Effect of ileo-rectal anastomosis and post-valve T-caecum cannulation on growing pigs

1. Growth performance, N-balance and intestinal adaptation

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The effects of post-valve T-caecum (PVTC) cannulation and end-to-side ileo-rectal anastomosis (IRA) on growth performance, nitrogen retention and intestinal fermentation were measured in growing pigs by comparison with a control group of intact animals. There were no differences between PVTC-pigs and intact pigs in growth performance and N balance. In IRA-animals reduced growth ($P < 0.01$), less efficient feed conversion ($P < 0.01$) and decreased N retention ($P < 0.001$) were found. Indices of fermentation measured in ileal digesta of PVTC- and IRA-pigs were considerably different. In IRA-animals the concentration of volatile fatty acids (VFA) was about 112–162 mmol/l, higher ($P < 0.001$) than in digesta of PVTC-pigs (20–31 mmol/l). The molar proportions of acetate and propionate depended ($P < 0.01$ and $P < 0.001$ respectively) on the digesta-collection technique. Concentrations and ratios of VFA measured in PVTC-pigs were similar to reported values. Diaminopimelic acid (DAPA) concentration and N:DAPA ratios measured in digesta were significantly ($P < 0.05$ and $P < 0.001$ respectively) different between treatments. All digesta variables measured showed increased microbial activity in digesta of IRA-pigs; thus, an influence on digestibility measurement can be assumed.

Ileo-rectal anastomosis: Post-valve T-caecum cannulation: Growth performance: N balance: Pig

Digestibility measured at the terminal ileum has been shown to be the best method for calculating the availability of amino acids in the pig (Zebrowska, 1973). Therefore, three new methods for collection of intestinal digesta at the terminal ileum have been developed during the last decade. Ileo-colic post-valve fistulation (Darcy *et al.* 1980) has been described as very difficult and time-consuming for routine measurement (Darcy *et al.* 1980). Ileo-rectal anastomosis (IRA) has been proposed as an alternative collection method (Picard *et al.* 1984; Darcy-Vrillon & Laplace, 1985; Souffrant *et al.* 1985; Hennig *et al.* 1986). The most important advantage of IRA is that digesta can be collected quantitatively via the anus. Using this technique problems such as blockages and leakages which have been described for re-entrant cannulation (Sauer, 1976; Just *et al.* 1980) do not occur. This finding could be of interest, especially when using practical diets containing large quantities of fibrous byproducts. The most recent technique to be developed is the post-valve T-caecum (PVTC) cannula described by van Leeuwen *et al.* (1988, 1991). This new technique uses the site of the ileo-caecal valve which normally protrudes into the caecum. The caecum is replaced by a large T-cannula with internal and external diameters of 25 and 30 mm respectively. The relatively large size of the cannula permits the use of fibre-rich diets without the problem of blockages proximal to the cannula. In addition, the samples from the PVTC cannula can be assumed to be representative because marker recovery is about 100% (van Leeuwen *et al.* 1991).

In a previous experiment (Köhler *et al.* 1990) it was shown that there are no differences in digestibility measurements between the PVTC cannula, the simple T-cannula described by Just *et al.* (1985) and the ileo-caecal re-entrant cannula described by van Leeuwen *et al.* (1987). A new digesta collection method can also be evaluated from its influence on the physiological state of the animals.

In the present experiment a long-term study was made of some physiological effects of the new PVTC cannulation technique in comparison with the end-to-side IRA and with findings in intact pigs. The main criteria were growth, N retention and intestinal adaptation.

