

The sustenance of growing and fattening ruminants by intragastric infusion of volatile fatty acid and protein

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A technique is described for feeding young sheep for long periods entirely by the infusion of volatile fatty acids into the rumen and protein and other essential nutrients into the abomasum. When the energy infused was twice the estimated requirement for maintenance, growth rate and nitrogen retention were essentially the same as in normally-fed sheep.

There are several principles of the nutrition of ruminants which are difficult to study because their diets are fermented to yield volatile fatty acids (VFA). The VFA can vary both in the amounts produced and in composition, and both can vary during a feeding cycle. The rumen micro-organisms produce microbial protein in varying amounts and the dietary protein is degraded by rumen microbes to varying extents (Ørskov, 1977). Several attempts have been made to infuse known quantities of VFA and protein. At the maintenance feeding level, Armstrong & Blaxter (1957*a*) infused VFA for short periods as the only source of energy. Also Martin & Blaxter (1963) infused protein and Armstrong & Blaxter (1956*b*) glucose as the only nutrients for fasting sheep.

Infusion of VFA at higher levels was attempted by Armstrong & Blaxter (1957*b*) and Ørskov & Allen (1965) fed increments of salts of VFA with concentrate diets. These latter studies suffer from the disadvantage of possible interference of the VFA, or their salts, with the digestion and metabolism of the basal diet since it was only achieved when the animals were given a basal diet of solid food, and even with that regimen only small additions of VFA or VFA salts were possible. Attempts to sustain long-term infusion of VFA alone have generally been abandoned owing to problems of electrolyte imbalance and acidity of rumen contents. Tao & Asplund (1975), however, have recently sustained lambs at maintenance energy levels for periods of some weeks by infusion of partially-neutralized VFA and buffer solutions into the rumen, and amino acids into the abomasum, but they also reported several problems and deaths due to electrolyte imbalance.

The method reported here was developed to sustain ruminants at high feeding levels and maintain normal growth by complete intragastric infusion.

EXPERIMENTAL

The following is a description of the infusion technique as it was developed after several attempts which failed. Since, however, the blood composition and rumen pH were measured routinely it was possible when an animal showed signs of severe stress or died to make an appropriate change in the procedure. The first attempts failed because VFA alone was infused as a result of which the animal developed, after some days, a severe acidosis. Other attempts failed as a result of partially neutralizing the VFA with sodium hydroxide. Toxic levels of sodium in the blood in excess of 200 mmol/l were observed. It was finally realized that the rumen pH and blood electrolytes could be kept in the normal range provided a

buffer based both in quantity and composition on saliva was infused separately from the VFA and with a separate terminal in the rumen. A total of ten lambs was used to develop the technique.

Surgical preparations

The lambs were fitted with vulcathene rumen cannulas, made at the Rowett Institute, of internal diameter approximately 14 mm (McKenzie & Kay, 1968). The cannulas were exteriorized between the last rib and the lumbar transverse processes. For the abomasal infusion a transparent polyvinyl tube was used (Portex Ltd, Hythe, Kent). The tube was approximately 0.4 m long with 4 mm internal and 7 mm external diameter. A circular flange, 20 mm in diameter and 2 mm thick was made from polyethylene sheeting and glued (Portex Vinyl Cement; Portex Ltd, Hythe, Kent), to the end of the catheter (see Fig. 1). An incision was made within a 'purse-string' suture midway between the greater and lesser curvature on the right lateral wall of the abomasum, the flanged end of the catheter was inserted and the 'purse-string' tightened. Subsequently a second flange was pushed down the catheter so that the abomasal wall was contained between the two flanges (see Fig. 1). A collar of 7 mm internal diameter and with 11 mm external diameter was brought hard up against the second flange and glued in position. This provided a very secure and leak-proof abomasal entry. The free end of the catheter was exteriorized by passing the catheter through the eye of a large needle and puncturing the body wall from within just below the lumbar processes. To ensure that the tube was not pulled directly from outside it was securely anchored to the wool of the sheep.

