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

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1. The effects of giving milk once or twice daily (Expt 1) and of weaning (Expt 2) on the flow rate of digesta through the duodenum and on pancreatic secretion were studied in four and two Ayrshire calves respectively. The calves were prepared with duodenal re-entrant and pancreatic sac cannulas.

2. In Expt 1, when whole milk was offered *ad lib.* once daily, the calves ingested 141 g/kg live weight (46 g dry matter (DM)/kg live weight $^{0.75}$) at a single meal. The subsequent pattern of flow and total recovery of polyethylene glycol from the duodenum suggested that none of the ingested milk passed into the rumeno-reticulum. As the total daily quantity of milk ingested when the calves were fed once and twice daily was similar, it was concluded that abomasal distension is unlikely to be the sole factor limiting milk intake in the preruminant calf.

3. With twice-daily feeding, there were no differences in the pattern or total flow of fluid, electrolytes, nitrogen or fat through the duodenum of the calves following the 09.00 and 21.00 hours meals. The pattern of flow of duodenal and pancreatic fluids and the concentration of electrolytes, N and fat were markedly different when the calves were fed once or twice daily. The patterns of flow of fluid and the concentration of electrolytes in the duodenal digesta reflected the frequency of feeding and the size of the meal and the consequent balance between feed and endogenous components of the digesta. The quantity of the apparent endogenous secretion and pancreatic secretion was markedly less when the calves were fed once daily.

4. In Expt 2, the two Ayshire calves were given whole milk twice daily (diet MM), whole milk once daily with concentrates (diet MC), concentrates alone (diet CC) or dried grass alone (diet DG). The calves consumed 46, 49, 45 and 51 g DM/kg live weight $^{0.75}$ when given diets MM, MC, CC and DG respectively.

5. The twice-daily fluctuations in the flow and concentration of fluid, electrolytes, N and fat in the duodenal digesta and the pancreatic fluid observed when diet MM was given were replaced by relatively constant flow rates and composition when diet CC or DG was given.

6. Over the 24 h experimental period 97, 70, 50 and 58 % of the DM and 112, 98, 99 and 84 % of the N in the feed passed through the duodenum of calves when given diets MM, MC, CC and DG respectively.

7. When dry food was given, the rate of pancreatic fluid secretion was markedly lower (11·3 and 13·5 ml/kg live weight for diets CC and DG respectively) than when diet MM (19·7 ml/kg live weight) was given.

Johnstone-Wallace & Kennedy (1943) reported that beef calves grazing with their dams suck for three 15 min periods each day, whereas Walker (1962) has observed three to five suckings/d by young calves, the number decreasing with age. Dairy calves are normally fed twice daily but recently feeding only once daily has been advocated, particularly for 'early weaned' calves (*c.* 5 weeks of age). However, little attention appears to have been given to changes occurring in the digestive tract of the

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Table 1. *Age and milk intake of calves when fed once and twice daily*

Calf no.	Age of calves (d)		Daily milk intake (l)	
	Once-daily feeding	Twice-daily feeding	First collection	Second collection
3	43, 45	49, 51	5·70	7·46
4	43, 45	49, 51	8·70	8·66
5	53, 55	60, 62	6·00	8·80
6	43, 45	50, 52	8·05	8·30
Mean	47	53	7·71	

calf as a result of adopting this practice. The first experiment reported is a comparison of the effect of once- and twice-daily feeding of the same quantity of whole milk upon the flow of digesta through the duodenum of calves.

The second experiment is an investigation of the changes in the pattern of abomasal emptying and pancreatic secretion during and after weaning when the forestomachs of the calf become functional.

EXPERIMENTAL

Animals and experimental design

Expt 1. Four Ayrshire calves (nos 3–6) with duodenal re-entrant and pancreatic sac cannulas (Ternouth & Buttle, 1973) were given whole milk *ad lib.* by teat once daily for at least 5 d before the first collection period. The calves were allowed to drink as much milk as they wished at a single meal. Duodenal effluent and pancreatic secretions were collected from 0·5 h before until 24 h after the meal, using the procedures described by Ternouth, Roy & Siddons (1974). After 24 h had elapsed, the collection was repeated.

Immediately after the completion of the replicate collection, each calf was offered half the mean quantity of milk that it consumed when fed once daily, the other half being offered 12 h later. After 5 d had elapsed, the calves were subjected to duodenal effluent and pancreatic collections for a similar period of 24·5 h; this period represented two successive 12 h postprandial periods, with an identical quantity of milk given at each meal. A replicate 24·5 h collection with the twice-daily feeding schedule, was undertaken 24 h after the completion of the first. The age of the calves at each collection day is shown in Table 1.

