Br. J. Nutr. (1978), 39, 469

Effects of liquid feeding of concentrate from a pail on growth and on the digestibility of the diet in young calves

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(*Received* 7 *July* 1977 – *Accepted* 27 *July* 1977)

1. Studies were done on the effects of giving calves two types of concentrate diet, both in a liquid form from an open pail or in a dry pelleted form, on the closure of oesophageal groove, body-weight gains and the digestibility of rations.

2. Twenty-four Holstein calves were used in an experiment by dividing into two groups of twelve calves each. The 'dry-fed' group (DFG) was given a pelleted concentrate, F1, from 25 to 42 d of age, and then given another type of pelleted concentrate, F2, from 43 to 87 d of age, and again given F1 from 88 to 112 d of age. The 'liquid-fed' group (LFG) was given from a pail a liquid suspension of the equivalent amount of the same concentrates as those fed to DFG calves, for the same periods. F1 contained skim milk and glucose with lower levels of maize and soya-bean meal than F2 which did not contain skim milk or glucose; F1 and F2 were both supplemented with 10 g methionine/kg and also supplemented with lysine at 5 and 10 g/kg respectively. All calves were allowed free access to roughage, and digestibilities were measured at 12 and 16 weeks of age.

3. Wet weights of reticulo-rumen and abomasal tissues (% whole stomach weight) were respectively 69·8 and 17·6 in DFG, and 59·0 and 26·4 in LFG at 42 d of age; at 87 d of age, the corresponding values were 68·0 and 16·3 in DFG, and 52·8 and 36·6 in LFG, and further, LFG had significantly more developed caecums and large intestines as well as significantly less developed reticulo-rumens and omasums than DFG.

4. Free amino acid patterns in plasma did not vary in DFG, but varied in LFG in response to the change in diet from F1 to F2 and to the difference between diets in lysine supplementation.

5. Feeding F1 in a liquid form and F2 in a dry form significantly improved calf gains. The intake of roughage in DFG exceeded that in LFG especially when F2 was fed.

6. The digestibility of diethyl ether extracts did not vary with feeding procedures, but that of crude protein (nitrogen × 6·25) was significantly higher in DFG independent of the type of diet. Digestibilities of dry matter and N-free extracts were significantly higher in LFG for F1, while higher in DFG for F2. The digestibility of acid-detergent fibre did not differ significantly between groups at 12 weeks of age, but was significantly higher in LFG at 16 weeks of age, suggesting a possible compensatory contribution of the large intestine to the digestion of fibre in LFG.

7. The efficiency of liquid feeding of a concentrate diet to ruminants compared with that of dry feeding is discussed.

With respect to the efficiency of utilization of dietary energy and nitrogen, ruminants have some defects as compared with single-stomached animals. In a theoretical consideration of the efficiency of utilization of dietary energy and protein in lambs, Black (1971) suggested that many common foodstuffs would be more efficiently utilized if they by-pass the rumen for postruminal digestion. From a similar standpoint, Owens & Isaacson (1977) suggested that the rumen should be used to digest cellulose and hemicellulose and build microbial protein using non-protein-N and proteins of low biological value.

One of the methods used to by-pass the rumen for postruminal digestion of a feed is by using oesophageal groove (Black, 1971; Hedde & Ward, 1973; Chalupa, 1975; Robinson, Mowat, Chapman & Parkins, 1977). Ørskov & Benzie (1969) showed that voluntary and eager sucking of any liquid feed from a teat would produce a complete closure of the oesophageal groove in lambs trained to swallow from a teat at weaning. Drinking liquid feed from a trough did not produce the complete closure in lambs not trained (Ørskov & Benzie, 1969), but it took place in lambs that were trained to this feeding procedure after having been weaned from their dams (Ørskov, Benzie & Kay, 1970).

'Nipple'-feeding was adopted by many workers as a method of escaping rumen fermentation and directing supplemental proteins (Ørskov, Fraser & Corse, 1970; Lawlor & Hopkins, 1971; Ørskov, Fraser & Pirie, 1973; Robinson *et al.* 1977), or carbohydrates (Huber, Jacobson, McGilliard & Allen, 1961; Huber, Natrajan & Polan, 1967; Ørskov, Mayes & Mann, 1972; Coombe & Smith, 1974) to the abomasal region of ruminants. However, very limited information is available about the effects of a concentrate diet consisting of common foodstuffs by-passing the rumen to escape fermentation in it.

The purpose of the current studies was to investigate the effects of giving two different types of concentrate diet both in liquid suspension from an open pail or in a dry form, on the closure of oesophageal groove, the growth of calves and the digestibility of the diets. One type of diet (F1) contained skim milk and glucose, and the other type of diet (F2) contained maize and soya-bean meal as the major ingredients.

