

The optimum dietary amino acid pattern for growing pigs

2. Requirements for maintenance and for tissue protein accretion

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Experiments were made to estimate separately the amino acid requirements of growing pigs for maintenance and for protein accretion. The relationship between nitrogen retention and amino acid intake was estimated for each essential amino acid (except histidine) by giving, at rates of N intake of 0.25 and 2.0 g/kg body-weight (W)^{0.75} per d, diets in which one amino acid was made specifically deficient. From the regression coefficients it was calculated that, for the accretion of 1 g body protein, the dietary amino acid requirements were (mg) threonine 47, valine 53, methionine + cystine 36, methionine 19, isoleucine 43, leucine 78, phenylalanine + tyrosine 84, phenylalanine 41, lysine 68 and tryptophan 12. The daily amino acid requirements for N equilibrium were also estimated. From the relationship between N retention and amino acid intake the daily amino acid requirements for N equilibrium were estimated to be (mg/kg $W^{0.75}$ per d) threonine 53, valine 20, methionine + cystine 49, methionine 9, isoleucine 16, leucine 23, phenylalanine + tyrosine 37, phenylalanine 18, lysine 36 and tryptophan 11. It was estimated that both for maintenance and for protein accretion tyrosine could provide close to half the total phenylalanine + tyrosine needs. Cystine could supply close to half the total sulphur amino acid needs for protein accretion but 0.8 of the needs for maintenance.

Amino acids: Protein quality: Protein requirements: Pig

The amino acid requirements of a growing pig include two components, a requirement for maintenance and a requirement for tissue protein accretion. There is evidence from studies with other species (e.g. Said & Hegsted, 1970; Dreyer, 1975) that the pattern of amino acids required for each of these is quite different, and the animal's total requirement must, therefore, depend on the relative contributions of maintenance and tissue protein accretion to its total needs. The estimates of the optimal balance of amino acids made by Wang & Fuller (1989) referred to the sum of these components, and can only be considered strictly applicable to one particular rate of growth or protein accretion. The only direct estimates of the amino acid requirements of pigs for maintenance are those of Baker *et al.* (1966*a*, *b*, *c*; Baker & Allee, 1970) and there do not seem to have been any experiments to estimate simultaneously all the amino acid requirements of pigs for maintenance and for tissue accretion.

The approach used in the present experiments was to estimate the regression of daily protein accretion *v.* daily amino acid intake for each amino acid when it was given at different rates but was always limiting. The reciprocal of each regression coefficient was taken to represent the increment of amino acid needed to increase protein accretion by 1 g, and the ratios amongst these reciprocals describe the relative proportions in which amino acids are required for tissue protein accretion. The amount of each amino acid needed to maintain nitrogen equilibrium was also calculated as the *x*-intercept of the regression relating N accretion to amino acid intake.

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MATERIALS AND METHODS

There were three experiments. The first was primarily designed as a pilot trial for the second, main experiment. It was necessary to establish first that the response of N accretion to amino acid intake was linear within the range of amino acid intake used, and this was examined using three rates of intake for each of two amino acids, lysine and methionine (+cystine). In the second experiment estimates were made of the requirement for each essential amino acid for both maintenance (N equilibrium) and tissue protein accretion. Since these maintenance estimates were made by interpolation over a wide range of amino acid intakes a third experiment, to provide further estimates of maintenance needs, was made. In this experiment the interpolations were made over a narrow range of amino acid intakes.

Diets

The compositions of the main diets used in the three experiments are shown in Table 1. In the first experiment there were nine diets, in the second twenty-three diets, and the third had twenty-three diets also. All were semi-synthetic diets based on a mixture of casein and purified carbohydrates with added vegetable oil, vitamins and minerals. The amino acid composition of the medium- and high-N diets was varied by replacing part of the casein with a mixture of amino acids lacking the one (or two) under study. The N content was maintained by addition of alanine, aspartic acid and monosodium glutamate, each supplying one-third of the additional N required. The casein used was of the same batch as that used in a preceding study (Wang & Fuller, 1989).

Expt 1. The amino acid pattern of the three control diets was based on the Agricultural Research Council ideal protein (Agricultural Research Council, 1981). Diets 2 and 3 were formed by omitting, from the low-N control diet (LC, Table 1), all the lysine or all the methionine+cystine. Diets 5 and 6 were formed by removing 20% of the lysine or the methionine+cystine from the medium-N diet (MC, Table 1), and diets 8 and 9 likewise by removing 20% of the lysine or the methionine+cystine from the high-N diet (HC, Table 1).