Expt 2. Only calves 5 and 6 successfully completed this experiment which was carried out immediately after Expt 1.

The collection periods lasted 24·5 h and were replicated on each calf within each of the four dietary regimens. The four diets were: MM, limited quantities of whole milk given at 09.00 and 21.00 hours (these results have been included in Expt 1); MC, the same limited quantity of whole milk given at 09.00 hours as for diet MM, together with concentrates available *ad lib.* from 09.00 to 17.00 hours (no milk was offered at 21.00 hours); CC, concentrates only, available *ad lib.* from 09.00 to 17.00 hours; DG, dried grass available *ad lib.* throughout the 24 h.

Proximate analysis and digestibility data for the concentrate and dried grass are

Table 2. *Composition (g/kg dry matter) and digestibility of concentrate and dried grass diets*

Composition	Concentrates	Dried grass
Crude protein*	178	110
Fibre	54	296
Diethyl ether extract	20	15
Ash	66	80
Nitrogen-free extract (by difference)	682	499
Apparent digestibility		
Dry matter†	0·811	0·744
Nitrogen†	0·750	0·669

* N × 6·25.
† Figures taken from experiments with castrated bull calves of similar age.

shown in Table 2. The calves were given diets CC and DG for at least 7 d and diet MC for 21 d before their first collection period. The mean age of the calves at each experimental period and the mean dry matter (DM) intakes are shown in Table 7. Drinking-water was freely available to the calves when diets MC, CC and DG were being given.

Experimental procedure

The procedures for the collection and return of the duodenal digesta and the pancreatic secretions have been described by Ternouth & Buttle (1973). When the calves were given dry food (Expt 2), sedimentation of the digesta in the tubing used for returning the material to the calves, caused blockages which were not encountered with milk-fed calves. To overcome these blockages the water jacket and the tubing used to return the digesta to the calf were discarded and the digesta were rewarmed in a water bath and well-mixed aliquots (*c.* 100 ml) of digesta and pancreatic fluid were returned directly into the caudal duodenal cannula. The quantity of dry food ingested during each hour of the feeding period was recorded.

Analysis

Dry matter content of the duodenal digesta was estimated by drying to a constant weight at 100°. All other analyses, including polyethylene glycol (PEG) determination, done on duodenal digesta have been described by Ternouth *et al.* (1974).

RESULTS

Expt 1

The mean intake of milk by the calves when fed once daily was 7·71 l (Table 1), equivalent to 141 g/kg live weight or a DM intake of 46 g/kg live weight $^{0.75}$ per d.

The pattern of outflow from the duodenum differed markedly between the two feeding schedules. The results are shown in Fig. 1 and Table 3. When the diet was given once daily, 300 ml/h more duodenal outflow passed from the cranial duodenal cannula during the first 9 h after feeding than when the calves were fed twice daily; the duodenal outflow remained relatively constant at 200 ml/h during the final 9 h of

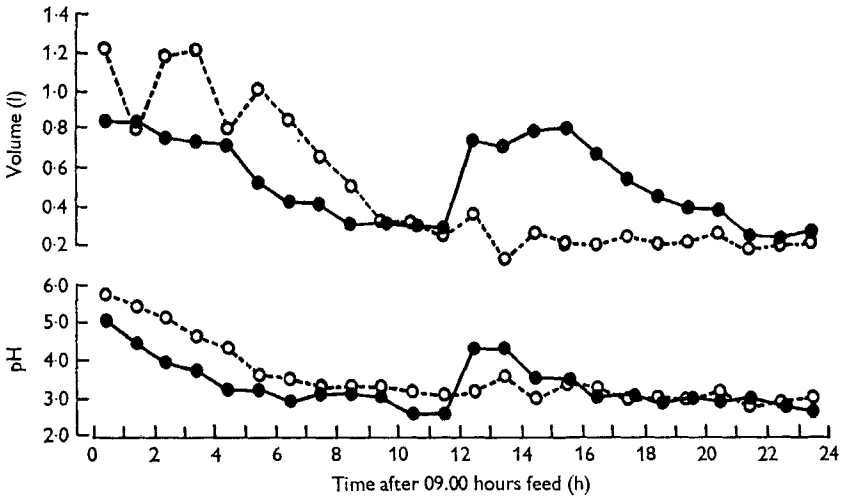

Fig. 1. Expt 1. Effect of giving whole milk once or twice daily to calves on the volume and pH of duodenal outflow: ○--○, once-daily feeding; ●—●, twice-daily feeding.