MATERIALS AND METHODS

Twenty-two crossbred barrows with an average live weight (LW) of approximately 30 kg were used in the study. Seven pigs were fitted with a PVTC cannula as described by van Leeuwen *et al.* (1988) and nine were prepared with an end-to-side IRA. The latter group was fasted preoperatively for 48 h to minimize contamination with digesta during surgery. The animals were given magnesium sulphate (75 g 2 d before surgery) as well as Prunacolon (Centrafarm; 100 ml 1 d before surgery) to stimulate emptying of the colon. The animals were anaesthetized by inhalation anaesthesia as described by Kik *et al.* (1988). An incision (about 150 mm) was made in the lower abdominal wall ventral median following the linea alba, starting 100 mm behind the breastbone, opening the abdominal cavity. The caecal apex and the terminal portion of the ileum were located and exteriorized and the main part of the caecum was removed using a GIA 50 Premium (Auto Suture Instruments/United States Surgical Corporation, Norwalk, CT, USA) instrument (Fig. 1(a)). Subsequently the colon was cut using a TA Premium (Auto Suture Instruments/United States Surgical Corporation, Norwalk, CT, USA) instrument, so that a pouch of caecal tissue was built keeping the vascularity of the pouch intact (Fig. 1(b)). Afterwards the side of anastomosis on the pouch was identified. A purse-string was placed there using a Purstring (Schering Corporation, USA) instrument and the excess tissue was excised. An EEA (Schering Corporation, USA) instrument, without anvil, was introduced transanally into the rectum. An incision (about 2 mm) was made in the rectal tissue 100 mm proximal to the anus. The centre rod was advanced through this incision and the anvil was placed on its top. The Purstring instrument was removed and the purse-string suture was tied and the EEA instrument closed. After this the staples were inserted and the IRA was created (Fig. 1(c)).

The post-operative medication was 1 ml analgesic (Finadyne; Schering Corporation, USA)/d for 3 d and 1 ml antibiotic (Tribrisse; Coopers Agrovet)/d for 5 d. After surgery the pigs were allowed to recover for a period of 2 weeks. Six of the animals were not subjected to any surgical interference (intact group). All the pigs were individually housed in adjustable cages in an environmentally controlled metabolism unit with continuous light and an air temperature in the range 19–21°.

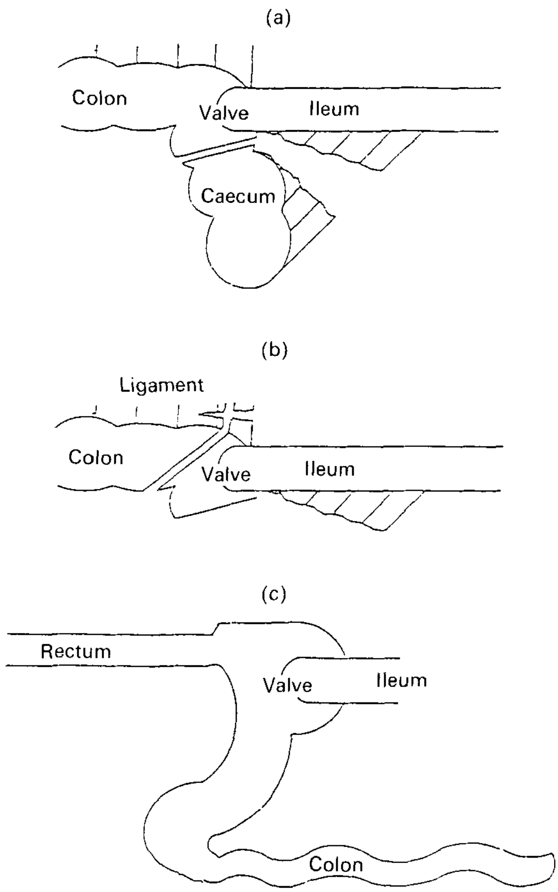

Fig. 1. Stages in the surgical procedure used to establish an ileo-rectal anastomosis. (a) Caecum is removed, (b) the colon is cut, (c) ileum, including the ileo-caecal value, is connected to the rectum.

Diet

The composition of the experimental diet in given in Table 1. Chromic oxide (2·5 g/kg) was included as a marker for the solid phase. The pigs were fed at about 2·4 times the maintenance requirement for energy (Agricultural Research Council, 1981), divided into two meals fed daily at 08.00 and 20.00 hours. Water was given with the feed at a ratio of 2·5:1 (w/w). The anastomosed pigs also received an electrolyte solution (200 ml/20 kg LW per d) twice daily as described by Hennig *et al.* (1986). In contrast to the PVTC-pigs, IRA-pigs had continuous access to fresh water.

LW gain

The LW of the animals were recorded every 2 weeks.

