Intragastric infusion of nutrients in cattle

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(Received 28th August 1981 – Accepted 23rd December 1981)

1. A method of continuous alimentation of cattle by total infusion of nutrients has been developed. Friesian steers within the weight range 100–400 kg live weight and dairy cows were used.

2. A multi-channel peristaltic pump was used to infuse solutions of volatile fatty acids (VFA), minerals, and buffer through a cannula in the rumen and a casein–vitamin solution into the abomasum.

3. The method described was successfully used with two cows and four steers in a series of trials over intervals of approximately 2 months. The levels of infusion were up to twice maintenance and with various relative proportions of VFA and protein. Blood metabolite levels, rumen osmotic pressure and pH were monitored and effectively controlled.

In ruminants where there are two interrelated sets of requirements: those of the microbial population and those of the host animal, interpretation of information collected from studies on normally-fed animals is difficult. These difficulties arise in predicting the fate of nutrients in the rumen, and in determining quantitatively the contribution made by bacteria and protozoa to the host animal’s requirements.

In order to reduce the contribution of the rumen fermentation to the animal’s requirement, diets have variously been supplemented with salts of volatile fatty acids (VFA) added to the diet, or with infusions of VFA directly into the rumen and infusions of protein into the abomasum. Armstrong & Blaxter (1957a,b) used infusions of acetic, propionic and butyric acids to supply part of the energy of a basal diet of dried grass and Martin & Blaxter (1963) infused protein only, in fasting sheep. Hovell (1972) conducted studies with lambs using salts of VFA, and Tao & Asplund (1975) developed a method by which they infused partially-neutralized VFA into the rumen of sheep and intravenously-infused amino acids. Difficulties were sometimes encountered however, primarily with the control of rumen pH and with electrolyte imbalances. Furthermore, with the exception of very low levels of infusion, the approach was generally that of supplementation of a normal basal diet. A method was developed however, using lambs (Ørskov, Grubb, Wenham et al. 1979) in which all nutrient requirements were met by infusion. Relatively few difficulties arose except with a VFA mixture containing a high proportion of acetic acid (mmol/mol: 850 C₂, 50 C₃, 100 C₄), when problems of metabolic disturbance and of controlling rumen pH were encountered (Ørskov, Grubb, Smith et al. 1979). The technique reported here is an adaptation of the method used for lambs.

MATERIALS AND METHODS

Rumen and abomasal cannulas. The rumen cannulas fitted to the cattle (Fig. 1) were Vulcathe ne waste-drain fitments modified by smoothing out the internal grid-shoulder and by forming an exterior flange and locking nut (McKenzie & Kay, 1968). A tight-fitting rubber stopper was inserted into the cannula and held in position with a threaded blanking cap. Transparent vinyl tubing, 3·5 mm bore and 6·5 mm external diameter, for the VFA, buffer, and water infusates were inserted through the stopper into the rumen and a fourth hole was provided in the rubber bung to facilitate sampling of rumen fluid by means of
Fig. 1. Arrangement for ruminal infusions. (a) Transparent vinyl tubing, (b) rubber stopper, (c) stoppered hole for sampling rumen fluid, (d) threaded retaining cap, (e) threaded flange and locking nut, (f) body wall, (g) perforated polythene disc, (h) rumen wall, (i) volatile fatty acid and water outlets, (j) buffer outlet.

A syringe and tube. The VFA and water tubes inside the rumen were fused at their outlets inside a small perforated 60 × 25 mm polythene vial in order to effect a more rapid dilution and to avoid the possibility of irritation of the rumen wall at the point of outflow. The tubes extended into the rumen approximately 250 mm to ensure the outlets would be immersed in rumen fluid.

The abomasal cannula used for casein and vitamin infusion (Fig. 2) consisted of a 1 m long surgical non-toxic, translucent vinyl tubing 5.0 mm bore and 7.0 mm external diameter (Portex Ltd, Hythe, Kent). The end inserted into the abomasum was prepared by cementing a vinyl collar approximately 5 mm deep to the extremity and cementing on to this a 25 mm diameter by 2 mm thick disc of Vitrathene polythene (Stanley Smith & Co., Islesworth, Middlesex). The prepared end was then inserted in the mid-lateral body of the abomasum and the incision closed by a ‘purse-string’ suture. The tubing was drawn up inside the body cavity and exteriorized immediately behind the last rib, care being taken to ensure that there was no tension which might cause displacement of the abomasum. The exteriorized portion was trimmed to approximately 300 mm and fixed to the back of the animal with adhesive patches.