Table 3. *Volume of duodenal outflow of calves given whole milk once or twice daily*

(Mean values for four calves)

Twice-daily feeding		Comparison of 09.00 and 21.00 hours feeding		Once-daily feeding		Comparison of once- and twice-daily feeding	
Time after feeding (h)	Volume of duodenal outflow (ml)	Pooled SE of mean	Significance of difference	Time after feeding (h)	Volume of duodenal outflow (ml)	Pooled SE of mean	Significance of difference
0–3†	2433	—	—	0–3†	3221	229·8	*
3–6	2056	—	—	3–6	3040	140·8	***
6–9	1139	—	—	6–9	2024	93·6	***
9–12	910	—	—	9–12	914	53·6	—
0–12	6538						
0–3‡	2241	195·2	—	12–15	801	149·4	***
3–6	2049	115·2	—	15–18	666	121·5	***
6–9	1238	73·2	—	18–21	685	76·7	***
9–12	755	74·6	—	21–24	615	64·4	—
0–12	6283	204·5	—				
Total	12820			Total	11968	321·5	

* $P < 0{\cdot}05$; *** $P < 0{\cdot}001$.
† 0 h = 09.00 hours.
‡ 0 h = 21.00 hours.

the 24 h period after milk was given once daily. When the calves were fed twice daily the pattern of duodenal emptying was similar to that previously observed (Ternouth & Buttle, 1973; Ternouth *et al.* 1974) and was not significantly different between the 09.00 and 21.00 hours postprandial feeding periods. The pH of the duodenal outflow of the calves fed once daily was higher than that of the calves fed twice daily for the first 12 h after the 09.00 hours meal (Fig. 1).

Table 4. *Total flow of electrolytes in duodenal outflow and in apparent secretion of calves given whole milk once or twice daily*

(Mean values for four calves)

	Comparison of 09.00 and 21.00 hours feeding				Comparison of once- and twice-daily feeding			
Total duodenal outflow (mmol)	09.00 hours	21.00 hours	Pooled SE of mean	Significance of difference	Once daily	Twice daily	Pooled SE of mean	Significance of difference
Ionized H^+	41·2	43·9	7·5	—	41·5	85·0	15·3	*
Na^+	219·8	202·9	6·5	—	347·7	422·7	14·7	**
K^+	69·8	70·2	4·9	—	144·4	139·9	8·5	—
Cl^-	607·8	584·8	17·0	—	1023	1192	41·2	*
Apparent secretion in duodenal outflow								
Volume (l)	—	—	—	—	4·26	5·12	0·16	**
Na^+ (mmol)	—	—	—	—	243·6	328·0	16·5	**
Cl^- (mmol)	—	—	—	—	832·5	1002·1	31·9	**

* $P < 0.05$; ** $P < 0.01$.