Expt 2. The amino acid composition of the basal low-N (LC) and high-N (HC) diets was based on the pattern established in a preceding study (Wang & Fuller, 1989). The other low-N diets were made by omitting one (or two) amino acid(s) entirely from diet LC; the other high-N diets were made by replacing 20% of the casein with a mixture of amino acids having the same composition, but omitting one (or two) from the amino acid mixture included in each diet. At each rate of N intake, omissions were made of both methionine+cystine, or of methionine alone, maintaining the same total sulphur amino acid content as the control diet by addition of extra cystine. Similarly, phenylalanine+tryosine were both omitted from one diet and phenylalanine alone from another, with additional tyrosine to maintain the total concentration of aromatic amino acids at the same level as in the control diet. The N content of all diets was maintained constant by additions of alanine, aspartic acid and monosodium glutamate, each supplying one-third of the N. The protein-free diet (PF) included no casein or amino acids but there were trace quantities of amino acids in the maize starch, and in Expts 2 and 3 allowance was made for these in the calculation of the results.

Expt 3. The estimates of amino acids needed for N equilibrium derived from the second experiment were used to design the third. In this, a series of high-N diets was given, each supplying one essential amino acid in the quantity estimated to be needed for N equilibrium but with twice as much of every other essential amino acid as was estimated to be needed for maintenance, with a total of 500 mg N/kg body-weight (W)^{0.75} per d. If our previous

Table 1. *Composition (g/kg) of the primary diets used in the three experiments*
(Other diets were made by varying the composition of the amino acid mixture, for details see p. 256)

Expt....	1			2			3	
	LC	MC	HC	PF	LC	HC	LC	HC
Nominal nitrogen intake (g/kg W ^{0.75} per d)	0.25	1.00	2.00	0.00	0.25	1.35	0.25	0.50
Amino acid mixture	26.0	54.8	101.7	0.0	24.7	42.3	23.3	56.4
Casein*	0.0	38.2	69.8	0.0	0.0	70.8	2.94	2.94
Maize starch	402.7	335.7	257.2	412.3	387.6	299.2	350.0	350.0
Glucose	295.0	295.0	295.0	295.0	295.0	295.0	300.0	300.0
Sucrose	136.0	136.0	136.0	136.0	136.0	136.0	167.1	134.0
Cellulose	49.0	49.0	49.0	60.0	60.0	60.0	60.0	60.0
Vegetable oil	45.0	45.0	45.0	40.0	40.0	40.0	40.0	40.0
Vitamin-mineral premix†	46.3	46.3	46.3	56.7	56.7	56.7	56.7	56.7
N	3.99	12.29	22.65	0.25	2.97	14.73	3.12	6.25
DE (MJ/kg)	14.2	14.2	14.2	14.1	14.2	14.1	14.2	14.2
Amino acid mixture contained (g)								
Aspartic acid	4.95	11.05	20.23		7.12	14.67	8.79	23.03
Threonine	0.87	1.95	3.57		0.76	1.52	0.52	0.52
Serine	1.03	2.09	3.84		—	—	—	—
Glutamic acid	5.47	12.22	22.37		9.05	18.66	29.27	29.27
Proline	2.06	3.92	7.17		—	—	—	—
Glycine	0.41	0.95	1.75		—	—	—	—
Alanine	3.31	7.39	13.54		0.61	1.02	1.28	1.28
Valine	1.02	2.03	3.72		0.80	0.35	0.04	0.04
Cystine	0.21	0.65	1.18		0.07	0.17	0.32	0.32
Methionine	0.52	1.00	1.84		0.59	1.41	0.24	0.24
Isoleucine	0.78	1.52	2.77		0.63	0.23	0.05	0.05
Leucine	1.44	2.59	4.73		1.17	0.61	—	—
Tyrosine	0.48	0.00	0.00		0.67	—	0.06	0.06
Phenylalanine	0.95	1.93	3.54		0.59	—	0.15	0.15
Lysine	1.44	2.98	5.46		1.04	1.27	0.34	0.34
Histidine	0.48	0.86	1.58		0.42	0.59	0.35	0.35
Arginine	0.82	1.89	3.45		0.64	1.16	0.69	0.69
Tryptophan	0.21	0.35	0.63		0.20	0.28	0.09	0.09

W, body-weight; DE, digestible energy; LC, low-N diet; MC, medium-N diet; HC, high-N diet; PF, protein-free diet.

