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Nutrition and enteric diseases in calves

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Enteric diseases are of considerable economic importance in calves (a) during the first 2–3 weeks of life, when *Escherichia coli* is the main organism involved; (b) in the slightly older pre-ruminant calf and also in the young ruminant calf when salmonellosis, particularly that associated with *Salmonella dublin* and *S. typhimurium*, may cause severe losses;
(c) in the ruminant calf at pasture when a sufficiently heavy burden of internal parasites may cause clinical disease.

The discussion in this paper will be limited to enteric disease during the early neonatal period, many aspects of which have been discussed at a recent conference in the USA (Tennant, 1971). The manifestation of this disease is considered to depend on the interactions of the immunological, nutritional and microbiological environments of the calf, with its genotypic resistance.

The microbiological environment

In the normal healthy calf, *E. coli* is one of the first organisms to become established in the alimentary tract after birth, followed by the lactobacilli which become the commonest organism in the stomach and small intestine (Smith, 1965). The temporary dominance of the first organisms to colonize the tract has been attributed to the high pH of the abomasal contents in the neonate and the subsequent decline of these organisms has been associated with the increased secretion of abomasal acid.

A strain of *E. coli* is only likely to be pathogenic either if it manages to enter the tissues during the first few days of life, resulting in a septicaemia, or if the strain, although restricted to the alimentary tract, has the ability to proliferate in the anterior region of the small intestine and to produce an enterotoxin. An *E. coli* septicaemia is usually associated with deprivation of colostrum or with the feeding of inadequate amounts, although a virulent serotype such as 078:K (?) B will regularly cause a septicaemia in calves given colostrum.

The proliferation of an enteropathogenic strain of *E. coli*, which as long ago as 1925 was shown by Smith & Orcutt (1925) to adhere to the epithelial cells of the mucosa, results in profuse diarrhoea, dehydration and death from an *E. coli* localized intestinal infection associated with a metabolic acidosis.

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The production of profuse diarrhoea and the passage of water and particularly the electrolytes HCO_3^-, Na^+, Cl^- into the lumen of the intestine as a result of the proliferation of enterotoxaemic strains have been demonstrated by Smith & Halls (1967) and Bywater (1970). It has also been shown that the 'enterotoxaemic' factor (Ent) can be transmitted from one strain of *E. coli* to another. The selection advantage possessed by enteropathogenic *E. coli* organisms probably resides in their ability to proliferate in the anterior small intestine (Smith & Halls, 1968). One factor that certainly predisposes to the change from non-pathogenic to enterotoxaemic strains of coli is the passage of a large number of newborn susceptible animals through a confined air-space (Roy, Palmer, Shillam, Ingram & Wood, 1955; Wood, 1955). A similar association between enterotoxaemic strains of *E. coli* and the physical environment is shown in infantile diarrhoea, since the majority of outbreaks occur in hospital wards or nurseries (Anonymous, 1970).

The immunological environment

The mode of transmission of passive immunity to the calf from its dam by way of colostrum is universally agreed. It can be seen from Table 1 that serum and most body secretions contain immune globulins (Ig), and that IgA is produced by all the normal secretory organs. Large quantities of IgG, mainly in the form of IgG_1, are present in colostrum; the relatively high content of IgM has been associated with antibodies against Gram-negative bacteria, such as *E. coli* (Michael & Rosen, 1963). Both IgG and IgM are selectively transferred to colostrum from the blood (Porter, 1971). The IgA in colostrum is presumed to be synthesized in the udder tissue. It has been shown in the pig that IgA contains antibodies to *E. coli* (Porter, 1969). Although IgA has a localized action in the intestinal tract in the human, and a deficiency may allow multiplication of bacteria in the duodenum (Hersh, Floch, Binder, Conn, Prizont & Spiro, 1970; Prizont, Hersh & Floch, 1970),

Table 1. *Immune globulins (Ig) in bovine external secretions and serum (Mach & Pahud, 1971)*

	Protein concentration (mg/100 ml)			
	IgA (secretory Ig)	IgG_1	IgG_2	IgM
Lachrymal secretions	260	30	12	0·6
Nasal secretions	195	4	2·5	Tr
Saliva	56	3	1	1
Spermatic fluid	13	13	11	Tr
Gastro-intestinal secretions	24	25	6	Tr
Bile	8	10	9	5
Urine	0·07	0·08	0·1	Tr
Colostrum	440	7500	190	490
Milk	5	35	6	4
Serum	30	1050	790	250

Tr, trace.

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the role of IgA in the alimentary tract of the young calf has not yet been established; the concentration in cow's milk is, however, considerably lower than that in the milk of the sow (Porter, 1971).

