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Changes in the chemical composition of sow-reared piglets during the 1st month of life

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Lawes & Gilbert (1858) recognized over a century ago that proper nutrition of the growing animal requires an understanding of the chemical composition of live-weight gain. They presented very detailed results of chemical analyses of ten farm animals—three cattle, five sheep and two pigs. Unfortunately, the cattle were not all of one breed, and the sheep were not a strictly comparable series. The two pigs slaughtered, however, were litter-mates, killed at different stages during fattening, and Lawes & Gilbert pointed out that using the values for these two animals was 'likely to lead to a pretty trustworthy estimate of the composition of the increase of this particular fattening pig'. Since they also recorded and analysed the food intake of the second pig they were able to calculate the net efficiency of conversion of food nutrients into body tissue, and, for example, were able to show that the fat laid down in the body of the second pig was greatly in excess of that in the food consumed, confirming that fat must have been synthesized from other food components. This classic experiment pointed the way for further work on similar lines. However, in the century that has passed remarkably little work of this type on pigs has been published. There have been considerable advances in analytical techniques, such as the acid hydrolysis method of Venn, McCance & Widdowson (1947) suitable for trace-element studies, and the method of Williams, Curtin, Abraham, Loosli & Maynard (1954) for amino acid studies, so it is possible that more use will be made of chemical analysis of carcasses in the future. Indirect estimation of changes in carcass composition by balance experiments has received much attention and has given a large amount of valuable information. The fact remains that the proof of the indirect method lies in the direct approach, and in recent instances when such proof has been sought there have been disturbing inconsistencies. Nehring, Laube, Schwerdtfeger, Schiemann, Haesler & Hoffmann (1957), studying nitrogen retention, were only able to find, in the live-weight increase of pigs, 84% of the nitrogen which the balance experiment on the same animals had indicated to be laid down as body protein. Larger discrepancies were observed in similar experiments with rats. Errors in balance experiments are unlikely to be discovered unless they are checked by direct means, and it is alarming to consider the lack of such checks in the work of the past century.

There have been only a few investigations of changes in chemical composition of piglets during the first few weeks of life. Newlander & Jones (1935) gave figures for the dry-matter, ash, protein and fat content of sixteen 2-day-old piglets and eighty

3- to 4-week-old artificially reared piglets. They also quoted data of Washburn & Jones (1916) for the composition of twenty-four 4- to 5-week-old sow-reared piglets. Three other studies of composition of sow-reared piglets are especially pertinent to the work now presented. Venn *et al.* (1947) studied iron content and iron retention of piglets. Berge & Indrebø (1954), using the Norwegian Landrace breed, slaughtered four live-born piglets at birth and three at each of 1, 2, 3 and 4 weeks of age, as well as two at 6 weeks, three at 8 weeks and one at 10 weeks of age. They did not remove the contents of the gut and did not give details of chemical methods, but values were presented for dry matter, ash, crude fat, crude protein, sugar, N-free extract, calcium and phosphorus in numerical as well as in graphical form. They gave no indication of variability observed in composition at a given age. Spray & Widdowson (1950) provided the only other comprehensive data on the chemical composition of very young piglets. Of particular interest in connexion with our study are their results for sixteen newborn, ten 3-week-old and four 8-week-old piglets of Wessex × Large White or Wessex × Wessex–Large White breeding. They used the technique, which we also adopted, of acid hydrolysis, and measured the trace-element content of the piglets as well as their content of the major chemical components. Their data were largely in graphical form. For six out of the ten piglets slaughtered at 3 weeks of age individual figures for chemical composition were given; otherwise variability in composition at a given age was not shown. Our intention was to establish the pattern of normal chemical development up to 4 weeks of age in a piglet receiving only its dam's milk together with an oral iron supplement. Our methods, or reference to them, are given fully to facilitate further work in this field and to define precisely the precautions taken.

EXPERIMENTAL

Animals

Three litters of Large White × Wessex piglets were used. They were specially chosen for their uniformity in size at birth. Litter-mates were killed at birth and at 2, 7, 14 and 28 days of age. Anti-anaemia paste (500 mg reduced iron per dose; Boots Pure Drug Co. Ltd) was given to the surviving piglets at 2, 7 and 14 days of age. Creep feeding was not practised and piglets had no opportunity to eat the sow's food. The animals were kept in wooden-floored huts with concrete runs. The huts were littered with straw and the runs were cleaned out daily. No precautions were taken to prevent the piglets from eating straw or other debris. The sows were given 6 lb of proprietary sow-and-weaner nuts per day during the last third of gestation. During the week after farrowing the intake was raised gradually so that by the 7th day the sows were getting 2 lb of nuts plus 1 lb for each piglet in the litter. This level of feeding was maintained throughout the suckling period. A sample of the sow's food was analysed.

Analytical procedure

General

All glassware used in the experiment was cleaned with chromic acid cleaning mixture, and then was rinsed thoroughly with de-ionized water. The stainless steel balance pans and dissecting instruments, and the Polythene and polypropylene ware

were washed with detergent solution and thoroughly rinsed with de-ionized water before use. De-ionized water was used in the preparation and dilution of all solutions. AR grade reagents were always used.

The preparation of the piglets for chemical analysis took place in seven stages: (1) anaesthesia, (2) external washing, (3) bleeding, (4) dissection to remove the gut and bladder in order to empty them and wash out all traces of their contents, (5) acid hydrolysis, (6) siphoning off the bulk of the fat, (7) sampling of the hydrolysate. The hydrolysis was carried out in a wide-necked reaction flask fitted with a stirrer and condenser. A 5 l. flask was used for pigs up to 1 week of age. Beyond this stage a 20 l. flask was used.

Preparation of the piglet for hydrolysis

The piglet was anaesthetized by intraperitoneal injection of a solution containing 0·194 g of pentobarbitone sodium/ml at the rate of 0·75 ml/kg live weight. Urine was expressed manually from females to avoid the risk of leakage on to the dissection tray. The animals were then carefully washed with warm tap water, the mouth and feet receiving special attention. When clean, they were rinsed with de-ionized water, dried with filter-paper and weighed. The anaesthetized piglet was next held over the hydrolysis flask and the jugular veins were severed. Removal of much of the blood simplified the subsequent dissection. The piglet was then placed in a shallow polypropylene tray which sloped towards the operator. The slope ensured that blood collected at the bottom of the tray from whence it could be rinsed with the minimum of water into the hydrolysis flask. For the removal of the gut the limbs of the piglet were tied with nylon cord to hooks outside the tray and the abdomen and thorax were opened in the mid-line. The weights of the gut contents and of bladder contents were calculated by weighing before and after emptying the respective organs. The gut was washed very carefully with tap water after emptying, and was then rinsed thoroughly with de-ionized water and dried on filter-paper before re-weighing. The carcass and intestinal tract were transferred to the hydrolysis flask. Blood on the operator's hands, on the instruments, and in the dissection tray was carefully rinsed into the flask with de-ionized water.

We based our method of acid hydrolysis of the piglets on that of Venn *et al.* (1947). Hydrochloric acid (sp. gr. 1·18) was added to the flask at the rate of 1 ml/6 g piglet. The contents of the flask were heated to 95° and kept at this temperature for 2 days with newborn and 2-day-old piglets, and for 3 days with older animals. The extra day was needed with older piglets because a small amount of tissue remained at the junction between the fat layer and the acid solution and did not become hydrolysed until the bulk of the fat was removed on the 2nd day. After 6–12 h heating the contents of the flask were sufficiently softened to permit the operation of a glass stirrer. The contents were stirred gently throughout the rest of the hydrolysis. A 'blank' hydrolysis was carried out and the resulting solution was analysed for the various minerals in the same way as with the piglets. Results were corrected for any readings given by this solution.

