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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

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1. The effects of bucket- *v.* teat-feeding and warm- *v.* cold-milk feeding on the flow of duodenal digesta and the concurrent pancreatic secretion were studied in two experiments in preruminant Ayrshire calves (28–43 d of age), fitted with duodenal re-entrant and pancreatic sac cannulas.

2. As measured by the time interval taken for total recovery of the polyethylene glycol fed in the milk, the whey fluids had a more rapid passage through the abomasum when the calves were given warm milk by teat rather than by bucket (Expts 1 and 2). The duodenal digesta contained less sodium ions and more '$Cl^- - Na^+$' when the calves were fed by teat even though the volumes of milk drunk and duodenal flow were similar. It was concluded that more abomasal acid was secreted when calves were fed by teat.

3. When the calves were fed by teat rather than by bucket, the protein-nitrogen : N (PN : N) in the duodenal digesta was lower, especially during the first 6 h after feeding and there was a tendency for more pancreatic proteases to be secreted.

4. In Expt 1, when the calves were given warm milk the total flow of N and lipid in the duodenal digesta was 22 and 19 % greater than that ingested. This was considered to be due to the coagulum from the penultimate meal plus the experimental meal passing more readily through the duodenum when sampling and to endogenous secretion of N and lipid.

5. When four Ayrshire calves were bucket-fed cold, rather than warm milk there was a reduced secretion of abomasal and pancreatic fluids and abomasal acid. There were no differences in the time interval required for the whey fluids to leave the abomasum or the PN : N value.

6. There was a positive correlation between the total duodenal flow of non-whey fluids and the pancreatic secretion regardless of the method of feeding.

7. The completeness of digestion and susceptibility of calves to diarrhoea when fed by teat and bucket is discussed.

Milk is commonly fed to calves by bucket rather than by teat because it is cheaper to maintain and clean a simple bucket-feeding system and because more milk can be ingested when calves are fed by bucket (J. H. B. Roy, unpublished results). However, Wise & La Master (1968) found that bucket-feeding whole milk to calves at daily levels greater than 140 g/kg live weight resulted in a higher incidence and persistence of diarrhoea during the first 3–4 weeks of life than when the calves were fed by teat. This higher incidence of diarrhoea may be due to the faster rate of milk ingestion, with less salivation by the bucket-fed calves, resulting in less efficient coagulation and fat and protein hydrolysis in the abomasum.

The possibility of feeding cold milk to lambs and calves has evoked a considerable number of experiments. Large & Penning (1967) found no difference in the weight gains and food conversion of lambs given cold or warm milk. In contrast, Tayler & Lonsdale (1969) showed that live-weight gains and food conversion efficiencies were reduced when cold milk was offered *ad lib.* to penned calves that had access to fresh grass. However, Tayler & Lonsdale (1969) and Kostov & Sinivirski (1969) found no difference in the incidence of diarrhoea in calves, whether given cold or warm milk.

The purpose of the present experiment was to examine the effects of bucket- *v.* teat-feeding and of warm- *v.* cold-milk feeding on the passage of digesta through the duodenum, on abomasal digestion of the milk and the concurrent exocrine pancreatic secretions.

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Table 1. *Experimental designs and ages of calves given milk by bucket (WB) or teat (WT) at 39°, or by bucket at 10° (CB)*

	Expt 1				Expt 2	
Calf no. ...	1	2	3	4	5	6
Milk fed ...	Milk substitute				Whole milk	
Age range during collection periods (d) ...	31–42	29–40	31–42	31–42	34–43	28–37
	Technique of milk feeding					
Period						
1	WT	WT	CB	CB	WB	WT
2	WB	WB	WB	WB	WB	WT
3	CB	CB	WT	WT	WT	WB
4	CB	CB	WT	WT	WT	WB
5	WB	WB	WB	WB		
6	WT	WT	CB	CB		

EXPERIMENTAL

Four Ayrshire bull calves with duodenal re-entrant and pancreatic sac cannulas (Ternouth & Buttle, 1973) were given a reconstituted milk at a temperature of 39° by teat (WT), at 39° by bucket (WB) and at 10° by bucket (CB). In a second experiment, two further Ayrshire bull calves were given whole milk by bucket and teat at 39°. The calves were those used in a previous experiment and the details of the general management and housing have been described (Ternouth, Roy & Siddons, 1974).

