Digestive development of the early-weaned pig

1. Effect of continuous nutrient supply on the development of the digestive tract and on changes in digestive enzyme activity during the first week post-weaning

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Gastric intubation was adopted to examine the effect of continuous nutrient supply on digestive development of the pig during the immediate post-weaning period. The 14 d-weaned animals were slaughtered at 3, 5 and 7 d post-weaning (3W, 5W and 7W respectively) and the suckled animals were slaughtered at 14 and 22 d of age (14SR and 22SR respectively). The weight of the pancreas (g/kg body-weight) was significantly greater ($P < 0.05$) in the 5W and 7W groups, as was the weight of large intestine (g/kg) in all weaned groups ($P < 0.01$) compared with sow-reared pigs. The stomach weight (g/kg) tended to be greater in the weaned groups. Weaning, in conjunction with a continuous nutrient supply, did not significantly alter the time-related changes in the weight of the small intestine (SI) or the SI mucosa, although both variables tended to be lowest in the 3W group. However, there was a 20% reduction in the protein content of the mucosa within the first 3 d post-weaning ($P < 0.01$) which persisted during the 7 d experimental period. Lactase, (β-galactosidase; *EC* 3.2.1.23) activity (μmol/g protein and mol/d) of the 7W group was reduced to approximately 40% of the 22SR value. Hence, continuous nutrient supply may have delayed, but did not prevent, the loss of lactase activity at weaning. The activity of sucrase (sucrose-α-glucosidase; *EC* 3.2.1.48) was significantly higher in 22SR compared with 14SR animals. Sucrase activity in weaned pigs was intermediate to the values for sow-reared pigs whereas maltase (α-glucosidase; *EC* 3.2.1.20) and glucoamylase (glucan 1, 4-α-glucosidase; *EC* 3.2.1.3) were significantly increased in relation to their sow-reared counterparts. Continuous nutrient supply did not prevent the reduction in villous height and the crypt hypertrophy associated with weaning. The results of the present study suggest that there may be some degree of interaction between nutrient intake and gut development during the immediate post-weaning period but that there is also a component of the adaptive response which is independent of nutrient intake. They confirm the rapid substrate induction of the brush-border glucoamylases and indicate the importance of considering total as well as specific enzyme activity for satisfactory interpretation of changes in digestive function.

Digestive development: Nutrient intake: Pig

The small intestine of the early-weaned pig undergoes major changes in villous architecture and reductions in specific enzyme activity during the immediate post-weaning period (Gay, 1976; Gay *et al.* 1976; Armstrong & Clawson, 1980; Hampson, 1983; Hampson & Kidder, 1986). Smith (1984) reported that the alterations in mucosal architecture resulted in reduced ability of villi to transport amino acids. The cumulative effect of these factors has been considered to result in a reduced digestive capacity in vivo and to explain the low feed intake frequently encountered during the post-weaning period (Hampson, 1983). However,

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K. J. McCracken (unpublished results) observed that low enzyme levels at 7 d post-weaning appeared to be the result rather than the cause of low feed intakes. Reductions in mucosal mass and a depression of digestive enzyme capacity occur in malnourished or fasted states (Steiner *et al.* 1968; McManus & Isselbacher, 1970), illustrating the importance of nutrient intake in maintaining mucosal integrity. It is, therefore, unclear to what extent the reported anatomical, biochemical and histological effects observed in the weaned gut merely reflect the interruption in nutrient intake, which normally occurs at weaning and may last for up to 48 h or more.

Gastric intubation has been demonstrated to be an effective means of ensuring controlled intakes in weaned pigs (Kelly *et al.* 1984) and examination of such pigs confirmed that some of the changes observed are related to nutrient intake. The present study extends these results by providing (*a*) a detailed time-course analysis of events during the first 7 d after weaning in pigs given feed at 3 h intervals by gastric intubation, and (*b*) a direct comparison with sow-reared littermates.

Enzyme activity is normally expressed as specific activity (μmol/g supernatant-fraction protein), but is also variously reported in the literature as activity per ml homogenate, per g mucosa, per g DNA or as total gut activity. This leads to major problems in interpretation of literature results. Shields *et al.* (1980) questioned the ability of specific activity to reflect digestive capacity in vivo since various factors may influence specific activity without altering the total enzyme levels. Likewise, Widdowson (1984) commented that, in the newborn pig, specific lactase activity fell by 40% during the first 24 h whereas total activity increased by 50%.