Plate 1 shows the arrangement of infusion tubes and cannulas. It was found better to connect the main infusion lines (shown taped together in Plate 1) to the tubes inserted into the rumen and abomasum via connectors. This created a weak point which could break fairly easily thus lessening the possibility of damage or discomfort to the animal should there be excess tension on the flow lines.

Control of infusion. Four calibrated infusion reservoirs (WCB Containers Ltd, Stalybridge, Cheshire) each of 30 l capacity, were used per animal (Plate 2). These contained respectively a solution of casein, one of the VFA and major minerals, the buffer solution, and water. Solutions to be infused were prepared daily from more concentrated bulk preparations...
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Fig. 2. Abomasal cannula. (a) Body wall, (b) vinyl infusion tube, (c) wall of abomasum, (d) polythene disc, (e) vinyl collar.

(Table 1) and pumping speeds were set to give the required volumes within the 24 h period. A variable speed peristaltic metering pump with multi-channel pumping module (Watson and Marlowe Ltd, Falmouth, Cornwall) was used to infuse the solutions. Control of flow-rate was effected by selecting an appropriate bore-size of silicone rubber tubing for the module and by adjusting the pump speed. Plastic nipple connectors were used to join the module onto the main infusion circuit which consisted of 3·0 mm bore, 4·2 mm external diameter transparent vinyl tubing. There were slight differential flow rates, in particular with casein at higher concentrations where the rate of flow was slowed by the high viscosity. In order to ensure that all the diluted casein was infused over the same period of time it was found more convenient to reduce its volume slightly in comparison to the other infusates rather than to introduce various tube sizes on the pump module. When the amounts infused were sufficient to cover maintenance requirements, at approximately 10 d from commencement, the normal feed offered the animals was removed and eight plastic pan scrubbers inserted into the rumen via the cannula. These were used in an attempt to ensure that rumen motility and muscle tonus were maintained. The pH and osmotic pressure of rumen fluid were routinely checked twice daily and blood samples were removed once weekly to enable the metabolic profiles to be measured (Table 2). pH was determined on a Model 3030 portable pH meter with combination electrode (Electronic Instruments Ltd, Chertsey, Surrey). The check on osmotic pressure was maintained using a model 3L Advanced Osmometer (Advanced Instruments Inc., Needham Heights, Massachusetts, USA).

Preparation of solutions (Table 1). A series of concentrated solutions were prepared and diluted to a standard volume to give the solutions for infusion. In practice it was best to maintain the volume infused more or less constant, and to vary the concentration in order to change the level of nutrition. The volumes of VFA and buffer as infused into the rumen...
Table 1. Composition (g/kg) of concentrated preparations
(These were further diluted to give a combined rumen and abomasal infusate volume of approximately 0.8 l/kg body-weight

<table>
<thead>
<tr>
<th>Casein solution</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>Casein (89% DM)</td>
<td>100:0</td>
</tr>
<tr>
<td>Na₂CO₃</td>
<td>5.3</td>
</tr>
<tr>
<td>Vitamin solution</td>
<td>25:7</td>
</tr>
<tr>
<td>Water</td>
<td>869:0</td>
</tr>
</tbody>
</table>

VFA solution: mixture 'C'
- Acetic (C₃) | 388:2
- Propionic (C₅) | 183:9
- Butyric (C₈) | 87:8
- CaCO₃ | 18:0
- Water | 322:1

Mineral solution
- Ca(H₂PO₄)₂ · H₂O | 15:0
- MgCl₂ · 6H₂O | 7:5
- Water | 977:5

Buffer solution
- NaHCO₃ | 73:0
- KHCO₃ | 38:0
- NaCl | 7:0
- Water | 882:0

Vitamin preparation
- Thiamine hydrochloride | 0:76
- Riboflavin | 3:04
- Nicotinic acid | 3:04
- Choline chloride | 113:89
- Pyridoxine hydrochloride | 0:30
- P-amino-benzoic acid | 0:08
- Calcium D₃-pantothenate | 2:28
- Folic acid | 0:01
- Cyanocobalamin | 0:01
- Myo-inositol | 113:89
- D-biotin | 0:05
- 2-Methyl-1,4-Napthaquinone | 0:38
- D-L-tocopheryl acetate | 3:04
- Linoleic acid | 759:23