The design of the experiments, including the range in age of the calves at the time of each experiment, is shown in Table 1. Each calf was given at least three meals by the particular feeding system before an experimental meal, which was followed by a 12 h collection period. In Expt 1, to overcome the expected low intakes of cold milk, the calves were given only 2·5 l milk-substitute at each meal. On three occasions (once for treatment WB and twice for treatment CB) 0·3 l milk was refused at the experimental meal, and on five occasions quantities of cold milk were not drunk at the penultimate meal. Calves nos. 5 and 6 did not receive cold milk, but were given 3·8 l whole milk at 39° by bucket and by teat. On one occasion, calf no. 5 refused 1·2 l milk when fed by bucket, so it was fed 2·6 l in the corresponding period of teat-feeding.

The milk-substitute was identical in composition and method of preparation to milk SKF (Ternouth *et al.* 1974) except that a margarine fat containing no groundnut oil ('Delfia' margarine; Craigmillar (BEOL) Ltd, London) was substituted for the margarine fat (non-vitaminized margarine, special quality; Craigmillar (BEOL) Ltd) used in that experiment. The composition of the milk-substitute is given by Roy, Stobo, Gaston, Shotton & Ganderton (1973) as their diet CP. Polyethylene glycol (PEG) (approximately 1 g/l) was added to the milk.

Duodenal digesta and pancreatic secretions were collected, sampled and returned to the calves from 0·5 h before ingestion to 12 h after the ingestion of the experimental meal, using the technique described by Ternouth *et al.* (1974). The chemical analyses and enzyme assay techniques have been described by Ternouth *et al.* (1974).

The results were subjected to analysis of variance with missing values fitted by the method of least squares (Bartlett, 1934). The square root of the quantity of PEG remaining in the abomasum was extrapolated to zero as an estimate of the time interval required for all the whey fluids to leave the abomasum (Ternouth *et al.* 1974). Because of the experimental design used in Expt 1, comparisons were confined to the effects of WB *v.* WT and WB *v.* CB.

Table 2. *Milk intake and duodenal flow of fluid and electrolytes of Ayrshire calves during* 12 *h after being given milk by three feeding methods*†

	Expt 1 (milk-substitute)					Expt 2 (whole milk)			
	Method of feeding				Statistical significance of difference	Method of feeding			Statistical significance of difference
	WB	WT	CB	SE	(18 df)	WB	WT	SE	(5 df)
Milk intake (l)	2·46	2·50	2·43	0·03	NS	3·49	3·49	0·24	NS
Duodenal volume (l)	4·70	4·50	3·87	0·21	*	5·29	5·92	0·18	NS
PEG outflow time (h)	15·3	11·4	15·0	1·6	NS	12·0	7·6	1·1	NS
pH	3·51	3·55	3·72	na	NS	3·43	3·77	na	NS
Electrolytes (mmol)									
H^+	1·41	1·25	0·72	0·20	*	1·96	1·04	0·31	NS
Na^+	233	153	199	16·8	*	172	168	6·2	NS
K^+	46·3	51·3	38·5	3·8	*	67·7	71·7	4·7	NS
Cl^-	457	424	350	27·9	*	539	587	20·4	NS
'$Cl^- - Na^+$'	224	271	150	21·4	**	367	419	16·9	NS

WB, 39° by bucket; WT, 39° by teat; CB 10° by bucket; PEG, polyethylene glycol; na, values not available.

NS, Not significant. * $P < 0·05$, ** $P < 0·01$.

† For details, see p. 554 and Table 1.

RESULTS

Bucket- and teat-feeding comparisons (WB v. *WT)*

In both experiments, as intended, the mean consumption of milk was similar for each feeding method; the volumes of duodenal digesta were also similar. However, the time interval taken for all the PEG to leave the abomasum tended to be greater when the calves were fed by bucket (Table 2). The PEG in the experimental meal was used to partition the duodenal digesta into whey fluids from the experimental meal and 'non-whey fluids'. 'Non-whey fluids' are of endogenous origin but may contain residual fluids from the penultimate meal. The mean rate of flow of non-whey fluids was higher when the calves were fed by bucket (Fig. 1). The duodenal outflow of whey fluids was markedly lower and non-whey fluids markedly higher during the first hour after WB rather than WT. The concentration of PEG in the digesta relative to that in the milk at this time, was 0·540 and 0·704 (SE 0·036; $P < 0·01$) so that 14·2 and 21·3% of fluids from the ingested milk passed through the duodenum in the first hour after WB and WT respectively. During the next 9 h more non-whey fluids passed through the duodenum when the calves were fed by teat.