EXPERIMENTAL

Animals and design

Twenty-four Holstein calves (twelve males and twelve females) weaned from their dams at 1 week of age were used. They were fed on a liquid milk-substitute from an open pail at 08.30 and 16.30 hours until 24 d of age. At 25 d of age they were divided into two groups of six males and six females each according to weight, and were allocated to the experimental treatments.

One group of calves ('dry-fed' group; DFG) was given concentrate diets in a pelleted form from 25 to 112 d of age, and another group ('liquid-fed' group; LFG) was given an equivalent amount of the diets in liquid suspension from a pail for the same period. Diets were divided into two equal portions and given at 08.30 and 16.30 hours every day, and further, all calves were allowed free access to roughage throughout the experimental period, except the two intervals of 10 d each when digestibilities were measured at 12 and 16 weeks of age. At 42 and 87 d of age, two calves each (one male and one female) in both groups were slaughtered at approximately 12.00 hours.

Feeds and feeding

From 25 to 42 d of age, calves were given F1 which contained 400 g skim milk and 100 g glucose/kg either in the form of a pellet of 4·76 mm in diameter to DFG or in liquid suspension to LFG. From 43 to 87 d of age, they were given F2 which contained maize and soya-bean meal as the major ingredients, either as a pellet of the same size as F1 to DFG or in a liquid form to LFG. From 88 to 112 d cf age, they were again given F1 in a dry form to DFG or in a liquid form to LFG. Details of the ingredients and the chemical composition of F1 and F2 together with those of the milk-substitute fed before the experimental diets are shown in Table 1. All the foodstuffs were ground to pass a 1 mm mesh screen of a Wiley mill. As markers for the determination of the efficiency of rumen by-pass in LFG, 10 g methionine and 5 g lysine/kg were included in F1, while 10 g methionine and 10 g lysine/kg were added to F2.

The feeding level was increased stepwise and the feeding regimen is shown in Table 2. The daily amount of F2 decreased temporarily after 70 d of age, but the reason for the decrease will be stated later (see p. 473). LFG was given concentrate diets by suspending in 4–6 parts of warm water at approximately 40° with 30 g guar gum/l solution to avoid a rapid settlement of any foodstuff. Daily amounts of drinking-water were adjusted to be equal in both groups, including the part used to make liquid suspension.

In addition to the concentrate feed, lucerne hay was fed on an *ad lib.* basis to all calves

Table 1. *Composition and component of experimental diets and milk-substitute fed to calves*

	Milk-substitute	Concentrate F1	Concentrate F2
Ingredients (g/kg):			
Skim milk	650	400	—
Whey powder	100	—	—
Glucose	90	100	—
Spray-dried fat premix†	150	50	—
Maize	—	105	—
Roasted wheat	—	150	—
Fish meal	—	50	—
Dehulled soya-bean meal	—	100	—
Soya-bean meal	—	—	170
Linseed meal	—	—	50
Defatted rice bran	—	—	130
Dehydrated lucerne meal	—	—	50
$Na_3PO_4.12H_2O$	5	—	—
$CaHPO_4.2H_2O$	—	20	20
NaCl	—	5	5
Trace mineral premix‡	1	1	1
Vitamin premix§	4	4	4
DL-methionine	—	10	10
L-lysine	—	5	10
Chemical composition (g/kg DM):			
Dry matter (DM) (g/kg)	907	922	866
Crude protein (nitrogen × 6·25)	282	278	212
Diethyl ether extract	135	56	36
Acid-detergent fibre‖	1	14	55
Ash	75	86	86
N-free extract	507	488	477

† The premix contained 800 g tallow (homogenized and stabilized)/kg.
‡ The premix contained (g/kg): 320 KCl, 240 $MgSO_4.7H_2O$, 80 Na_2SO_4, 30 $FeSO_4.7H_2O$, 28 $ZnSO_4.7H_2O$, 8 $MnCO_3$, 2 KI, 290 $CaCO_3$.
§ The premix contained (/kg): 150 mg retinol, 2·5 mg cholecalciferol, 50 g DL-α-tocopheryl acetate.
‖ Acid-detergent fibre was determined by the method of Van Soest (1963).

from 25 to 42 d of age. The mixture of lucerne hay and rice straw (1:1, w/w) or rice straw alone was fed *ad lib.* after 43 d of age. The periods from 78 to 87 d of age and from 103 to 112 d of age were assigned for the determination of digestibilities, and the roughage and its daily amount were restricted to 300 g lucerne hay in the former period and 400 g rice straw in the latter period. The lucerne hay and the rice straw were chopped to a length of approximately 50 mm before being fed to calves.

Determination of tissue weight

After slaughter, the alimentary canal was separated into its individual digestive parts. But reticulo-rumen was treated as one section, and the jejunum and ileum were not separated but divided into three portions of equal length. After the connective tissue, adhesive fat and the contents were removed, each section was rinsed with isotonic saline solution (9 g sodium chloride/l), and blotted with gauze, and then weighed.