The second objective of the present study was, therefore, to assess how the adopted basis of expression of activity affects interpretation of enzyme development in the early-weaned pig.

MATERIALS AND METHODS

Experimental treatments

Twenty piglets were selected from four litters obtained from the minimal disease herd at the Agricultural Research Institute, Hillsborough. It was intended to use five pigs per litter, randomly allocated across five treatments using litters as a blocking factor, as follows:

(1) sow-reared, slaughtered at 14 d of age (14SR);
(2) weaned at 14 d, continuous-fed for 3 d and slaughtered (3W);
(3) weaned at 14 d, continuous-fed for 5 d and slaughtered (5W);
(4) weaned at 14 d, continuous-fed for 7 d and slaughtered (7W);
(5) sow-reared, slaughtered at 22 d of age (22SR).

Due to problems with one litter, only four pigs were suitable. These were allocated to treatments 1–4 and an extra pig from one of the other litters was allocated to treatment 5 (22SR).

Weaned pigs (mean weaning weight, 4·5 kg) were penned in individual metabolism cages in a controlled-environment room (29°, relative humidity 50%). The pigs were given a diet (Table 1) by gastric intubation seven times daily (at 06.00, 09.00, 12.00, 15.00, 18.00, 21.00 and 24.00 hours). Feed (110 g) was given on the first day post-weaning followed by 150 g feed/d until slaughter. In addition pelleted diet was offered to appetite and daily feed intake was recorded. The general condition and performance of the pigs were closely observed. On the morning of days 4, 6 and 8 post-weaning, pigs were slaughtered. The sow-reared (22SR) group were slaughtered on the day after the last weaned group because of the time required to complete the sampling sequence.

Table 1. *Composition (g/kg) and analysis (per kg dry matter) of the diet fed*

Fat-filled skim-milk powder	340
Flaked maize	255
Maize meal	64
Ground wheat	100
Fish meal (680 g CP/kg)	100
Soya-bean meal 50 (480 g CP/kg)	65
Sucrose	50
Dicalcium phosphate	20
Sodium chloride	3
Trace minerals–vitamins*	3
CP (g/kg)	237
Fat (g/kg)	109
Ash (g/kg)	67
Crude fibre (g/kg)	11·3
Calcium (g/kg)	13·1
Phosphorus (g/kg)	8·8
Sodium chloride (g/kg)	14·0
Gross energy (MJ/kg)	19·5

CP, crude protein (nitrogen × 6·25).

* Supplied (mg/kg): iron 120, zinc 65, copper 35, manganese 25, iodine 2, cobalt 1, selenium 0·1, ascorbic acid 50, choline chloride 100, nicotinic acid 10, calcium pantothenate 8, riboflavin 4, menadione 4, pyridoxine hydrochloride 3, thiamin hydrochloride 1, retinol 12, α-tocopheryl acetate 4, cholecalciferol 0·035, cyanocobalamin 0·001.

Post-mortem procedure

Weaned pigs were given a feed of 40 g diet, 2 h before slaughter. Sow-reared pigs were removed from the sow approximately 2 h before slaughter. Anaesthesia was induced using trichloroethylene and a midline laparotomy was performed. Five small intestine (SI) sites were sampled at distances of 10, 30, 50, 70 and 90% from the pylorus to the ileo-caecal valve (sites 1–5 respectively). Samples (100 mm) from sites 1–5 were excised and frozen in liquid nitrogen for enzyme and protein determinations. Further samples from sites 1, 3 and 5 were collected for histological investigation. After removal of the gut samples, which normally took approximately 20 min to complete, the animal was killed by injection of sodium pentobarbitone into the heart. Digestive and other organs were then removed and weighed. The remainder of the SI was measured for length, washed free of gut contents and weighed.

