unrelated virus that caused diarrhea for only 24 h in gnotobiotic calves resulted in mortality if an *E. coli* strain with K99 antigen was also present (117).

In colostrum-deprived calves, *E. coli* septicemia tends to be associated with a heterogeneous collection of strains of *E. coli*, but in colostrum-fed calves, septicemia arising from *E. coli* seems to be associated with increased virulence of certain strains that produce colicine V (158). Enteropathogenic strains usually are associated both with K99 antigen (128), which assists in adherence to the intestinal epithelium, and with a heat-stable toxin (20, 61, 127, 155). It has been claimed that the ileal site has a specificity for adherence of the K99 antigen.

In conscious calves, the enterotoxin resulted in increased intestinal secretion of water and a variable change in sodium (19), but in anesthetized calves it resulted in a decrease in unidirectional fluxes of water and of sodium (21). The fluxes of fluid into and out of the intestine are large, being 80 liters/day, although 5.5 to 6.0 liters/h based on fluxes at the ileum has been suggested. In the normal healthy calf, the differences in the fluxes may be only 50 ml/day, but in the diarrheic calf the difference may be 1 liter/day, and a difference of up to 2.5 liter/day will cause dehydration and death. The flux of fluid seems to occur into the abomasum as well, but the fluid is not gastric gland secretion since it is of high pH and hypertonic (184). Although continuing to feed milk to calves that have diarrhea can help maintain normal plasma volume, the practice does not appear to reduce mortality (43, 44).

The enterotoxin, at least in the rabbit, affects gut movement as well as secretion (18). It is possibly similar to the vasoactive intestinal peptide that causes watery diarrhea in man. In pigs this peptide caused diarrhea associated with a hypokalemia (125).

The colon seems at first to increase its absorption of fluid to make up for the loss into the small intestine (21), but it in turn becomes overwhelmed. This situation could be aggravated by a secondary fermentation that may increase osmotic activity and stimulate fluid excretion into the colon. The calf may succumb from dehydration and a metabolic acidosis, but how far adrenal exhaustion and lack of aldosterone (21) play a part is not known. There is disagreement on how often a hyperkalemia occurs before death (143); some reports consider hyperkalemia to be rare (39).

Interference with the balance of *E. coli* and lactobacilli in the intestine can result from infection with highly invasive enteropathogenic strains of *E. coli*, from changes in the composition of the abomasal outflow, particularly abnormal amounts of protein and peptides, or from the use of antibiotics (186). Malabsorption of Ig may be closely related to the microbial population (63), and in damage by rotavirus, malabsorption has been measured by impaired D-xylose absorption (195).

A "build up" of infection may occur in a calfhouse when a large number of newborn calves are introduced successively into a building (142). It is associated with an increasing incidence of diarrhea and mortality associated with the development and dominance of enteropathogenic strains of *E. coli* (191).

The rate of build up is related to: (a) the immune status of the calf, (b) the postcolostral diet of the calves, and (c) probably the air space in terms of cubic capacity per calf and the ventilation rate in the calfhouse.

The use of an uncontaminated or disinfected house to break the cycle of infection and the rearing of calves on an all-in, all-out basis have the greatest effect on the disease pattern on farms (119, 121, 197). The purchase of calves for farms which mainly rear home-bred calves is another potent cause of increased mortality (13).

Reduced mortality in newborn calves has been reported by Czechoslovakian workers who vaccinated the dams with a polyvalent serum

against six *E. coli* "O" groups. In addition, the recovery of calves affected with enteritis was achieved by feeding them four doses of 50 ml immune serum against the same six strains of *E. coli* (146). Other workers have suggested that vaccination of the pregnant cow reinforces the protective properties of her colostrum, is effective against septicemic colibacillosis, and may be satisfactory against the enteric form (72), especially if K99 antigen is used as a vaccine (27). With rotavirus, inoculation of gnotobiotic calves with an attenuated strain produced protection within 7 to 21 days but not within 3 to 5 days (193).

In respiratory disorders, the relative importance of bacteria, viruses, chlamydia, and mycoplasmas still has not been elucidated (12, 133), but here also virus(es) appear to be established first and exacerbate the effect of secondary bacterial invasion (67). Multiple infection with viruses seems to be of particular importance (122, 178). For parainfluenza type 3, complete protection against challenge has been claimed for two subcutaneous injections with an inactivated vaccine (135).

The Immunological Environment

The quantity of each class of immunoglobulin (Ig) ingested and the time after birth that ingestion occurs are vital factors in determining the immunological status of the calf. As little as 14 g Ig administered within 12 h postpartum will protect the majority of calves against a septicemia (5), but 300 to 400 g Ig are required to ensure complete protection of calves against a heavy challenge of infection with enteropathogens. In terms of quantity of colostrum, complete protection normally requires about 1.7 kg/feed in four feeds over the first 36 to 48 h of life. When two feeds, each of 2 kg first-milking colostrum, were given by bucket at 4 h and 14 h postpartum, Ig concentration in serum was higher than in calves receiving colostrum from their dams, whereas the concentration was lower when only the first feed was given (34). The amount of colostrum given in the first feed has been considered to be of considerably greater importance than the time that elapses between birth and the first feed of colostrum. In this work, the concentration of serum Ig was not influenced to any great extent by the amount of colostrum given in subsequent feeds (120). Even colostrum given by stomach tube

allowed adequate absorption of Ig and it appears that the preruminant rumen can empty itself efficiently (126).

The rate of absorption of the different classes of Ig varies, and it has been suggested that IgM, because of its greater molecular size, is absorbed less efficiently than IgG and IgA and that percentage absorption of IgM, unlike that of IgG and IgA, increases as the amount ingested decreases. With 1 to 5 g, IgM absorption exceeded 90%. However there was a wide variation in absorption of Ig from different samples of colostrum of similar Ig concentration (168). Maximum serum Ig concentrations were reached sooner after sucking for IgG than for IgM and earlier for IgM than for IgA. This difference could be due to different rates of transport across the epithelial cells or to different intravascular and extravascular distribution of the different Ig classes (97). The percentages absorption of IgG, IgM, and IgA have been 90, 59, and 48% (132). The time of "closure" to absorption of intact Ig varies from 16 h after birth for IgM to 22 h for IgA and 27 h for IgG. Thus, if colostrum is ingested late, the calf may be deficient in IgM (132). To be effective prophylactically and prevent bacterial adherence, colostrum must be fed prior to establishment of the microflora (98). Bacteria that become established in the small intestine before the first colostrum feed can be absorbed by pinocytosis in the same manner as for Ig (29), and, moreover, the presence and multiplication of bacteria may affect absorption by accelerating cell migration along the villi and reduce "closure" time (62, 63).

The role of the lymphocytes in colostrum in the transfer of cell-mediated immunity to the calf is yet to be elucidated (130). A marked increase occurs in blood neutrophils between 6 and 12 h after birth in colostrum-fed calves, and phagocytosis is much more efficient in colostrum-fed than colostrum-deprived calves (84). In fact neutrophil counts are correlated with serum IgG₁ concentrations at 24 h of life (48). Administration of corticosteroids to suppress cell-mediated immunity in calves resulted in deaths from bovine viral diarrhea (BVD) virus but only if calves did not have passive immunity in the form of neutralizing antibodies to BVD virus. It has been suggested that some viruses can be controlled by antibody alone, whereas both cellular and humoral immunity are required to

protect against other viruses such as infectious bovine rhinotracheitis (153). The role of other nonspecific antimicrobial factors in colostrum and milk such as lysozyme, lactoferrin, and the lactoperoxidase/thiocyanate/hydrogen peroxide system has yet to be elucidated (136).

Yield of colostrum, but not Ig concentration, may be reduced by prepartum nutrition (94); for instance, low protein intakes by suckling beef cows had no effect on the Ig concentration in their colostrum (46). Although it was considered that the mass of Ig produced in colostrum by individual cows was similar irrespective of yield (78), little is known about the control of Ig concentration (101). High yielding dairy cows have higher Ig concentrations than one might expect, suggesting that passage of Ig into the udder is under hormonal control, possibly by estrogens causing an increased permeability of the capillaries (32, 138). Concentrations of Ig in colostrum were similar for the first three parities of Holstein cows, but older animals had a higher IgG concentration in colostrum (78, 129). The rate of reduction of Ig concentration in successive milkings was greater in younger animals (129), but no reduction occurred until 9 h postpartum if only colostrum samples were taken (171). However, calves from greater than the eighth parity tended to have lower Ig concentration in their serum (95).