* Contained (g/16 g N): aspartic acid 6.52, threonine 3.91, serine 5.34, glutamic acid 17.82, proline 11.54, glycine 1.79, alanine 2.74, valine 5.30, cystine 0.37, methionine 2.81, isoleucine 4.30, leucine 8.54, tyrosine 5.40, phenylalanine 4.91, lysine 7.35, histidine 2.77, arginine 3.65 and tryptophan 1.30.

† Supplying (g/tonne diet): retinol 1.5, cholecalciferol 25 mg, α -tocopherylacetate 5, phytolmetaquinone 1, thiamin 2, riboflavin 3.4, nicotinic acid 19, pyridoxine 2.73, vitamin B₁₂ 21 mg, choline chloride 1150, pantothenic acid 12, biotin 50 mg, folic acid 2, ascorbic acid 12, salt 3.5 kg, dicalcium phosphate 40 kg, potassium bicarbonate 7 kg, iron 100, zinc 100, manganese 42, magnesium 420, copper 15, iodine 2, cobalt 0.5, selenium 0.15.

estimate of the maintenance requirement for any amino acid was excessive, the provision of a relative excess of every other amino acid with additional non-essential amino acids would permit a positive N retention. A series of low-N diets was also given, each supplying half the estimated maintenance need for one amino acid, together with the full maintenance requirement for every other essential amino acid and with a total of 250 mg N/kg W^{0.75} per d. Thus, one amino acid in each diet was limiting for maintenance and would result in negative N retention.

As in Expt 2, methionine and the total S amino acids were treated separately, as were phenylalanine and the total aromatic amino acids. There were thus ten pairs of diets, each pair having one or two amino acids limiting at two levels of N intake. There was also a low-N control diet, supplying exactly the estimated maintenance requirement for each essential amino acid (from Expt 2) with total N intake of 250 mg/kg $W^{0.75}$ per d. The additional N was supplied by a mixture of alanine, aspartic acid and monosodium glutamate supplying 0.2, 0.4 and 0.4 of the additional N respectively.

Animals and procedures

All the pigs were Large White \times (Large White \times Landrace) females from the Rowett Research Institute herd. In Expt 1, eighteen pigs, averaging 41 kg, were kept in metabolism cages for three periods of 7 d, preceded by a 7 d adjustment period before measurements began. Each period consisted of a 3 d preliminary feeding period, followed by two successive 48 h urine collections, using bladder catheters. The pigs were divided into six sets of three to give the greatest uniformity in terms of body-weight within sets. Each set of three animals received all nine diets in the three periods: within each of the two groups of three sets all treatments occurred in each of the three periods and each pig had one control diet, one lysine-deficient diet and one methionine + cystine-deficient diet.

In the second experiment twenty-four female pigs with an average weight of 46 kg were kept in metabolism cages for six periods, in three of which low-N diets were given and in the other three high-N diets. In each period two animals were given the high-N control (HC) diet, two were given the low-N control diet (LC) and one animal was given each of the other twenty-two diets. After 7 d adaptation to the first diet, bladder catheters were introduced and two successive 48 h collections of urine were made. The diet was then changed to one of the same N content but with a different amino acid deleted and, after a further 3 d adaptation, a further two 48 h urine collections were made, after which a third diet, again with the same N content, was given and after 3 d adaptation two more 48 h urine collections were made. The pigs were then allowed 1 week in loose pens during which time they were adapted to the other level of N intake; they were then put back into cages, fitted with bladder catheters, and the same schedule of adaptation and collection periods was repeated, giving a total of 144 duplicated observations, six for each diet except HC, for which there were twelve.

The third experiment was similar to the second, with two series of three 7 d periods with high-N diets given in one series of three periods and low-N diets in the other. Twenty-four pigs with an average weight of 34 kg were used.

Analytical methods

N was estimated by the automated Kjeldahl method of Davidson *et al.* (1970). Details of the amino acid analysis are given by Wang & Fuller (1989).

Statistical analysis

Results were analysed using GENSTAT 5 (Lawes Agricultural Trust, 1982). Mean rates of N retention were calculated by analysis of variance. For each amino acid, a regression analysis was made to estimate the relationship between daily N accretion and daily amino acid intake, adjusting for the effects of animal and period.