Quite small amounts of colostral Ig (14 g) will offer good protection against an *E. coli* septicaemia, provided that the Ig contains antibodies against the antigens of the strains of coli to which the calves have been exposed (Aschaffenburg, Bartlett, Kon, Roy, Sears, Thompson, Ingram, Lovell & Wood, 1953). More recently, Logan & Penhale (1971) have obtained 95% protection against an *E. coli* septicaemia with an intraperitoneal injection of 0·26 g IgM and 1·5 g IgG as colostral whey/30 kg live weight; either Ig given alone was ineffective.

These small quantities of colostrum, however, will not protect against the enterotoxaemic form of the disease in which the *E. coli* does not invade further than the mesenteric lymph-nodes. The amount of Ig necessary to protect against this condition is not known. Kruse (1970*a*) has suggested that 100 g Ig should be given in the first feed to ensure a normal serum Ig concentration. Since 3·4 kg colostrum, containing about 200 g Ig, followed by a diet of whole milk does not prevent the depression in growth rate that occurs when successive calves are introduced into a calf-house (Roy *et al.* 1955), it would appear that in an adverse microbiological environment, considerably greater amounts of Ig may be necessary. To ensure complete protection under these conditions one would recommend giving at least 7 kg colostrum collected during the first 24 h after parturition. This quantity would supply about 400 g Ig during the first 24–36 h of life.

Weijers & van de Kamer (1965) have suggested that, in the human, the harmful effects of *E. coli* in the small intestine and colon, as a result of amine and toxin production, will depend on the amount of antibodies and the activity of the amine oxidase in the cell walls of the colon. Although in the severely diarrhoeic piglet the small intestine is the principal site of amine production compared with the colon in unaffected animals (Hill, Kenworthy & Porter, 1970), no experiments have so far directly implicated production of amine as a factor in the aetiology of an *E. coli* localized intestinal infection in the calf. However, increased amounts of amines, particularly histamine and putrescine, have been obtained from strains isolated from calves that died compared to those from healthy calves (Ferenčik, Koppel & Križánova, 1970).

The nutritional environment

The association of putrefactive diarrhoea in man with the dominance of *E. coli* and with inefficient digestion of protein and of fermentative diarrhoea with inefficient carbohydrate utilization has been reviewed by Weijers & van de Kamer (1965). The relevance of these findings to diarrhoea in calves has been discussed by Roy (1969).

In the normal healthy young calf, clotting of the casein with the entrapped fat occurs within 3–4 min of ingestion of milk. Complete passage of the whey fluid, which contains the lactose, the whey proteins including the small amount of Ig that is present and much of the minerals, requires about 7–9 h (Mylrea, 1966; Hill,

Noakes & Lowe, 1970; Ternouth, 1971). The casein retained in the abomasum is partly degraded into peptides as a result of the action of rennin or pepsin, or both, and HCl, and together with the fat is passed continuously through the pylorus for further degradation by the pancreatic enzymes. In calves being fed *ad lib.* twice daily, the slow passage of casein out of the abomasum, presumably necessary to allow sufficient time for effective abomasal proteolysis to occur, results in the clot that is formed after a meal entrapping some of the clot formed from a previous meal (Hill, Noakes & Lowe, 1970; Ternouth, 1971). Some neonatal calves appear to produce mainly rennin whereas others produce only pepsin, but pepsin production predominates as the calf gets older (Henschel, Hill & Porter, 1961).

Milk substitutes for calves generally contain at least 50% of skim-milk powder. When milk is heat-treated in the production of milk powders and the time–temperature relationship is such that the majority of the whey proteins, including the small amount of Ig present are denatured, normal clotting of the reconstituted milk powder does not occur and instead of a firm curd, a flocculent precipitate may be produced in vitro (Roy, 1969). Milk substitutes containing such powders have a reduced digestibility, particularly of protein and also of fat and ash. Such diets will predispose the calf to death from an *E. coli* localized intestinal infection in an adverse microbiological environment. Gastric digestion is reduced and undigested casein passes into the duodenum. Abomasal fluids pass more slowly through the pylorus and have a higher pH, which appears to be associated with the production of less acid (Tagari & Roy, 1969; Ternouth, 1971). Poor gastric digestion is not complemented by an increased output of pancreatic proteolytic enzymes. Indeed, the effect of feeding a 'severely' heat-treated milk is also to reduce the secretion of pancreatic fluids and proteases (Table 2). Associated with the reduction in the output of proteases, is an increase in the secretion of amylase from the pancreas (Ternouth, 1971).