The relative immunological status of the calf depends on the burden of infection in the environment. Small amounts of colostrum will protect against enteropathogenic strains of *E. coli* in one environment but not in another (141). Calves that subsequently die from enteropathogenic *E. coli* infection in general have lower serum Ig concentrations than those that are affected but survive (13). In the US, calves in low-mortality herds survived with serum Ig concentrations that would not protect them in high-mortality herds (38). However, for purchased calves about 1 wk of age, it has been suggested that serum Ig concentration is not a good predictor of subsequent health (7). The Ig requirement for protection against salmonellosis appears to be about twice that required for protection against *E. coli* (40).

The IgM (10% of total colostrum Ig) is of most importance in protection against septicemia. The role of Ig in the lumen of the alimentary tract is not clear. The IgG and IgM are of comparable activity in prevention, but not of

curing, enteric infection with IgA being less effective (99, 100). After colostrum-feeding, secretory IgA concentration was high in serum but disappeared rapidly, reentering the intestinal lumen. The IgA in the feces steadily declined over the first 2 wk of life (134). The necessity to prevent interference with rumen fermentation was considered the reason for the low IgA concentration in colostrum, but rumen fermentation does not start before 7 to 10 days of age. Moreover, IgA deficiency in secretions is overcome partly by enhanced local synthesis and secretion of IgM, which has been associated with a secretory component (151). Although high serum Ig concentrations have been associated with reduced susceptibility of calves to rotavirus infection (192), absorbed antibodies apparently do not give protection whereas maternal antibodies remaining in the intestine are effective. Thus, there is benefit from continued feeding of colostrum even after "closure" (56, 161, 192).

Although colostrum whey presumably passes out rapidly from the abomasum and acid secretion in the neonate is limited, little is known about conditions required for Ig degradation. Although all three main classes appear in the feces within 48 h of birth (99), the amounts that survive have not been determined. The IgG₁ is digested easily by pepsin (80, 81) but not by pancreatic enzymes (16), whereas the reverse is true for IgG₂ (74).

Fecal excretion of IgG has been inversely related to serum IgG and IgA concentrations and has been greatest in those calves that die (45), suggesting malabsorption of Ig due to early bacterial establishment or possibly intraluminal leakage of Ig.

Turbidity tests for Ig are a measure of the intravascular concentration of total Ig (42). In man, 40% IgG, 40% IgA, and 80% IgM are intravascular. In cows around parturition, both IgG₁ and IgG₂ are divided equally between the intravascular and extravascular pools (147). In the infant, it was considered that the main harmful products of the multiplication of *E. coli* were toxins and amines, and it was suggested that the degree of injury to the intestinal walls depends on the activity of the amine oxidases and the amount of antibody in the cell walls of the colon (186). In the calf it has been suggested that microorganisms multiplying in the digestive tract may degrade Ig (63) and that

hypercatabolism of IgG in diarrheic calves may be playing a role in detoxification (113).

Determinations of the half-lives of IgG, IgM, and IgA have given varied results, but IgG has the longest. One report gave these half-lives: IgG, 20 to 21.5 days; IgM, 4 days; and IgA, 2 to 2.8 days (134). From measurements of the disappearance of I¹²⁵, the half-life of IgG₁ was 11.5 days (148), and another report gives 11 days for IgG, 3.4 days for IgM, and 3 days for IgA (41). The rate of decline of passively acquired antibodies varies with initial level and among different calves (75). Although precolostral calf serum in normally devoid of Ig or contains only small amounts, antibodies against viruses before suckling have been found in calves from vaccinated and unvaccinated dams (49, 120). Calves born with a high titer to BVD virus retained a high titer for 1 yr (28), whereas colostrum-derived antibodies to BVD generally decreased during the first 4 to 6 mo of age (28, 75). Colostrum-deprived calves that survive begin producing their own autogenous antibodies to *E. coli* from about 10 days of age, the serum concentrations reaching normal at about 8 wk of age. Autogenous or endogenous antibody production begins much earlier in colostrum-deprived or hypogammaglobulinemic than in colostrum-fed calves (58, 96). If only one class of Ig is fed, then the autogenous appearance of only that class will be delayed (99). High Ig concentrations in blood are important in protection from arthritis and pneumonia as well as from enteric disorders since Ig appears in synovial fluid within 4 to 8 h of colostrum ingestion (167) and IgG₁ and IgG₂ are transferred with equal facility to the fluid bathing the mucosa of the respiratory tract in lambs (187). High concentrations in serum of IgG₁ in particular, and also of IgG₂ and IgA but not of IgM, at 2.5 wk of age were associated with a reduced susceptibility to pneumonia at 2.5 mo (188). High serum Ig concentrations at 24 h also were associated with subsequent protection against pneumonia and delayed its onset (48).

Nutritional Environment

Under good management conditions, the ad lib feeding of whole milk or good quality milk substitute does not lead to diarrhea (86). Although differences in mortality between calves given whole milk and those given milk substi-

tutes have not always been significant (55), the composition of the diet fed after the colostrum-feeding period can have a major effect on the incidence of enteric disease and of mortality (164). The severity of the effect will depend on the immune status of the calf in relation to the burden of infection in the environment (141). The burden of infection, in turn, may be affected by the proportion of calves in a calf house that are receiving a detrimental diet. Severely preheated skim milk powders (83, 91, 92, 93, 141) and nonmilk proteins (182), which do not coagulate in the abomasum (35), may reduce gastric acid (172) (an important protective barrier to the multiplication of *E. coli*) and gastric enzyme secretion (50, 189), reduce proteolysis (87), increase escape of undigested protein into the duodenum (69, 172), and reduce pancreatic enzyme secretion (175, 177). However, severe heat treatment of milk may have no ill effects with calves reared out of doors (33). Similarly, within nonmilk protein sources differences in the rate of release of intact protein from the abomasum may not be a major factor in determining the overall digestibility of such proteins in milk substitute diets (26). Nevertheless, increases in the proportion of pathogenic to total *E. coli* under farm conditions often follow changes in diet (197). In the US, there is the American Dry Milk Institute (ADMI) classification of milk powders (3) so that a powder processed with a mild heat treatment can be used in milk substitute diets, but no such system exists in Europe.

The rate of flow of fluids from the abomasum after a feed does not differ markedly between diets except during the 1st h after feeding unless gastric stasis occurs as with certain soya preparations (154, 159). The outflow is controlled by a feedback mechanism associated with hormones possibly gastrin, from osmo- and pH-receptors in the duodenum. The pattern of emptying in relation to time after a feed is exponential, and the halftime of emptying is the same irrespective of volume consumed. Very acid conditions in the duodenum completely inhibit emptying and gastric electromyograms except after a very large meal when inhibition is incomplete (9, 10, 11). In man gastric emptying is fastest with isotonic solutions (118), and it has been suggested that the products of digestion of isoenergetic amounts of carbohydrate, fat, and protein have equal

effects in the duodenum in slowing the rate of gastric emptying (17, 59). In spite of small differences between diets in the rate of flow of liquid from the abomasum, the rate of flow of nutrients, e.g., protein and lipids, differs markedly between diets, especially if they do not coagulate in the abomasum (15, 177).

Diarrhea in suckled calves has been associated with changes in the composition of whole milk as a result of their dams grazing particular pastures (152). High nitrogen fertilization may affect coagulation of milk (25). Moreover, suckler cows may be sufficiently deficient in calcium to prevent coagulation of their milk, thus causing diarrhea in their calves associated with a marked distension of the abomasum, either due to gastric stasis or due to hypersecretion of fluid into the abomasum (70). Both these conditions of suckling calves could be alleviated by feeding additional calcium to the calves (70, 152).

Increased incidence of diarrhea will occur in calves given diets containing high concentrations of fat, especially if the fat is of low inherent digestibility, but the diarrhea is rarely watery. However, even with butterfat, concentrations of 490 and 550 g/kg dry matter resulted in a high incidence of diarrhea (89). Low-fat diets (skim milk containing only 10 g fat/kg dry matter) in comparison with high-fat diets (200 g/kg dry matter) also caused an increased incidence of diarrhea (144); this possibly may be exacerbated if the diet contains only a low concentration of dry matter, i.e., 90 to 100 g dry matter/kg. However, with once-daily feeding high dry matter concentrations (200 g dry matter/kg), have been associated with an increased incidence of diarrhea (65).