Digestive enzyme determinations

The mucosa was removed from the partially thawed 100 mm lengths of SI and homogenized in 50 ml distilled water. The supernatant fraction was recovered and two dilutions prepared as follows: 5 ml supernatant fraction + 5 ml distilled water, dilution A; 5 ml dilution A + 5 ml distilled water, dilution B. Dilution A was used for the determination of lactase (β-galactosidase; *EC* 3.2.1.23), sucrase (sucrose-α-glucosidase; *EC* 3.2.1.48) and maltase (α-glucosidase; *EC* 3.2.1.20). Dilution B was used for the determination of glucoamylase (glucan 1,4-α-glucosidase; *EC* 3.2.1.3). The substrate concentrations and incubation conditions used for enzyme determinations were the same as those used by Kidder & Manners (1980). After a 30 min incubation at 37°, the reaction was terminated by submerging the tubes in boiling water. The free glucose liberated by the action of mucosal enzymes was then determined using the glucose-6-phosphate dehydrogenase

(*EC* 1.1.1.49)–hexokinase (*EC* 2.7.1.1) assay (Boehringer, Mannheim) for the determination of glucose.

Protein determination

The protein content of the supernatant fraction was determined using the method described by Gornall *et al.* (1949).

Histology

The samples of SI from sites 1, 3 and 5 were fixed in buffered formalin (100 ml/l) and processed by the standard paraffin method. Sections (4–6 μm) were cut and stained with haematoxylin and eosin. Measurements of villous height and crypt depth were made on twenty to fifty well-orientated villi using either an ocular micrometer or an image analyser (Tasplus, Leitz Instruments).

Calculations and statistical analysis

Total mucosa and mucosal protein weights were calculated from the mean values per 100 mm over the five sites and the SI length. Enzyme activities were expressed as specific activity (per g supernatant protein), per g mucosa or as total activity. The values presented for specific activity or per g mucosa are the means for the five sites. Total activity was calculated from the mean value per 100 mm over the five sites and the SI length.

The results in Table 2 and total enzyme activity (Table 3) were subjected to an unbalanced analysis of variance for group effects taking account of litters as a blocking factor and using initial live weight as a co-variate. Enzyme activity, and villous and crypt measurements were analysed in an unbalanced, split-plot design. Litter effects were non-significant and the values were re-analysed and presented in Tables 3–5 as a balanced split-plot excluding litter blocking. In order to take account of the 1 d discrepancy in age between 22SR and 7W pigs, adjusted 21SR values were linearly interpolated from the 14SR and 22SR values and are included in the tables.

RESULTS

The overall performance and condition of the pigs were excellent during the feeding period. The mean weight gains for the 3, 5 and 7 d periods post-weaning were 0·24, 0·37 and 0·76 kg respectively. Only limited quantities of pellets were consumed voluntarily except for one of the 7W pigs where voluntary consumption over the 7 d period amounted to 33% of the quantity tube-fed. The weight gain of this animal was comparable with that of the 22SR pigs. The 7W group had consumed approximately 1 kg diet, which is above the average voluntary consumption of 14 d weaned pigs during the post-weaning week. Faeces were of normal appearance in all pigs during the feeding period and at slaughter there was no indication that digestive processes were in any way impaired.

The mean live weight increased linearly across the weaned groups but the 7W group was significantly lighter ($P < 0·05$) than the 22SR or 21SR pigs (Table 2). Pancreas weight was significantly higher ($P < 0·05$) in 5W and 7W pigs than in 14SR pigs but similar to that in 22SR pigs. A similar trend was observed for stomach weight. SI weights tended to be lower in 3W and 5W animals than in 14SR pigs and were significantly lower ($P < 0·05$) than those for 7W or 22SR pigs, but there was no significant difference between 7W and 22SR values. Large intestine weight was increased in 3W and 5W pigs relative to 14SR pigs ($P < 0·05$) and was significantly higher in 7W pigs relative to 3W, 5W, 22SR and 21SR values.

When corrected for body-weight the weights of the pancreas (g/kg) and of the large intestine (g/kg) were similar in both sow-reared groups. However, the weight (g/kg) of the

Table 2. *Live weight (kg), organ weights (g or g/kg body-weight) and small intestine (SI) mucosal protein content of sow-reared pigs (14 d, 22 d and calculated 21 d† values) and weaned (W) pigs (3, 5 or 7 d post-weaning) given continuous nutrient supply by gastric intubation*

(Mean values for four pigs; 11 df)