Trace minerals
- FeSO₄ · 7H₂O | 822:79
- ZnSO₄ · 7H₂O | 48:26
- KI | 43:91
- MnSO₄ · 4H₂O | 22:94
- CuSO₄ · 5H₂O | 22:15
- CoSO₄ · 7H₂O | 8:70
- NaF | 31:25

The vitamin–linoleic acid mixture was homogenized at a rate of 1 kg in 7.59 l ethanol:water mixture (30:70, v/v) and the homogenate incorporated in the casein concentrated solution at 25:7 g/kg.

A further intramuscular injection of vitamins A, D and E was administered at 14 d intervals according to manufacturer’s recommendation.

The trace minerals were dissolved at a concentration of 253 g in 10 l water and the solution then used at the rate of 1 ml/kg body-weight

were each in the order of 0.2–0.3 l/kg body-weight

Casein was prepared as a 100 g/l solution by adding 53 g sodium carbonate/kg air-dry lactic casein and homogenizing for 20 min in warm water. During homogenization the vitamin solution was added in amounts calculated to meet the animal’s requirement at maintenance. In the event of animals being fed submaintenance levels of protein, supple-

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mentary vitamins were added directly to the infusate reservoirs. Vitamins A, D and E were
given by the intramuscular injection of Vetrivite at fortnightly intervals according to the
manufacturer’s recommendations (C-Vet Ltd, Minster House, Western Way, Bury St
Edmunds, Suffolk).

Calcium carbonate was added to the concentrated VFA solution while the remainder of
the major minerals, calcium tetrahydrogen diorthophosphate and magnesium chloride, were
prepared as a separate concentrated solution and added to the VFA only when daily
infusates were prepared. The calculations of the total energy to be supplied were based on
the assumption that the requirement was 450 kJ/kg body-weight^{0.75} per d at maintenance.
Observations were made using various molar proportions of VFA up to levels of twice
maintenance energy.

The amounts of buffer solution containing sodium and potassium bicarbonates and
sodium chloride were adjusted to maintain the rumen pH between 6.0 and 6.5. The amounts
required were calculated in relation to the level of VFA infused. Increases in the level of
infusion of VFA generally resulted in a greater proportion of buffer being needed. Expressed
as concentrated buffer:VFA solutions (see Table 1) these ranged from approximately 2:1
at lower levels of infusion to approximately 4:1 at the higher levels. During the changeover
from a normal diet to intragastric alimentation the buffer requirements were less,
presumably because the residual food debris in the rumen stimulated rumination and
salivation. In this respect an interesting observation (E. Storm, unpublished results)
indicated that when salivation was artificially stimulated by encouraging the animals to chew
on rubber tubing no additional buffer was required at the maintenance level and at twice
maintenance only minimal amounts.

RESULTS AND DISCUSSION

There were a few problems initially in adapting the same techniques used with lambs to
mature cows and steers. One of these was related to controlling osmotic pressure and pH
of rumen fluid. Increases in osmotic pressure to approximately 400 mosmol/l were
generally associated with a fall in pH and it was therefore found better to maintain an
osmotic pressure below 350 mosmol/l (Engelhardt, 1969). In the event, simply diluting the
rumen contents by an additional infusion of water was usually sufficient to correct the
imbalance. Although water was freely available, the animals did not respond to osmotic
pressure rises in rumen fluid by drinking more. In terms of total infusates, aqueous solutions
had to be given at approximately 0.7-1.0 l/kg body-weight{0.75} per d and in the instance of
the dairy cows under observation this amounted to total daily infusates in excess of
100 kg/d. The quantities were 87 l infused into the rumen and 26 l as dilute casein to the
abomasum. Sheep and lambs on the other hand appeared to tolerate lower infusate volumes
of approximately 0.5-0.7 l/kg body-weight^{0.75} per d.