Nitrogen balances

At 2 weeks before surgery as well as during the fifth and eleventh week after surgery N balances were carried out over 5 d. The experimental groups were allocated to treatments after the first N balance.

Table 1. *Composition of the experimental diet (g/kg)*

Ingredients	
Maize	32·95
Barley	6·00
Wheat	10·50
Soya-bean meal, solvent extracted	22·50
Molasses	4·00
Potato pulp	9·20
Beet pulp	10·00
Animal fat	1·00
L-lysine hydrochloride	0·18
DL-methionine	0·12
Vitamins and minerals*	1·00
$Ca(H_2PO_4).H_2O$	1·50
$CaCO_3$	0·50
NaCl	0·30
Cr_2O_3	0·25
Chemical composition (g/kg dry matter)	
Crude protein (nitrogen × 6·25)	199·00
Gross energy (MJ)	18·04
Sodium	1·60
Potassium	13·00
Crude fibre†	65·00

* Contributed the following (mg/kg diet): retinol 2·7, cholecalciferol 45 μg, α-tocopherol 40; menadione 3, riboflavin 5, cobalamine 40 μg, nicotinic acid 30, D-pantothenic acid 12, choline chloride 150, ascorbic acid 50, KI 500 μg, $CoSO_4.7H_2O$ 2·5, Na_2SeO_3 0·2, $FeSO_4.7H_2O$ 0·40 g, $CuSO_4.5H_2O$ 0·1 g, MnO_2 0·07 g, $ZnSO_4.H_2O$ 0·2 g. This mixture also supplied 20 mg virginiamycin/kg to the diet. The mixture was made up to 1 kg with ground maize.

† Calculated value.

Digesta collection

The ileal digesta were collected quantitatively for 5 d for 12 h/d from 09.00 to 21.00 hours, 3, 9 and 12 weeks after surgery. The digesta from the IRA-animals were collected in faeces boxes and immediately frozen at −20°. The digesta from the pigs fitted with a PVTC cannula were collected continuously through polyethylene tubing into a collection container packed with crushed ice. All samples were stored at −20° until required for analysis.

Chemical and statistical analyses

Digesta, faeces and urine samples for each animal and period were pooled before chemical analyses. Analyses for N and dry matter were carried out according to International Organization for Standardization (1979, 1983). Volatile fatty acids (VFA) were determined as described by Kaufmann & Hagemeister (1969). Diaminopimelic acid (DAPA) analyses were carried out according to Ahrens *et al.* (1985). Differences among treatment means were tested according to the Tukey range test procedure of SAS (1990).

RESULTS

LW gain

Fig. 2 shows the cumulative LW gain from 2 weeks after surgery until the 13th week after surgery. The average LW gain of the IRA-pigs was significantly lower ($P < 0·01$) than for the intact pigs. The average daily gain of the animals with an IRA was only 221 g/d,

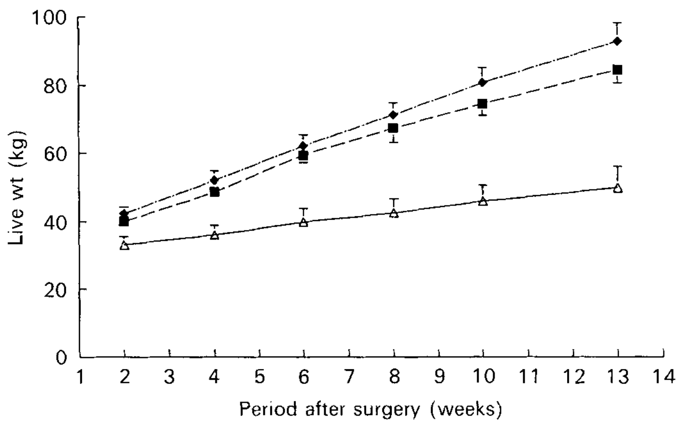

Fig. 2. Live weight gain of pigs fitted with ileo-rectal anastomosis (△——△), post-valve T-caecum cannula (■——■) and with intact intestinal tract (◆——◆). Values are means and standard deviations represented by vertical bars. For details of techniques and procedures, see pp. 294–296.

whereas the average daily gain of the pigs with a PVTC cannula was 572 g/d and for the intact pigs it was 656 (SEM 21·7) g/d. The difference in daily gain between the PVTC-animals and the intact pigs was not significant.