Although low-fat diets do not adversely affect gastric proteolysis, pancreatic enzyme activity is reduced (175, 177). The diarrhea may be of a fermentative type similar to that produced by diets containing too much soluble carbohydrate. The highest amount of soluble carbohydrate that can be included without causing fermentative diarrhea (150 g dry matter/kg feces) in the lamb is a hexose-equivalent of about 13.9 g/kg live weight (51). Similarly in young calves, increasing the lactose intake to 480 g/day resulted in increased incidence of diarrhea (156).

Management practices such as bucket rather than teat-feeding, cold-milk feeding, and

once-daily-feeding may alter the delicate balance between the calf and its microbial flora since all have an effect on digestive function (87, 173, 176). Of these only cold-milk feeding seems to involve a major risk in causing diarrhea or bloat, but a tendency for higher mortality of calves being bucket-reared rather than teat-fed or reared on nurse cows has been reported (164). Rate of milk consumption is much faster with bucket feeding, but rate of coagulation of milk by rennin is greater for teat-feeding (190). Some nonmilk proteins may also cause bloat as a result of passage into the rumen (166). However, with bucket feeding, little milk passes into the rumen in preruminant calves even when milk feeding is continued to 6 mo of age (52).

It is claimed that acidified milk and possibly also fermented colostrum reduce the incidence of diarrhea and that fermentation of mastitic milk is a method of utilizing this milk for calf feeding without causing health problems (77). Treatment of a milk substitute with HCl to pH 4.25 and then dispersal of the casein clot by high-speed stirring reduced the incidence of diarrhea compared to that with the untreated milk substitute (181); appetite and digestibility during the first 3 wk of life also was reduced. How far the acid supplied in an acidified-milk alleviates a deficiency of gastric acid production because of the poor quality of the milk substitute used is not known.

Fermented rather than fresh colostrum certainly reduces serum Ig concentrations if given before "closure" of the intestines to the transfer of intact Ig into the blood stream (162), although adjusting the pH to that of fresh colostrum by addition of 7 g NaHCO₃/kg fermented colostrum improved Ig absorption (47). When fermentation was for 7 days, minimal breakdown of Ig occurred, the majority of the degradation being of casein (47). There is little evidence of a beneficial effect of feeding fermented colostrum, but it has been suggested that the natural bactericidal activity of colostrum is of greater importance in killing pathogens than the low pH because pH of 3.4 and 3.0 was required for killing salmonella and *E. coli*, respectively (196); the lactic acid produced is not sufficient to eliminate *E. coli* (179). On occasions, reduction in incidence of diarrhea has been reported for calves given fermented colostrum in comparison with those

given whole milk (137) or a milk substitute (30). On the other hand, a higher incidence of diarrhea has been reported when the colostrum was treated with .05% formaldehyde (24). However, even .1% formaldehyde was without ill-effect if the preserved colostrum was not fed until 7 days had elapsed (73). Weaning at a young age, i.e., 5 wk, may increase susceptibility of calves to respiratory infections (140, 145). Similarly, an increased incidence of pneumonia in October to December was associated with moving bull calves to testing stations within 14 days of weaning (4). However, increased susceptibility to respiratory infections has been associated with the high growth rates (1.57 kg/day) and fat deposition resulting from feeding a milk substitute diet at high dry matter concentration (165).

Genetic Environment

Associated with the marked decrease in susceptibility to enteric infections as calves grow older (88, 106) is an increase in gastric acid production and in digestibility of protein (174). However, differences exist between breeds in their susceptibility to enteric and respiratory infections.

Ayrshire and Jersey calves appear to be more susceptible than Friesians to enteric disorders, and there appear to be breed differences in efficiency of Ig absorption. Black and White Danish and Jersey calves had a higher efficiency of absorption than that of Red Danish calves (79). Friesian × Ayrshire were more efficient than Ayrshires (150) and Holsteins more efficient than Ayrshires in absorbing total Ig from Holstein colostrum with no difference for specific Ig's (8). Blue-grey cows had higher concentrations of IgG₁ and IgM but not of IgG₂ in their colostrum than did Hereford × Friesian cows, and this was reflected in the serum Ig concentrations in their calves (53). Thus, the amount of colostral antibody that reaches the neonatal blood stream depends not only on management but also on genetic attributes of both mother and offspring (163). Breed differences in digestive efficiency of postcolostral diets (144) may be due to differences in amounts of digestive enzymes (174). A breed difference in susceptibility to rotavirus also has been suggested (2).

Ayrshire calves are more resistant than Friesian or Jersey calves to respiratory infec-

tions (139, 144), and Hereford × Friesian calves are more resistant than Friesian calves. Calf losses after transportation, due mainly to pneumonia, were less for beef calves than for dairy calves which in turn were lower than for beef × dairy calves (164).

Reduced mothering ability (111), difficult calvings, weak calves, and badly shaped udders may affect colostrum ingestion by the calf (6, 96). Thus, calves left with their dams may have lower Ig concentrations than those hand-fed colostrum (124). Moreover, individual cows transfer similar amounts of Ig to their calves in successive parities (48, 53), and there is a correlation between Ig concentration of colostrum from daughters and that of their dam (31).

Physical Environment

In the US, large herds have been associated with a high incidence of calf mortality (55). With single suckler cows a high density of stocking in a building was associated with hypogammaglobulinemia in their calves because of poor mothering and poor supervision (48, 111). Large-capacity houses in Eastern Europe have been associated with a high incidence of respiratory infection (71). Lower calf mortality is associated with the calf rearer being either a farmer or a member of the farmer's family rather than an employee (55, 109). Single rather than group-penning resulted in a much lower incidence of salmonellosis (90), but in a survey in the US, overall mortality was lower for calves in group-penning (164). Solid-fronted pens and pen covers reduce air speed around the calf (123); air speed should not exceed .2 m/s except in the hot season when .3 m/s is acceptable (105). A low cubic capacity per calf and low ventilation rates may exacerbate a build up of infection. To overcome salmonellosis, a ventilation rate of 51 changes air/h and an ambient temperature of 16 to 18 C was adopted (76). Moreover, there is a marked seasonal effect in serum Ig concentrations in calves in that they decline throughout the winter even though colostrum Ig concentration does not fall (48). However, serum Ig concentrations have been correlated both positively (48) and negatively (23) with ambient temperature. Calves exposed to a hot environment with poor ventilation had lower serum IgG₁ concentrations, higher corticosteroid concen-

trations, and higher mortality (170). Calves born outside had higher Ig serum concentrations at 24 h than those born indoors (48). However, suckled calves born outside may have a much lower immune status than those born indoors without showing signs of ill-health (6, 95).

Experiments in controlled environments with few calves in climatic chambers have shown little evidence of any effect of physical environment on susceptibility to respiratory infections (66, 67). However, in groups of 24 calves, low relative humidities at a high environmental temperature and high relative humidity at a low environmental temperature appeared to increase susceptibility of calves to respiratory disease (145). Hot, dry air has been associated with histological changes in the respiratory tract (68), and in California increases in calf mortality were associated with cold, wet, and windy weather in winter and, to less extent, with hot and dry weather in summer (107, 108). Large diurnal variations in temperature (107) and relative humidity also may be important (105). Calves that were chilled when artificially infected with viruses were affected more severely and showed more extensive lung lesions (64). In the US, highest mortality in calves after transportation occurs between December and February, and movement of calves at a young age is likely to increase mortality (164).

The effect of high concentrations of gases, particularly NH₃, of fungal spores (82), and of dust on the health of the calf is equivocal. A maximum of about 25 ppm NH₃ (105, 180), under practical conditions, has been suggested although calves have been exposed to 100 ppm for 2.5 h without ill effect (110).

Psychological Environment

Calves, when in the presence of their dams rather than in isolation, appear to absorb more Ig from colostrum (36, 37, 149, 150). Induction of parturition by slow-acting (14 days) corticosteroids resulted in reduced IgG₁ transfer to colostrum (14) and reduced efficiency of absorption of Ig by calves born of such cows (57). However, quick-acting (62 h) corticosteroids appeared to have less adverse effect on colostrum Ig or on absorption of Ig by the calf (85).