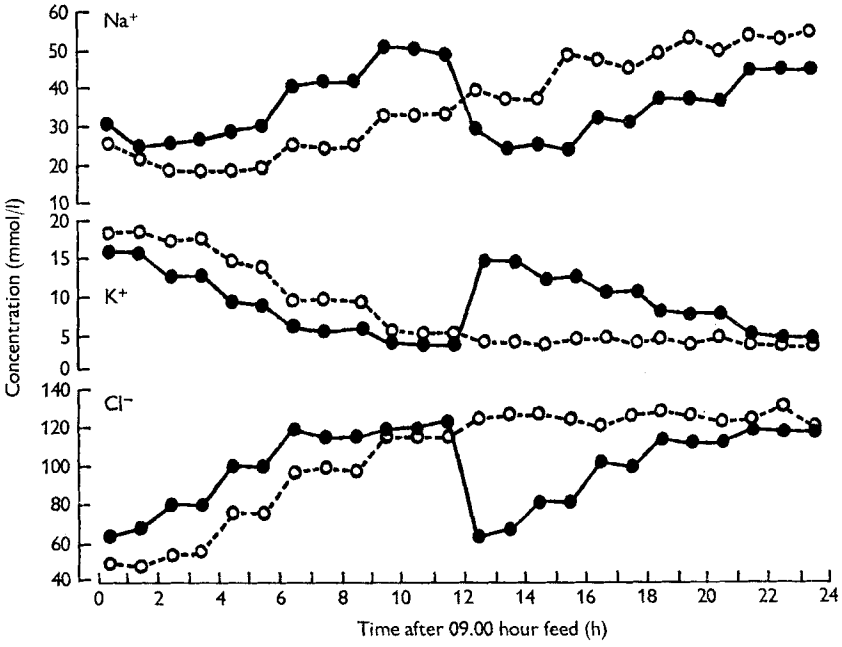

Fig. 2. Expt 1. Effect of giving whole milk once or twice daily to calves on the concentration or Na^+, K^+ and Cl^- in the duodenal outflow: ○--○, once-daily feeding; ●—●, twice-daily feeding.

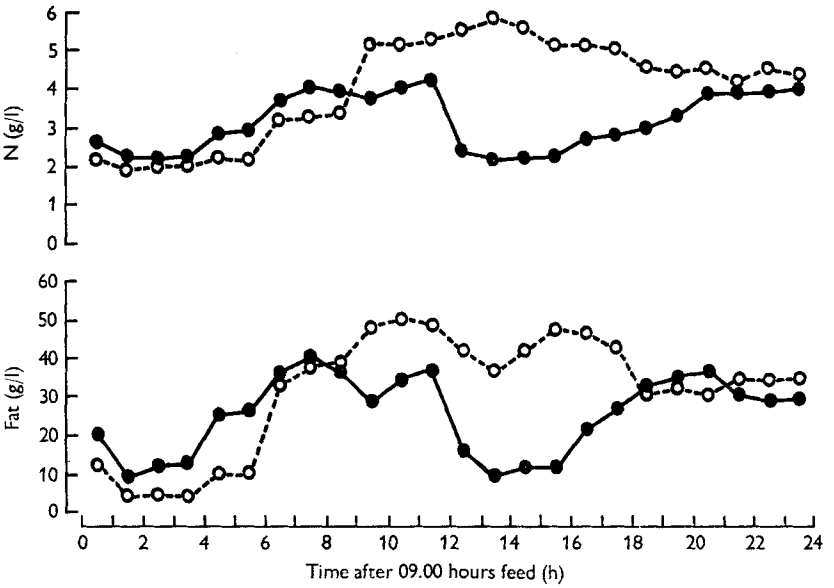

Fig. 3. Expt 1. Effect of giving whole milk once or twice daily to calves on the concentration of N and fat in the duodenal outflow: ○--○, once-daily feeding; ●—●, twice-daily feeding.

When the calves were fed once daily, the pattern of outflow of PEG with time after feeding was linear when the amount retained in the abomasum, as a percentage of that ingested, was transformed to a square root; it was calculated that the PEG took 13·5 ± 0·5 h to leave the abomasum. When the diet was given twice daily, the corresponding values were 10·2 ± 1·44 and 11·0 ± 2·18 h for the 09.00 and 21.00 hours feeding periods respectively and the pattern of outflow was slightly curvilinear.

The total quantities of H^+, Na^+, K^+ and Cl^- in the duodenal outflow are shown in Table 4 and the concentrations of the electrolytes in Fig. 2. Significantly more ionized H^+, Na^+ and Cl^- passed through the cranial duodenal cannula over the 24 h period when the calves were fed twice daily. These changes appeared to be caused by the increased volume of apparent secretion (Table 4). The total quantities of Na^+ and Cl^- in the apparent secretion were increased although the changes in concentration were insignificant. There were no differences in the quantities of electrolytes or their concentration in the duodenal outflow between the 12 h periods following the 09.00 and 21.00 hours meals.

The concentrations of nitrogen and fat in the duodenal outflow are shown in Fig. 3 and the mean concentration and total outflow in Table 5. When the calves were fed once daily, the concentrations of N and fat in the duodenal outflow were lower for the first 7–8 h than when the diet was given twice daily. During the period 9–18 h after feeding once daily, the concentration of both N and fat were higher than at any time during the twice-daily feeding schedule. However, after a single feed daily, the total quantities of N and fat passing through the duodenal cannula during the period 9–18 h after feeding were no higher than the total quantities flowing through the duodenum during the period 6–10 h after feeding on the twice-daily feeding routine. Quantities

Table. 5. *Daily nitrogen and fat outflow, and concentration of N and fat in the duodenal outflow of calves given whole milk once or twice daily*

(Mean values for four calves)