Table 2. *Feeding schedule for milk-substitute, concentrate diets and roughage in 'dry-fed' (DFG) and 'liquid-fed' (LFG) groups of calves*

	Milk-substitute		Concentrate†			Roughage	
Age (d)	Amount (g/d)	Vol. of warm water used (l)	Type‡	Amount (g/d)	Vol. of warm water used in liquid suspension§ (l)	Type	Amount (g/d)
8–10	400	3·6	—	—	—	—	—
11–24	600	3·6	—	—	—	—	—
25–28	—	—		600	3·6		
29–35	—	—	F1	800	4·6	LH	
36–42	—	—		1000	5·0		
43–49	—	—		1200	5·0		*ad lib.*
50–57	—	—		1400	5·6		
58–63	—	—	F2	1600	6·4	LH+RS	
64–70	—	—		1800	7·2		
71–77	—	—		1400	5·6		
(78–87)‖	—	—		1400	5·6	LH	300
88–91	—	—		1400	5·6		*ad. lib.*
92–102	—	—	F1	1600	6·4	RS	
(103–112)‖	—	—		1600	6·4		400

LH, lucerne hay; RS, rice straw; LH+RS, lucerne hay–rice straw (1:1, w/w).
† F1 and F2 were fed to DFG in a pelleted form and to LFG in liquid suspension.
‡ Compositions of F1 and F2 are shown in Table 1.
§ Warm water used in making up the liquid suspension contained 30 g guar gum/l.
‖ Periods assigned to the determination of digestibility.

Determination of plasma free amino acids

At 42 and 87 d of age when F1 and F2 respectively were fed, jugular blood was taken at 11.30 and 13.30 hours for the determination of plasma amino acid patterns. At 42 d of age, two calves (one male and one female) per group were used for the determination, and at 87 d of age, five calves each (three males and two females) were used. On each occasion 200 ml blood from each calf was placed in heparinized tubes, centrifuged immediately, and an equal amount of each plasma sample was combined to give one sample/calf.

Determination of digestibility

Digestibilities were measured by using chromic oxide as a marker. For this purpose, 20 g Cr_2O_3/kg diet were added to both concentrate diets fed in the two intervals assigned for the determination of digestibilities. Faeces were collected for the last 4 d in each interval. For this determination, five male calves in DFG and four male calves in LFG were used at 12 weeks of age, and four and three male calves in DFG and LFG, respectively, were used at 16 weeks of age. The reason for using only male calves was the simplicity of separating faeces from urine.

Analysis

The Cr_2O_3 content of the diets and faeces was determined as described previously by Abe, Iriki, Kondoh & Kawai (1976). The concentrations of free amino acids in plasma were determined using an amino acid analyser (model KLA-5; Hitachi Co., Minato-ku, Tokyo) by the method of Stein & Moore (1954).

The results were subjected to standard analysis of variance procedures.

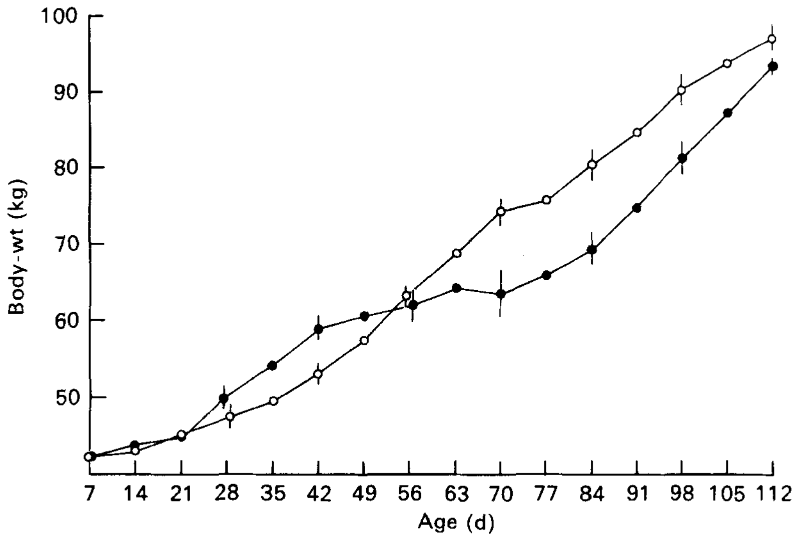

Fig. 1. Growth curve of 'dry-fed' group (○) and 'liquid-fed' group (●) of calves given two types of concentrate in a pelleted form and in a liquid suspension respectively; for details, see Tables 1 and 2. The vertical bars represent the standard errors.