Infusion procedure

A multichannel flow inducer (Watson Marlow MC/10; Watson Marlow Ltd, Falmouth, Cornwall) was used and the speed adjusted to infuse the daily allowance in 23 h. The length of the tubing inside the rumen cannulas was approximately 150 mm to ensure that the infusates were added directly to the rumen fluid. In order to prevent the strong acid solution from affecting the rumen wall, a small polyethylene cylinder, 10 mm diameter and 30 mm long, was glued to the end of the infusion tubes so that rumen fluid entered the cylinder and diluted the acids (see Plate 1).

Before infusion began approximately six plastic pan scrubbers were inserted into the rumen via the cannula (see Plate 1(a)). A similar type has been used by Dr J. G. Gordon (unpublished results). These had the effect of maintaining motility and of continually abrading the rumen papillae. Plate 1(b) shows the rumen wall of a lamb which was given intraruminal infusion and no food by mouth for 2 months. When the lambs were slaughtered the pan scrubbers were recovered and used again. The development of the infusion procedure was facilitated by continual monitoring of the metabolic state of the animals. The pH of rumen contents was determined twice daily. Blood samples were taken twice weekly and sometimes more frequently for estimation of Na, potassium calcium, magnesium, inorganic phosphorus, blood sugar and ketones by standard methods. Erythrocytes and white blood cells were estimated together with packed cell volume and haemoglobin concentration. When the problems referred to earlier were solved, no abnormalities developed other than those that might be expected from experimental constraints.

Casein

The casein was dissolved in warm water to which 2 M-sodium carbonate was added to give a final casein solution of 2.5 l/d. The level of casein used was calculated to give 1.41 g N/kg body weight ($W^{0.75}$) per day at twice maintenance energy level, with the same proportion to energy at lower infusion rates. It was given via the abomasal catheter as continuous infusion.

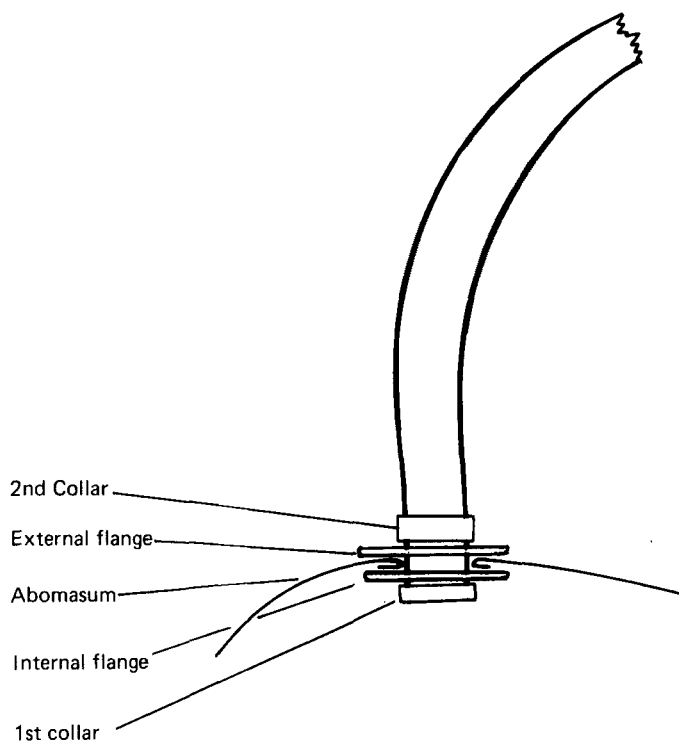


Fig. 1. The method of securing the abomasal catheter to abomasal wall.

VFA

The VFA were given in several molar proportions indicated in Table 2. The VFA, together with the major minerals were given as a final solution of 2.5 l/d. It was given via the rumen cannulas as continuous infusion.