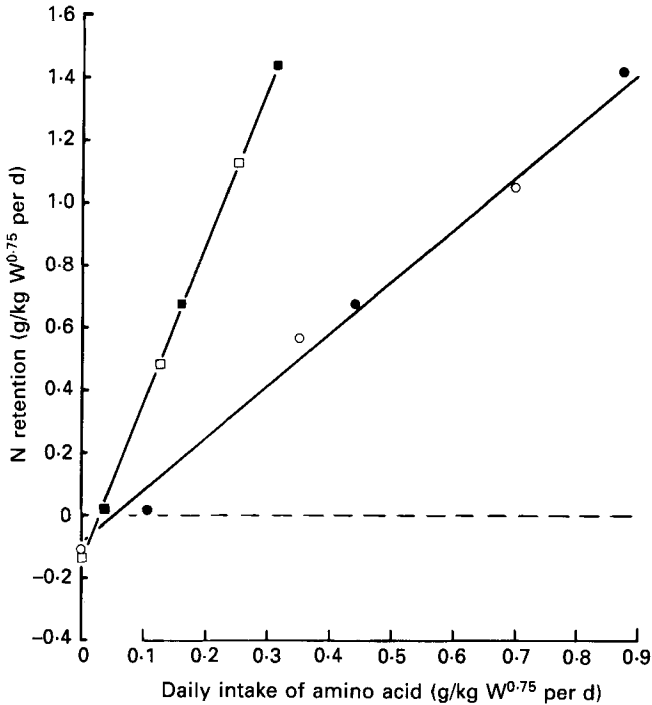


Fig. 1. Expt 1. The relationship between nitrogen retention and amino acid intake of pigs given diets supplying 0.25, 1.0 or 2.0 g N/kg body-weight($W^{0.75}$ per d) with an amino acid pattern conforming to that proposed by the Agricultural Research Council (1981) (●, ■) or that pattern with specific deletions of lysine (○) or of methionine + cystine (□). For details of diets, see p. 256 and Table 1.

RESULTS

Expt 1

A regression analysis examining the effects of diet, pig and period accounted for 96% of the variance in daily N retention. The main results are shown in Fig. 1. For the diets without amino acid deletions the relationship between N retention (y) and N intake (x) did not depart from linearity over the range examined. The regression was: $y = -0.156 + 0.85x$ (SE 0.1044). There was no evidence of any departure from linearity in the relationship between daily N accretion and daily amino acid intake when the diet was limiting in lysine or in methionine + cystine.

Expt 2

The rates of body N loss resulting from the complete omission of one amino acid from the diet are shown in Table 2. The LC diet, intended to provide for N equilibrium, actually gave a body N loss of 18 mg/kg $W^{0.75}$ per d. With the removal of all protein (diet PF) the daily N loss was 268 mg/kg $W^{0.75}$ per d; i.e. removal of 250 mg/kg $W^{0.75}$ per d dietary N reduced N accretion by exactly the same amount, indicating that the N of the control diet was utilized for maintenance with 100% efficiency.

Removal of all S amino acids resulted in almost as great a loss as with the protein-free diet, 250 mg/kg $W^{0.75}$ per d; the next greatest rate of N loss was with omission of threonine, 182 mg/kg $W^{0.75}$ per d, and the least was with omission of the branched-chain amino acids, all giving values of approximately 60 mg/kg $W^{0.75}$ per d. With omission of methionine in

Table 2. Rates of nitrogen retention (g/kg body weight (W)^{0.75} per d) by pigs given diets limiting in a single amino acid, or a protein-free diet*

N intake (g/kg $W^{0.75}$ per d)...	0.25	1.35
Limiting amino acid		
None (control)	-0.018	0.965
Threonine	-0.182	0.839
Valine	-0.061	0.889
Methionine + cystine	-0.250	0.850
Methionine	-0.101	0.787
Isoleucine	-0.064	0.855
Leucine	-0.056	0.922
Phenylalanine + tyrosine	-0.090	0.864
Phenylalanine	-0.093	0.825
Lysine	-0.089	0.863
Tryptophan	-0.141	0.863
All (protein-free)	-0.268	—
SEM	0.0239	

* For details, see p. 256 and Table 1.

the presence of cystine the rate of N loss was only 0.4 of that with complete omission of both methionine + cystine. The inclusion of tyrosine in a phenylalanine-free diet did not result in any lower rate of body protein loss than when both amino acids were omitted. Also given in Table 2 are the rates of N retention observed with selective removal of amino acids from diet HC.