RESULTS

Though twenty-four calves were used in the experiment, one female calf in DFG died from diarrhoea immediately after the start of experiment, and three calves (one male and two females) in LFG were excluded from experiment due to death or severe debility. This occurred when the daily amount of F2 reached 1·8 kg after 64 d of age. Fig. 1 shows the growth record of DFG and LFG. Though the values for the three calves in LFG and for one female in DFG were omitted from the results, the growth curve for LFG decreased at 10 weeks of age while that for DFG showed a constant increase, suggesting that the daily amount of F2 was too high for calves of this age to be given in a liquid form. Calves in LFG drank the liquid feed much more rapidly than calves in DFG consumed dry feed. Anatomical observations of dead calves showed that the high dry matter (DM) intake in a short period overloaded the abomasum and the duodenum. When the daily amount of F2 was decreased from 1·8 to 1·4 kg after 71 d of age, the growth curve for LFG began to increase, while the growth of DFG showed little change for a period after the decrease in diet.

Table 3 shows the body-weight gain and the averaged daily intake of roughage for each period of feeding the different types of concentrate. Roughage fed during the periods for the determination of digestibility was nct included in the mean values. When F1 was fed, gains of LFG were significantly greater than those of DFG ($P < 0.05$). On the other hand, calves given F2 in a liquid form gained significantly less than calves given the same amount of the concentrate in a pelleted form ($P < 0.01$). The daily intake of roughage did not differ significantly between feeding procedures when F1 was fed from 25 to 42 d of age. When F2 was fed from 43 to 87 d of age, roughage intake was significantly reduced when F2 was given in liquid suspension rather than in a dry form ($P < 0.01$). The reduction in intake was extreme until the daily amount decreased from 1·8 to 1·4 kg after 71 d of age. After the decrease in the amount of F2 and the successive change in diet from F2 to F1, the desire for roughage was gradually restored in LFG though the average intake after 88 d of age was still significantly less in LFG ($P < 0.05$).

In Fig. 2, patterns of plasma free amino acids in LFG were compared with those in DFG

Table 3. *Body-weight gains of calves and average daily intakes of roughage in 'dry-fed' (DFG) and 'liquid-fed' (LFG) groups of calves*

(Mean values with their standard errors; no. of calves in parentheses)

	Concentrate diet‡					
Type† ...	F1		F2		F1	
	Body-wt gain (kg)					
Age (d)	25–42		43–87		88–112	
	Mean	SE	Mean	SE	Mean	SE
DFG	7·7	1·1 (11)	26·0**	0·8 (9)	17·3	2·1 (7)
LFG	13·8*	1·2 (9)	5·5	2·8 (7)	24·2*	1·6 (5)
	Daily roughage intake (g)					
Type ...	LH		LH+RS		RS	
Age (d)	25–42		43–77		88–102	
	Mean	SE	Mean	SE	Mean	SE
DFG	302	31 (11)	274**	18 (9)	450*	18 (7)
LFG	337	59 (9)	128	25 (7)	329	26 (5)

LH, lucerne hay; RS, rice straw; LH+RS, lucerne hay–rice straw (1:1, w/w).

The values were significantly higher than the corresponding values for the other groups: * $P < 0·05$, ** $P < 0·01$.

† F1 and F2 were fed to DFG in a pelleted form and to LFG in liquid suspension.

‡ Compositions of F1 and F2 are shown in Table 1.

at 42 and 87 d of age when F1 and F2 respectively had been fed. The pattern in LFG was remarkably different from that in DFG at both ages, especially in the proportion of methionine. Although no great difference was observed in amino acid patterns of DFG between 42 and 87 d of age, a slight but important difference was detected in those of LFG. The proportion of lysine at 87 d of age increased to approximately twofold that at 42 d of age in response to the higher level of supplementary lysine in F2 compared with F1.

In Table 4, the wet weight of whole stomach tissue and the proportion in weight of each compartment were compared between the groups at 42 and 87 d of age. The LFG had extremely undeveloped rumen tissue compared with DFG. In DFG, reticulo-rumen occupied 68–70 % of the whole stomach at both ages, but in LFG, it occupied only 59 % at 42 d of age, and even decreased to 53 % at 87 d of age. A remarkable development of papillae was found in the rumen of calves in DFG, but no appreciable papillary growth was observed in LFG. Fig. 3 shows the tissue weights of various parts of the digestive tract and some organs expressed as percentages of the 'empty' body-weight after slaugher at 87 d of age. Values for 'empty' body-weight were obtained by deducting the weights of ruminal and intestinal contents from the body-weight measured just before slaughter. The reticulo-rumen and omasum were significantly heavier in DFG than in LFG ($P < 0·05$). However, the caecum, colon and rectum were significantly heavier in LFG than in DFG ($P < 0·05$). There was also a tendency for enlargement of the abomasum and duodenum in LFG and for development of liver in DFG, though the differences between groups were not significant.