The effect of the IRA on feed conversion was also significant ($P < 0{\cdot}01$). For the IRA-pigs it was 5·19, 2·3 times higher than for the intact pigs (2·29). The average feed conversion calculated for the animals fitted with a PVTC cannula was 2·56.

N retention

Table 2 shows values for the three N balances. Before surgical intervention there were no significant differences between the groups. After surgery, however, N retention of IRA-pigs was considerably lower than that of the other animals ($P < 0{\cdot}001$). N retentions of the intact and PVTC-cannulated animals were about twice that of IRA-animals and decreased with time. After surgery N retention of the IRA-pigs remained almost constant throughout the experiment. Intact and PVTC-animals showed the normal increase in the accretion of N. Values for faecal and urinary N excretion for IRA-pigs were constant and, apart from the renal N excretion in period three, significantly higher ($P < 0{\cdot}001$) than those in the other two groups.

VFA

The total amounts of VFA are shown in Table 3. In all three periods the concentrations of VFA measured in digesta from IRA-animals were significantly ($P < 0{\cdot}001$) higher than those in digesta of PVTC-pigs. In PVTC-pigs the highest concentration of each VFA was observed 3 weeks after surgery. At 6 and 13 weeks after surgery the concentrations were lower and similar. In IRA-animals the absolute amounts of acetate, propionate and butyrate increased during the experiment. Thus, 13 weeks after surgery the concentration of acetate in the digesta of IRA-animals was about six times higher than that in digesta of PVTC-animals. For propionate and butyrate this factor was about 20 and for valerate 35.

Table 3 also shows the molar proportions of VFA in digesta. In both treatments acetate was present in the highest ($P < 0{\cdot}05$) amount followed by propionate, butyrate and valerate. In PVTC-animals the amount of acetate was significantly ($P < 0{\cdot}001$) higher (74–83 mol/100 mol) than that in IRA-animals (55–58 mol/100 mol) and increased with time. On the other hand, in IRA-animals, the amounts of propionate and butyrate (31 and

Table 2. *Nitrogen balances (g N/d per kg metabolic live weight ($LW^{0.75}$)) in pigs fitted with ileo-rectal anastomosis (IRA), post-valve T caecum (PVTC) cannula and intact pigs (INT)*†

Period	$LW^{0.75}$	N intake	N excretion		N retention
			Faeces	Urine	
2 weeks before surgery					
IRA	12·05	2·28	0·43	0·49	1·36
PVTC	11·79	2·28	0·43	0·53	1·32
INT	11·67	2·29	0·42	0·53	1·34
SEM	0·202	0·004	0·031	0·021	0·026
5 weeks after surgery					
IRA	14·69	2·22	0·65	1·10	0·45
PVTC	18·62***	2·18***	0·34***	0·63***	1·21***
INT	19·38***	2·18***	0·28***	0·76***	1·14***
SEM	0·327	0·004	0·022	0·054	0·060
11 weeks after surgery					
IRA	17·77	2·25	0·68	1·14	0·43
PVTC	25·36***	2·22***	0·37***	0·90*	0·95***
INT	26·94***	2·22***	0·33***	0·95	0·90***
SEM	0·439	0·003	0·034	0·059	0·076

Mean values were significantly different from those for IRA-animals: * $P < 0.05$; *** $P < 0.001$.
† For details of techniques and procedures, see pp. 294–296.

Table 3. *Contents of volatile fatty acids (VFA; mmol/l) and their molar proportions (mol/100 mol) in digesta of pigs fitted with ileo-rectal anastomosis (IRA) and post-valve T-caecum cannula (PVTC) 3, 9 and 12 weeks after surgery*†