The regressions of daily N retention on daily amino acid intake are given in Table 3. The reciprocals of the regression coefficients describe the increment of amino acid required to increase N retention by 1 g and these, expressed as mg/g protein ($N \times 6.25$), are also given in the table. The ratios between these values are taken as estimates of the pattern of amino acids required for protein accretion in the growing pig. All these regressions are presented together in Fig. 2.

The amount of each amino acid required to maintain N equilibrium was also estimated as the intercept on the x -axis of the same regression, and these estimates, expressed as mg/kg $W^{0.75}$ per d, are also presented in Table 3.

The estimates can also be expressed as amino acid patterns in protein. Since the protein-free diet gave a body N loss of 268 mg/kg $W^{0.75}$ per d and addition of 250 mg N/kg $W^{0.75}$ per d in diet LC reduced this loss by an exactly equal amount, it appears that 268 mg N/kg $W^{0.75}$ per d would be required to maintain N equilibrium. Dividing the maintenance requirement for each amino acid by this amount gives the pattern shown in Table 3.

Expt 3

The rates of N retention on each diet are given in Table 4. From regressions (Fig. 3) relating N retention to amino acid intake estimates were made of the intake of each amino acid required to maintain N equilibrium, and these are also given in Table 4. In one instance (threonine) the original estimate was inadequate, involving some extrapolation (see Fig. 3). The estimates generally agreed closely with those obtained in Expt 2. The exceptions were for the S amino acids and the aromatic amino acids. In both these instances the new estimates were lower than the earlier ones.

The standard errors of the estimates were in all cases lower than in Expt 2.

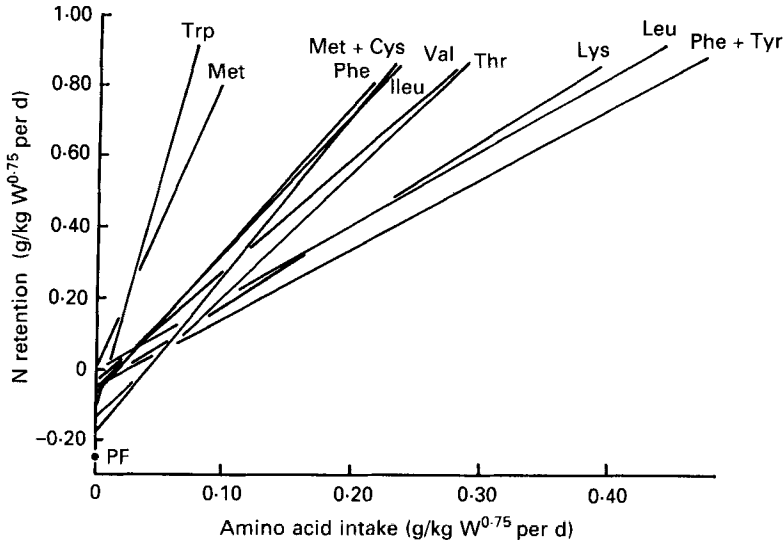


Fig. 2. Expt 2. The relationship between nitrogen retention and amino acid intake of pigs given diets supplying 0.25 or 2.0 g N/kg body-weight ($W^{0.75}$ per d) with an amino acid pattern based on that described by Wang & Fuller (1989) but with specific deletions of individual amino acids. The corresponding regression equations are given in Table 3. For details of diets, see p. 256 and Table 1. ●, PF, protein-free diet.

Table 3. Regression coefficients relating nitrogen retention (g/kg body-weight ($W^{0.75}$ per d) to amino acid intake* (g/kg $W^{0.75}$ per d), reciprocals of these regression coefficients, expressed per 16 g N, the estimated amino acid requirement (mg)/g increment of body protein accretion and the estimate of the amount of each amino acid required to maintain N equilibrium, calculated from the regressions (mg/kg $W^{0.75}$ per d and g/16 g N required for maintenance)

(Each regression is based on twelve observations with adjustment for the effects of differences between animals and periods)