In Table 5, the digestibility of dietary components was compared between DFG and LFG at 12 and 16 weeks of age when F2 with lucerne hay and F1 with rice straw respectively were fed. The digestibility of diethyl ether extracts did not vary significantly with the feeding procedure of the concentrate at both ages, and that of DM and N-free extract (NFE) was significantly higher ($P < 0·01$) in DFG at 12 weeks of age, while significantly higher ($P < 0·05$)

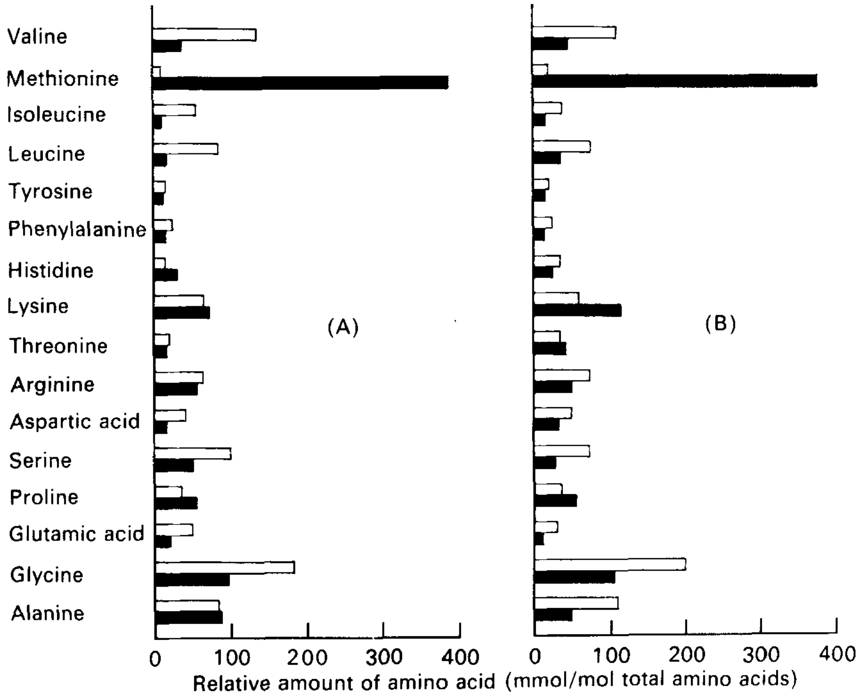

Fig. 2. Patterns of plasma free amino acids (mmol/mol total amino acids) in 'dry-fed' group (□) and 'liquid-fed' group (■) of calves at 42 d of age (A) and at 87 d of age (B). The calves were given two types of concentrate either pelleted ('dry-fed') or in liquid suspension ('liquid-fed'); for details, see Tables 1 and 2. Mean values for two calves (one male and one female)/group at 42 d of age and for five calves (three males and two females)/group at 87 d of age.

in LFG at 16 weeks of age. The digestibility of crude protein ($N \times 6.25$) was significantly higher in DFG at both ages ($P < 0.05$ and $P < 0.01$ at 12 and 16 weeks of age respectively). The digestibility of acid-detergent fibre was not significantly different between the groups at 12 weeks of age, but was significantly higher in LFG than in DFG at 16 weeks of age ($P < 0.01$). As for the fibre digestibility, there was a wide variation within the LFG at 12 weeks of age, and it had a clear relationship to the roughage intake of the individual calf during the period for the determination of digestibility. Two of the four calves used for the determination of digestibility in LFG at 12 weeks of age, consumed almost completely the daily amount of lucerne hay, and the individual values for digestibility of acid-detergent fibre were 0·382 and 0·276. However, the remaining two calves left one-third to half of the daily hay, and had individual fibre digestibility values as low as 0·026 and 0·084. Calves in DFG at both ages and in LFG at 16 weeks of age consumed almost all the daily roughage, and the variation within a group was narrow as shown in Table 5.

Faeces excreted by calves in LFG were of a whitish and spongy appearance with a peculiar odour easily distinguishable from the normal faeces excreted by calves in DFG.

DISCUSSION

Oesophageal groove reflex

Concerning the functioning of oesophageal groove reflex, the results obtained in the present study verify the conclusion of Ørskov, Benzie & Kay (1970) that the reflex closure of the groove can be conditioned by the feeding procedure adopted at weaning so that it does not

Table 4. *Weight (g) of whole stomach tissue and relative weights (%) of reticulo-rumen, omasum and abomasum in 'dry-fed' (DFG) and 'liquid-fed' (LFG) groups* of calves at 42 and 87 d of age*

Age (d) ...	42					87				
		Wet wt of whole stomach	Relative wt (%) of:				Wet wt of whole stomach	Relative wt (%) of:		
Group	Calf no.	(g)	Reticulo-rumen	Omasum	Abomasum	Calf no.	(g)	Reticulo-rumen	Omasum	Abomasum
DFG	18 (♂)	1990	72·0	13·9	14·1	19 (♂)	1830	65·3	17·0	17·7
	5 (♀)	1440	67·6	11·4	21·0	6 (♀)	2090	70·6	14·5	14·9
	Average	1715	69·8	12·6	17·6	Average	1960	68·0	15·7	16·3
LFG	13 (♂)	860	54·7	15·8	29·5	9 (♂)	1010	59·4	10·8	29·7
	11 (♀)	700	63·4	13·4	23·2	17 (♀)	760	46·1	10·5	43·4
	Average	780	59·0	14·6	26·4	Average	885	52·8	10·6	36·6

* Concentrates F1 and F2 were fed to DFG in a pelleted form and to LFG in liquid suspension; compositions of F1 and F2 are shown in Table 1.