There was less hydrogen and sodium ions but more chloride ions minus Na^+ flowing through the duodenum during a 12 h period after the calves were fed by teat (Table 2). These differences are reflected in the differences in the quantities of '$Cl^- - Na^+$' in the apparent secretions passing through the duodenum (Table 3). The flow of nitrogen and protein-N : N (PN : N) values are shown in Fig. 2. There was little difference between feeding systems in the pattern of N flow but after adjustment for differences in N intake at the penultimate and experimental meals, 20% more N passed through the duodenum than was ingested (Table 4). There was a markedly higher value for PN : N in the duodenum during the first 6 h after feeding the calves by bucket (Fig. 2). The general mean PN : N values were much lower (0·262) in Expt 2 than in Expt 1 (0·458) regardless of the method of feeding (Table 4).

WB calves tended to secrete more pancreatic fluids (Table 5), the greater volume of

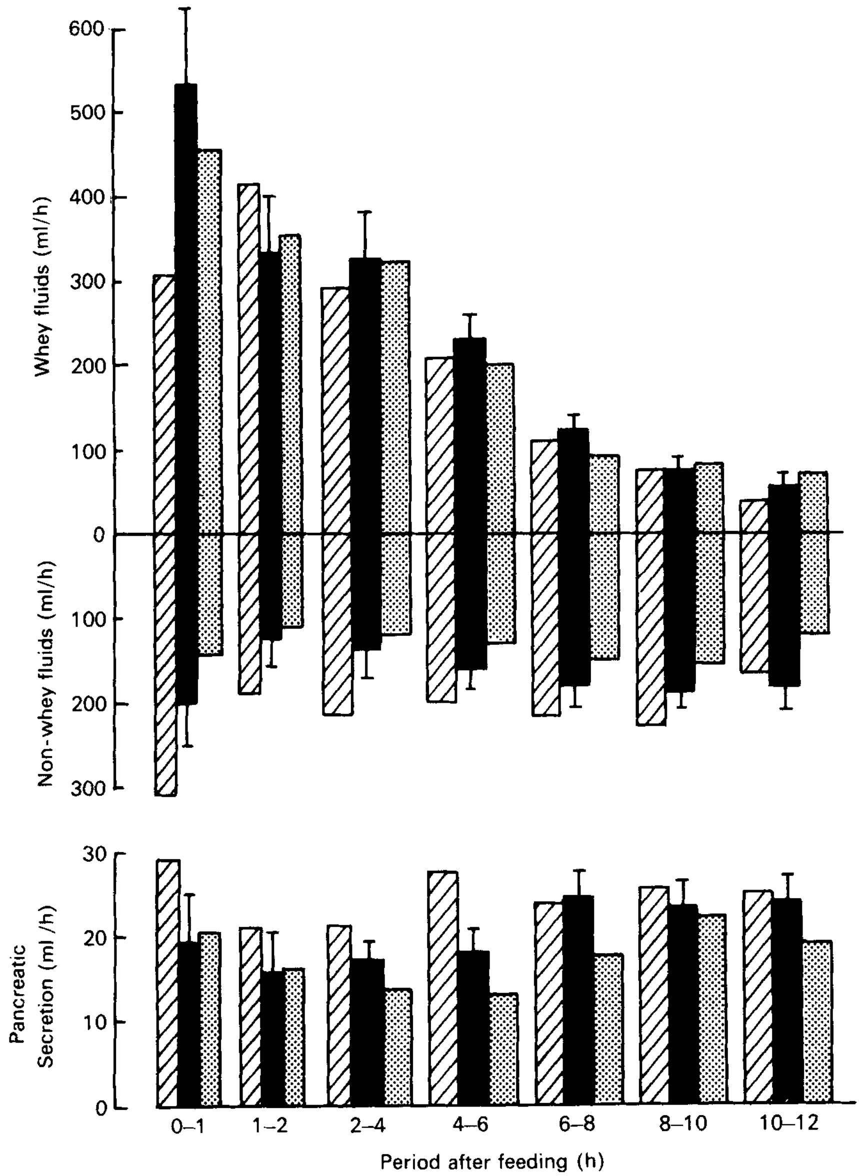

Fig. 1. Expt 1. Volume (ml/h) of whey and non-whey fluids flowing through the duodenum and pancreatic secretion of calves given 2·5 l milk-substitute by bucket (▨) and teat (■) at 39° and by bucket at 10° (▦). The vertical bar is the SE of the mean for all three treatments.

secretion occurring mainly during the first 6 h after feeding (Fig. 1). WT calves tended to secrete more proteases, this increased rate of secretion occurring mainly in the period 6–12 h after feeding (Fig. 2). In Expt 2 only, more trypsin (*EC* 3.4.21.4) tended to be secreted and more amylase (*EC* 3.2.1.1) was secreted when the calves were fed by bucket.

Warm–cold feeding comparisons (*WB* v. *CB*)

There were no significant differences in the quantity of milk drunk, or in the time interval for all the PEG to leave the abomasum when the milk was given warm or cold. However the

Table 3. *Flow of fluid and of sodium and chloride ions, in excess of that ingested, in the duodenal digesta of Ayrshire calves during 12 h after being given milk by three feeding methods*†

	Expt 1 (milk-substitute)					Expt 2 (whole milk)			