Period after surgery (weeks)	Total VFA	Molar proportions (mol/100 mol) of:				
		C_2	C_3	C_4	C_5	C_2:C_3
3						
IRA	108·0	56·3	32·1	9·1	2·5	1·76
PVTC	31·2***	74·2***	18·9***	5·7**	1·3**	4·1***
SEM	‡	1·66	1·13	0·68	0·29	0·31
9						
IRA	116·4	58·2	31·8	8·2	1·8	1·84
PVTC	21·4***	79·5***	15·3***	4·6***	0·7***	5·80***
SEM	‡	1·35	1·12	0·49	0·19	0·69
12						
IRA	162·7	58·1	31·3	8·5	2·1	1·86
PVTC	20·5***	85·3***	12·5***	3·5***	0·7**	7·13***
SEM	‡	1·38	0·85	0·53	0·29	0·57

Mean values were significantly different from those for IRA-animals: ** $P < 0.01$, *** $P < 0.001$.
† For details of techniques and procedures, see pp. 294–296.
‡ SEM could not be given as SE differed mainly between IRA-pigs (9·2, 11·5 and 5·8) and PVTC-pigs (3·7, 2·9 and 2·6) at 3, 9 and 12 weeks respectively.

8–9 mol/100 mol) were significantly ($P < 0.001$ and $P < 0.01$ respectively) higher than those in PVTC-animals (12–19 and 3·0–5·2 mol/100 mol). These differences resulted in a different C_2:C_3 ratio. Thus, in PVTC-animals this ratio was 4·10–7·13 and increased during the experiment; in IRA-animals it was about 1·80.

Table 4. *Diaminopimelic acid (DAPA) concentration (mg/g dry matter (DM)) and the ratio nitrogen (mg/100 mg DM): DAPA (mg/100 mg DM) in digesta of pigs fitted with ileo-rectal anastomosis (IRA) or post-valve T-caecum (PVTC) cannula 3, 9 and 12 weeks after surgery*

Period after surgery (weeks)	DAPA IRA	DAPA PVTC	DAPA SEM	N:DAPA IRA	N:DAPA PVTC	N:DAPA SEM
3	0·60	0·47*	0·04	51·8	59·8	3·97
9	0·68	0·34***	0·04	43·4	71·7***	3·91
12	0·80	0·34***	0·04	36·3	68·6***	3·36

Mean values were significantly different from those for IRA-animals: * $P < 0.05$, *** $P < 0.001$.

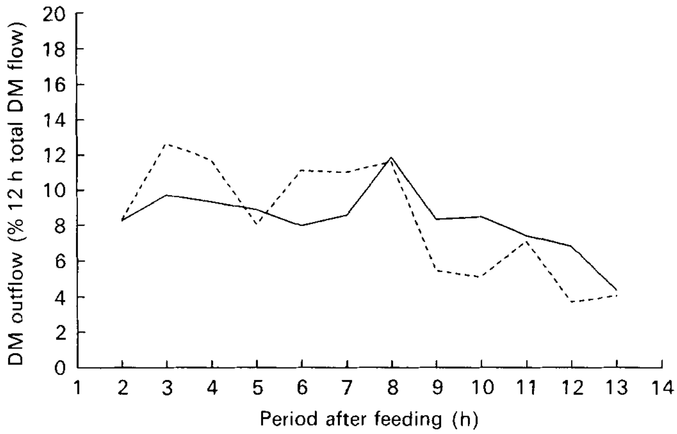

Fig. 3. Hourly dry matter (DM) outflow as % total DM flow over a 12 h period in pigs fitted with ileo-rectal anastomosis (IRA) (---) and post-valve T-caecum cannula (PVTC) (——). Standard deviation: PVTC-pigs 4·75, IRA-pigs 9·43. For details of techniques and procedures, see pp. 294–296.

DAPA

DAPA concentrations in digesta recovered from PVTC- and IRA-animals are presented in Table 4. In all three digesta-collection periods the concentration of DAPA in the digesta of the IRA-pigs was significantly higher ($P < 0.05$ and $P < 0.001$) than those in digesta of PVTC-pigs. In addition, in IRA-animals the concentration of this amino acid increased with time. In digesta collected from PVTC-pigs the highest DAPA concentration was observed 3 weeks after surgery. Results measured in week 9 and week 12 post-surgery were smaller and similar.

N:DAPA ratios were given in Table 4. In weeks 9 and 12 after surgery the differences between the treatments were significant ($P < 0.001$). In digesta of IRA-animals this ratio became smaller with time ($P < 0.01$), thus, the amount of microbial N increased. In PVTC-animals this ratio was similar ($P > 0.05$) throughout the experiment.