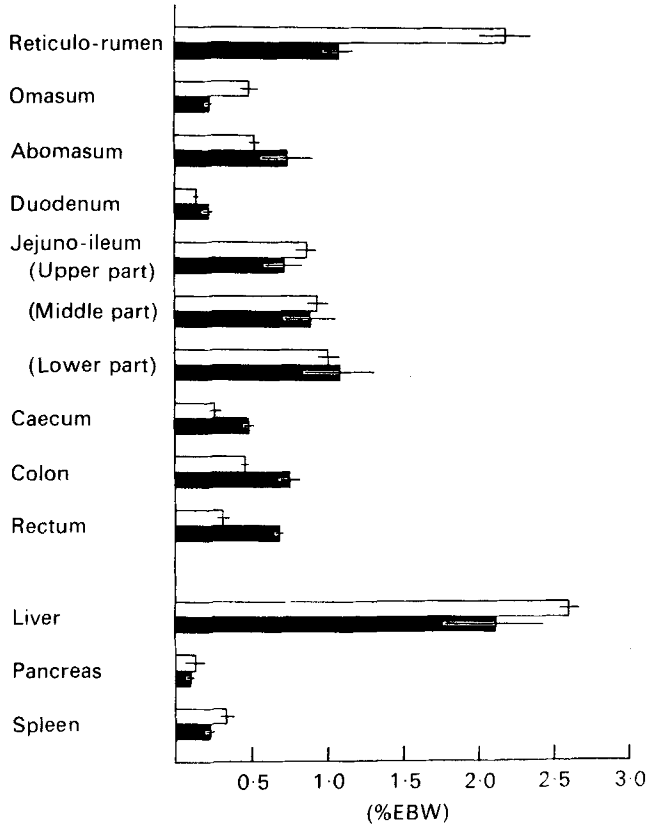

Fig. 3. The tissue weight (% 'empty' body-weight (EBW)) of various parts of the alimentary tract and some organs in 'dry-fed' group (□) and 'liquid-fed' group (■) of calves given two types of concentrate in a pelleted form and in a liquid suspension respectively; for details, see Tables 1 and 2. EBW is the value obtained by deducting the weight of rumen and intestinal contents from the body-weight measured immediately before slaughter. The horizontal bars represent the standard errors for means of two calves (one male and one female)/group.

depend on the type of liquid suspension and on the stimuli associated with sucking and swallowing. In DFG, plasma patterns of free amino acids were quite similar for the two types of diet, indicating the onset of a complete rumen function after 6 weeks of age in calves weaned as early as 25 d of age. The relationship between dietary amino acid intakes and plasma amino acid patterns in ruminants becomes obscure after the onset of rumen function on account of its fermentive activity (Bergen, Henneman & Magee, 1973). In LFG, on the other hand, dietary supplementation with methionine and lysine in varying amounts was reflected in the plasma amino acid patterns, suggesting the diets avoided rumen fermentation on account of their by-passing the iumen via the oesophageal groove.

If the feed given in a liquid form was directed to the rumen, it would inevitably develop the rumen function and give LFG similar results to DFG, because the development of rumen tissue and its papillary growth depend on the production rate of volatile fatty acids (VFA) in the rumen (Sander, Warner, Harrison & Loosli, 1959; Tamate, McGilliard, Jacobson & Getty, 1962). In the present work, although calves were given hay and straw *ad lib.* from 25 to 87 d of age, there was no remarkable development in rumen tissue and papillae when calves were given concentrate diets in a liquid form. However, these calves had a remarkably developed large intestine. Similar compensatory growth of the caecum

Table 5. *Apparent digestibility of the diet in 'dry-fed' (DFG) and 'liquid-fed' (LFG) groups† of calves at 12 and 16 weeks of age*

(At 12 weeks of age, 1·4 kg concentrate F2‡ and 0·3 kg lucerne hay were fed daily, and 1·6 kg concentrate F1‡ and 0·4 kg rice straw were fed daily at 16 weeks of age)

(Mean values with their standard errors)

Age (weeks)	Group	No. of calves§	Dry matter		Crude protein‖		Diethyl ether extract		Acid-detergent fibre¶		Nitrogen-free extract	
			Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
12	DFG	5	0·702**	0·014	0·691*	0·020	0·642	0·036	0·255	0·051	0·818**	0·009
	LFG	4	0·418	0·048	0·318	0·057	0·708	0·009	0·192	0·079	0·498	0·046
16	DFG	4	0·707	0·002	0·814**	0·004	0·809	0·015	0·291	0·029	0·792	0·003
	LFG	3	0·724*	0·005	0·741	0·012	0·829	0·012	0·469**	0·047	0·817*	0·008

The values were significantly higher than the corresponding values for the other groups: * $P < 0.05$, ** $P < 0.01$.