	Method of feeding				Statistical significance of difference	Method of feeding			Statistical significance of difference
	WB	WT	CB	SE		WB	WT	SE	
Volume (l)	2·24	2·00	1·45	0·22	NS	1·80	2·43	0·29	NS
Electrolytes (mmol)									
Na^+	184	100	148	16·1	**	99	95	6·7	NS
Cl^-	366	331	272	28·2	NS	417	465	22·7	NS
'$Cl^- - Na^+$'	182	231	124	21·5	**	318	370	17·9	NS

WB, 39° by bucket; WT, 39° by teat; CB, 10° by bucket.
NS, Not significant. * $P < 0·05$, ** $P < 0·01$.
† For details, see p. 554 and Table 1.

volume of duodenal digesta was less when the milk was fed cold (Table 2) owing to a reduction in the volume of non-whey fluids throughout the 12 h period (Fig. 1, Table 3). Less H^+ and '$Cl^- - Na^+$' passed through the duodenum. The cumulative flow of N, PN and lipid and PN : N tended to be lower when the milk was fed cold (Table 4). The differences in N and PN : N were apparent throughout the 12 h postprandial period (Fig. 2). There were larger quantities of pancreatic fluids secreted during the first 2 h after feeding cold milk (Fig. 1), but the total quantity secreted over the 12 h period was less (Table 5). There were no differences in the quantities of enzymes secreted but the pattern of secretion was markedly different. The secretion of proteases was relatively constant when milk was given warm but high 0–2 h and low 4–8 h after being given cold.

DISCUSSION

The calves used in these experiments had previously been given warm milk by teat (Ternouth & Buttle, 1973). In Expt 1, two reversed sequential changes were made in the feeding of the calves (e.g. calves nos. 1 and 2 were changed from treatment WT to WB and then from treatment WB to CB). Thus, all four calves were given warm milk-substitute by bucket in periods nos. 2 and 5 only, creating a potential source of bias in the experiment. In Expt 2, calves were given warm whole milk by bucket and teat only, in a balanced experiment. The observed differences between the two feeding systems in the two experiments were similar and it is concluded that no significant bias was created by the design used in Expt 1.