	SR	W			SR			Statistical significance
	14 d	3 d	5 d	7 d	22 d	21 d†	SED*	$P =$
Live wt (kg)	4·50[a]	4·72[a]	4·81[a]	5·21[a]	6·49[b]	6·24‡	0·333	< 0·001
Pancreas (g)	6·8[a]	7·6[a]	9·4[b]	10·4[b]	9·7[b]	9·4	0·74	0·002
Stomach (g)	22·3[a]	30·3[ab]	34·6[bc]	39·4[c]	37·5[bc]	35·7	4·14	0·016
SI (g)	172·3[ab]	148·3[a]	148·1[a]	185·4[b]	196·5[b]	193·5	16·16	0·029
Large intestine (g)	33·8[a]	47·8[b]	46·5[b]	59·4[c]	48·5[b]	46·7‡	5·01	0·004
Pancreas (g/kg)	1·53[a]	1·60[ab]	1·93[bc]	1·99[c]	1·55[a]	1·55‡	0·158	0·023
Stomach (g/kg)	5·19[a]	6·47[bc]	7·19[bc]	7·56[c]	6·03[ab]	5·92‡	0·619	0·014
SI (g/kg)	39·3[b]	31·6[a]	31·4[a]	35·6[ab]	31·5[a]	32·5	2·26	0·014
Large intestine (g/kg)	7·43[a]	10·24[b]	9·61[b]	11·34[b]	7·66[a]	7·63‡	0·909	0·003
Total SI mucosa (g)	85·9	70·5	71·4	98·7	99·2	97·7	12·81	0·083
Protein content (mg/g mucosa)	144·0[b]	114·3[a]	113·3[a]	101·7[a]	148·6[b]	148·2‡	11·71	0·004
Total SI mucosal protein (g)	12·6[bc]	8·2[a]	8·0[a]	9·8[ab]	14·4[c]	14·2‡	1·54	0·003

SED, standard error of difference.
[a,b,c] Means with different superscript letters were significantly different ($P < 0·05$).
* Refers to comparison of 22SR pigs with other groups.
† 21 d values by linear interpolation from 14SR and 22SR values.
‡ Mean values for 21SR pigs were significantly different from those for 7W pigs ($P < 0·05$).

pancreas was significantly higher ($P < 0·05$) in the 5W and 7W groups, as was the weight of the large intestine in all weaned groups compared with sow-reared animals. There was a trend towards increased stomach weight with age in the weaned pigs and all three values were significantly higher than for 14SR pigs. Only the 7W value was significantly greater than the 22SR and 21SR means. The weight of the small intestine relative to body size decreased with age and was not affected by weaning. Mean mucosal weight (per 100 mm) increased significantly ($P < 0·001$, SEM 0·07) from site 1 to site 5 of the SI, the respective values being 1·43 and 1·84 g, but there was no significant treatment effect at individual sites. The total weight of the SI mucosa was not significantly altered by weaning or by age. The change in the weight of the mucosa closely mirrored the change in the weight of the SI, both weights tending to be lowest in the 3W and 5W groups. The protein content of the mucosa was reduced ($P < 0·01$) in weaned pigs compared with sow-reared animals when expressed per g mucosa. When total protein was considered the same trend was apparent. The 3W and 5W values were lower than for sow-reared pigs and the 7W value was lower than the 21SR value. There were no significant differences between the three weaned groups.

There were highly significant ($P < 0·001$) site effects for lactase and sucrase whether expressed per g mucosa, per g protein or per 100 mm (Figs. 1–3). These were mainly associated with lower values at site 5. For maltase the values tended to rise from site 1 to site 4 with site 5 values being similar to site 1. The effects were significant ($P < 0·05$) when activity was expressed per g protein or per 100 mm. A similar trend existed for total glucoamylase but no significant site differences occurred.