† F1 and F2 were fed to DFG in a pelleted form and to LFG in liquid suspension.

‡ Compositions of F1 and F2 are shown in Table 1.

§ Only male calves were used for the determination of digestibility.

‖ $N \times 6.25$.

¶ Determined by the method of Van Soest (1963).

was observed by Hamada (1973) in kids having the forestomach removed and fed on highly-digestible solid diets containing whole-milk powder and glucose together with lower amounts of fish meal and wheat flour. Lack of development of rumen tissue and papillae as well as the concomitant development of large intestine were considered to be the result of the by-passing of the rumen of liquid feed via the oesophageal groove in LFG.

Digestion of carbohydrates

The digestibility of NFE in F2 containing maize as a major carbohydrate source was higher in DFG than in LFG at 12 weeks of age. This suggests that the postruminal digestion of starch contained in maize is considerably low even in calves aged 12 weeks. It is well established that dietary starch is poorly utilized by very young calves aged up to 4 to 6 weeks, and this is correlated with the low activities of pancreatic α-amylase (*EC* 3.2.1.1) and intestinal α-glucosidase (maltase; *EC* 3.2.1.20) (Huber, 1969). However, the extent of postruminal starch digestion in older calves has not been established. Larsen, Stoddard, Jacobson & Allen (1956) reported that the starch introduced directly into the abomasum of 9-month-old calves appeared almost undigested in faeces. To the contrary, some workers reported that the starch having passed from the rumen disappeared almost completely from the small intestine of steers (Karr, Little & Mitchell, 1966) and of mature sheep (Wright, Grainger & Marco, 1966). Many other workers, on the other hand, reported various starch digestibilities in the intestine of older calves ranging from 0·60 to 0·80 (Noller, Ward, McGilliard, Huffman & Duncan, 1956; Huber *et al.* 1961; Natrajan, Polan, Chandler, Jahn & Huber, 1972). Apparent NFE digestibility determined in this work for LFG given F2 was below the range of 0·60–0·80, but it may be explained by the difference in the experimental conditions, especially in dietary conditions. Extracted pure starch was used in those studies, but a concentrate mixture containing 550 g ground maize/kg was used in the present study, and further, many carbohydrates other than starch originating from many foodstuffs were included in the NFE fraction.

It has been recognized that the extent of starch digestion posterior to the rumen increases with age of animals (Huber, Natrajan & Polan, 1968). However, Huber *et al.* (1961) reported that no appreciable change was detected in the level of blood reducing sugar when tapioca starch was introduced directly into the abomasal region of cattle aged from 22 to 660 d, predicting that a considerably large part of the starch digestion posterior to the rumen is due to fermentation in the large intestine. Coombe & Smith (1974) showed that the starch digestibility in small intestine of bull calves aged between 4 and 20 weeks was approximately 0·50–0·70, and suggested that the fermentation in large intestine was responsible for the disappearance of some of the starch. The small intestine of sheep has only a limited capacity for starch digestion (Ørskov, Fraser & Kay, 1969), but the large intestine has a substantial capacity for its digestion (Ørskov, Fraser, Mason & Mann, 1970; Ørskov, Fraser & McDonald, 1971). In the present studies, it was noticeable that the NFE digestibility was higher in LFG than in DFG at 16 weeks of age though the concentrate diet given at that period contained 105 g ground maize and 150 g roasted wheat flour/kg together with skim milk and glucose.

Apparent fibre digestibility at 12 weeks of age was not significantly different between groups, and further, the digestibility at 16 weeks of age was remarkably higher in LFG than in DFG. Similar results were obtained by Black & Tribe (1973) when they compared the effects of infusing a liquid suspension of a milk-based diet into the rumen and abomasum of lambs given orally pelleted lucerne hay. They reported that apparent fibre digestibility was significantly less in lambs given the rumen infusion, though they had a heavier reticulo-rumen than lambs receiving abomasal infusion. Hamada (1973) reported that apparent digestibility of dietary fibre was not reduced in kids having the forestomach removed, and that they had more developed caecums than normal kids. Post-mortem observations in this work revealed compensatory growth of the caecum, colon and rectum as well as an undeveloped reticulo-rumen and omasum in calves receiving the liquid feed. The appearance and the odour of faeces excreted by those calves differed greatly from those excreted by calves receiving the dry feed. These findings suggest that when the supply of VFA from rumen is limited or ceases, it would be compensated for, at least in part, from the large intestine by increasing its capacity for fermentation of carbohydrates, and that an active digestion of fibre might take place in the large intestine of calves in LFG. By comparing the rates of cellulolysis and gas production in large intestinal contents with those in rumen contents of sheep, Hecker (1971) reported that rates of breakdown of cellulose in vivo were similar in the rumen and caecum, and that gas production rate in the caecal contents was higher than in the rumen contents. Liang, Morrill & Noordsy (1967) showed that VFA can be efficiently absorbed and metabolized by young calves whether the VFA are produced in the rumen or in the large intestine.