	Feeding schedule		Pooled SE of mean
	Once daily	Twice daily	
Total N (g)	38·6	37·3	1·48
Total fat (g)	278·3	289·4	32·5
Total N concentration (g/l)	3·2	2·9	0·1
Total fat concentration (g/l)	22·4	22·1	1·9

Table 6. *Pancreatic secretion of calves given whole milk once or twice daily*

(Mean values for four calves)

Twice-daily feeding		Comparison of 09.00 and 21.00 hours feeding		Once-daily feeding		Comparison of once- and twice-daily feeding	
Time after feeding (h)	Total pancreatic secretion (ml)	Pooled SE	Significance of difference	Time after feeding (h)	Total pancreatic secretion (ml)	Pooled SE	Significance of difference
0–3†	112	—	—	0–3†	75	4·8	***
3–6	153	—	—	3–6	77	6·2	***
6–9	144	—	—	6–9	140	11·0	—
9–12	135	—	—	9–12	102	14·0	—
0–12	545	—	—				
0–3‡	105	6·0	—	12–15	96	5·6	—
3–6	173	5·6	*	15–18	90	8·3	***
6–9	159	8·4	—	18–21	104	8·2	***
9–12	117	15·0	—	21–24	98	12·2	—
0–12	554	23·0	—				
Total	1098			Total	782	44·5	***

* $P < 0.05$; *** $P < 0.001$.
† 0 h = 09.00 hours.
‡ 0 h = 21.00 hours.

of N in excess of 2 g/h were present in the duodenal outflow during the periods 0–1, 2–5 and 6–8 h after feeding the calves once daily, whilst quantities of fat in excess of 18 g/h were present only during the period 6–8 h after feeding.

When the diet was given twice daily, the patterns of duodenal outflow of N and fat were similar to those observed previously (Ternouth *et al.* 1974). Only during the first hour after the 09.00 hours meal on the twice-daily feeding routine were the duodenal outflow of N and fat in excess of 2 and 18 g/h respectively.

With the exception of the periods 7–8 and 13–14 h after feeding, the volume of pancreatic secretion of the calves fed once daily was consistently lower than when the calves were fed twice daily (Table 6). When the calves were fed twice daily, pancreatic volume during the period 3–9 h was higher after the 21.00 hours meal than after the 09.00 hours meal. However, the volumes of pancreatic secretion collected in the two 12 h periods were similar.

Table 7. *Age and daily dry matter* (DM) *intakes of two calves given diets of milk* (*MM*), *milk and concentrates* (*MC*), *concentrates* (*CC*), *or dried grass* (*DG*)

(Mean values with their standard error where given)

	Diet			
	MM	MC	CC	DG
Mean age (d)	56	93	114	126
DM intake (kg)*				
Milk	0·97 ± 0·07	0·50 ± 0·02	—	—
Concentrates	—	0·69 ± 0·04	1·12 ± 0·09	—
Dried grass	—	—	—	1·33 ± 0·17
Total (kg)	0·97	1·19	1·12	1·33
Total (g/kg$^{0·75}$†)	46	49	45	51

* Based on values of 125, 850 and 815 g/kg for the DM contents of the milk, concentrates and dried grass respectively.

† Based on mean live weights of 59, 70, 73 and 78 kg for dietary regimens MM, MC, CC and DG respectively.

Table 8. *Total outflow and concentration of dry matter* (DM), *electrolytes and nitrogen in the duodenal digesta and the concurrent total pancreatic secretion of two calves given diets of milk* (*MM*), *milk and concentrates* (*MC*), *concentrates* (*CC*), *or dried grass* (*DG*)

	Diets				Least significant difference ($P < 0·05$) between means
	MM	MC	CC	DG	
Total duodenal outflow (l/24 h)	12·53	14·85	15·19	22·99	5·69
pH	2·9	3·2	3·1	2·9	—
Na^+ (mmol/l)	29·7	38·8	44·7	23·7	6·4
K^+ (mmol/l)	12·05	9·99	8·21	29·91	3·87
Cl^- (mmol/l)	95·5	113·6	123·1	89·3	9·7
N (g/l)	2·87	2·79	2·11	1·23	0·41
DM (g/kg)	74·4	56·1	36·3	33·7	6·5
Total ionized H^+ (mmol/24 h)	165·0	92·2	127·3	271·8	113·3
Total Na^+ (mmol/24 h)	369·9	573·2	675·9	537·6	166·7
Total K^+ (mmol/24 h)	151·7	147·2	127·0	682·8	161·5
Total Cl^- (mmol/24 h)	1192	1683	1881	2045	599
Total N (g/24 h)	36·04	41·49	32·28	27·91	12·42
Total DM (g/24 h)	936	830	556	766	250
Concurrent total pancreatic secretion (l/24 h)	1·162	1·120	0·822	1·055	0·386