Amino acid	Regression coefficient	SE	1 g protein accretion	Requirement for		
				Maintenance		
				mg/kg $W^{0.75}$ per d	SE	g/16 g N
Threonine	3.41	0.110	46.9	53	5.9	3.16
Valine	3.05	0.106	52.5	20	7.3	1.19
Methionine + cystine	4.47	0.153	35.8	56	3.9	3.34
Methionine	8.51	0.412	18.8	12	2.2	0.72
Isoleucine	3.72	0.136	43.0	17	6.0	1.01
Leucine	2.05	0.073	78.0	27	10.9	1.61
Phenylalanine + tyrosine	1.90	0.067	84.2	47	14.4	2.81
Phenylalanine	3.89	0.158	41.1	24	5.4	1.43
Lysine	2.35	0.084	68.1	38	9.2	2.27
Tryptophan	13.27	0.451	12.1	11	1.5	0.66

* For details of diets, see p. 256 and Table 1.

Table 4. Expt 3. Rates of nitrogen retention ($\text{mg/kg body-weight } (W)^{0.75}$ per d) on each of the diets given *, the regressions of N retention on amino acid intake ($\text{mg/kg } W^{0.75}$ per d) and the corresponding estimates of the requirement for N equilibrium

Limiting amino acid	N intake ...	N retention		Regression			Requirement for N equilibrium	
		Low	High	Intercept	Coefficient	SE	Mean	SE
None (control)		-73	21					
Threonine		-155	-13	-303	5.74	1.25	53	4.2
Valine		-62	-1	-124	6.30	1.48	20	1.6
Methionine + cystine		-156	32	-351	7.17	1.42	49	3.1
Methionine		-67	56	-203	22.8	4.84	9	0.6
Isoleucine		-39	4	-124	7.8	3.67	16	3.0
Leucine		-73	23	-166	7.3	1.61	23	1.6
Phenylalanine + tyrosine		-47	27	-149	4.0	0.78	37	6.2
Phenylalanine		-53	42	-150	8.4	1.84	18	1.3
Lysine		-75	6	-156	4.36	0.83	36	2.3
Tryptophan		-63	2	-163	15.1	8.4	11	2.6
Arginine†		-65	nd					
Pooled SED			28.7					

nd, not determined; SED, standard error of difference.

* For details, see p. 256 and Table 1.

† Complete omission of arginine.

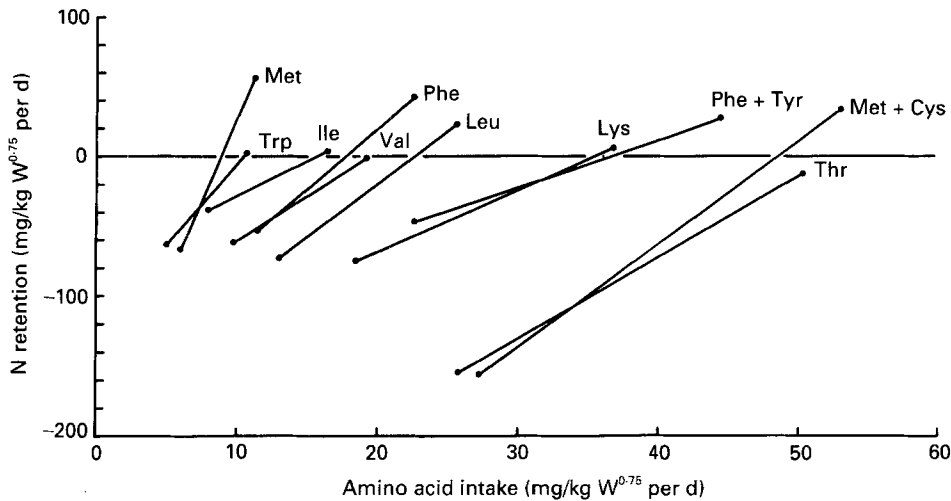


Fig. 3. Expt 3. The relationship between nitrogen retention and amino acid intake of pigs given diets supplying 0.25 or 0.50 g N/kg body-weight ($W^{0.75}$ per d) with an amino acid pattern based on the maintenance requirements estimated in Expt 2 but with specific deletions of individual amino acids. The corresponding regression equations are given in Table 4. For details of diets, see p. 256 and Table 1.