In both experiments, the duodenal N : N intake values were considerably greater than unity for calves given warm milk by bucket and teat. In Expt 1, after adjustment for N intake at the penultimate and experimental meals, the value was 1·03 for CB and 1·23 and 1·20 for WB and WT respectively. These latter two values are higher than that previously recorded, i.e. 1·03 (Ternouth, 1971) when calves were given warm milk-substitute *ad lib.* by teat. Some of the increase above unity is due to endogenous secretion of N. Sheep bile contains 2·47 g N/l (Altman & Dittmer, 1968) and Ternouth *et al.* (1974) concluded that these calves have a biliary secretion rate of 0·4 l/12 h. The secretions of a segment of duodenal mucosa of the calves contain 1·48 g N/l (Ternouth & Buttle, 1973). In Expt 1, 2·2, 2·0 and 1·5 l endogenous fluids passed through the duodenum in a 12 h period. However the recovery of ingested lipid was also 20% higher with warm milk-substitute than with cold milk-substitute. These differences in the values for output : input may result from techniques used for the collection and return of digesta that encourage the

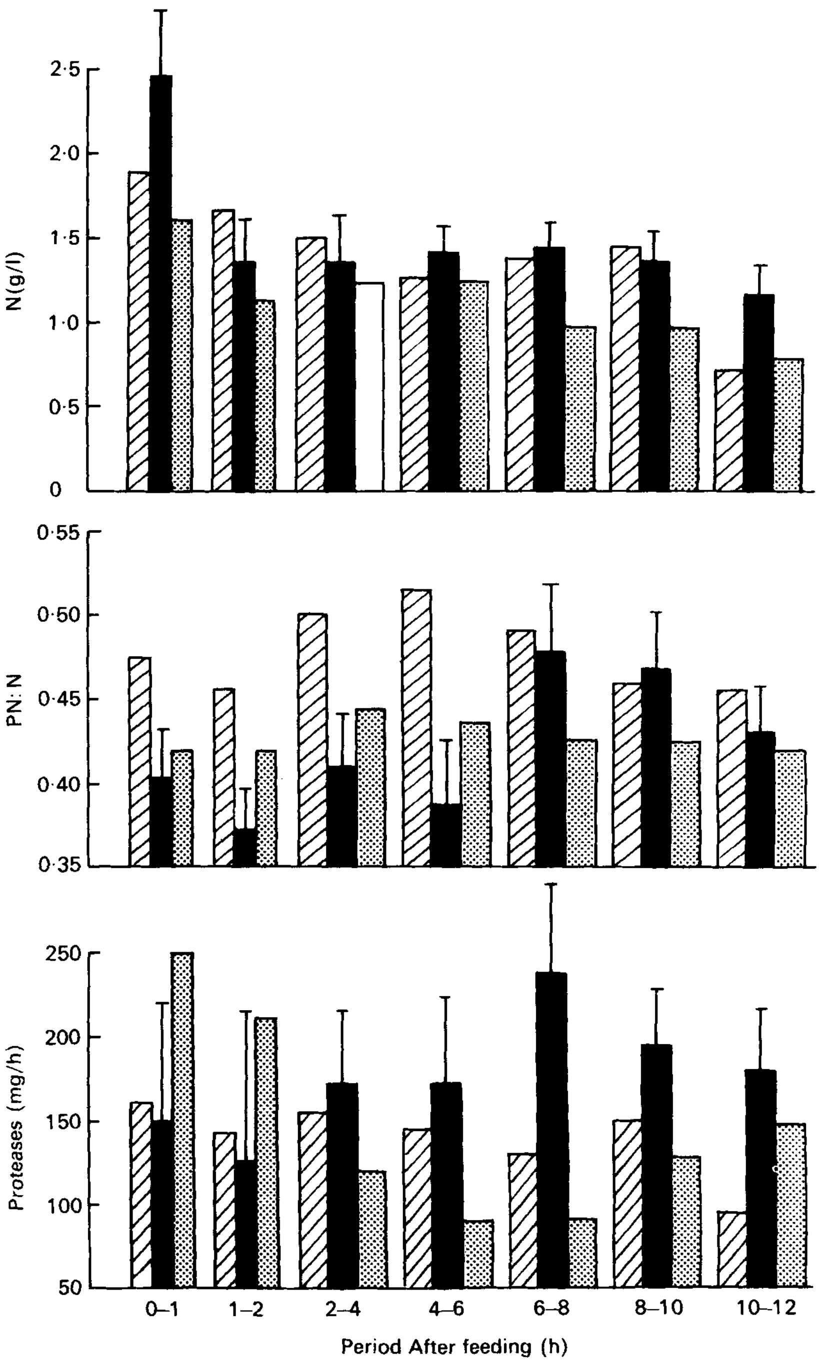

Fig. 2. Duodenal flow of nitrogen (N), the protein-N : N (PN : N) and secretion of pancreatic proteases of calves given 2·5 l milk-substitute by bucket (▨) and teat (■) at 39° and by bucket at 10° (▩). The vertical bar is the mean for all three treatments.