Sampling

The hydrolysate was weighed. It was then poured through a glass separator (see Fig. 1) to collect a representative sample for the chemical work. By suitable choice of outlet a sample of about 500 ml was obtained, and was stored in a tightly stoppered flask. To assess the reliability of the sampling technique portions of the hydrolysate from two different spouts of the glass separator were collected from four of the piglets, in the first litter studied. While the sample was still hot, portions were taken for determination of fat, protein, ash and phosphorus. After the flask had been shaken

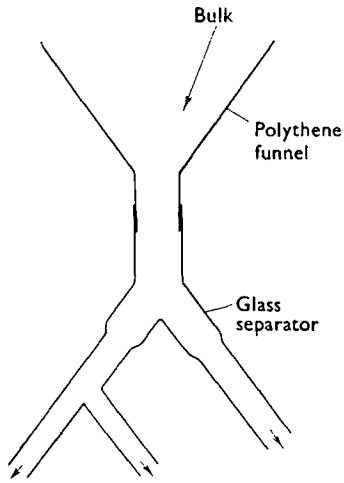

Fig. 1. Arrangement used for collecting a sample of the hydrolysate.

vigorously, wide-mouthed pipettes (with safety bulbs) were used to measure the portions which were weighed immediately to the nearest mg on a well-damped balance. Speed was essential in the sampling operation as evaporation was taking place.

Chemical methods

Fat. Stage 1. After 48 h of hydrolysis most of the clear layer of fat floating on top of the hydrolysate was siphoned off into a weighed beaker, dried in an oven at 100° overnight and weighed. A further portion of fat was removed by allowing the hydrolysate to cool somewhat and then adding light petroleum (b.p. 40–60°), stirring, and siphoning off into a weighed beaker. A volume of light petroleum equal to the volume of fat siphoned off was used. This procedure was repeated once. The light petroleum was evaporated off and the fat was weighed. Newborn and 2-day-old piglets contained little fat and stage 1 was not necessary for them.

Stage 2. The fat remaining in the hydrolysate was determined by the method of von Lieberman & Szekely (1898) used by McCance & Shipp (1933). Because of the large amount of hydrochloric acid in the hydrolysate we raised the amount of 50% (w/v) sodium hydroxide solution used to 18 ml.

Protein ($N \times 6{\cdot}25$). N was determined by macro-Kjeldahl analysis.

Ash. Samples of hydrolysate (40 ml) were evaporated to dryness and then ashed in silica basins at 450° for 6 h in an electric furnace. The grey-coloured ash was cooled and weighed. The remaining carbon was oxidized by thoroughly moistening the ash with nitric acid (sp. gr. 1·42) and then heating for a further 4 h at 450°. This treatment produced a white ash.

Water. The water content was estimated by subtracting the percentage of protein and ash in the fat-free body tissue from 100.

Dissolving of the ash. (*a*) For the determination of manganese. A basin containing ash was placed over a water-bath and 2 ml nitric acid (sp. gr. 1·42) were added per g ash. The ash was then stirred with a glass rod and with the addition of a small amount of water it appeared to dissolve completely.

(*b*) For the determination of calcium, magnesium, potassium, sodium, iron, zinc and copper. A basin containing ash was placed over a water-bath and hydrochloric acid (sp. gr. 1·18) was added at the rate of 2 ml/g ash. The contents were stirred with a glass rod and diluted slightly with water, and an apparently clear solution was obtained. This solution was transferred to a beaker, boiled gently for 30 min, and then filtered through Whatman no. 40 paper.

Determination of minerals in the ash. P was measured by the method of Hanson (1950) after wet digestion of a sample of the hydrolysate (Spray & Widdowson, 1950). Ca was measured by the method of Clark & Collip (1925), Mg by the method of Bradfield (1961). For the estimation of Na and K an EEL (Evans Electroselenium Ltd) flame photometer operated with butane gas was used. The mutual interference between Na and K was obliterated by raising to saturation point (100 p.p.m.) the level of the alkali metal not being estimated in both unknown and standard solutions. The effects of Ca and P on Na and K readings were compensated for by adding the same amount of Ca and P to the standard solutions as had been found to be present in the unknown solutions. A correction was made for the small amount of Na contributed by the anaesthetic. Fe was measured by the thioglycollic acid method used by McCance, Widdowson & Shackleton (1936), Zn by the method of Holmes (1945), and Cu by an adaptation of the method of Martens & Githens (1952) using Zn dibenzyldithiocarbamate. For measurement of Mn the nitric acid solution of ash was transferred to a 250 ml conical flask and an adaptation of the periodate method of Nicholas (1949) was used.

RESULTS

Variability

Very little material remained undigested by the acid hydrolysis. Although small particles did remain it was found that very satisfactory agreement between results was obtained when samples from different spouts of the sampling device were analysed separately. Table 1 shows the results of such a comparison. Of the major components fat showed the greatest variability between samples.

The variability between litter-mates within ages was not measured since only one piglet from each litter was slaughtered at each age. For calculation of the composition

of the weight increase between slaughter ages it was assumed that each piglet slaughtered was representative of its litter-mates in chemical composition. Variability between litters is shown by Figs. 2, 4, 6, 8, 10, 12 and 14 in which the proportions of each chemical component in each piglet at each age are given. The percentages of fat, protein, ash and major mineral constituents showed a good agreement between litters,

Table 1. *Agreement between results obtained from the analysis of separate samples of hydrolysate (from different spouts of the sampling device shown in Fig. 1) in one of the three litters*

Age of piglet (days)	Fat (g/100 g hydrolysate)	Protein	Ash	Calcium	Phosphorus	Magnesium	Sodium	Potassium	Iron (p.p.m. fat-free body tissue)
		(g/100 g fat-free body tissue)							
2	1·84	13·9	3·89	1·08	0·639	0·0278	0·186	0·238	34·9
	1·68	13·8	3·88	1·08	0·630	0·0281	0·182	0·242	33·4
7	1·64	16·3	3·44	0·906	0·590	0·0304	0·158	0·267	35·7
	1·49	16·1	3·43	0·903	0·593	0·0302	0·154	0·265	32·9
14	1·63	17·2	3·57	0·912	0·614	0·0341	0·161	0·283	22·4
	1·66	17·2	3·58	0·935	0·618	0·0344	0·158	0·281	25·6
28	2·48	18·0	4·32	1·16	0·743	0·0419	0·162	0·269	23·9
	2·31	18·1	4·36	1·18	0·744	0·0419	0·164	0·276	21·7

Table 2. *Details of the weight and sex of the piglets together with the mean weights of chemical components in their bodies at the five ages at slaughter*