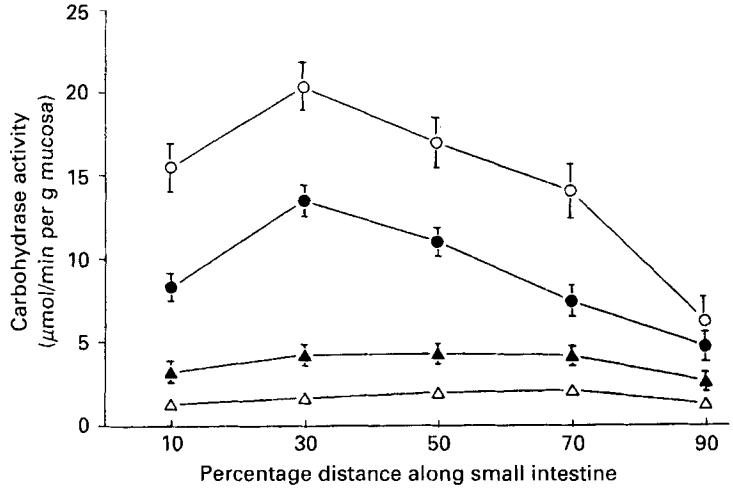

Fig. 1. Distribution of carbohydrase activity (per g mucosa) along the small intestine in pigs from 14 to 22 d of age. (○) Lactase (*EC* 3.2.1.23); (●), sucrase (*EC* 3.2.1.48); (△), maltase (*EC* 3.2.1.20); (▲), total glucoamylase (*EC* 3.2.1.3). For details of procedures, see p. 171. Values are means with their standard errors represented by vertical bars.

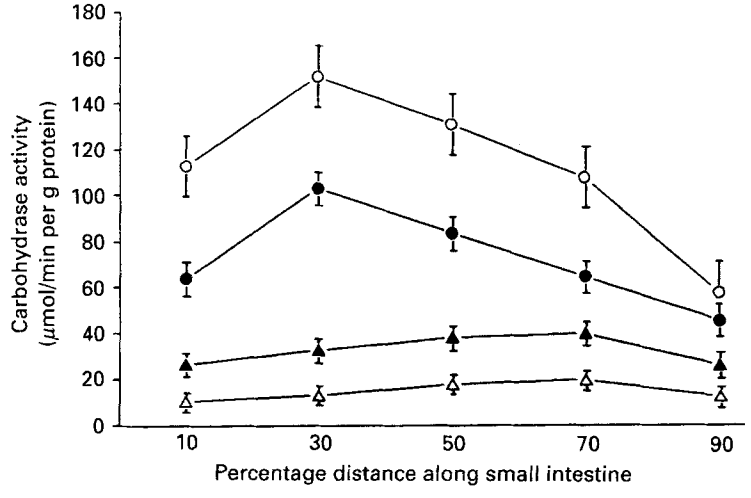

Fig. 2. Distribution of carbohydrase activity (per g protein) along the small intestine in pigs from 14 to 22 d of age. (○), Lactase (*EC* 3.2.1.23); (●), sucrase (*EC* 3.2.1.48); (△), maltase (*EC* 3.2.1.20); (▲), total glucoamylase (*EC* 3.2.1.3). For details of procedures, see p. 171. Values are means with their standard errors represented by vertical bars.

Although none of the treatment effects was statistically significant there appeared to be a decline in lactase activity in the weaned pigs (Table 3). The values for 7W pigs were only 45, 33 and 42% respectively of those for their unweaned 21SR counterparts when compared on the three bases of expression.

Sucrase activity was significantly higher in weaned pigs and in 22SR compared with 14SR pigs. The values for the three weaned groups were not significantly different but activity (per g mucosa or total) was significantly lower ($P < 0.05$) compared with 22SR pigs. The 7W mean was also significantly lower than the 21SR value.

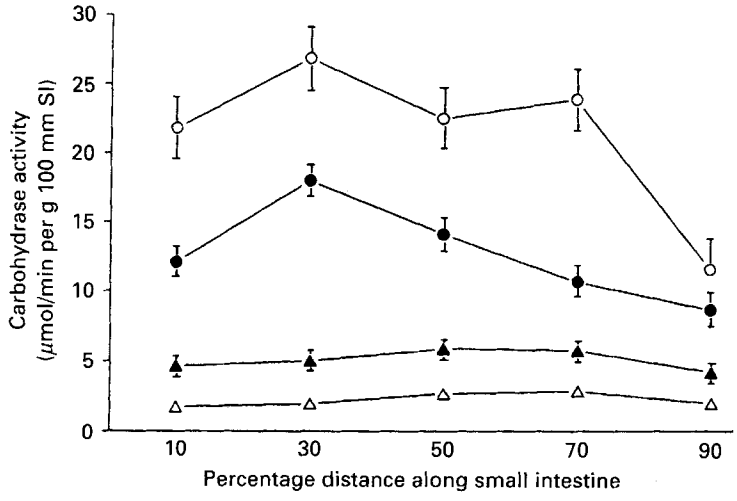

Fig. 3. Distribution of carbohydrase activity (per 100 mm length) along the small intestine (SI) in pigs from 14 to 22 d of age. (○), Lactase (*EC* 3.2.1.23); (●), sucrase (*EC* 3.2.1.48); (△), maltase (*EC* 3.2.1.20); 9▲), total glucoamylase (*EC* 3.2.1.3). For details of procedures, see p. 171. Values are means with their standard errors represented by vertical bars.