Major minerals

The calcium carbonate was dissolved directly in the VFA solutions when they were prepared. The calcium phosphate and magnesium sulphate were dissolved separately and added to the VFA solution only when the 24 h infusate was prepared. The quantities are given in Table 1.

Buffer solution

Buffer solution (2.5 l/d) was given containing the quantities in Table 2 which were found by experience to be sufficient to prevent the rumen pH from dropping below 6.0. It can be seen that it was necessary to increase the buffer concentration at the high rate of energy infusion, and more was required with increasing proportion of acetic acid, probably because of the increase in hydrogen ions necessary to give iso-energetic VFA solutions. The solution was given as continuous infusion via the rumen cannulas.

Trace minerals

Since the trace minerals in suspension precipitated the soluble casein it was not possible to infuse them into the abomasum along with the protein. Instead they were injected via the abomasal cannulas once daily. To prevent blockage by precipitated casein, the abomasal catheter was rinsed with water before and after the injection. The quantities used are given in Table 1.

Table 1. *Quantities of vitamins, trace minerals and major minerals infused when energy intake was twice the maintenance level; below that energy level the quantities were calculated to be proportional to the infusion of energy-yielding constituents*

Vitamins	Daily quantity		Method of infusion	
	per kg $W^{0.75}$	for 25 kg lambs		
Thiamin hydrochloride (mg)	0.25	2.8	Dissolved in a solution of ethanol – water (30 : 70, v/v) and mixed with casein for abomasal infusion	
Riboflavin (mg)	1.00	11.2		
Nicotinic acid (mg)	1.00	11.2		
Choline chloride (mg)	37.50	308.0		
Calcium DL-pantothenate (mg)	0.75	8.4		
<i>Myo</i> -inositol (mg)	37.50	308.0		
α -Tocopheryl acetate (mg)	1.00	11.2		
Pyridoxin hydrochloride (μ g)	100.00	1120.0		
P-Amino benzoic acid (μ g)	25.00	280.0		
Folic acid (μ g)	2.50	28.0		
Cyanocobalamin (μ g)	2.50	28.0		
D-biotin (μ g)	15.00	168.0		
2-Methyl-1,4-naphthaquinone (μ g)	125.00	1400.0		
Linoleic acid (ml)	0.25	2.8		
Trace minerals (mg)				Given as suspension once daily into the abomasum
FeSO ₄ .7H ₂ O	43.80	490.5		
ZnSO ₄ .7H ₂ O	2.53	28.3		
KI	2.34	26.2		
MnSO ₄ .4H ₂ O	1.23	13.8		
CuSO ₄ .5H ₂ O	1.12	12.5		
CoSO ₄ .7H ₂ O	0.46	5.1		
NaF	1.59	17.8		
Major minerals (g)			Dissolved in VFA solution	
CaCO ₃	1.08	12.1		
Ca(H ₂ PO ₄) ₂ .H ₂ O	1.02	11.4		
MgSO ₄ .4H ₂ O	0.28	3.1		
Na ₂ CO ₃	0.572	6.4		
			Used as 2 M solution to dissolve casein	

W, body-weight.

Table 2. *Level of buffer minerals infused consisting of sodium bicarbonate (0.62), potassium bicarbonate (0.32) and sodium chloride (0.06); the mineral mixture was infused according to volatile fatty acid (VFA) solution and level of infusion at maintenance (450 kJ/W^{0.75}) and twice (900 kJ/W^{0.75}) maintenance energy intake*

Proportions of VFA (mmol/mol)			Level of infusion			
Acetic	Propionic	Butyric	g/W ^{0.75}		For lambs weighing 25 kg	
			450 kJ/W ^{0.75}	900 kJ/W ^{0.75}	450 kJ/W ^{0.75}	900 kJ/W ^{0.75}
350	550	100	6.27	14.34	70.2	160.6
450	450	100	6.61	15.12	74.0	169.3
550	350	100	6.94	16.02	77.7	179.4
650	250	100	7.39	16.91	82.8	189.4
750	150	100	7.84	18.03	87.8	201.9

W, body weight.