Increased serum corticosteroid concentrations as a result of pain or fear might result in

reduced Ig absorption (170), but calves normally have a high serum cortisol concentration at birth, which tends to be lower in cases of dystocia; dystocia certainly does not seem to affect IgG absorption (169). In fact, giving a long-acting ACTH preparation to calves raised serum cortisol and Ig concentration at 24 h (48). The newborn calf also appears to have the competence to increase corticosterone and aldosterone production in response to the severe stress, and water and electrolyte loss that occurs in diarrhea (102). Hyperthyroidism of calves at birth seems to reduce absorption of Ig (23).

Conclusion

In this review, I have attempted to describe the interacting factors that alter the balance between the host animal and microbiological flora, thus predisposing the calf to disease. Knowledge of these interactions are necessary to give effective advice to the farming community so that ill-health in calves can be reduced.

In particular, by ensuring the ingestion of 300 to 400 g Ig from colostrum in the first 48 h of life, by the subsequent use of a milk substitute containing a mildly heat-treated milk powder (>160 mg noncasein N/g total N), and by use of well ventilated but draft-free buildings, it should be possible to reduce mortality and morbidity to negligible proportions.

REFERENCES

- 1 Acres, S. D., C. J. Laing, J. R. Saunders, and O. M. Radostits. 1975. Acute undifferentiated neonatal diarrhea in beef calves. 1. Occurrence and distribution of infectious agents. *Can. J. Comp. Med.* 39:116.
- 2 Almeida, J. D., C. R. Craig, and T. E. Hall. 1978. Multiple viruses present in the feces of scouring calf. *Vet. Rec.* 102:170.
- 3 American Dry Milk Institute Inc. 1971. Standards for grades of dry milks including methods of analysis. Bull. 916. Am. Dry Milk Inst., Chicago, IL.
- 4 Andrews, A. H. 1976. Factors affecting the incidence of pneumonia in growing bulls. *Vet. Rec.* 98:146.
- 5 Aschaffenburg, R., S. Bartlett, S. K. Kon, J. H. B. Roy, D. M. Walker, C. Briggs, and R. Lovell. 1951. The nutritive value of colostrum for the calf. 4. The effect of small quantities of colostrum whey, dialysed whey and immune lactoglobulins. *Brit. J. Nutr.* 5:171.
- 6 Barber, D. M. L. 1976. Assessment of immune globulin status. *Vet. Rec.* 98:121.
- 7 Barber, D. M. L. 1978. Serum immune globulin status of purchased calves: an unreliable guide to viability and performance. *Vet. Rec.* 102: 418.
- 8 Baumwart, A. L., L. J. Bush, and M. Mungle. 1977. Effect of potassium isobutyrate on absorption of immunoglobulins from colostrum by calves. *J. Dairy Sci.* 60:759.
- 9 Bell, F. R., and M.-L. Grivel. 1974. The role of the duodenal infusate on gastric emptying measured by the e.m.g. of gastric muscle. *J. Physiol.* 239:48P.
- 10 Bell, F. R., D. A. Titchen, and D. J. Watson. 1977. The effects of the gastric analogue, pentagastrin, on the gastric electromyogram and abomasal emptying in the calf. *Res. Vet. Sci.* 23:165.
- 11 Bell, F. R., and D. J. Watson. 1976. The influence of gastric distension and the duodenal infusate on the pattern of stomach (abomasal) emptying in the preruminant calf. *J. Physiol.* 259:445.
- 12 Bitsch, V., N. F. Friis, and H. V. Krogh. 1976. A microbiological study of pneumonic calf lungs. *Acta. Vet. Scand.* 17:32.
- 13 Boyd, J. W., J. R. Baker, and A. Leyland. 1974. Neonatal diarrhea in calves. *Vet. Rec.* 95:310.
- 14 Brandon, M. R., A. J. Husband, and A. K. Lascelles. 1975. The effect of glucocorticoid on immunoglobulin secretion into colostrum in cows. *Australian J. Exp. Biol. Med. Sci.* 53:43.
- 15 Brisson, G. J., and J. M. Gaudreau. 1977. Dietary protein sources and emptying time of the abomasum in milk-fed calves. *Can. J. Anim. Sci.* 57:849.
- 16 Brock, J. H., A. Pineiro, and F. Lampreave. 1978. The effect of trypsin and chymotrypsin on the antibacterial activity of complement, antibodies and lactoferrin and transferrin in bovine colostrum. *Ann. Rech. Vet.* 9:287.
- 17 Burn-Murdock, R. A., M. A. Fisher, and J. H. Hunt. 1978. The slowing of gastric emptying by proteins in test meals. *J. Physiol.* 274:477.
- 18 Burns, T. W., J. R. Mathias, G. M. Carlson, and J. L. Martin. 1978. Effect of toxigenic *Escherichia coli* on myoelectric activity of small intestine. *Am. J. Physiol.* 235:E311.
- 19 Bywater, R. J. 1973. Some effects of *Escherichia coli* on unidirectional fluxes of water and sodium in calf Thiry-Vella loops. *Res. Vet. Sci.* 14:35.
- 20 Bywater, R. J. 1975. A secretory effect produced in calf intestine by heat stable *Escherichia coli* enterotoxin without direct mucosal contact. *Res. Vet. Sci.* 18:107.
- 21 Bywater, R. J., and E. F. Logan. 1974. The site and characteristics of intestinal water and electrolyte loss in *Escherichia coli* induced diarrhea in calves. *J. Comp. Pathol.* 84:599.
- 22 Bywater, R. J., and W. J. Penhale. 1969. Depressed lactase activity in the intestinal mucous membrane of calves after neonatal diarrhea. *Res. Vet. Sci.* 10:591.
- 23 Cabello, G., and E. Levieux. 1978. The effects of thyroxine and climatic factors on colostrum gam-