Maltase activity increased in sow-reared animals from 14 d to 22 d. This effect was significant ($P < 0.05$) for total activity. Enzyme induction occurred in all weaned groups. By 3 d post-weaning substantial increases ($P < 0.05$) in activity per g protein and per g mucosa were observed. Total maltase activity almost doubled from 3 to 7 d post-weaning, although negligible changes occurred in the activity per g protein and per g mucosa. The value for total maltase activity in 7W pigs was significantly higher than the 22SR or 21SR values.

Total glucoamylase activity was higher in sow-reared pigs at 22 d of age than at 14 d and significantly higher in weaned pigs. Although differences in weaned groups (expressed per g protein, per g mucosa) were not statistically significant, activity at 5 d and 7 d post-weaning tended to be higher than at 3 d. Total activity steadily increased during the post-weaning period and the activity of 7W pigs was double ($P < 0.01$) that of 3W. The total activity in this group was also significantly higher ($P < 0.05$) than that in 22SR pigs and significantly different from the 21SR value.

Villous height was not significantly different at the three sites examined but was consistently higher ($P < 0.001$) in sow-reared compared with weaned pigs (Table 4). There were no significant differences between the three weaned groups. There was a significant ($P < 0.05$) decrease in crypt depth from site 1 to site 5 (Table 5). Crypt depth (μm) was similar in sow-reared pigs at 14 and 22 d of age but tended to be increased in the weaned groups at all sites and the effect was significant ($P < 0.05$) in the 7W group. As a consequence of the changes in villous and crypt measurements the villous:crypt ratio was significantly lower ($P < 0.001$) in weaned pigs compared with sow-reared animals, the values being 7·69, 3·47, 2·92, 2·44 and 6·62 (SEM 0·51) respectively.

DISCUSSION

The use of gastric intubation, although very labour-intensive, proved effective as a means of obtaining controlled feed intakes throughout the 7 d period. The changes in organ

Table 3. *Lactase* (EC *3.2.1.23*), *sucrase* (EC *3.2.1.48*), *maltase* (EC *3.2.1.20*) *and glucoamylase* (EC *3.2.1.3*) *activity of sow-reared* (*SR*) *pigs* (*14 and 22 d and calculated 21 d values*) *and weaned* (*W*) *pigs* (*3, 5, and 7 d post-weaning*)

(Mean of five sites of the small intestine expressed on three bases (per g protein, per g mucosa, total activity); mean values for four pigs; 15 df)

	SR	W			SR			Statistical significance:
	14 d	3 d	5 d	7 d	22 d	21 d*	SEM	$P =$
Lactase activity								
μmol/min per g protein	113·6	132·6	109·5	66·4	150·4	145·8	24·12	0·202
μmol/min per g mucosa	18·7	15·4	12·8	6·9	21·8	21·2	3·49	0·071
mol/d	2·29	1·41	1·14	0·91	2·13	2·15	0·443	0·166
Sucrase activity								
μmol/min per g protein	24·8[a]	78·2[b]	96·2[b]	72·0[b]	100·8[b]	91·0	15·39	0·024
μmol/min per g mucosa	4·5[a]	9·0[a]	10·8[b]	7·4[a]	14·9[b]	13·6†	1·72	0·009
mol/d	0·52[a]	0·81[a]	0·98[a]	0·94[a]	1·88[b]	1·71	0·202	0·003
Maltase activity								
μmol/min per g protein	3·1[a]	18·6[b]	24·9[b]	22·2[b]	7·0[a]	6·5†	3·80	0·003
μmol/min per g mucosa	0·54[a]	2·11[bc]	2·65[b]	2·28[c]	0·94[ab]	0·89†	0·43	0·015
mol/d	0·03[a]	0·15[b]	0·24[c]	0·29[c]	0·14[b]	0·13†	0·028	< 0·001
Glucoamylase activity								
μmol/min per g protein	4·5[a]	36·1[bc]	52·4[c]	48·8[c]	22·9[ab]	20·6†	8·52	0·007
μmol/min per g mucosa	0·84[a]	4·08[b]	5·55[b]	5·00[b]	3·17[ab]	2·88	0·99	0·033
mol/d	0·05[a]	0·36[b]	0·55[bc]	0·71[c]	0·49[b]	0·43†	0·074	< 0·001