Vitamins

The solution of vitamins was mixed daily with the casein after the casein was dissolved with sodium carbonate. The quantities given are shown in Table 1. Retinoic acid, cholecalciferol and α -tocopherol were given as intramuscular injection. Vetrivite (1 ml; C-Vet Ltd, Minster House, Western Way, Bury St Edmunds, Suffolk) containing (/ml): 150 mg retinol, 1.875 mg cholecalciferol and 50 mg α -tocopheryl acetate, was given every 15 d.

Management

The level of infusion was aimed at a total of 900 kJ/W^{0.75}. The animals were cannulated and approximately 2 weeks were allowed for post-surgery recovery after which the infusion began. The lambs had free access to dried grass but when infusion reached the intended level little if any was consumed, and it was subsequently removed. Drinking-water was always available. The intended level was reached during a period of 2 weeks in the instance of maintenance energy (450 W^{0.75}/d) and 3 weeks for the twice maintenance energy level (900 W^{0.75}).

DISCUSSION

The problems of rumen pH, electrolyte imbalance, etc. were essentially overcome when it was realized that only a buffer solution was required and that attempts to partially neutralize the VFA were only creating problems of electrolyte imbalance. This is in complete agreement with the findings of Ash & Dobson (1965), namely that the VFA are absorbed as free acids so that a buffer is only required to neutralize or maintain the pH between 6 and 7 of the VFA actually present in the rumen and not the VFA after absorption. The blood measurements of minerals, ketones and glucose have been in the normal range except for the inorganic P which was generally elevated. In long-term experiments with lambs of up to 3 months duration the post-mortem findings have essentially been normal though sometimes an enlargement of the kidneys was noted. Growth rates of 150–200 g/d, with no apparent differences between infusion mixture have been noted. A common feature was a somewhat regressed and thin-walled intestine and a large amount of cellular debris in the ventral sac of the rumen, which presumably consisted of abraded epithelial cells. No faeces were produced, except during the first few days after solid feed was withdrawn. The lambs which were slaughtered when the infusion was terminated had fat of normal composition and colour and the amount of fatness was similar to those of normal lambs. On occasions when it was desired to adapt the lambs to solid food again, normal intakes could generally be achieved in a period of 8–10 d, provided the lambs were incubated with a rumen fluid sample from another sheep.

The use of the technique in the study of protein and energy utilization in ruminants will be reported elsewhere.

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REFERENCES

- Armstrong, D. G. & Blaxter, K. L. (1956). *Proc. Nutr. Soc.* **15**, i.
Armstrong, D. G. & Blaxter, K. L. (1957*a*). *Br. J. Nutr.* **11**, 247.
Armstrong, D. G. & Blaxter, K. L. (1957*b*). *Br. J. Nutr.* **11**, 413.
Ash, R. W. & Dobson, A. (1965). *J. Physiol., Lond.* **169**, 39.
McKenzie, J. D. & Kay, R. N. B. (1968). *J. Sci. Technol.* **14**, 15.
Martin, A. K. & Blaxter, K. L. (1963). *Proc. Nutr. Soc.* **22**, xiv.
Ørskov, E. R. (1977). *Wld Rev. Nutr. Diet.* **26**, 225.
Ørskov, E. R. & Allen, D. M. (1965). *Br. J. Nutr.* **20**, 519.
Tao, R. C. & Asplund, J. M. (1975). *J. Anim. Sci.* **41**, 1653.

EXPLANATION OF PLATE

(*a*) A section of the rumen wall; note the flat, well developed papillas, (*b*) the plastic scrubbers of which six were inserted via the rumen cannulas. They were the normal domestic type (Spong & Co. Ltd, Crompton Close, Basildon, Essex, England).