The blood metabolites in both steers and cows were monitored (Table 2) and they were
similar to those reported for sheep by Ørskov, Grubb, Wenham et al. (1979). Observations
have now been made over prolonged periods of time on steers, and on dairy cows at different
stages of pregnancy, lactation and when dry; and at varying inputs of nutrients up to a
calculated level of twice maintenance for both energy and protein.

Reproduction appeared to be perfectly normal with regular oestrous cycling. The cows
were artificially inseminated to an Aberdeen Angus bull for their third gestation while still
being maintained by infusion, held to first service and gave birth to healthy 30 kg live-weight
calves. The cows have again been inseminated for their fourth gestation and pregnancy
diagnosis confirms that they are in calf to first service.

The Friesian steers used ranged in weight between 100 and 400 kg live weight and the
only difficulties encountered were those associated with leakage from the cannulas. In our
experience one of the essentials is to have a tight seal between the rumen cannula and
Table 2. Accepted values in normal dairy cow metabolic profiles compared to values derived from Friesian cows sustained on infusion (Mean of forty observations)

<table>
<thead>
<tr>
<th></th>
<th>Accepted range</th>
<th>Cows on infusion</th>
<th>SD for infusion observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red blood cells (10^12/l)</td>
<td>5-9</td>
<td>6.3</td>
<td>0.71</td>
</tr>
<tr>
<td>White blood cells (10^9/l)</td>
<td>4-10</td>
<td>9.2</td>
<td>3.15</td>
</tr>
<tr>
<td>Packed cell volume (l/l)</td>
<td>0.24-0.40</td>
<td>0.3</td>
<td>0.30</td>
</tr>
<tr>
<td>Haemoglobin (g/l)</td>
<td>80-140</td>
<td>117</td>
<td>12.2</td>
</tr>
<tr>
<td>Sodium (mmol/l)</td>
<td>136-144</td>
<td>136.0</td>
<td>5.81</td>
</tr>
<tr>
<td>Potassium (mmol/l)</td>
<td>4.3-5.7</td>
<td>4.5</td>
<td>0.35</td>
</tr>
<tr>
<td>Magnesium (mmol/l)</td>
<td>0.8-1.3</td>
<td>1.3</td>
<td>0.08</td>
</tr>
<tr>
<td>Calcium (mmol/l)</td>
<td>2.0-2.5</td>
<td>2.4</td>
<td>0.16</td>
</tr>
<tr>
<td>Phosphate (mg/l)</td>
<td>43-77</td>
<td>51.0</td>
<td>9.3</td>
</tr>
<tr>
<td>Total reducing sugars (mg/l)</td>
<td>600-700</td>
<td>812.0</td>
<td>90.0</td>
</tr>
<tr>
<td>Ketones (qualitative test)</td>
<td>Negative</td>
<td>Negative</td>
<td>--</td>
</tr>
</tbody>
</table>

The fused rumen and body wall to ensure that there are no leakages which will lead to loss of metabolites.

The volumes of urine were closely related to the amounts of liquids infused. In general, the mean daily excretion, over all treatments, of faecal dry matter with the dairy cows amounted to 100 g/d. The nitrogen and ash contents of faeces were usually approximately 30 and 550 g/kg dry faeces respectively.

Changing animals from total infusion to normal feeds was effected easily and there were no apparent problems or disturbances to the animals. When an infusion period was completed, a large rumen fluid inoculum from normally-fed animals was introduced via the cannula and normal feed was offered. In the instance of the dairy cows, the inoculum amounted to 4 l on two successive days. The amount of inoculum was purely arbitrary and probably not required in this quantity since microscopic examination on the second day indicated a thriving mixed rumen microflora. The animals established an appetite for solid food immediately and food intakes were back to normal within one week.

The authors wish to thank Mr G. Wenham for the surgical preparation of the animals, Mr J. C. Gill of the Duthie Experimental Farm for his help and management supervision and his staff, Mr J. Hamilton and Mr D. Reid, for the feeding, care and welfare of the animals.

REFERENCES


EXPLANATION OF PLATES
Plate 1. Arrangement of infusion tubes on 600 kg Friesian dairy cow.
Plate 2. Peristaltic pumps and infusion reservoirs.

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