Age at slaughter (days) ...	0	2	7	14	28
No. of animals used ...	3	3	3	3	3
Sex ...	2♀, 1♂	3♀	1♀, 2♂	2♀, 1♂	3♂
Live weight (g)	1520	1815	3221	5563	9928
Empty live weight (g)	1450	1741	3044	5284	9651
Empty live weight as % of live weight	95·2	95·2	94·5	95·0	97·2
Fat-free body tissue (g)	1432	1701	2738	4487	7888
Fat (g)	18	40	306	796	1763
Water (g)	1198	1398	2207	3557	6138
Protein (g)	174	237	437	770	1427
Ash (g)	60·4	66·8	94·1	160·8	323·9
Calcium (g)	16·7	17·9	24·1	41·7	87·6
Phosphorus (g)	9·3	10·8	16·3	28·1	56·3
Potassium (g)	2·8	3·8	6·8	11·5	19·9
Sodium (g)	2·8	3·1	4·3	6·9	12·3
Magnesium (g)	0·42	0·48	0·83	1·53	3·01
Iron (mg)	54	49	77	118	153
Zinc (mg)	26	33	60	114	236
Copper (mg)	3·9	5·4	10·9	18·6	23·2
Manganese (mg)	0·69	0·75	0·70	0·98	1·94

which might be taken to indicate that between-piglet, within-litter differences at a given age were small. Proportions of trace elements were more variable, but fairly consistent trends were still shown. The figures showing mean proportions of chemical components in the mean weight increase between slaughter ages (Figs. 3, 5, 7, 9, 11, 13 and 15) are placed next to the appropriate graphs showing variability in concentra-

tion of the same components in the individual piglets at successive ages, to allow assessment of the variability of the values, and thus the reliability of the calculated storage.

Weight gain and body composition

The sex of the animals slaughtered, their mean weights and the mean weights of chemical components in their bodies are given in Table 2.

Gain in weight. Fig. 2 shows the weights at which the individual piglets from the three litters were slaughtered. Table 2 gives the mean of these weights and, in addition, the mean empty live weight and mean weight of fat-free body tissue of the piglets

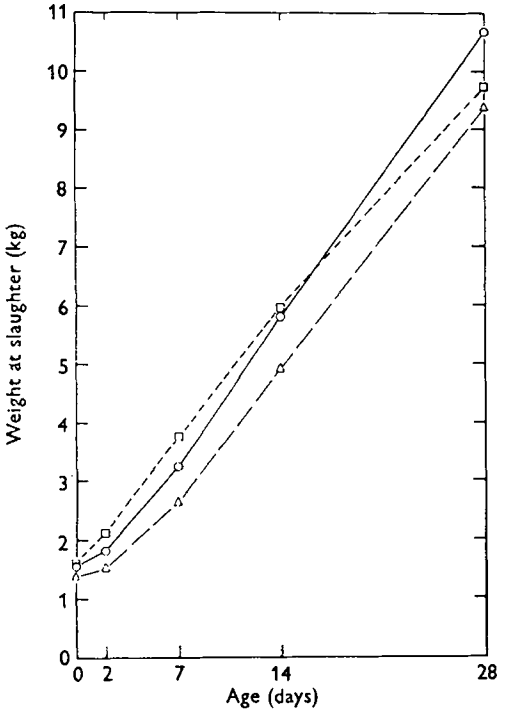

Fig. 2

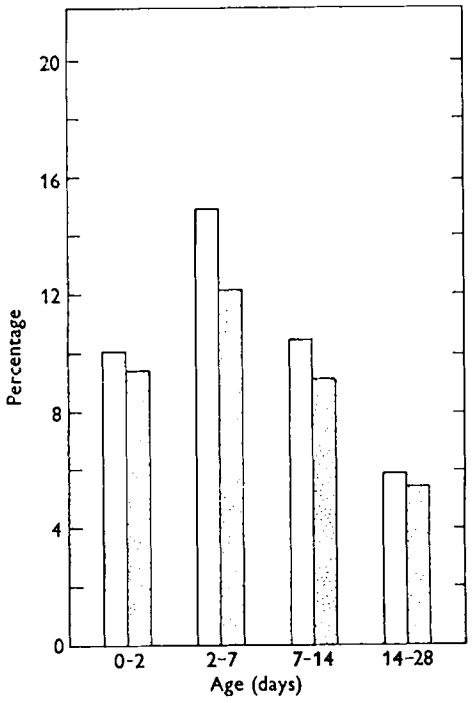

Fig. 3

Fig. 2. Live weights at which the piglets were killed. Individual values for three litters (○, △, □) of piglets.

Fig. 3. Relative rates of gain in weight over four successive periods during the 1st month of life of the piglets. □, daily increase in empty live weight as percentage of empty live weight at the beginning of the period; ▦, daily increase in fat-free body tissue as percentage of fat-free body tissue at the beginning of the period.

killed at the five different ages. The mean empty live weight and mean weight of fat-free body tissue of the piglets slaughtered at 28 days of age were 6·6 times and 5·5 times respectively those of the piglets killed at birth. Thus the period studied, although short, was one in which body tissue increased very rapidly. The relative rates of gain during the periods between slaughter ages may be of interest because they help to explain some of the differences in storage of individual body components in the different

periods. Fig. 3 shows the daily gain in weight between one slaughter age and the next as a percentage of weight at the previous slaughter age, and it can be seen that the greatest relative gain was between 2 and 7 days of age. The rate of gain in weight fell successively in the two subsequent periods.

Fat. Of the components measured, the proportion of fat in the body showed the greatest change between birth and 4 weeks of age (Fig. 4). The percentage fat in the body at 2 days was twice that at birth, and at 1 week the percentage was eight times that at birth. The mean back-fat thickness at 0, 2 and 7 days of age was 3·3, 4·9 and

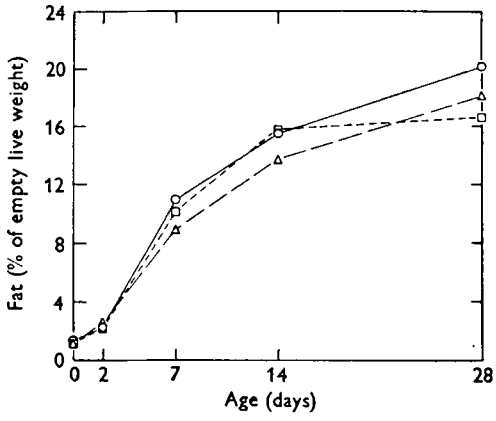

Fig. 4

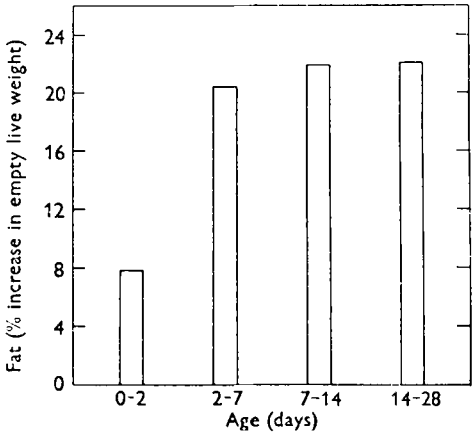

Fig. 5

Fig. 4. Variation with age in the proportion of fat in empty live weight. Individual results for three litters (○, △, □) of piglets.

Fig. 5. Increments of fat as percentage increase in empty live weight of the piglets over four successive periods during the 1st month of life.

8·0 mm respectively at the shoulder and 1·7, 2·0 and 6·0 mm at the loin. If the fat storage is calculated as a percentage of increase in empty live weight it can be seen from Fig. 5 that after 2 days of age fat formed a fairly constant proportion of the increase in body tissue.

The amounts of the components other than fat are given in Figs. 6–15 as proportions of fat-free body tissue. Presentation in this form eliminates the confusing effect of changes in body fat content.