Digesta flow

Fig. 3 shows the average digesta flow calculated over 5 d and expressed as percentage of the total dry matter outflow over 12 h for the first digesta collection period. The between-hours digesta flow was less variable for PVTC-pigs compared with IRA-pigs and seemed to be reduced from the 10th to 13th hour after feeding. However, during the 8th hour after feeding the digesta flow increased to 11% of the total outflow. For PVTC-pigs the within-hours mean standard deviation was 4·75%. In IRA-pigs the hourly digesta flow was relatively irregular. Thus, the calculated hourly digesta flow varied between 3·7 and 12·6% of the total outflow over 12 h. As with the PVTC-pigs the digesta flow decreased from the 8th hour after feeding. In contrast to the results obtained with PVTC-pigs the mean variation for IRA-pigs was about twofold higher.

DISCUSSION

It is questionable whether IRA-animals and intact animals have similar metabolic rates. An increased metabolic rate as a result of discomfort might be expected. MacRae *et al.* (1982) found an increased metabolic rate in some of the sheep provided with re-entrant cannulas when compared with intact animals. With the IRA technique an increased metabolic rate would result in a lower rate of energy gain and an increased feed:gain ratio on a similar metabolizable energy (ME) intake. Hennig *et al.* (1986) reported a 55% reduction in LW gain for IRA-pigs and a feed conversion which was 2·3 times higher than that for intact pigs. These workers suggested that energy utilization was reduced as a result of the absence of the large intestine. In the present investigation pigs were fed at a level of 2·4 times the maintenance requirement for energy (2·4 × 420 kJ/kg metabolic live weight ($LW^{0.75}$)); this is about 90% of the Agricultural Research Council (1981) standards. Herrmann *et al.* (1989) measured the energy digestibility and metabolizability in anastomosed pigs in comparison with intact animals. They found that IRA-pigs have a 15% lower metabolizability of energy compared with intact animals. Thus, when applied to our animals, this means that compared with the control group which had 2·4 × 420 = 1008 kJ ME/kg $LW^{0.75}$ the IRA-animals had a feeding level of 15% less or 857 kJ ME/kg $LW^{0.75}$. Furthermore, Herrmann *et al.* (1989) found that maintenance requirement for energy was increased by 12% in IRA-pigs. For IRA-pigs they calculated a maintenance requirement for energy of 504 kJ/kg $LW^{0.75}$. In our experiment the control pigs had 1008 − 420 = 588 kJ ME/kg $LW^{0.75}$ available for performance. In IRA-animals both the reduced metabolizability and the increased maintenance requirement for energy would result in energy available for growth of 857 − 504 = 353 kJ ME/kg $LW^{0.75}$; this is much less than that for intact animals. Based on values for gain expressed per unit metabolic LW the IRA-animals had an average gain of 13·9 g/kg $LW^{0.75}$ and the intact pigs 29·5 g/kg $LW^{0.75}$. PVTC-pigs had an average LW gain of about 27·4 g/kg $LW^{0.75}$. Compared with the intact animals the IRA-animals gained 47% and the PVTC-pigs 93%. Based on energy supply and a similar composition of gain IRA-animals could gain about 60% of that of the intact animals. The difference of 3·8 g/kg $LW^{0.75}$ between IRA- and intact pigs can be partly explained by the different diet in our study compared with that of Herrmann *et al.* (1989). In addition, the composition of gain may be different. In general our findings compared favourably with those of Herrmann *et al.* (1989). The somewhat reduced gain in PVTC-animals can be attributed to the digesta collection. Digesta to be collected do not contribute to large intestine digestion. With our technique of feeding, based on $LW^{0.75}$, a small reduction in rate of gain would result in less feed for the rest of the experiment.