Expt 2

When calves were given diets MC and CC, almost two-thirds of the total quantity of concentrates was eaten during the period 09.00–11.00 hours. When dried grass was given, one third was ingested during the period 09.00–13.00 hours and a further one-third in the period 18.00–22.00 hours. The quantity of DM ingested tended to be lowest when limited quantities of milk were given (diet MM) and highest with diet DG (Table 7) although none of the differences was significant. When intake was expressed on a metabolic body-weight basis (kg live weight $^{0·75}$), the differences in intakes between diets were considerably reduced.

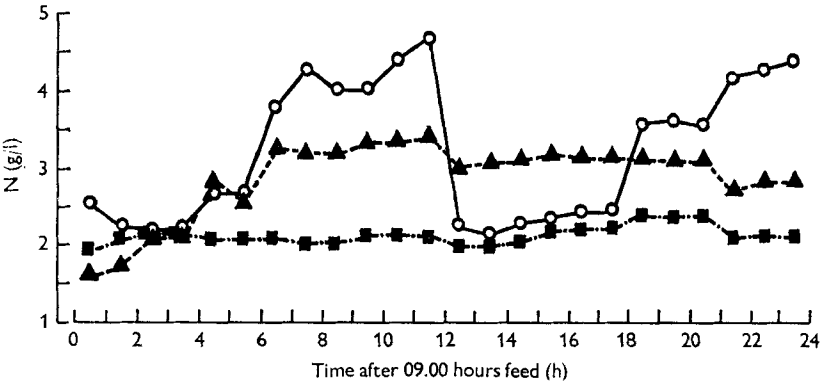

Fig. 4. Expt 2. Effect of giving whole milk twice-daily (○—○), whole milk once daily with concentrates (▲--▲), or concentrates alone (■--■) on the nitrogen concentration in duodenal outflow of calves.

After milk (diet MM) was given, the pattern during each 12 h period was similar to that observed in Expt 1, high duodenal flow rates being associated with a high pH and a low concentration of Na^+, Cl^- and N for the first 3–4 h, followed during the period 6–10 h by a low duodenal flow rate, a low pH and a high concentration of Na^+, Cl^- and N. When either concentrates (diet CC) or dried grass (diet DG) were given alone, there was a relatively constant outflow of duodenal digesta over the whole 24 h period and variation in the concentrations of Na^+, Cl^- and N were small. The pattern of duodenal outflow for diet MC was similar to that for diet CC, except that, during the first 6 h after feeding, the pH, and Na^+ and Cl^- concentrations in the duodenal digesta closely paralleled those obtained when the calves were given diet MM. The volume of duodenal outflow was particularly high (1500 ml) for the first hour after the milk was ingested.

The total quantity and mean concentration of the constituents of the duodenal effluent of the calves are shown in Table 8. The total quantity of duodenal fluids tended to increase and that of Na^+ and Cl^- in the duodenal outflow significantly increased when the calves were weaned from the milk to the concentrate diet. Comparison of the flow of fluids and electrolytes through the duodenum of the calves when they were given diets CC and DG indicates that the total quantity of fluids and of ionized H^+ was considerably greater when diet DG was given. The quantity of K^+ flowing through the duodenum was also markedly higher when diet DG was given, reflecting the high quantities of K^+ (30 g/kg DM) in the dried grass. Associated with the increased outflow of duodenal fluids for diet DG, the concentration of Na^+, Cl^- and N were all lower than when diet CC was given. The pattern of concentration of N, in the duodenal outflow, when diets MM, MC, and CC were given, is shown in Fig. 4.

The pancreatic volume tended to be lower when concentrates (diet CC) were given than when milk (diet MM) was the sole diet (Table 8), and the flow rate for dried grass (diet DG) tended to be higher than that for concentrates. The pattern of flow of pancreatic secretion throughout the 24 h collection period was relatively constant when either diet CC or DG was given.

DISCUSSION

No information about the quantity of milk that a calf can ingest at a single meal when fed once daily was available before the start of the experiment. To ensure that the studies of once- and twice-daily feeding were made with the same milk intakes, the calves in Expt 1 were fed milk *ad lib.* once daily before being fed half the quantity at each of two meals. Although the comparison made between once- and twice-daily feeding is confounded by the effect of age, it is unlikely that the 6 d difference in age had a significant effect upon the comparisons made.