[a,b,c] Means with different superscript letters were significantly different ($P < 0·05$).
* 21 d values by linear interpolation from 14SR and 22SR values.
† Mean values for 21SR pigs were significantly different from those for 7W pigs ($P < 0·05$).

weights were similar to those in earlier reports (Efird *et al.* 1982*a*, *b*; Hampson, 1983; McCracken, 1984; Cranwell, 1985). However, as a consequence of the observed weight difference between the 7W and 22SR or adjusted 21SR groups, it is difficult to discern the extent to which the observed changes in absolute organ weight reflect age-related development or the process of weaning. For example, hypertrophy of the pancreas has frequently been reported in weaned animals even with milk-based diets (Efird *et al.* 1982*a*) but in the present study the absolute pancreas weight was similar in 7W and 22SR/21SR pigs whereas significant hypertrophy appears to have occurred in all three weaned groups when pancreas weight is expressed relative to body-weight.

The changes in SI weight, SI mucosa weight and SI supernatant-fraction protein are of interest in relation to their chronological development and also to other studies where the pattern of food intake was not controlled. Whereas the total SI weights in 14SR and 22SR pigs were similar to those observed by McCracken (1984), SI mucosa weight and protein content per g mucosa tended to be higher. The similarity of SI weight and SI mucosa weight in 7W and 22SR pigs agrees with the results of McCracken (1984) but contrasts with the results of Hampson (1983). The difference is probably due to the relatively high feed intakes

Table 4. *Villous height (μm) at sites 1, 3 and 5 of the small intestine of sow-reared (SR) pigs (14 d, 22 d and calculated 21 d values) and of weaned (W) pigs (3, 5 and 7 d post-weaning)*

Site	SR	W			SR		Mean
	14 d	3 d	5 d	7 d	22 d	21 d*	
1	787^{bc}	631^{ab}	401^{a}	516^{a}	958^{c}	921†	659
3	1065^{b}	533^{a}	488^{a}	440^{a}	937^{b}	968†	693
5	953^{b}	431^{a}	382^{a}	419^{a}	866^{b}	885†	618
Mean	948^{b}	532^{a}	424^{a}	459^{a}	924^{b}		

Statistical significance:

	$P =$	SEM	df
Treatment	< 0·001	58·0	15
Site	0·194	28·2	29
Treatment × site	0·081	77·6	29

^{a,b,c} Treatment means with different superscript letters were significantly different ($P < 0·05$).
* 21 d values by linear interpolation from 14SR and 22SR values.
† Mean values for 21SR pigs were significantly different from those for 7W pigs ($P < 0·05$).

Table 5. *Crypt depth (μm) at sites 1, 3 and 5 of the small intestine of sow-reared (SR) pigs (14 d, 22 d and calculated 21 d values) and of weaned (W) pigs (3, 5 and 7 d post-weaning)*

Site	SR	W			SR		Mean
	14 d	3 d	5 d	7 d	22 d	21 d*	
1	153^{a}	163^{ab}	186^{ab}	209^{b}	156^{ab}	156	174
3	136^{a}	143^{ab}	148^{ab}	197^{b}	152^{ab}	150	155
5	102^{a}	183^{b}	145^{ab}	177^{b}	118^{a}	116†	145‡
Mean	130^{a}	163^{ab}	160^{ab}	195^{b}	142^{a}		

Statistical significance:

	$P =$	SEM	df
Treatment	0·043	13·6	15
Site	0·015	6·6	29
Treatment × site	0·223	18·13	29

^{a,b} Treatment means with different superscript letters were significantly different ($P < 0·05$).
* 21 d values by linear interpolation from 14SR and 22SR values.
† Mean values for 21SR pigs were significantly different from those for 7W pigs ($P < 0·05$).
‡ Site 5 mean significantly different from site 1 ($P < 0·05$).

in both studies from this laboratory since Kelly *et al.* (1984) demonstrated a marked effect of nutrient intake on the weights at 3 d post-weaning.

The marked reduction (approximately 25%) in the protein content of the mucosa is consistent with previous observations (Hampson, 1983; McCracken, 1984; Kelly *et al.* 1984) and these results confirm that this effect occurs within the first 3 d post-weaning.