Digestibility measurement at the distal ileum has been shown to be more sensitive than faecal measurement, because microbial activity in the hind-gut of pigs influences the composition of faeces (Mason, 1984). On the other hand, with the IRA-procedure, digesta flow through the rectum which may permit some fermentation to take place. In PVTC-animals the cannula is placed post-valvularly, thus, it is possible that digesta from the colon may have an effect on digesta composition. As an indirect indication of microbial activity, VFA levels in digesta from IRA- and PVTC-animals were measured (Table 3). In PVTC-animals the concentrations of VFA in ileal digesta were comparable with reported values (Argenzio & Southworth, 1975; Clemens *et al.* 1975; Drochner, 1984; Mosenthin, 1987). Values obtained with IRA-pigs were quite different from those for PVTC-pigs. In IRA-animals concentrations of VFA were about three to eight times higher and the molar proportions of acetate and propionate were quite different. While in PVTC-pigs the percentage of acetate was in a range of 74–83%, the corresponding value was about 58% in digesta recovered from IRA-animals. In the literature acetate:propionate ratios measured in different segments of the intestinal tract were considerably different (Argenzio & Southworth, 1975; Clemens *et al.* 1975; Drochner, 1984; Mosenthin, 1987). Differences between these sections of the intestinal tract were similar to those found between PVTC- and IRA-animals. Thus, molar proportions of VFA in ileal digesta of PVTC-pigs were similar to reported values when VFA concentrations were measured in ileal digesta. Molar proportions of acetate of about 50–60 mol/100 mol found in digesta of IRA-pigs have also been reported for faeces (Argenzio & Southworth, 1975; Drochner, 1984; Sauer *et al.* 1991) and in digesta collected from the colon (Münchow *et al.* 1989). As an additional indication of microbial activity, DAPA was determined (Table 4). DAPA concentrations in digesta of IRA-animals were 1·3–2·3 times higher than those in digesta collected from PVTC-pigs. Differences between treatments with regard to both VFA and DAPA concentrations indicate increased microbial activity in the digesta recovered from IRA-pigs. This fact may be especially important for amino acid digestibility measurements, because it can be assumed that the amino acid composition of microbial protein is different from that of digesta. The relative amount of microbial protein contributing to total protein is given as the N:DAPA ratio (Table 4). While in digesta from PVTC-animals this ratio slightly increased with time, in IRA-pigs the value decreased. Thus the proportion of microbial protein relative to total protein in digesta from IRA-pigs increased with time. This increase in the population of micro-organisms corresponds with the increase in the concentration of VFA.

As mentioned previously, in the IRA technique the ileo-caecal valve is used, as proposed by Souffrant (1985), to prevent a backflow of digesta from the rectum into the small intestine. On the other hand it can be accepted that there is no synchronization of the ileo-caecal valve and the anus, so that the digesta outflow via the anus is not similar to that in cannulated animals (Fig. 3). This interruption of digesta flow in IRA-pigs resulted in an irregular digesta outflow and a significantly ($P < 0{\cdot}05$) higher variation between the IRA-animals. An accumulation of ileal digesta in the rectum represents optimal conditions for fermentation. Although Green (1988) found no differences in the digestibility of amino acids between IRA-pigs in the presence or absence of the ileo-caecal valve, our findings for IRA-pigs with an intact sphincter suggest high microbial digestion which might influence digesta composition.

Differences between treatments in N losses from urine were not expected as urine was first collected in funnels, then in a container, in the presence of sulphuric acid which maintained the pH of the urine below 2. Overestimation of N retention has been reported previously (Oslage *et al.* 1987; Walz & Pallauf, 1989). In the present experiment N retention was overestimated, the values being higher for PVTC-animals and intact animals than for IRA-animals. Thus, more N may have been lost into the air from faeces of PVTC- and intact animals than from faeces of IRA-animals.

It can be concluded the PVTC-cannulation has no significant influence on growth performance. Fermentation variables were similar in value to those reported in the literature; thus, the influence of site (post-valvular) can be excluded. In IRA-pigs the effects of this technique on growth were considerable and in agreement with previously reported findings. Values for VFA and DAPA levels indicate a respectable level of microbial activity.

The latter may have an influence on digestibility measurements. Further studies will be necessary to investigate digestibility measurements in IRA-pigs, especially with regard to the digestibility of amino acids and carbohydrates, because the amino acid profile may be changed and a part of the carbohydrate may be broken down due to microbial fermentation.

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