Digestion of proteins

The apparent digestibility of crude protein was higher in DFG than in LFG, independent of the age of calves and the type of diet. One of the reasons for this could be that the proteolytic activity is more active in the rumen than in the posterior rumen. Rumen microbes degrade proteins rapidly, especially soluble ones, but soya-bean protein is relatively unsusceptible to enzymic digestion when it is included in a milk-substitute as a protein source for young calves (Walker & Kirk, 1975; Abe *et al.* 1976). This may explain the difference in the crude protein digestibility between DFG and LFG at 12 weeks of age when calves consumed F2. However, this does not explain the difference observed in 16-week-old calves which were given F1 containing a large amount of skim milk, because it has been reported that casein introduced directly into the abomasal region of sheep is completely digested and absorbed (Blaxter & Martin, 1962). There remains the possibility that active fermentation in the large intestine of calves in LFG lowered the apparent digestibility of crude protein, as the change in the site of fermentation from rumen to large intestine renders less microbial protein available to the host animal per unit of carbohydrate fermented (Ørskov, Fraser, Mason & Mann, 1970). However, the higher apparent digestibility of crude protein in DFG does not necessarily mean an increased protein utilization, because the absorption of ammonia produced from a rapid degradation of dietary protein in the rumen is regarded as a loss of N. The lower weight gains in DFG when F1 was fed may indicate the occurrence of the loss cf N as ammonia.

Efficiency of liquid feeding

Due to energy losses associated with fermentation and N losses incurred in the transformation of dietary protein to microbial protein, many carbohydrates except cellulose and hemicellulose and proteins of high biological value are thought to be less efficiently utilized when they are fed via the rumen than when they escape rumen fermentation (Black, 1971; Chalupa, 1975; Owens & Isaacson, 1977). In the present work, this is true of F1, a milk-based diet, and this is in general agreement with earlier studies (Raven & Robinson, 1961; Swanson, Thigpen, Huskey & Hazlewood, 1969; Pryor & Ternouth, 1972; Black & Tribe, 1973). However, it is not true of F2, which consisted of the foodstuffs often used to formulate an ordinary concentrate diet for calves in Japan.

Judging from the results of this work, increasing the extent of starch digestion in the small intestine of ruminants appears to be one of the most important problems to be solved for the practical use of the oesophageal groove reflex as a method of avoiding rumen fermentation and increasing the efficiency of diet utilization. Any increase in the ability of starch digestion posterior to rumen cannot be expected by the adaptation to starch (Huber *et al.* 1967). One of the possible methods to increase starch digestion in the small intestine may be a gelatinization, as was suggested by Huber *et al.* (1961). The other method might be to supply starch or starchy materials little by little to the intestine of ruminants. In the present work, calves were given the daily feed in two equal portions, resulting in too much of the feed reaching the abomasum at a time, overloading this region and the upper part of the small intestine. In order to avoid such a load and the resultant possible decrease in the digestion in these regions, it is considered that the daily feed should be divided into more than two portions.

The problem of digestibility in the small intestine exists also in the utilization of protein. But the advantage or disadvantage of some protein by-passing the rumen as compared with its undergoing rumen fermentation is defined not only by its biological value but also by the extent of N losses accompanied with the rumen fermentation. Because the production of rumen microbial protein using ammonia is an energy-dependent mechanism (Thomas, 1973; Smith, 1975; Owens & Isaacson, 1977), it would be of advantage to the host animal to introduce a relatively wide range of proteins directly into the abomasal region when available carbohydrates are supplied postruminally. It seems, however, that soya-bean meal is not included in suitable protein sources to be administered postruminally at least in calves aged up to 12 weeks due to its low digestibility in the small intestine.

As far as apparent digestibility is concerned, liquid feeding of the concentrate portion of the diet even increased fibre digestion as compared with the dry feeding of this portion. A part of this increase in fibre digestion is probably a result of less interference with cellulose digestion in the rumen of calves receiving liquid feed, since both fat and readily-available carbohydrate tend to reduce the rate and the extent of fibre digestion within the rumen (e.g. Kowalczyk, Ørskov, Robinson & Stewart, 1977). In the present work, however, the possibility cannot be excluded that the developed large intestine of calves receiving the liquid feed contributed to the increased fibre digestion of LFG. Further studies will need to be done to determine the reason for the compensatory growth of the large intestine and the effects of the fermentation in it on the nutrition and the physiological status of the host animal.

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Printed in Great Britain