Protein, ash and water. Values for the concentrations of these components in fat-free body tissue are given in Fig. 6. Increments as proportions of increase in fat-free body tissue are given in Fig. 7. There was a rise in protein concentration in the fat-free body tissue throughout the first 4 weeks of life. From Fig. 6 it appears that the rise in the 1st week was greater than that subsequently. However, when the increments of protein are plotted as percentages of the increase in fat-free body tissue, as in Fig. 7, it is apparent that, apart from the relatively higher rate of protein storage during the first 2 days of life, protein formed a constant proportion of the increase in fat-free body tissue. The concentration of ash in fat-free body tissue fell from birth to 7 days

of age and then rose again, so that at 28 days of age it had almost reached the level present at birth. Increments of ash as percentage of increases in fat-free body tissue rose throughout the period studied. It is evident that the rate of accumulation before 7 days was insufficient to maintain body levels, but that accretion of ash after 7 days was fast enough to restore them gradually. The figures for percentage of water were only approximate, being arrived at by subtraction of values for protein and ash from that for fat-free body tissue. Any carbohydrate in the body was included as water in these circumstances. The fall in percentage of water throughout the first 4 weeks of

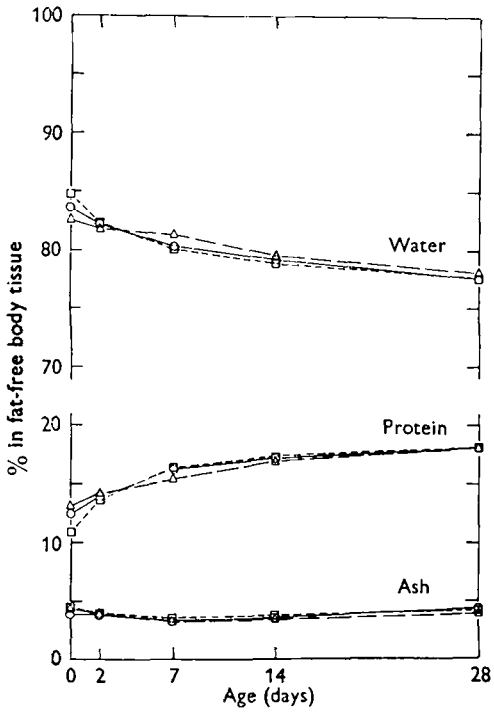

Fig. 6

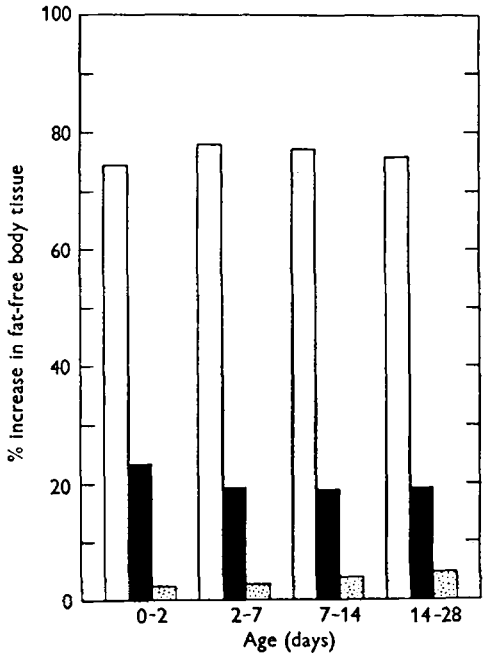

Fig. 7

Fig. 6. Variation with age in concentrations of water, protein and ash in fat-free body tissue. Individual results for three litters (○, △, □) of piglets.

Fig. 7. Increments of water (□), protein (■), and ash (▦) as percentage increase in fat-free body tissue of the piglets over four successive periods during the 1st month of life.

life showed that tissues laid down after birth contained less water than those in the newborn animal. The tissues laid down in the first 2 days contained least water, and those in the following 5 days most water. Thus in the period of greatest relative gain the tissues laid down were lowest in dry matter.

Hydrochloric acid solutions of ash. The ash appeared to dissolve completely in hydrochloric acid, but in fact a slight residue remained undissolved, which was not detectable by looking at the solutions. However, on ashing the filter-papers used with the batch of samples from one litter, the residue was found to amount to 0·14% of the weight of ash and to consist largely of calcium phosphate.

Ca and P. Fig. 8 shows the proportions of these two elements in the fat-free body tissue, and Fig. 9 the proportions in the increase in fat-free body tissue between slaughter ages. The concentration of Ca in fat-free body tissue fell up to the 7th day of life, and rose thereafter, whereas the proportion in the increase in fat-free body tissue between slaughter ages rose steadily. The behaviour of this mineral was largely responsible for the fluctuations observed in ash content. P concentration in the fat-free body tissue did not vary as much as that of Ca, although the lowest concentration was again at 7 days of age. As a proportion of the increase in fat-free body tissue between slaughter ages the value for P remained steady during the 0–2- and 2–7-day periods, and then rose successively during the next two periods.

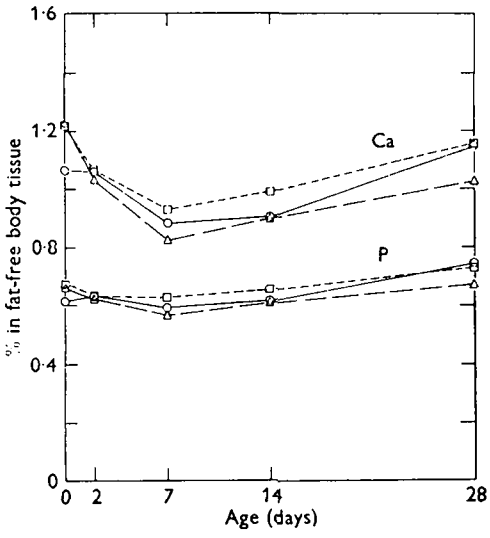

Fig. 8

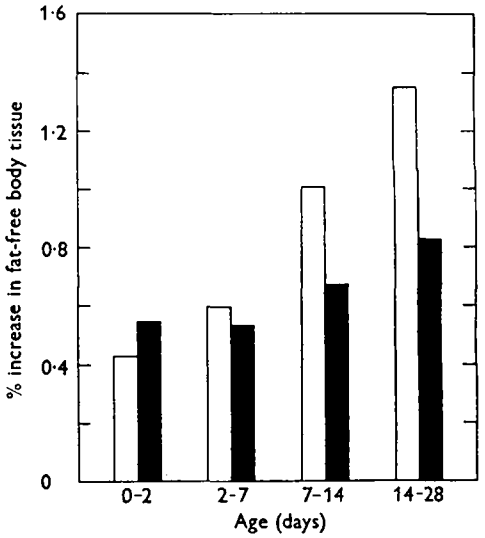

Fig. 9

Fig. 8. Variation with age in concentrations of calcium and phosphorus in fat-free body tissue. Individual results for three litters (○, △, □) of piglets.

Fig. 9. Increments of calcium (□) and phosphorus (■) as percentage increase in fat-free body tissue of the piglets over four successive periods during the 1st month of life.

K, Na and Mg. The concentration of these elements in the fat-free body tissue is shown in Fig. 10. Their concentration in the increase in fat-free body tissue during the four periods studied is shown in Fig. 11. In the newborn piglets the concentrations of K and Na were approximately equal, but during the first 7 days of life they showed marked complementary changes in concentration and at 7 days the ratio of K to Na was 5:3. Little change from this ratio occurred subsequently in the proportions in the fat-free body tissue. However, the relative amounts of the two metals laid down continued to change throughout the four periods. Between birth and 2 days of age the concentration of Mg in fat-free body tissue fell slightly. After 2 days it rose steadily. Levels in the increase in fat-free body tissue after 2 days of age were in excess of the levels found in the fat-free body tissue of the newborn piglet.