- maglobulin absorption in newborn calves. *Ann. Rech. Vet.* 9:309.
- 24 Carlson, S. M. A., and L. D. Muller. 1977. Composition and metabolic evaluation of colostrum preserved by four methods during warm ambient temperatures. *J. Dairy Sci.* 60:566.
 - 25 Chapman, H. R., F. T. Gillespie, D. J. Knight, and G. C. Cheeseman. 1973. Composition of milk for cheesemaking. Page 121 in *Rep. Nat. Inst. Res. Dairying 1971-1972*.
 - 26 Christison, G. I., and J. M. Bell. 1977. The disappearance of vegetable protein from the abomasum of young calves. *Can. J. Anim. Sci.* 57:822.
 - 27 Contrepois, M., J. P. Girardeau, H. C. Dubourguier, Ph. Gouet, and D. Levieux. 1978. Specific protection by colostrum from cows vaccinated with the K99 antigen in newborn calves experimentally infected with *E. coli* Ent⁺, K99⁺. *Ann. Rech. Vet.* 9:385.
 - 28 Coria, M. F., and A. W. McClurkin. 1978. Duration of active and colostrum-derived passive antibodies to bovine viral diarrhoea virus in calves. *Can. J. Comp. Med.* 42:239.
 - 29 Corley, L. D., T. E. Staley, L. J. Bush, and E. W. Jones. 1977. Influence of colostrum on trans-epithelial movement of *Escherichia coli* 055. *J. Dairy Sci.* 60:1416.
 - 30 Daniels, L. B., J. R. Hall, Q. R. Hornsby, and J. A. Collins. 1977. Feeding naturally fermented, cultured and direct acidified colostrum to dairy calves. *J. Dairy Sci.* 60:992.
 - 31 Dardillat, J., G. Trillat, and P. Larvor. 1978. Colostrum immunoglobulin concentration in cows: relationship with their calf mortality and with the colostrum quality of their female offspring. *Ann. Rech. Vet.* 9:375.
 - 32 Delouis, C. 1978. Physiology of colostrum production. *Ann. Rech. Vet.* 9:193.
 - 33 Donnelly, P. E., R. J. Dean, and C. Kevey. 1976. The effects of heat treatment during processing in calf milk replacer quality. *Proc. New Zealand Soc. Anim. Prod.* 36:87.
 - 34 Dornaus, A., H.-J. Marx, H. Meyer, and H. Luster-mann. 1977. Studies on motherless calf raising with homologous outside colostrum, with special reference to feeding calves born by beef heifers. *Arch. Tierz.* 20:85.
 - 35 Emmons, D. B., and E. E. Lister. 1976. Quality of protein in milk replacers for young calves. I. Factors affecting *in vitro* curd formation by rennet (chymosin, rennin) from reconstituted skim milk powder. *Can. J. Anim. Sci.* 56:317.
 - 36 Fallon, R. J. 1977. The effect of different methods of feeding colostrum on calf blood serum immunoglobulin levels. *Anim. Prod.* 24:142.
 - 37 Fallon, R. J. 1978. The effect of immunoglobulin levels on calf performance and methods of artificially feeding colostrum to the newborn calf. *Ann. Rech. Vet.* 9:347.
 - 38 Ferris, T. A., and J. W. Thomas. 1974. Relationship of immunoglobulin to dairy calf mortality and influence of herd environment. *J. Dairy Sci.* 57:641.
 - 39 Fischer, W., and R. Butte. 1974. Comparative study of electrolyte and blood status in healthy calves and calves with enteritis. *Dtsch. Tierarz. Wochenschr.* 81:567.
 - 40 Fisher, E. W. 1977. Rehydration in calf diarrhoea. *Vet. Rec.* 101:227.
 - 41 Fisher, E. W., and A. A. Martinez. 1975. Serum immune globulins in calves receiving *Escherichia coli* endotoxin. *Vet. Rec.* 96:527.
 - 42 Fisher, E. W., and A. A. Martinez. 1976. Immune globulins and enterotoxic colibacillosis. *Vet. Rec.* 98:31.
 - 43 Fisher, E. W., and A. A. Martinez. 1976. Aspects of body fluid dynamics of neonatal calf diarrhoea. *Res. Vet. Sci.* 20:302.
 - 44 Fisher, E. W., and A. A. Martinez. 1978. Studies in neonatal calf diarrhoea. 7. The effects of milk intake. *Brit. Vet. J.* 134:234.
 - 45 Fisher, E. W., A. A. Martinez, Z. Trainin, and R. Meirum. 1975. Studies of neonatal calf diarrhoea. 2. Serum and faecal immune globulin in enteric colibacillosis. *Brit. Vet. J.* 131:402.
 - 46 Fishwick, G., and D. Clifford. 1975. The effects of a low protein intake by beef cows during pregnancy on the voluntary intake of roughage, the composition of the colostrum and the serum immune globulin concentration of their calves. *Proc. Nutr. Soc.* 34:74.
 - 47 Foley, J. A., A. G. Hunter, and D. E. Otterby. 1978. Absorption of colostrum proteins by newborn calves fed unfermented, fermented or buffered colostrum. *J. Dairy Sci.* 61:1450.
 - 48 Ford, E. J. H., J. W. Boyd, and R. A. Hogg. 1978. Investigation into possible relationships between the quality of colostrum and the subsequent performance of calves. Page 4 in *Index Res. Meat and Livestock Comm.*
 - 49 Franz, J., J. Krejci, and J. Mensik. 1974. Serum antibodies and immunoglobulins of newborn calves. *Zbl. Vet. Med.* B21:540.
 - 50 Garnot, P., R. Toullec, J. L. Thapon, P. Martin, M-T Hoang, C. M. Mathieu, and B. R. Dumas. 1977. Influence of age, dietary protein and weaning on calf abomasal enzymic secretion. *J. Dairy Res.* 44:9.
 - 51 Gibney, M. J., and D. M. Walker. 1978. Milk replacers for preruminant lambs: protein and carbohydrate interactions. *Australian J. Agric. Res.* 29:133.
 - 52 Guilhermet, R., C. M. Mathieu, and R. Toullec. 1975. Transit of liquid food through the oesophageal groove in the preruminant and ruminant calf. *Ann. Zootech.* 24:69.
 - 53 Halliday, R., A. J. F. Russel, M. R. Williams, and J. N. Peart. 1978. Effects of energy intake during late pregnancy and of genotype on immunoglobulin transfer to calves in suckler herds. *Res. Vet. Sci.* 24:26.
 - 54 Halpin, C. G., and I. W. Caple. 1976. Changes in intestinal structure and function of neonatal calves infected with reovirus-like agent and *Escherichia coli*. *Australian Vet. J.* 52:438.
 - 55 Hartman, D. A., R. W. Everett, S. Y. Slack, and

- R. G. Warner. 1974. Calf mortality. *J. Dairy Sci.* 57:576.
- 56 Henderson, W. M. 1976. The disease handicap to animal production. *Brit. Vet. J.* 132:136.
- 57 Husband, A. J., N. R. Brandon, and A. K. Lascelles. 1973. The effect of corticosteroid on absorption and endogenous production of immunoglobulins in calves. *Australian J. Exp. Biol. Med. Sci.* 51:707
- 58 Husband, A. J., and A. K. Lascelles. 1975. Antibody responses to neonatal immunisation in calves. *Res. Vet. Sci.* 18:201.
- 59 Hunt, J. N., and D. F. Stubbs. 1975. The volume and energy content of meals as determinants of gastric emptying. *J. Physiol.* 245:209.
- 60 Ingram, P. L. 1962. Observations on the pathology and pathogenesis of experimental colibacillosis in calves. Ph.D. thesis, University of London, London, England.
- 61 Isaacson, R. E., and R. A. Schneider. 1978. Distribution and virulence of *Escherichia coli* in the small intestines of calves with and without diarrhea. *Am. J. Vet. Res.* 39:1750.
- 62 James, R. E., and C. E. Polan. 1978. Effect of orally administered duodenal fluid on serum proteins in neonatal calves. *J. Dairy Sci.* 61:1444.
- 63 James, R. E., C. E. Polan, T. L. Bibb, and B. E. Laughon. 1976. Effect of orally administered duodenal fluid on susceptibility of newborn calves to an *Escherichia coli* challenge. *J. Dairy Sci.* 59:1493.
- 64 Jennings, A. R., and R. E. Glover. 1952. Enzootic pneumonia in calves. II. The experimental disease. *J. Comp. Pathol.* 62:6.
- 65 Jenny, B. F., S. E. Mills, W. E. Johnston, and G. D. O'Dell. 1978. Effect of fluid intake and dry matter concentration on scours and water intake in calves fed once daily. *J. Dairy Sci.* 61:765.
- 66 Jericho, K. W. F., and C. le Q. Darcel. 1978. Response of the respiratory tract of calves kept at controlled climatic conditions to bovine herpesvirus 1. *Can. J. Comp. Med.* 42:156.
- 67 Jericho, K. W. F., and E. V. Langford. 1978. Pneumonia in calves produced with aerosols of Bovine herpesvirus 1 and *Pasteurella haemolytica*. *Can. J. Comp. Med.* 42:269.
- 68 Jericho, K. W. F., and S. E. Magwood. 1977. Histological features of respiratory epithelium of calves held at differing temperature and humidity. *Can. J. Comp. Med.* 41:369.
- 69 Johnson, R. J., and J. Leibholz. 1976. The flow of nutrients from the abomasum in calves fed on heat-treated milks. *Australian J. Agric. Res.* 27:903.
- 70 Johnston, W. S., and G. K. Maclachlan. 1977. Digestive illness in the calf associated with coagulation of cows' milk. *Vet. Rec.* 101:325.
- 71 Jurmanova, K., M. Hajkova, J. Krejci, and J. Cerna. 1975. The participation of mycoplasma in the respiratory diseases of calves in large-capacity calf-houses in the Czech-Socialist Republic. *Vet. Med., Praha.* 20:583.
- 72 Kaeckenbeeck, A. 1976. On the neo-natal infection of the calf. 9th Int. Congr. Dis. Cattle, Paris 1:193.
- 73 Kaiser, A. G. 1977. The use of colostrum preserved with formalin for rearing calves. *Australian J. Exp. Agric. Anim. Husb.* 17:221.
- 74 Kanamura, Y., R. Niki, and S. Arima. 1977. Susceptibility of bovine colostrum immunoglobulin G (IgG) subclasses to digestive enzymes and reducing agents. *Agric. Biol. Chem.* 41:1203.
- 75 Kendrick, J. W., and C. E. Franti. 1974. Bovine viral diarrhea decay of colostrum-conferred antibody in the calf. *Am. J. Vet. Res.* 35:589.
- 76 Kertz, A. F. 1977. Calf health, performance and experimental results under a commercial research facility and program. *J. Dairy Sci.* 60:1006.
- 77 Keys, J. E. 1977. Mastitic milk can be fed to calves after fermentation, it causes no health problems. *Hoard's Dairyman.* 122:1219.
- 78 Kruse, V. 1970. Yield of colostrum and immunoglobulin in cattle at the first milking after parturition. *Anim. Prod.* 12:619.
- 79 Kruse, V. 1970. Absorption of immunoglobulin from colostrum in newborn calves. *Anim. Prod.* 12:627.
- 80 Kumano, Y., Y. Kanamaru, R. Niki, and S. Arima. 1976. Degradation of bovine IgG₁ immunoglobulin by rennin and pepsin. *Japanese J. Zootechnol. Sci.* 47:543.
- 81 Kamano, Y., Y. Kanamaru, R. Niki, and S. Arima. 1976. Occurrence of bovine IgG₁ fragment in faeces of newborn calf. *Japanese J. Zootechnol. Sci.* 47:554.
- 82 Lacey, J. 1968. The microflora of fodders associated with bovine respiratory disease. *J. Gen. Microbiol.* 51:173.
- 83 Laksessvela, B., P. Slagsvold, and T. Landsverk. 1978. Indigestion in young calves. 3. The influence of powders from heat-treated skim milk and whey. *Acta. Vet. Scand.* 19:159.
- 84 Lamotte, G. B., and R. J. Eberhart. 1976. Blood leukocytes, neutrophil phagocytosis and plasma corticosteroids in colostrum-fed and colostrum-deprived calves. *Am. J. Vet. Res.* 37:1189.
- 85 Langley, O. H., and K. J. O'Farrell. 1976. Immune status of dairy calves following induced parturition. *Vet. Rec.* 99:187.
- 86 Leibholz, J. 1975. Diarrhea of nutritional origin in young calves. *New South Wales Vet. Proc.* 11:19.
- 87 Leibholz, J. 1975. Dietary effects on the flow of nutrients from the abomasum of the preruminant calf. *Australian J. Agric. Res.* 26:623.
- 88 Leonard, H. A., and D. L. Gardner. 1975. Dairy heifer and calf mortality. *J. Dairy Sci.* 58:1240. (Abstr.)
- 89 Liebenberg, L. H. P., and F. J. van der Merwe. 1974. The utilisation of milk diets with different fat content by the preruminant calf. 1. Digestibility and metabolizability of the diets and live mass gain of calves. *S. African J. Anim. Sci.* 4:21.
- 90 Linton, A. H., K. Howe, W. Pethiyagoda, and A. D. Osborne. 1974. Epidemiology of salmonella infection in calves. 1. Its relation to their husbandry and management. *Vet. Rec.* 94:581.
- 91 Lister, E. E., and D. B. Emmons. 1974. Gel formation as a quality index of calf milk replacers. *Int. Dairy Congr.* 19:IE 120.