Commencing in the week after the completion of Expt 1, the four calves were offered whole milk *ad lib.* twice daily as part of another experiment (Ternouth, Roy & Shotton, 1976), during which time the mean milk intake was 4·9 l/meal, equivalent to a daily DM intake of 45 g/kg $W^{0.75}$. The amount of milk consumed in the present experiment, when given only once daily, was 7·7 l/d, which is equivalent to a DM intake of 46 g/kg $W^{0.75}$. Thus, it would appear that when two feeds are given daily, abomasal distension is not the factor controlling milk intake, although when giving milk twice daily a considerable amount of the material passing out of the abomasum arises from the residual clot formed at the previous meal (Ternouth, Roy, Thompson, Toothill, Gillies & Edwards-Webb, 1975).

The outflow of PEG from the duodenal cannula with time has previously been found to be linear when expressed as the square root of the percentage of the amount ingested that is retained in the abomasum. The existence of this linear relationship in Expt 1 is critical as it would indicate that all the ingested milk passed to and remained within the abomasum and none escaped into the rumeno-reticulum. When the diet was given once daily, the linearity of the regression existed during the first 9 h after feeding, in which time 88% (range 83–96%) of the ingested PEG had been recovered. In contrast, the standard error of the estimate of time taken for all the PEG to leave the abomasum ($\pm$2·18 h), for the calves fed twice daily, was larger than that previously observed by Ternouth *et al.* (1974, 1975) and the pattern of emptying was slightly curvilinear. Much of this variability was due to calf 3, which had an abnormal pattern of emptying after the 09.00 hours meal at 49 d of age and after the 21.00 hours meal at 51 d of age, when the time for all whey fluids to leave the abomasum was calculated to be 19·3 and 25·7 h respectively. These two abnormal emptying periods were possibly due to passage to the rumeno-reticulum of some of the ingested milk. Apparently this occurred despite the small quantity of milk that was given. The calf appeared to be normal in all other respects, and showed no difficulty or hesitation in drinking. The only other abnormality was a smaller volume of duodenal effluent recovered during the first 2 h after these two particular meals. If these two records for calf 3 are omitted from the mean results then the PEG required 9·00 $\pm$ 0·7 h and 9·00 $\pm$ 0·6 h to leave the abomasum after the 09.00 and 21.00 hours meals respectively and the linearity of the results is re-established. However, it is surprising that a similar or larger escape of milk into the rumeno-reticulum did not occur when that calf drank 5·7 or 7·5 l milk at a single meal. Ternouth *et al.* (1974) calculated that an additional 0·86 h was required

for all the PEG to leave the abomasum for each additional l of milk drunk. In Expt 1, the corresponding value is 1·01 ± 0·21 h/l.

The results from Expt 2 on the effect of weaning are confounded by the non-significant differences in DM intakes and also by the age of the calves, especially the large difference between the ages when diets MM and MC were given.

A relatively constant rate of abomasal emptying has been observed when dry diets were given to sheep (Hogan & Phillipson, 1960; Harrison & Hill, 1962; Badawy & Mackie, 1964). Badawy & Mackie (1964) showed that the variations in flow of digesta through the duodenum, 250 mm distal to the common bile duct, were much smaller than the variations of abomasal outflow. It is not certain whether this 'smoothing out' of the variations in volume of abomasal outflow is the result of the secretion of digestive juices within the duodenum as suggested by Badawy & Mackie (1964) and Sineshchekov (1968), or because cannulation at the more caudal site causes less interference with an entero-abomasal reflex mechanism controlling abomasal emptying. The cannulation site used in the present experiment is similar to that used by Badawy & Mackie (1964), but the duodenal digesta in the present experiment did not contain any pancreatic fluids. When diet MC was given, there was a very high outflow of duodenal digesta during the first hour after the milk was ingested, the volume being consistently higher for both replications for both calves than that obtained with any of the other three diets in Expt 2 and in all except one instance in Expt 1. The associated low concentrations of Na^+, Cl^- and N strongly suggest that the whey fluids from the milk were rapidly expelled from the abomasum (cf. Expt 1). When milk was ingested, the abomasum probably contained a quantity of digesta which had passed there from the rumeno-reticulum. Thus the high duodenal flow rate during this first hour may have occurred because the digesta already present in the abomasum were solidified within the coagulating milk proteins whilst the whey fluids were passed very rapidly out of the abomasum. Ternouth *et al.* (1976) have shown that with increasing age of the calf, ingested whey fluids are passed into the duodenum more rapidly. Almost one-third of the whey fluids ingested appeared to pass out of the abomasum in this 1 h period. The subsequent high concentration of N in the duodenal digesta is likely to be due to the progressive liquefaction of the coagulated milk proteins to which has been added additional digesta N that passed from the rumeno-reticulum. When the abomasal outflow of fluids is rapid and mainly of exogenous origin directly after a milk feed, the concentration of Na^+ and Cl^- is relatively low whilst the concentration of K^+ is high. Towards the end of the postprandial period, the concentration of the electrolytes approximates those in the endogenous secretions. When the calves were fed once daily the concentration of Na^+ and Cl^- was lower and the concentration of K^+ higher during the first 3 h after feeding than when the calves were fed twice daily. In Expt 2, no measurements were made of the quantities of water drunk, so that increased outflow of duodenal digesta and lower concentration of electrolytes (particularly for dried grass) may reflect an increased water intake. Conversely, the calves may have had considerably higher salivary secretion rates with diet DG, as a result of increased rumination. Thus it is not clear from these studies which factors play a significant role in determining the total volume of fluid and the concentration of electrolytes in the