Heat denaturation of the small amount of Ig and of other inhibitory factors, such as lactoperoxidase, in milk may also encourage certain enteropathogenic organisms. For instance, Singh & Mikolajcik (1971) have shown in in vitro studies that the heat treatment of skim milk has a marked stimulatory effect on the growth of *S. typhi-murium*.

Experiments with milk substitute containing 40% or more of the protein as soya have indicated a similar train of events to that arising from a diet containing a 'severely' heat-treated milk, namely a reduced rate of abomasal outflow, a higher pH, a reduction in proteolysis in the abomasum and an escape of undigested protein into the duodenum (Colvin, Lowe & Ramsey, 1969; Ternouth, 1971), together with less pancreatic secretion and a lower protease outflow (Gorrill & Thomas, 1967; Gorrill, Thomas, Stewart & Morrill, 1967; Ternouth, 1971).

Poor clotting of milk, as a result of heat treatment, has also been reported to have an immunological effect (Frens, van der Grift & Dammers, 1961; Frens, 1961). Absorption in the small intestine of only partially broken-down milk proteins may occur, with the resultant formation of antibodies in the blood, so that at a later stage anaphylactic shock symptoms may be observed. This observation has not been

Table 2. *Comparison of a milk substitute diet containing 'mildly' and 'severely' pre-heated spray-dried skim-milk powder*

	'Mild' pre-heating treatment (77°C for 15 s)	'Severe' pre-heating treatment (74°C for 30 min+)	Change (%)	Reference
Incidence of mortality during first 21 d of life (%)	24	53	+125	Shillam, Roy & Ingram (1962)
No. of days in which calves had diarrhoea during first 21 d of life	1	3	+	Shillam & Roy (1963*b*)
Live-weight gain/d in first 21 d of life (kg)	0·20	0·09	− 55	Shillam & Roy (1963*b*)
Dry-matter content of faeces at 7 d (%)	14	12	− 13	Shillam & Roy (1963*a*)
Indigestibility of protein at 7 d (%)	25	37	+ 48	Shillam & Roy (1963*a*)
Abomasal outflow:				
Protein N as % of total N during first 6·5 h after a feed	38	55	+ 45	Tagari & Roy (1969)
Duodenal flow:*				
Volume of fluid during first 3 h after a feed (l)	2·54	2·30	− 10	Ternouth (1971)
Protein concentration during first 3 h after a feed (mg/100 ml)	105	124	+ 18	Ternouth (1971)
Protein N as % of total N during 12 h after a feed	41	39	− 5	Ternouth (1971)
Recovery of ^{3}H from casein during 12 h after a feed (%)	53	(84)†	+ 58	Ternouth (1971)
Estimated gastric acid production from duodenal flow:				Ternouth (1971)
Ionized H^+ in first 3 h after a feed (mmol/h)	0·015	0·004	− 73	Ternouth (1971)
Cl^- less Na^+ in excess of intake during first 3 h after a feed (mmol)	52	43	− 17	Ternouth (1971)
12 h after a feed (mmol)	239	210	− 12	Ternouth (1971)
Pancreatic secretion:				Ternouth (1971)
Volume (ml/12 h)	336	300	− 11	Ternouth (1971)
Protease activity (g/12 h)	2·30	1·67	− 27	Ternouth (1971)
Amylase activity (mg/12 h)	37	51	+ 38	Ternouth (1971)

*At the site 150 mm caudal to the pylorus.

†Whole milk heated to 80–85° for 30 min.

confirmed by others (Boogaerdt & van Koetsveld, 1961), but it has been shown (van Adrichem & Frens, 1965; van Leeuwen, Weide & Braas, 1969) and more recently confirmed (Smith & Wynn, 1971) that antibodies against soya protein may be produced in the blood as a result of giving this protein. Moreover, it has been suggested that there is an association between the production of antibodies and gastric stasis, followed by diarrhoea, which can by induced when soya is the sole source of protein (Smith, Hill & Sissons, 1970).

Liquid skim-milk is also known to cause a greater incidence of diarrhoea than whole milk and it has been assumed (Roy, 1969) that the higher protein content of skim milk was responsible. However, Ternouth (1971) has found that abomasal proteolysis is greater when skim milk is given (Table 3). This suggests that the diarrhoea may be of the fermentative rather than the putrefactive type, due to

Table 3. *Comparison of a milk substitute diet containing 20% fat with a diet of liquid skim-milk*