Measurements of villous height at individual sites in similar regions of the SI are in agreement with those of Hampson (1983) for both 21-d-old unweaned and weaned animals.

Clearly the reductions in villous height occurred within the first 3 d post-weaning and were not prevented by the relatively high supply of nutrients to the gut. The marked crypt hypertrophy observed in 7 d weaned animals but not in sow-reared pigs is similar to the results of Hornich *et al.* (1973) and of Smith (1983). It is concluded that the histological changes were associated with weaning and occur irrespective of whether nutrients are present throughout the initial weaning period. However, the magnitude of these changes may also be related to nutrient levels and will be further investigated.

In view of the marked decrease in villous length it is noteworthy that weaned pigs did not show the reduction in specific lactase activity at 3 or 5 d post-weaning described by Gay *et al.* (1976) and Hampson (1983). However, at 7 d post-weaning lactase activity was less than half the value for the 22SR group and this coincided with a statistically significant degree of crypt hypertrophy. Tsuboi *et al.* (1981) suggested that increased crypt cell production rate (CCPR) may be responsible for the decline in lactase activity which occurs during the post-weaning period. Although measurements of CCPR were not made in the present study, the increased crypt depth observed in the 7 d group indicates that CCPR had increased. The delay in loss of specific lactase activity may be partly attributable to the continuous supply of nutrients to the gut. Conversely, it may be related to the absence of crypt elongation before 7 d post-weaning as a consequence of the clean environment in which the animals were housed (Miller *et al.* 1986). Whatever the reason, it is axiomatic that factors which alter enterocyte kinetics or gut morphology must be considered when assessing the influence of weaning and nutrition on digestive enzyme activity.

The increase in specific sucrase activity in all weaned groups compared with 14SR animals again contrasts with the results of Gay *et al.* (1976) and Hampson (1983), although the level of sucrase activity (per g protein) observed in the 22SR pigs is in very good agreement with the results of Hampson (1983). It is probably relevant that the diet in the present study contained 50 g sucrose/kg. The increase in crypt depth in the 7 d weaned group, and increased CCPR, would also explain the drop in specific sucrase activity. That the effect was less marked than for lactase activity is not surprising since maximum expression of lactase occurs more apically on the villus than for sucrase (Nordstrom & Dalqvist, 1973).

The dramatic increases in maltase and glucoamylase, even by 3 d post-weaning, extend the observations of McCracken (1984) and provide unequivocal evidence of rapid substrate induction of these brush-border enzymes, superimposed on the age-related increase, despite the changes in mucosal architecture discussed previously. This aspect of digestive enzyme development has been largely ignored in other studies but is of both physiological and practical interest, in view of the fact that weaner diets contain substantial quantities of cereal carbohydrate but much lower levels of lactose than sow's milk. It seems probable that the levels of these two enzymes may be more relevant in limiting absorption of a weaner diet than either lactase or sucrase.

Reference has been made earlier to the debate about the relevance of different bases of expression of enzyme activity. Obviously all methods are limited by measurement at a limited number of specific sites and problems of site variation cannot be ignored. However, the results shown in Figs. 1–3 indicate that, overall, the activities along the SI change in a characteristic manner and that the differences between values at individual sites were not large. It is therefore concluded that the results as presented give a meaningful picture of the effects of treatments on enzyme activity. However, the results in Table 3 indicate that interpretation of the post-weaning changes would have differed had only specific activity been considered. For example, sucrase specific activity was not significantly different for all weaned groups and 22SR pigs whereas total activity was significantly higher for the 22SR pigs. With maltase and glucoamylase, consideration of specific activity would indicate no

change from 3W to 7W pigs whereas total activity doubled, these differences being due to different weights of mucosa recovered. These results, therefore, support the view of Shields *et al.* (1980) and Widdowson (1984) that measurements of specific activity alone are likely to be a poor indicator of digestive capacity.

In conclusion, the results of the present study suggest that there may be some degree of interaction between nutrient level and gut development during the immediate post-weaning period but that there is also a component of the adaptive response which is independent of nutrient intake. They confirm the rapid substrate induction of the brush-border glucoamylases with diets based on cereals and indicate the importance of considering total as well as specific enzyme activity for satisfactory interpretation of changes in digestive function.

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