Fe, Zn and Cu. The values for the concentrations in the fat-free body tissue are shown in Fig. 12 and changes in concentration as proportions of the increase in fat-free body tissue in Fig. 13. The concentration of Fe in fat-free body tissue was rather variable at each of the ages studied. The mean Fe level in the fat-free body tissue of the three piglets killed at 2 days of age was only 76% of that in the three newborn piglets killed. From 2 days onwards the concentration continued to fall, although much more slowly. When the proportions of Fe in the increase in fat-free body tissue were calculated, there appeared to have been a loss of Fe from the body between birth and 2 days. It is possible that this effect was due to the selection, by chance, of three 2-day-old piglets of lower initial Fe content than the three newborn piglets that were slaughtered. If it was not so, then the values indicate a loss of Fe during the first 2 days

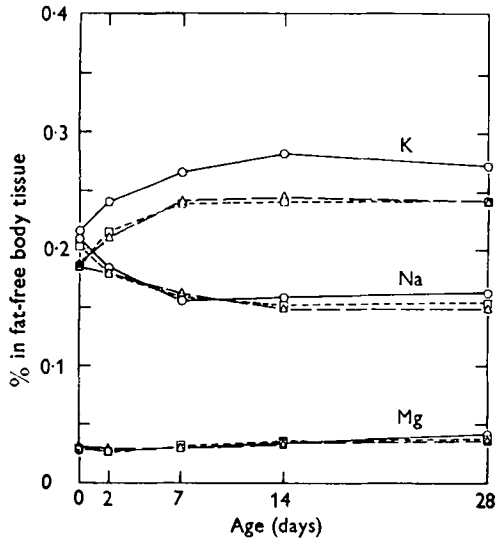

Fig. 10

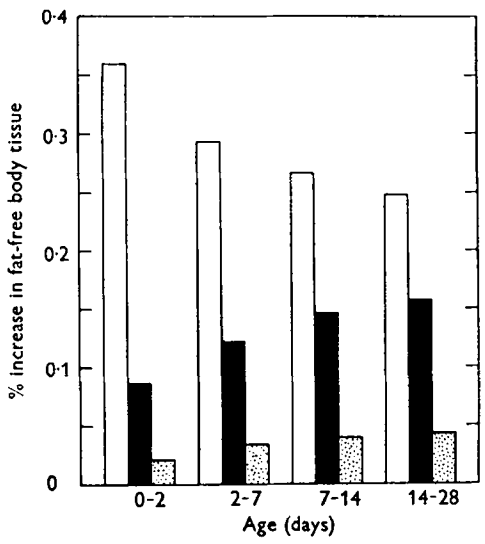

Fig. 11

Fig. 10. Variation with age in concentrations of potassium, sodium and magnesium in fat-free body tissue. Individual results for three litters (○, △, □) of piglets.

Fig. 11. Increments of potassium (□), sodium (■) and magnesium (▦) as percentage increase in fat-free body tissue of the piglets over four successive periods during the 1st month of life.

of life. The magnitude of the calculated loss (see Fig. 12) was largely due to a big difference in Fe concentration between the newborn and the 2-day-old piglet in one litter, though in both the other litters the 2-day-old piglets contained slightly less Fe than their newborn litter-mates. Since no control piglets were slaughtered to show what would have happened if supplementary Fe had not been given, it is not possible to calculate the efficiency of utilization of the supplementary Fe. However, a total of 1500 mg of supplementary Fe was given per piglet, in addition to any present in sow's milk, and only 99 mg Fe were stored between birth and 28 days. The concentration of Zn in the fat-free body tissue of piglets slaughtered at birth and 2 days of age was variable. From 7 days onwards concentration in fat-free tissue was remarkably uniform between litters. The general trend was for Zn concentration in fat-free body tissue to rise

throughout the period studied. The proportion of Zn in the increase in fat-free body tissue was constant during the 0–2- and 2–7-day periods, and rose successively in the two subsequent periods. At 28 days of age the Zn concentration in the fat-free body tissue was $1\frac{1}{2}$ times that in the newborn piglets. There was considerable variation in Cu concentration in fat-free body tissue between litters at all ages studied, except in the newborn piglets. The mean values rose from birth to 7 days of age, remained

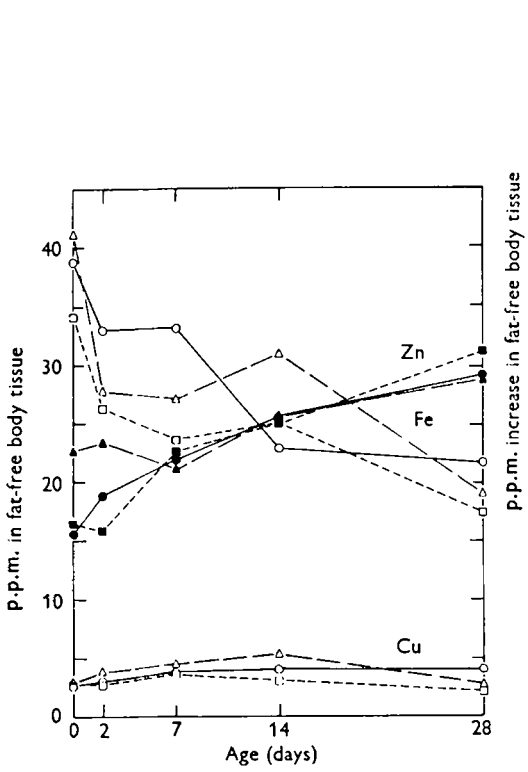

Fig. 12

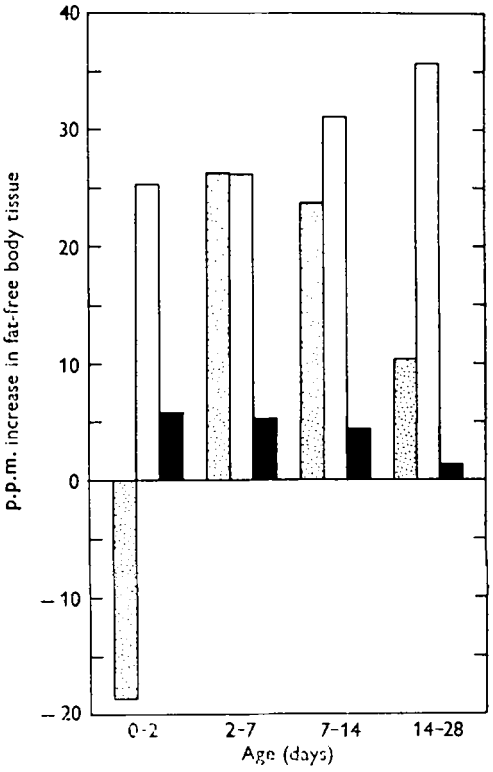

Fig. 13

Fig. 12. Variation with age in concentrations of iron, zinc and copper as p.p.m. in fat-free body tissue. Individual results for three litters (○, △, □) of piglets.