- 92 Lister, E. E., and D. B. Emmons. 1974. Skim milk quality and energy: protein ratios in calf milk replacer diets. *J. Dairy Sci.* 57:650. (Abstr.)
- 93 Lister, E. E., and D. B. Emmons. 1976. Quality of protein in milk replacers for young calves. 2. Effects of heat treatment of skim milk powder and fat levels on calf growth, feed intake and nitrogen balance. *Can. J. Anim. Sci.* 56:327.
- 94 Logan, E. F. 1977. The influence of husbandry on colostrum yield and immunoglobulin concentration in beef cows. *Br. Vet. J.* 133:120.
- 95 Logan, E. F., and T. Gibson. 1975. Serum immunoglobulin levels in suckled beef calves. *Vet. Rec.* 97:229.
- 96 Logan, E. F., D. G. McBeath, and B. G. Lowman. 1974. Quantitative studies on serum immunoglobulin levels in suckled calves from birth to five weeks. *Vet. Rec.* 94:367.
- 97 Logan, E. F., C. H. McMurray, D. G. O'Neill, P. J. McParland, and F. J. McRory. 1978. Absorption of colostral immunoglobulins by the neonatal calf. *Br. Vet. J.* 134:258.
- 98 Logan, E. F., G. R. Pearson, and M. S. McNulty. 1977. Studies on the immunity of the calf to colibacillosis. 7. The experimental reproduction of colibacillosis in colostrum-fed calves. *Vet. Rec.* 101:443.
- 99 Logan, E. F., A. Stenhouse, and D. J. Ormrod. 1974. The role of colostral immunoglobulins in intestinal immunity to enteric colibacillosis in the calf. *Res. Vet. Sci.* 17:290.
- 100 Logan, E. F., A. Stenhouse, W. J. Penhale, and M. Armishaw. 1974. Studies on the immunity of the calf to colibacillosis. 6. The prophylactic use of a pooled serum IgM-rich fraction under field conditions. *Vet. Rec.* 94:386.
- 101 Lomba, F., I. Fumiere, M. Tshibangu, G. Chauvaux, and V. Bienfet. 1978. Immunoglobulin transfer to calves and health problems in large bovine units. *Ann. Rech. Vet.* 9:353.
- 102 Lopez, G. A., R. W. Phillips, and L. D. Lewis. 1975. Plasma corticoid changes during diarrhea in neonatal calves. *Am. J. Vet. Res.* 36:1245.
- 103 Marin, M., S. Larivere, and R. Lallier. 1976. Pathological and microbiological observations made on spontaneous cases of acute neonatal calf diarrhoea. *Can. J. Comp. Med.* 40:228.
- 104 Marsolais, G., R. Assaf, C. Montpetit, and P. Marios. 1978. Diagnosis of viral agents associated with neonatal calf diarrhoea. *Can. J. Comp. Med.* 42:168.
- 105 Martig, J., P. H. Boss, J. Nicolet, and F. Steck. 1976. Etiology and predisposing factors in respiratory disease of milk-fattened veal calves. *Livestock Prod. Sci.* 3:285.
- 106 Martin, S. W., C. W. Schwabe, and C. E. Franti. 1975. Dairy calf mortality rates in Tulare County, California. *Am. J. Vet. Res.* 36:1099.
- 107 Martin, S. W., C. W. Schwabe, and C. E. Franti. 1975. Dairy calf mortality rate: the association of daily meteorological factors and calf mortality. *Can. J. Comp. Med.* 39:377.
- 108 Martin, S. W., C. W. Schwabe, and C. E. Franti. 1975. Dairy calf mortality rate: influence of meteorologic factors on calf mortality rate in Tulare County, California. *Am. J. Vet. Res.* 36:1105.
- 109 Martin, S. W., C. W. Schwabe, and C. E. Franti. 1975. Dairy calf mortality rate: influence of management and housing factors on calf mortality rate in Tulare County, California. *Am. J. Vet. Res.* 36:1111.
- 110 Mayan, M. H. 1974. The effects of ammonia inhalation on young bovine animals. Dissertation Abstr. Int. B 35:1007B.
- 111 McBeath, D. G., and E. F. Logan. 1974. Influence of neonatal management on serum immunoglobulin levels of suckled calves. *Vet. Rec.* 95:466.
- 112 McClurkin, A. W. 1977. Probable role of viruses in calfhood diseases. *J. Dairy Sci.* 60:278.
- 113 McDougall, D. F. 1973. The metabolism of plasma proteins in the young calf. Ph.D. thesis, University of Glasgow, Glasgow, UK.
- 114 McNulty, M. S., J. B. McFerran, D. G. Bryson, E. F. Logan, and W. L. Curran. 1976. Studies on rotavirus infection and diarrhoea in young calves. *Vet. Rec.* 99:229.
- 115 Mebus, C. A. 1976. Viral calf enteritis. *J. Dairy Sci.* 59:1175.
- 116 Mebus, C. A., and L. E. Newman. 1977. Scanning electron, light and immunofluorescent microscopy of intestine of gnotobiotic calf infected with reovirus-like agent. *Am. J. Vet. Res.* 38:553.
- 117 Mebus, C. A., M. B. Rhodes, and N. R. Underdahl. 1978. Neonatal calf diarrhoea caused by a virus that induces villous epithelial cell syncytia. *Am. J. Vet. Res.* 39:1223.
- 118 Meeroff, J. C., V. L. W. Go, and S. F. Phillips. 1975. Control of gastric emptying by osmolality of duodenal contents in man. *Gastroenterology* 68:1144.
- 119 Mensik, J., J. Dressler, and J. Franz. 1977. A trial to prevent respiratory syndrome by rearing calves with minimum morbidity rate. *Vet. Med. Praha.* 22:463.
- 120 Mensik, J., J. Dressler, J. Franz, and J. Pokorny. 1977. The effect of different systems of colostrum nutrition on the level of immunoglobulins in the blood of calves. *Vet. Med., Praha.* 22:449.
- 121 Mensik, J., Z. Pospisil, A. Cepica, and J. Dressler. 1977. The effect of different conditions of housing on the occurrence of the respiratory syndrome in calves. *Vet. Med., Praha.* 22:475.
- 122 Mensik, J., Z. Pospisil, A. Suchankova, A. Cepica, V. Rozkosby, and M. Machatkova. 1976. Activation of latent infectious bovine rhinotracheitis after experimental infection with parainfluenza 3 virus in young calves. *Zbl. Vet. Med. B* 23:854.
- 123 Mitchell, C. D., and P. A. Ross. 1977. Model study of air flow in two calf houses. *Farm Bldg. Progr.* 47:19.
- 124 Mitchell, J. G., G. C. McCoy, and H. H. Olson. 1974. Influence of colostrum feeding on serum protein constituents of neonatal calves. *J. Dairy Sci.* 57:642. (Abstr.)
- 125 Modlin, I. M., S. R. Bloom, and S. J. Mitchell. 1978. Experimental evidence for vasoactive intestinal peptide as the cause of the watery diarrhoea syndrome. *Gastroenterology* 75:1051.