duodenal fluids. For Na^+ and K^+ the changes may be determined by the need to maintain the osmolality of the rumen fluids within certain closely defined limits. It is interesting to note that the Na^+ plus K^+ concentration in the duodenal digesta of calves given diets CC and DG was 52·9 and 53·6 mmol/l respectively.

Shannon & Lascelles (1967) observed that when calves were fed once daily, the flow of lymph through the thoracic duct was highest 4–5 h after feeding but the flow and concentration of fat were highest 10 h after feeding. When calves were fed once daily in Expt 1, the greatest quantity of fat was present in the duodenal digesta during the seventh and eighth hours after feeding. The coincidence in time of these peaks of fat concentration in the lumen of the duodenum and in the thoracic lymph suggests that fat is rapidly absorbed, probably from the more cranial portions of the small intestine.

Quantities of N equivalent to 112, 98, 99, and 84% of those ingested during the same 24 h period were passed through the duodenum of calves given diets MM, MC, CC and DG respectively. Corresponding values for DM were 97, 70, 50 and 58%. The differences within treatments between the percentages of N and DM passing through the duodenum strongly suggest that the carbohydrate fraction of the dry diets was subjected to considerable fermentation before leaving the rumeno-reticulum. Although the concentrates contained more crude protein (CP; $N \times 6{\cdot}25$) than the dried grass, the CP in the dried grass was probably degraded more rapidly with loss of rumen ammonia. A greater fermentation of CP in dried grass than in concentrates would be in conformity with the results obtained by Badawy & Mackie (1964) when grass, concentrates plus hay, or hay were given to sheep.

The pancreatic volume tended to be lower, with little variation over the 24 h period, when concentrates were given than when the sole diet was milk. When the calves were weaned, the rates of secretion appeared to decline to the rates recorded in the literature for adult ruminants (Ternouth & Buttle, 1973). The daily rates of secretion of the calves given diets CC and DG were 11·3 and 13·5 ml/kg live weight respectively, these values being considerably lower than when calves were fed on milk diets (19–23 ml/kg live weight) but still considerably higher than the values recorded by Zerebcov & Seryh (1962) and Wass (1965). The lack of variation in pancreatic secretion with time after feeding observed for both diets CC and DG, is in keeping with Taylor's (1962) results. Thus it is likely that the lower rate of secretion in the ruminant calf is due to a reduced stimulation of the pancreatic gland by the duodenal digesta. When milk is given, greater stimulation is likely to be caused either by butterfat or casein, or the products of their hydrolysis, rather than by abomasal acid (Ternouth *et al.* 1975).

Since Burt (1966) reported his results on feeding calves once daily, many further experiments have been made throughout the world indicating its economic advantages for early-weaned calves (Burt, 1968; Wilson, 1968; Ackerman, Thomas, Thayne & Butcher, 1969; White & Radcliffe, 1970). In the present experiment, no deleterious effects were observed when the calves were fed *ad lib.* by nipple once daily, and large quantities of milk were ingested at a single meal. Although somewhat reduced quantities of gastric acid and pancreatic fluid were secreted when the calves were

fed once daily, this did not appear to effect adversely the digestion of the milk.

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