Table 4. *Duodenal flow of nitrogen (N), protein-N (PN) and lipid in Ayrshire calves during* 12 h *after being given milk by three feeding methods*†

	Expt 1 (milk-substitute)					Expt 2 (whole milk)			
	Method of feeding				Statistical significance of difference	Method of feeding			Statistical significance of difference
	WB	WT	CB	SE		WB	WT	SE	
N (g)	15·9	17·3	12·3	1·44	NS	19·4	25·9	2·77	NS
N : N intake	1·31	1·15	0·99	0·10	NS	1·11	1·46	0·13	NS
Adjusted N : N intake‡	1·23	1·20	1·03	0·13	NS				
PN (g)	7·22	7·48	4·99	0·47	**	5·63	5·64	0·54	NS
Adjusted PN (g)§	7·54	7·00	5·15	0·44	**				
PN : N	0·49	0·43	0·43	0·03	NS	0·30	0·22	0·03	NS
Lipid (g)	60·2	66·5	50·8	5·7	NS	67·3	78·1	8·6	NS
Lipid : lipid intake	1·18	1·20	0·98	0·12	NS	0·65	0·75	0·06	NS

WB, 39° by bucket; WT, 39° by teat; CB, 10° by bucket.
NS, Not significant. ** $P < 0·01$.
† For details, see p. 554 and Table 1.
‡ Values adjusted for N intakes at penultimate and experimental meals.
§ Values adjusted for N intake at experimental meal.

Table 5. *Pancreatic secretion of fluid and enzymes by Ayrshire calves during* 12 h *after being given milk by three feeding methods*†

	Expt 1 (milk-substitute)					Expt 2 (whole milk)			
	Method of feeding				Statistical significance of difference	Method of feeding			Statistical significance of difference
	WB	WT	CB	SE		WB	WT	SE	
Volume (ml)	294	249	206	22·7	*	386	324	30·1	NS
Trypsin (*EC* 3.4.4.4) (mg)	75·9	71·1	68·2	11·0	NS	147·4	98·2	15·4	NS
Protease (g)	1·65	2·16	1·62	0·35	NS	1·94	2·87	0·29	NS
Amylase (*EC* 3.2.1.1) (mg)	52·7	53·9	53·4	11·3	NS	150·9	75·5	18·4	*

WB, 39° by bucket; WT, 39° by teat; CB, 10° by bucket.
NS, Not significant. * $P < 0·05$.
† For details, see p. 554 and Table 1.

flow of N and lipid from the penultimate meal when warm milk is fed. Ternouth *et al.* (1974) and Ternouth, Roy, Thompson, Toothill, Gillies & Edwards-Webb (1975) found that there was a significant relationship between duodenal flow of N and lipid with the intake of N and lipid of a similar milk (milk SKF) at the penultimate rather than the experimental meal.

High rates of secretion of pancreatic fluid within the 12 h experimental period were associated with the flow of large quantities of non-whey fluids through the duodenum (Fig. 1). If the total non-whey fluids (NWF) and the pancreatic fluids (PF) are compared for four calves fed by all three techniques, the regression equation is:

$$\mathrm{PF} = 6{\cdot}25 + \underset{(\pm 0{\cdot}0202)}{0{\cdot}1022^{***}}\ \mathrm{NWF}\ (\mathrm{SD}\ 5{\cdot}30,\ r\ 0{\cdot}765),$$

where all values are expressed as ml/h. (This regression was established after doubling the values for pancreatic fluid for calf no. 3, whose accessory pancreatic duct was not ligated (Ternouth & Buttle, 1973).) The rate of secretion of the pancreas appeared to be responding to some enteric stimulus associated with the endogenous (including abomasal acid) fluids which enter the alimentary tract cranial to the duodenal cannulas. The residual rate of secretion (6·25 ml/h), based upon the intercept value in the regression equation given previously, was much less than the minimal rates of secretion (22–26 ml/h) observed 2 h after feeding 'raw' milk (Ternouth & Buttle, 1973).