	20% fat milk	Skim milk	Change (%)	Reference
Dry-matter content of faeces (%)	14	10	−28	Roy, Stobo & Gaston (1970)
No. of days in which calves had diarrhoea during first 14 d of life	0·1	1·3	+	
Apparent digestibility of protein at 49 d	94	94	0	
Duodenal flow at 16–37 d:				Ternouth (1971)
Protein N as % of total N during 12 h	46	36	−22	
Recovery of ^{3}H from casein during 12 h after a feed (%)	53	45	−15	
Pancreatic secretion at 16–37 d:				
Volume (ml/12 h)	305	276	−10	
Protease activity (g/12 h)	6·5	5·3	−18	
Trypsin activity (mg/12 h)	295	233	−21	
Chymotrypsin activity (g/12 h)	1·29	1·02	−21	J. H. Ternouth (unpublished)

excessive concentration of lactose in the diet. However, since the pancreatic secretion of proteases, trypsin and chymotrypsin are also reduced as a result of giving skim milk, a finding that may be related to the absence of a stimulatory effect by fat, the possibility of putrefactive diarrhoea cannot be ruled out.

Feeding techniques, which have on occasions been reported as a cause of diarrhoea or of a reduced growth rate, all tend to cause a reduction in gastric acid production, the degree of abomasal proteolysis or pancreatic protease production, or both (Ternouth, 1971). For instance, bucket-feeding versus teat-feeding (Wise & LaMaster, 1968), once-daily feeding versus twice-daily feeding (Wood, Bayley & MacLeod, 1971) and cold milk versus warm milk (Walker, 1950) have been associated with an increased incidence of diarrhoea and also cause alterations in the digestive processes.

The genetic environment

The lower susceptibility of Friesian compared with Jersey and Ayrshire calves to diarrhoea under the same nutritional and microbiological conditions, and its possible relationship with the higher apparent digestibility of protein by the Friesian breed have been discussed by Roy (1969, 1970). It would thus seem to be more than a coincidence that Friesian calves appear to have a greater secretion of trypsin and protease from the pancreas than do Ayrshire calves of the same age (Table 4) (Ternouth, 1971). As with the effect of a 'severely' heat-treated milk, the lower rate of protease secretion in the Ayrshire calves is associated with a higher rate of amylase secretion.

The Black and White Danish Breed (SDM) is also claimed to absorb Ig more efficiently than the Red Danish (Kruse, 1970*b*), the Friesian ♂ × Ayrshire ♀ calves to absorb Ig better than Ayrshire calves (Selman, McEwan & Fisher, 1971*b*). Moreover, beef calves of various crosses have been shown to suckle their dams

earlier (81 min from birth) than pure bred Ayrshire or Friesian ♂ × Ayrshire ♀ calves out of heifers (218 min) or cows (261 min) (Selman, McEwan & Fisher, 1970*a*,*b*).

Table 4. *Comparison at the same age of calves of the Friesian and Ayrshire breeds given milk diets*

	Friesian	Ayrshire	Change (%)	Reference
Dry-matter content of faeces at 32 d (%)	16	12	− 25	Roy, Stobo & Gaston (1970)
Apparent indigestibility of protein at 32 d (%)	4·9	9·2	+ 88	
Metabolic faecal N at 32 d (g/100 g dry-matter intake)	0·12	0·49	+308	
No. of days in which calves had diarrhoea during first 14 d of life	0·1	1·2	+	
Serum concentration of absorbed Ig—48 h after birth (zinc sulphate turbidity units)	14·9*	11·0	− 26	Selman, McEwan & Fisher (1971*b*)
Secreted pancreatic protease activity at 24 d (g/12 h)†	6·0	2·8	− 53	Ternouth, Siddons & Toothill (1971)
Secreted pancreatic trypsin activity at 24 d (mg/12 h)†	257	176	− 32	

*Friesian ♂ × Ayrshire ♀.

†The dietary regimens for the two breeds were not identical.

The psychological environment

In man, fear may result in gastric function being delayed and food remaining undigested in the stomach for many hours. In baby piglets, diminishing gastric activity followed by gastric stasis had been shown to occur before the onset of diarrhoea (White, Wenham, Sharman, Jones, Rattray & McDonald, 1969). Gastric stasis may well arise in calves as a result of the stress of transport and could be partly associated with the high incidence of enteric infection in purchased calves. The importance of the psychological environment has recently been further emphasized by the finding that calves given colostrum by hand, but left in the presence of their dams, absorb more Ig from colostrum than calves given the same amount of colostrum but reared in isolation; possibly this 'mothering' effect is related to grooming by the dam (Selman, McEwan, & Fisher 1971*a*,*b*).

Conclusion

Enteric disease of the newborn calf is basically a result of alterations in gastric and intestinal function in response to a less than optimum diet, but the severity of the condition and its clinical manifestation as an infectious disease will depend on the age of the calf and the balance between the immunological and microbiological environment of the calf.

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