Fig. 13. Variation with age in concentrations of iron (▨), zinc (□) and copper (■) as p.p.m. increase in fat-free body tissue of the piglets over four successive periods during the 1st month of life.

steady to 14 days of age, and then decreased so that at 28 days of age the level was only slightly above that at birth. The concentration of Cu in the increase in fat-free body tissue decreased slowly during the first three periods studied, but was much lower in the 14–28-day period.

Mn. Of the trace elements measured, Mn was present in the least amount. The concentrations found in the fat-free body tissue of individual piglets at each age are given in Fig. 14 and the calculated storage of Mn between slaughter ages is given in Fig. 15. At 7 days of age the concentration of Mn in the fat-free body tissue was approximately half that at birth, indicating a very low level of Mn in sow's milk. At

14 and 28 days there was increasing variability in concentration, but appreciable storage occurred in the 7–14- and 14–28-day periods (Fig. 15), possibly as a result of the consumption of litter and other debris from the floor of the pen.

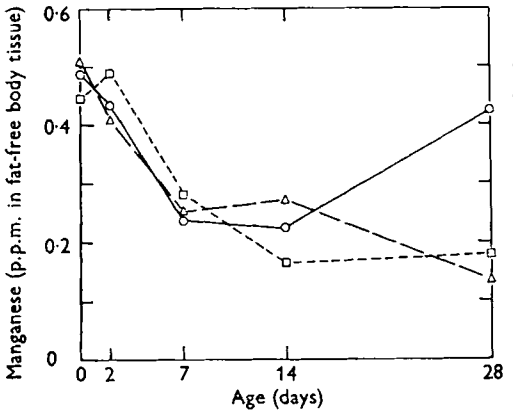

Fig. 14

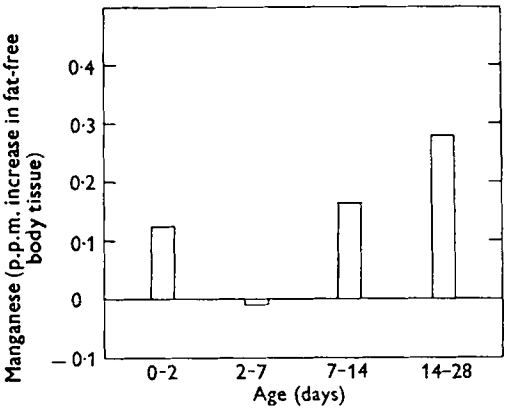

Fig. 15

Fig. 14. Variation with age in concentration of manganese as p.p.m in fat-free body tissue. Individual results for three litters (○, △, □) of piglets.

Fig. 15. Variation with age in manganese as p.p.m. increase in fat-free body tissue of the piglets over four successive periods during the 1st month of life.

Table 3. *Chemical composition of the sow's diet, together with a comparison between the calculated amounts stored by the piglets over the 1st month of life and the quantities in the meal consumed per piglet by the sows over the same period*

Component	In sow's diet (fresh basis) (g/100 g)	In 32·9 lb of sow's diet* (g)	Stored per piglet between birth and 28 days of age, (g)
Dry matter	88·4	—	—
Protein	15·5	2310	1253
Fat	2·6	387	1746
Fibre	3·6	—	—
Nitrogen-free extract	61·5	9178	—
Ash	5·31	792	263
Calcium	0·99	148	71
Phosphorus	0·64	96	47
Magnesium	0·203	30	2·6
Potassium	0·66	98	17·1
Sodium	0·11	16	9·4
	(p.p.m.)	(mg)	(mg)
Iron	332	4950	99
Zinc	129	1930	210
Manganese	60	888	1·2
Copper	14	210	19

* The amount of meal consumed by the sow per piglet during the 1st month after farrowing.

Comparison between nutrients in the sow's diet and calculated storage of nutrients by piglets over the first 4 weeks of life

For the three litters studied the mean intake of sow-and-weaner nuts was about 33 lb/piglet during the 4 weeks. The protein, fat and mineral contents of this amount of food and those of the live-weight increase of the piglets over the same period have been compared in Table 3. Together the fat and N-free extractives in the sow's food supplied $2\frac{1}{2}$ times as much energy as was retained by the piglets in the form of fat. The weights of protein, Ca, P and Na stored by the piglets were about half of the weights of the respective nutrients consumed by the sow. The amounts of K and Mg and of trace elements that the piglets retained in their bodies were very much lower than the quantities in the sow's food, and in the extreme instance of Mn the amount stored by the piglets was only 0·135% of the quantity in the sow's food.

DISCUSSION

The main value of the results of a serial slaughter experiment is not the picture provided of the chemical composition at the different ages studied, but the inferences that can be drawn about the composition of the weight increase between these ages, since it represents the net storage of food nutrients. The values make it possible to assess how the piglet's net requirements for nutrients change as it grows.

The accuracy of estimates of the chemical composition of the weight increase of an animal derived from the analysis of serially slaughtered animals depends on a number of factors. If the animals to be slaughtered are of uniform initial weight, if they grow uniformly, if weight gains are large in relation to initial weight, and if individuals of a given age on a given treatment show uniformity of body composition, then calculation of the composition of the weight increase in the way that we have done seems valid. Over periods when weight gain is small, however, caution must be used in interpreting calculated gains or losses. In these circumstances the natural variability in composition between one animal and another can have a much greater, and possibly a misleading, effect on calculated storage. The baby pig grows rapidly and is very suitable as a subject for serial slaughter studies to elucidate the needs for growth in the young animal. In addition, individuals in a litter of pigs are genetically similar, and have the same uterine environment and maternal milk supply, so that differences between animals are likely to be small. It is thus unnecessary to use inbreeding to obtain uniformity and so lose vigour. McMeekan's (1940) results with inbred pigs, although of great practical and theoretical interest, do suffer from the effect of the poor growth rate of the serially slaughtered animals. For example, at birth the weight of McMeekan's piglets was 92% of that of ours, but at 4 weeks it was only 61%. In fact our piglets weighed almost as much at 2 weeks as did McMeekan's at 4 weeks. Growth rates of experimental animals should be as high as possible to be of practical value and to emphasize differences.

Comparisons with slaughter experiments of other workers

The piglets we studied grew faster than those in slaughter experiments of other workers. Comparisons can be at similar ages and different weights, or at different ages but similar weights. With either method it is difficult to interpret any differences observed. Spray & Widdowson (1950) studied pigs of very similar breeding to ours, and our values can be compared with theirs on the basis of age of piglet. Our figures for body composition agree reasonably well with theirs except for Na, for which our values are lower, and for Zn, of which levels in our piglets were much higher, possibly as a result of supplemental Zn in the sow's diet. Mn levels were not determined by Spray & Widdowson, but our values for newborn piglets agree well with those obtained by Newland & Davis (1961) for 110-day pig foetuses.

In attempting to compare our results with those of Berge & Indrebø (1954) we encounter the added difficulty that these authors did not remove gut contents before analysis. However, they stated the fat content and the weight of their pigs and the two sets of values can be compared on the basis of composition of the increase in fat-free body tissue (including gut contents for their pigs, but not for ours). As our piglets grew more rapidly than theirs it is best to compare the deposition of water, protein, ash, Ca and P over similar ranges of weight of fat-free body tissues. Such a comparison reveals differences in the storage calculated from the two sets of values. The percentages of protein, ash, Ca and P stored by the Norwegian Landrace piglets were considerably less than for the Large White–Wessex piglets which we studied over virtually identical ranges of fat-free body weight. The two sets of values may reflect a real difference between the breeds of pig studied. It is possible that part of the difference was due to dissimilarities in the chemical composition of the milk of the sows of the two breeds. Comparison of the data of Lodge (1959) for the composition of the milk of the Wessex Saddleback breed and of Berge & Indrebø (1953) for the Norwegian Landrace breed shows that the milk of the latter breed appears to contain lower concentrations of both proteins and ash.