- 126 Molla, A. 1978. Immunoglobulin levels in calves fed colostrum by stomach tube. *Vet. Rec.* 103:377.
- 127 Moon, H., S. Whipp, and S. Donta. 1976. Enterotoxigenicity of bovine *Escherichia coli* and enterotoxin neutralizing activity of serum from domestic animals. 9th Int. Congr. Dis. Cattle, Paris 1:273.
- 128 Ørskov, L. F., H. Ørskov, H. W. Smith, and W. J. Sojka. 1975. The establishment of K₉₉, a thermolabile, transmissible *Escherichia coli* K antigen, previously called 'K_{CO}', possessed by calf and lamb entero-pathogenic strains. *Acta. Pathol. Microbiol. Scand. B* 83:31.
- 129 Oyeniyi, O. O., and A. G. Hunter. 1978. Colostral constituents including immunoglobulins in the first three milkings postpartum. *J. Dairy Sci.* 61:44.
- 130 Parmely, M. J., and A. E. Beer. 1977. Colostral cell-mediated immunity and the concept of a common secretory immune system. *J. Dairy Sci.* 60:655.
- 131 Pearson, C. R., M. S. McNulty, and E. F. Logan. 1978. Pathological changes in the small intestine of neonatal calves naturally infected with reo-like virus (rotavirus). *Vet. Rec.* 102:454.
- 132 Penhale, W. J., E. F. Logan, I. E. Selman, E. W. Fisher, and A. D. McEwan. 1973. Observations on the absorption of colostral immunoglobulins by the neonatal calf and their significance in colibacillosis. *Ann. Rech. Vet.* 4:223.
- 133 Pirie, H. M. 1977. Recent advances in respiratory conditions in cattle. *Vet. Rec.* 101:225.
- 134 Porter, P. 1972. Quantitative changes in early lactation and absorption by the neonatal calf. *Immunology* 23:225.
- 135 Probert, M., E. J. Stott, L. H. Thomas, A. P. Collins, and J. Jebbett. 1978. An inactivated parainfluenza virus type 3 vaccine: the influence of vaccination regime on the response of calves and their subsequent resistance to challenge. *Res. Vet. Sci.* 24:222.
- 136 Reiter, B. 1978. Review of non specific antimicrobial factors in colostrum. *Ann. Rech. Vet.* 9:205.
- 137 Rindsig, R. B. 1976. Sour colostrum dilutions compared to whole milk for calves. *J. Dairy Sci.* 59:1293.
- 138 Rowland, S. J., J. H. B. Roy, H. J. Sears, and S. Y. Thompson. 1953. The effect of prepartum milking on the composition of the prepartum and postpartum secretions of the cow. *J. Dairy Res.* 20:16.
- 139 Roy, J. H. B. 1971. Decision-making and calf health. *J. Roy. Agric. Soc.* 132:81.
- 140 Roy, J. H. B. 1973. The role of nutrition in calf health. *Span.* 16:101.
- 141 Roy, J. H. B. 1975. Nutrition and management: factors affecting perinatal mortality in calves. Page 125 in *Perinatal ill-health in calves*. *Comm. Europ. Commun.*
- 142 Roy, J. H. B., J. Palmer, K. W. G. Shillam, P. L. Ingram, and P. C. Wood. 1955. The nutritive value of colostrum for the calf. 10. The relationship between the period of time that a calf-house has been occupied and the incidence of scouring and mortality in young calves. *Brit. J. Nutr.* 9:11.
- 143 Roy, J. H. B., K. W. G. Shillam, G. M. Hawkins, J. M. Lang, and P. L. Ingram. 1959. The effect of white scours on the sodium and potassium concentration in the serum of newborn calves. *Brit. J. Nutr.* 13:219.
- 144 Roy, J. H. B., I. J. F. Stobo, and H. J. Gaston. 1970. The nutrition of the veal calf. 3. A comparison of liquid skim milk with a diet of reconstituted spray-dried skim-milk powder containing 20% margarine fat. *Brit. J. Nutr.* 24:459.
- 145 Roy, J. H. B., I. J. F. Stobo, H. J. Gaston, P. Ganderton, S. M. Shotton, and D. C. Ostler. 1971. The effect of environmental temperature on the performance and health of the pruruminant and ruminant calf. *Brit. J. Nutr.* 26:363.
- 146 Salajka, E., L. Ulmann, Z. Sarmanova, and M. Hornich. 1975. Specific prevention and treatment of diarrhoeic *E. coli* infections in newborn calves. *Vet. Med., Praha.* 20:659.
- 147 Sasaki, M., C. L. Davis, and B. L. Larson. 1976. Production and turnover of IgG₁ and IgG₂ immunoglobulins in the bovine around parturition. *J. Dairy Sci.* 59:2046.
- 148 Sasaki, M., C. L. Davis, and B. L. Larson. 1977. Immunoglobulin IgG₁ metabolism in newborn calves. *J. Dairy Sci.* 60:623.
- 149 Selman, I. E., A. D. McEwan, and E. W. Fisher. 1971. Studies on dairy calves allowed to suckle their dams at fixed times post-partum. *Res. Vet. Sci.* 12:1.
- 150 Selman, I. E., A. D. McEwan, and E. W. Fisher. 1971. Absorption of immune lactoglobulin by newborn dairy calves. Attempts to produce consistent immune lactoglobulin absorptions in newborn dairy calves using standardised methods of colostrum feeding and management. *Res. Vet. Sci.* 12:205.
- 151 Seto, A., T. Okabe, and Y. Ito. 1977. Immunoglobulin M association with secretory component and immunoglobulin A deficiency in bovine colostrum. *Am. J. Vet. Res.* 38:1895.
- 152 Shanks, P. L. 1950. Scouring in calves fed on milk from cows grazing new leys. *Vet. Rec.* 62:315.
- 153 Shope, R. E., C. C. Muscopolat, A. W. Chen, and D. W. Johnson. 1976. Mechanism of protection from primary bovine viral diarrhoea virus infection. 1. The effects of dexamethasone. *Can. J. Comp. Med.* 40:355.
- 154 Sissons, J. W., and R. H. Smith. 1976. The effect of different diets including those containing soya-bean products, on digesta movement and water and nitrogen absorption in the small intestine of the pre-ruminant calf. *Brit. J. Nutr.* 36:421.
- 155 Sivaswamy, G., and C. L. Gyles. 1976. The prevalence of enterotoxigenic *Escherichia coli* in the faeces of calves with diarrhoea. *Can. J. Comp. Med.* 40:241.
- 156 Slagsvold, P., B. Laksesvela, K. Flatlandsmo, N. Krogh, T. L. Ulsterin, N. Ek, and T. Landsverk. 1977. Indigestion in young calves. 1. Different