In comparison with bucket-feeding, teat feeding results in higher negative pressures in the buccal cavity (Smith & Peterson, 1945), slower rates of drinking milk and greater secretion of saliva and salivary lipase (Wise, Miller & Anderson, 1947; Grosskopf, 1965; Wise, Miller, Anderson & Jones, 1968). Grosskopf (1965) has found also that sham-fed milk has a thicker consistency after being given by teat. In addition, teat-feeding of milk stimulates more abomasal proteolytic activity than bucket-feeding (Grosskopf, 1959). In the present experiments, the reasons for the faster duodenal flow of whey fluids with teat-feeding were not readily apparent but more effective coagulation and contraction of the coagulum was likely when the calves are fed by this method. In comparison with WT, the higher rate of flow of 'non-whey fluids' during the first hour after WB was due to the presence of fluidsfrom the previous meal, since WB calves had a PEG outflow time of 15 h compared with 12 h for WT fed animals.

When calves were fed by teat, rather than by bucket, it appeared from the '$Cl^- - Na^+$' value that more acid was secreted, although this conclusion was not substantiated by the pH of the duodenal digesta. However small changes in the logarithmic pH term make large differences in the H^+ secretion, especially when the pH is low. Moreover the pH is influenced by the buffering capacity of the digesta. It is therefore concluded that WT stimulates the secretion of more abomasal acid as well as abomasal enzymes.

The PN : N in the duodenal digesta tended to be lower for WT than WB. This is likely to be due to the increased acid secretion and the increased enzyme secretion recorded by Grosskopf (1959) for teat-feeding. In spite of the reduced abomasal proteolysis when the calves were given warm milk by bucket, less pancreatic proteases also tended to be secreted.

In Expt 1 when warm milk-substitute was given, the mean value for PN : N was 0·458 whereas in Expt 2 the comparable value was 0·262 for whole milk. These values may be compared with those of 0·408 for the reconstituted-milk diet SKF, (Ternouth *et al.* 1974) and 0·266 for whole milk (26 d of age) (Ternouth, Roy & Shotton, 1976). This strongly suggests that even with 'mildly' heat-treated skim-milk powders, abomasal proteolysis is considerably less than when whole milk is given.

The corresponding general mean duodenal flows of lipid relative to lipid intake of calves given warm milk-substitute (Expt 1) or whole milk (Expt 2), were 1·19 and 0·70 respectively. This difference may reflect the increased rate of hydrolysis and absorption of the butterfat in the abomasum and cranial duodenum compared to that occurring with margarine fat.

In an earlier experiment when a milk-substitute containing a 'severely' heat-treated skim-milk powder was given to calves, considerably smaller quantities of pancreatic proteases were secreted that when the same calves were fed on a diet containing a 'mildly' heat-treated skim-milk powder (Ternouth *et al.* 1974). These findings were associated with the earlier reports that a 'severely' heat-treated skim-milk powder could act as a predisposing factor to enteric disorders in calves. In the present experiment also, lower protease secretion tended to occur when calves were fed by bucket rather than by teat, the bucket-feeding method being associated by Wise & La Master (1968) with an increased incidence and persistence of diarrhoea in calves. In the experiments of Tagari & Roy (1969) and Ternouth *et al.* (1974) there was a higher PN : N in the duodenal outflow of calves given 'severely' heat-treated skim-milk than in that of calves given 'mildly' heat-treated skim-milk. Similarly, in the present experiment, WB was associated with a higher PN : N in the duodenal digesta than occurred with WT.

The comparison of WB and CB showed that the volume of apparent secretion was less when the milk-substitute was given cold, and this was partly accounted for by a reduction in the secretion of abomasal acid. The reduced PN : N in the duodenal outflow from calves given cold milk-substitute may have been the result of reduced enzyme-protein secretion rather than improved proteolysis in the abomasum. Associated with the lower abomasal secretion was a reduced secretion of pancreatic fluids but no change in the quantity of pancreatic enzymes.

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