Freese (1958) reported the protein, Ca, P and Mg content of ten piglets, four of which were suckled and six fed on artificial diets. Unfortunately, the fat content of these piglets was not given. If the weights of the four components studied in the four sow-reared piglets are plotted against weight of piglet, Freese's data agree well with ours for protein and P, but less well for Ca, for which three of his results were higher than ours. However, for Mg his results were different from ours, the amounts he found at a given weight being three or more times those found by us.

In his study of the development of the pig foetus, Pomeroy (1960) gave values for the concentrations of water, protein, Ca, P, Na, K and Mg in Large White and Essex foetuses during the second half of gestation. The levels of all components studied by Pomeroy in full-term foetuses corresponded closely to those we found in newborn piglets, and so the two sets of values together may tentatively be used to trace the chemical development of the piglet from early gestation to the 28th day of postnatal life. The data of Spray & Widdowson (1950) can then be used to follow the trends until maturity is reached. The most striking change in chemical composition that

occurs over the whole period is the reversal in the relative concentrations of Na and K. During much of gestation Na is present in the foetus in amounts considerably in excess of those of K. The two elements change over in relative concentration at term, and by the 7th day of life K is greatly in excess of Na. From the 7th day until the pig is fully grown the relative concentration of these two elements does not alter materially.

Comparisons with data from balance trials by other workers

Retention of protein, Ca and P has been studied in artificially reared piglets by Ludvigsen & Thorbek (1960). In their experiment the piglets made gains from 11 to 20 and from 20 to 32 days, closely similar to those of our sow-reared piglets from 7 to 14 and from 14 to 28 days respectively. Over these comparable periods larger amounts of protein were retained by the artificially reared piglets, but Ca and P retentions were very similar. Freese (1958) has also shown, by comparison between sow-reared and artificially reared piglets, that piglets have the capacity to retain more protein than they receive in their dam's milk. Our own studies of the protein requirement of artificially reared piglets have led us to the same conclusion, since the ratio between energy and protein in sow's milk is much greater than that shown to be optimum in artificial diets over the first 4 weeks of life (Manners & McCrea, 1962, 1963*a*).

Relation between composition of sow's milk and of weight gain of piglets in our experiment

The higher rate of protein storage that we observed from 0 to 2 days compared with that in subsequent periods is paralleled by the relative amounts of protein in the colostrum and milk of the sow over the same period found by Hughes & Hart (1935), Braude, Coates, Henry, Kon, Rowland, Thompson & Walker (1947), Bowland, Grummer, Phillips & Bohstedt (1949), Perrin (1955), Trávníček (1960) and Jylling & Sørensen (1960). Similarly, the changes we have found in relative amounts of Ca and P retained follow the changes in relative amounts of these two minerals found in the milk of the sow by Hughes & Hart (1935), Braude *et al.* (1947), Perrin (1955), Trávníček (1960) and Jylling & Sørensen (1960). In the first 2 days, and from 2 to 7 days, storage of Ca in the increase in fat-free body tissue of the piglets in our investigation was relatively low, and it appears that dietary Ca may be limiting during the 1st week of life. Alternatively, a shortage of P may limit Ca utilization. Vitamin D intake could be involved. We do not know of any reports of the vitamin D content of sow's colostrum, although the level in sow's milk is quoted by Braude (1954) as 0·55 i.u./g fat. A fall in Ca and P concentration in fat-free body tissue during the early suckling period when growth is relatively most rapid has been observed in other species. Slater & Widdowson (1962) showed that in kittens this fall could be prevented by supplementing the dam's milk by twice-daily administration of a suspension of $CaHPO_4$. In the pig the fall in Ca and P concentration in the 1st week of life is of little practical significance, since, by 4 weeks of age, Ca and P levels have fully recovered, and bone formation as measured by chemical studies is quite satisfactory (Manners & McCrea, 1963*b*). It should not be forgotten that by the 28th day of life the piglets that we studied weighed $6\frac{1}{2}$–7 times as much as they did at birth.

Bone formation was thus only temporarily affected during the period of very rapid growth, with no indication of permanent detriment to the animal.

Mg retention by our piglets rose over the four successive periods studied, the amount stored in the 1st period (from 0 to 2 days) being much lower than that in subsequent periods. Perrin (1955) found that Mg concentrations in sow's milk fell during the 1st day after farrowing to a minimum level at 27 h and then rose slowly throughout lactation. Trávníček (1960) found a rise throughout lactation. On the other hand, Gueguen & Salmon-Legagneur (1959) found a steady concentration of Mg throughout lactation. The concentrations of Na and K in sow's milk have been measured by Gueguen & Salmon-Legagneur (1959) and by Šimek, Trávníček & Mandel (1962). These two groups of workers found that the concentration of Na fell by more than one-third during the 1st week of lactation. In contrast the amount of Na stored by the piglets that we analysed rose over this period. The concentration of K found by Gueguen & Salmon-Legagneur (1959) was twice that found by Šimek *et al.* (1962). In both studies the concentration of K in milk fell from farrowing to the 4th week of lactation, although after the 2nd week the fall was only slight. Storage of K by the piglets that we analysed showed the same trend.

Of the trace elements in sow's milk only Cu and Fe have been studied. Over the first 4 days of lactation Šimek, Trávníček & Mandel (1961) found that concentrations of Cu in sow's milk fell sharply from 0·78 p.p.m. in colostrum to 0·39 p.p.m. There was a further fall between 4 and 14 days to 0·25 p.p.m. but thereafter the concentration was fairly constant. Up to the 14th day of life the proportion of Cu retained in the increase in fat-free body tissue of the piglets that we studied was in excess of the concentration of Cu in the newborn piglet. From 14 to 28 days it was much lower. Concentrations of Fe in sow's milk are higher than those of Cu. In colostrum, values of 2·65 and 1·28 p.p.m. respectively were found by Venn *et al.* (1947) and Šimek *et al.* (1961). In milk later in lactation the same groups of workers found 1·79–1·80 and 0·49–0·74 p.p.m. respectively. Venn *et al.* showed that the concentration of Fe in sow's milk is quite insufficient to maintain tissue levels in the piglet at the high value found at birth, and that the giving of Fe to the sow does not raise the Fe content of sow's milk. More recently Pond, Lowrey, Maner & Loosli (1961) have shown that intramuscular injection of iron dextran given to lactating sows causes little or no mammary transfer of Fe. It is therefore necessary to give the suckled piglet a supplementary source of Fe if the concentration of Fe in its growing body is to be maintained. A feature of the results of our determinations of body Fe was the poor retention despite the three doses of reduced Fe. Venn *et al.* (1947) studied Fe retention in piglets dosed with ferrous sulphate to prevent Fe deficiency anaemia, and in control litter-mates. Interpolation between the values for 14- and 28-day slaughtered piglets in our study shows that our piglets contained little more Fe at 21 days than the undosed control piglets of Venn *et al.*, and only half the amount in their animals treated with ferrous sulphate. We have previously observed that treatment with reduced iron paste is not particularly effective in maintaining blood haemoglobin levels (Manners & McCrea, 1962). Nevertheless, it may be sufficiently effective to prevent the occurrence of clinical Fe-deficiency anaemia.