- lactose levels in milk diets and milk replacers. *Acta Vet. Scand.* 18:194.
- 157 Smith, H. W. 1962. Observations on the aetiology of neonatal diarrhoea (scours) in calves. *J. Pathol. Bact.* 84:147.
- 158 Smith, H. W., and M. G. Huggins. 1976. Further observations on the association of the colicine v plasmid of *Escherichia coli* with pathogenicity and with survival in the alimentary tract. *J. Gen. Microbiol.* 92:335.
- 159 Smith, R. H., and J. W. Sissons. 1975. The effect of different feeds, including those containing soya-bean products, on the passage of digesta from the abomasum of the preruminant calf. *Brit. J. Nutr.* 33:329.
- 160 Smith, T., and M. L. Orcutt. 1925. The bacteriology of the intestinal tract of young calves with special reference to the early diarrhoea ("scours"). *J. Exp. Med.* 41:80.
- 161 Snodgrass, D. A., and P. W. Wells. 1978. The influence of colostrum on neonatal rotaviral infections. *Ann. Rech. Vet.* 9:335.
- 162 Snyder, A. C., J. D. Schuh, T. N. Wegner, and J. R. Gebert. 1974. Passive immunization of the newborn dairy calf via fermented colostrum. *J. Dairy Sci.* 57:641. (Abstr.)
- 163 Spooner, R. L., J. S. Bradley, and G. B. Young. 1975. Genetics and disease in domestic animals with particular reference to dairy cattle. *Vet. Rec.* 97:125.
- 164 Staples, G. E., and C. N. Haygse. 1974. Losses in young calves after transportation. *Brit. Vet. J.* 130:374.
- 165 Stobo, I. J. F., J. H. B. Roy, and P. Ganderton. 1979. The effect of changes in concentrations of dry matter, and of fat and protein in milk substitute diets for veal calves. *J. Agric. Sci., Camb.* 93:95.
- 166 Stobo, I. J. F., J. H. B. Roy, P. Ganderton, and D. J. Jayne-Williams. 1974. Effect of single-cell protein in milk substitute diets on the performance and nutrient utilization of calves. Page 59 in *Rep. Nat. Inst. Res. Dairying, 1973-1974*.
- 167 Stone, S. S., and B. L. Deyoe. 1974. Appearance of Brucella-specific immunoglobulins in synovia of neonatal calves after colostrum feeding. *Am. J. Vet. Res.* 35:1259.
- 168 Stott, G. H., and B. E. Menefee. 1978. Selective absorption of immunoglobulin IgM in the newborn calf. *J. Dairy Sci.* 61:461.
- 169 Stott, G. H., and E. J. Reinhard. 1978. Adrenal function and passive immunity in the dystocial calf. *J. Dairy Sci.* 61:1457.
- 170 Stott, G. H., F. Wiersma, B. E. Menefee, and F. R. Radwanski. 1976. Influence of environment on passive immunity in calves. *J. Dairy Sci.* 59:1306.
- 171 Straub, O. C., and W. Matthaeus. 1978. The immunoglobulin composition of colostrum and the persistence of acquired immunoglobulins and specific antibodies in the calf. *Ann. Rech. Vet.* 9:269.
- 172 Tagari, H., and J. H. B. Roy. 1969. The effect of heat treatment on the nutritive value of milk for the young calf. 8. The effect of the pre-heating treatment of spray-dried skim milk on the pH and contents of total, protein and non-protein nitrogen of the pyloric outflow. *Brit. J. Nutr.* 23:763.
- 173 Ternouth, J. H., and J. H. B. Roy. 1978. Concurrent studies of the flow of digesta in the duodenum and of exocrine pancreatic secretion in calves. 6. The effect of feeding warm or cold milk by bucket or teat. *Brit. J. Nutr.* 40:553.
- 174 Ternouth, J. H., J. H. B. Roy, and S. M. Shotton. 1976. Concurrent studies of the flow of digesta in the duodenum and of exocrine pancreatic secretion of calves. 4. The effect of age. *Br. J. Nutr.* 36:523.
- 175 Ternouth, J. H., J. H. B. Roy, and R. C. Siddons. 1974. Concurrent studies of the flow of digesta in the duodenum and of exocrine pancreatic secretion of calves. 2. The effects of addition of fat to skim milk and of "severe" pre-heating treatment of spray-dried skim milk powder. *Brit. J. Nutr.* 31:13.
- 176 Ternouth, J. H., J. H. B. Roy, I. J. F. Stobo, S. M. Shotton, and C. M. Gillies. 1977. Concurrent studies of the flow of digesta in the duodenum and of exocrine pancreatic secretion in calves. 5. The effect of giving milk once and twice daily and of weaning. *Brit. J. Nutr.* 37:237.
- 177 Ternouth, J. H., J. H. B. Roy, S. Y. Thompson, J. Toothill, C. M. Gillies, and J. D. Edwards-Webb. 1975. Concurrent studies of the flow of digesta in the duodenum and of exocrine pancreatic secretion of calves. 3. Further studies on the addition of fat to skim milk and the use of non-milk proteins in milk substitute diets. *Brit. J. Nutr.* 33:181.
- 178 Thomas, L. H., E. J. Stott, A. P. Collins, N. J. Jebbett, and A. J. Stark. 1977. Evaluation of respiratory disease in calves: comparison of disease response to different viruses. *Res. Vet. Sci.* 23:157.
- 179 Thompson, T. L., and E. H. Marth. 1976. Changes in the microflora of bovine colostrum during natural fermentation. 1976. *J. Milk Food Technol.* 39:27.
- 180 Tomescu, V., and F. Marschang. 1977. Observations on the correlation between the dung disposal systems and the concentration of ammonia in the air of animal houses. *Br. Vet. J.* 133:629.
- 181 Toullec, R., J. F. Frantzen, and C. M. Mathieu. 1974. Effect of coagulation of milk protein on the digestibility of a milk replacer in preruminant calves. *Ann. Zootech.* 23:359.
- 182 Toullec, R., C. M. Mathieu, and R. Pion. 1974. Utilization of whey proteins by preruminant veal calves. 2. Digestibility and utilization for growth. *Ann. Zootech.* 23:75.
- 183 Tournut, J., P. Bezille, and P. Redon. 1976. Colibacillary neonatal enteritis of the calf: a new prophylactic method. 9th Int. Congr. Dis. Cattle 9. Paris 1:267.
- 184 Ward, D. E. 1976. Pathophysiology of enteric colibacillosis in the intact neonatal calf. *Dissertation Abstr. Int. B* 37:1133.

- 185 Ward, D. E., B. H. Baldwin, C. E. Stevens, and B. Tennant. 1976. Excretion of bicarbonate, lactate and volatile fatty acids in the faeces of calves with experimental colibacillosis. *Gastroenterology* 70:976.
- 186 Weijers, H. A., and J. H. van de Kamer. 1965. Alteration of intestinal bacterial flora as a cause of diarrhoea. *Nutr. Abstr. Rev.* 35:501.
- 187 Wells, P. W., A. McL. Dawson, W. D. Smith, and B. S. W. Smith. 1975. Transfer of IgG from plasma to nasal secretions in newborn lambs. *Vet. Rec.* 97:455.
- 188 Williams, M. R., R. L. Spooner, and L. H. Thomas. 1975. Quantitative studies on bovine immunoglobulins. *Vet. Rec.* 96:81.
- 189 Williams, V. J., J. H. B. Roy, and C. M. Gillies. 1976. Milk substitute diet composition and abomasal secretion in the calf. *Brit. J. Nutr.* 36:317.
- 190 Wise, G. H., P. G. Miller, G. W. Anderson, and A. C. Linnerud. 1976. Changes in milk products sham fed to calves. 4. Suckling from a nurse cow versus consuming from either a nipple feeder or an open pail. *J. Dairy Sci.* 59:97.
- 191 Wood, P. C. 1955. The epidemiology of white scours among calves kept under experimental conditions. *J. Pathol. Bact.* 70:179.
- 192 Woode, G. N. 1978. Epizootiology of bovine rotavirus infection. *Vet. Rec.* 103:44.
- 193 Woode, G. N., M. E. Bew, and M. J. Dennis. 1978. Studies on cross protection induced in calves by rotaviruses of calves, children and foals. *Vet. Rec.* 103:32.
- 194 Woode, G. N., and J. C. Bridger. 1975. Viral enteritis of calves. *Vet. Rec.* 96:85.
- 195 Woode, G. N., C. Smith, and M. J. Dennis. 1978. Intestinal damage in rotavirus infected calves assessed by D-xylose malabsorption. *Vet. Rec.* 102:340.
- 196 Wray, C., and R. J. Callow. 1974. Studies on the survival of *Salmonella dublin*, *Salmonella typhimurium* and *E. coli* in stored bovine colostrum. *Vet. Rec.* 94:407.
- 197 Wray, C., and J. R. Thomlinson. 1975. Factors influencing occurrence of colibacillosis in calves. *Vet. Rec.* 96:52.