Conclusions

Our detailed analyses of the chemical composition of fifteen sow-reared piglets have revealed a number of major changes in rate of nutrient retention over the four periods studied during the 1st month of life. If these changes reflect alterations in requirements for individual nutrients then clearly no single diet could be ideal for the whole period. Further work will be needed to discover whether the changes in storage which we have observed are due to changes in minimum requirements for nutrients, to changes in net utilization, to dietary insufficiency or to storage of nutrients in excess of requirements. It seems reasonable to suppose that all four of these possibilities may have affected the values we have collected.

SUMMARY

1. Large White × Wessex piglets from three separate litters were slaughtered at birth and at 2, 7, 14 and 28 days of age in order to obtain information on the changes in chemical composition which occur in suckled piglets during the first 4 weeks of life. The piglets were not given supplementary food, but were given doses of a paste containing reduced iron because of the known deficiency of Fe in sow's milk.

2. The chemical components studied were fat, crude protein, ash, calcium, phosphorus, potassium, sodium, magnesium, iron, zinc, copper and manganese.

3. Of the components measured, the percentage of fat in the body showed the greatest change between birth and 4 weeks of age, rising from 1·2% of empty live weight at birth to 18·3% at 28 days of age. The amounts of the other components measured were calculated as proportions of fat-free body tissue.

4. The concentration of protein in fat-free body tissue rose throughout the first 4 weeks of life, and at the same time the water content fell. Percentage of ash in fat-free body tissue fell from birth to the 7th day of life and rose thereafter.

5. Ca concentration in fat-free body tissue fell sharply from birth to the 7th day of life, and then rose steadily. Variations in the level of this mineral accounted for much of the fluctuation in ash content. P concentration in fat-free body tissue remained fairly steady. However, there was a slight fall from birth to 7 days of age, followed by a slight rise. Mg levels fell a little from birth to 2 days of age and then rose steadily so that at 28 days of age the concentration in fat-free body tissue was considerably above that in the newborn piglet.

6. The concentrations of Na and K in fat-free body tissue were similar at birth but diverged sharply in the first few days of life. By the 7th day the ratio of K to Na was 5:3 and thereafter it changed little.

7. Fe concentration in fat-free body tissue fell throughout the period studied despite oral supplements of Fe. Zn levels rose throughout the period studied. Cu levels rose from birth to 14 days of age and then fell. Mn levels fell rapidly from birth to 7 days of age and then remained fairly steady.

8. The composition of the weight increase between slaughter ages was calculated from the weights of chemical components found in the body at the five slaughter ages.

9. Our results are discussed in relation to those of other workers who have analysed

young pigs. In addition, the calculated retention of chemical components in our study has been compared with that in balance studies with suckled and artificially reared piglets by other workers, and with the composition of sow's milk reported by other workers.

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REFERENCES

Berge, S. & Indrebø, T. (1953). *Meld. Norg. LandbrHøisk.* **33**, 389.
Berge, S. & Indrebø, T. (1954). *Meld. Norg. LandbrHøisk.* **34**, 481.
Bowland, J. P., Grummer, R. H., Phillips, P. H. & Bohstedt, G. (1949). *J. Anim. Sci.* **8**, 199.
Bradfield, E. G. (1961). *Analyst*, **86**, 269.
Braude, R. (1954). In *Progress in the Physiology of Farm Animals.* Vol. 1, p. 40. [J. Hammond, editor.] London: Butterworths Publications Ltd.
Braude, R., Coates, M. E., Henry, K. M., Kon, S. K., Rowland, S. J., Thompson, S. Y. & Walker, D. M. (1947). *Brit. J. Nutr.* **1**, 64.
Clark, E. P. & Collip, J. B. (1925). *J. biol. Chem.* **63**, 461.
Freese, H. H. (1958). *Arch. Tierernähr.* **8**, 330.
Gueguen, L. & Salmon-Legagneur, E. (1959). *C.R. Acad. Sci., Paris*, **249**, 784.
Hanson, W. C. (1950). *J. Sci. Fd Agric.* **1**, 172.
Holmes, R. S. (1945). *Soil Sci.* **59**, 77.
Hughes, E. H. & Hart, H. G. (1935). *J. Nutr.* **9**, 311.
Jylling, B. & Sørensen, P. H. (1960). *K. VetHøjsk. Aarsskr.* p. 20.
Lawes, J. B. & Gilbert, J. H. (1858). *Phil. Trans.* **149**, 493.
Lodge, G. A. (1959). *J. Dairy Res.* **26**, 134.
Ludvigsen, J. & Thorbek, G. (1960). *Beretn. Forsøgslab. Kbh.* no. 320.
McCance, R. A. & Shipp, H. L. (1933). *Spec. Rep. Ser. med. Res. Coun., Lond.*, no. 187.
McCance, R. A., Widdowson, E. M. & Shackleton, L. R. B. (1936). *Spec. Rep. Ser. med. Res. Coun., Lond.*, no. 213.
McMeekan, C. P. (1940). *J. agric. Sci.* **30**, 276.
Manners, M. J. & McCrea, M. R. (1962). *Brit. J. Nutr.* **16**, 475.
Manners, M. J. & McCrea, M. R. (1963*a*). *Brit. J. Nutr.* **17**, 357.
Manners, M. J. & McCrea, M. R. (1963*b*). *Brit. J. Nutr.* **17**, 487.
Martens, R. I. & Githens, R. E. (1952). *Analyt. Chem.* **24**, 991.
Nehring, K., Laube, W., Schwerdtfeger, E., Schiemann, R., Haesler, E. & Hoffmann, L. (1957). *Biochem. Z.* **328**, 549.
Newland, H. W. & Davis, G. K. (1961). *J. Anim. Sci.* **20**, 15.
Newlander, J. A. & Jones, C. H. (1935). *Bull. Vt agric. Exp. Sta.* no. 389.
Nicholas, D. J. D. (1949). *J. hort. Sci.* **25**, 60.
Perrin, D. R. (1955). *J. Dairy Res.* **22**, 103.
Pomeroy, R. W. (1960). *J. agric. Sci.* **54**, 31.
Pond, W. G., Lowrey, R. S., Maner, J. H. & Loosli, J. K. (1961). *J. Anim. Sci.* **20**, 747.
Šimek, L., Trávníček, J. & Mandel, L. (1961). *Vet. Čas.* **10**, 160.
Šimek, L., Trávníček, J. & Mandel, L. (1962). *Vet. Čas.* **11**, 38.
Slater, J. E. & Widdowson, E. M. (1962). *Brit. J. Nutr.* **16**, 39.
Spray, C. M. & Widdowson, E. M. (1950). *Brit. J. Nutr.* **4**, 332.
Trávníček, J. (1960). *Sborn. Čsl. Akad. zeměd. Věd, živoč. Výr.* **33**, 497.
Venn, J. A. J., McCance, R. A. & Widdowson, E. M. (1947). *J. comp. Path.* **57**, 314.
von Lieberman, L. & Szekely, S. (1898). *Pflüg. Arch. ges. Physiol.* **72**, 360.
Washburn, R. M. & Jones, C. H. (1916). *Bull. Vt agric. Exp. Sta.* no. 195.
Williams, H. H., Curtin, L. V., Abraham, J., Loosli, J. K. & Maynard, L. A. (1954). *J. biol. Chem.* **208**, 277.

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