DISCUSSION

The aim of the present work was to make direct assessments of the pattern of amino acids needed by growing pigs, both for maintenance and for tissue growth. The approach used was based on the concept that when a single amino acid is limiting in the diet the rate of body protein accretion is directly related to the supply of that one amino acid. Although others have related N retention to amino acid intake, no one seems to have used such information as a means of establishing an optimum amino acid pattern in the diet. Dreyer (1975), for example, published equations for the growing rat which are essentially similar to those obtained here for the growing pig and may be interpreted in the same way. Estimates made from his findings show some general similarities to the present results but include some extremely high estimates, notably for lysine (122 mg/g protein) and phenylalanine + tyrosine (107 mg/g protein). There is no obvious explanation for these discrepancies.

The present study included the two pairings of an indispensable and a semi-dispensable amino acid, methionine + cystine and phenylalanine + tyrosine. When methionine + cystine were both omitted entirely from the diet the rate of body N loss was 250 mg/kg $W^{0.75}$ per d, a rate not significantly different from that observed when all amino acids were omitted. When methionine was omitted but cystine included, however, the rate of body N loss was only 101 mg/kg $W^{0.75}$ per d, implying that a large proportion of the obligatory methionine requirement can be met by cyst(e)ine. The importance of the S amino acids in maintenance has been evident in a number of studies. Mitchell (1950) particularly emphasized the importance of the keratinous tissues in maintenance, observing that the continued growth of these tissues is sustained at the expense of others which are catabolized 'to secure the needed amounts of sulphur containing amino acids'. Baker *et al.* (1966*c*) reiterated this argument, reporting that cystine constitutes over 20% of the protein of pig hair. As a corollary of this, addition of S amino acids to a protein-free diet diminishes body N loss (Yoshida & Moritoki, 1974).

In the complete absence of both phenylalanine and tyrosine from the diet the rate of body N loss was 90 mg/kg $W^{0.75}$ per d and this rate was not reduced by the addition of tyrosine. Since tyrosine serves as the precursor for the synthesis of a number of important substances in the body, this is surprising. One interpretation could be that the obligatory minimum metabolism of phenylalanine which, in the absence of dietary phenylalanine, presumably determines the net rate of body protein breakdown, includes a major component of hydroxylation, producing tyrosine at a rate sufficient to meet the requirement for those obligatory syntheses. It could also be that these syntheses, though physiologically important, are quantitatively very small.

The pattern of amino acids which was estimated to be required for body protein accretion is very similar to published estimates of the whole-body amino acid composition of pigs (Table 5). This echoes the concept (Mitchell, 1950) that 'the amino acid requirements of the growing animal are determined in the last analysis by the amino acid composition of the tissue proteins formed during growth'. It seems at first sight that, if a growing animal is being given a protein of such high biological value that all but a few percent of the N absorbed are retained, then dietary amino acids are being quantitatively incorporated into body protein. It does not follow, however, that such a protein which is fully utilizable for growth necessarily supplies the minimum of each essential amino acid consistent with maximum N utilization; it could equally well be true that one or more essential amino acids was in excess of that required. The excess quantities of these amino acids would then be catabolized, their amino groups being used in the synthesis of sufficient dispensable amino acids to maximize the utilization of dietary N.

Table 5. *The estimated amino acid requirements for body protein accretion compared with the amino acid composition of the whole bodies of growing pigs and those of sow's milk*

	Whole body			Present estimates for accretion
	Aumaitre & Duee (1974)	Zhang <i>et al.</i> (1986)	Sow's milk (Elliott <i>et al.</i> 1971)	
Threonine	3.7	3.81	4.2	4.69
Valine	4.7	4.77	5.4	5.25
Methionine + tyrosine	2.90	2.82	3.3	3.58
Methionine	1.65	1.87	1.7	1.88
Isoleucine	3.5	3.52	4.1	4.30
Leucine	6.8	7.18	8.6	7.80
Phenylalanine + tyrosine	6.45	7.20	4.85	8.42
Phenylalanine	3.7	4.21	4.0	4.11
Lysine	6.75	7.11	7.6	6.81
Histidine	2.55	2.81	2.8	nd
Arginine	6.85	6.96	4.2	nd
Tryptophan	nd	nd	1.3	1.21

nd, not determined.

It is interesting to note, in Table 5, that the estimated amino acid requirements tended to be higher than the amounts found in body tissue. In this respect our proposed 'ideal protein for accretion' is reminiscent of sow's milk protein (Table 5) which likewise contains concentrations of most essential amino acids above those found in body tissue. The reason may be the same, that at rates of N intake compatible with normal rates of growth, the rate of oxidation of each of the essential amino acids is increased above its minimum, and this means that to achieve maximum N utilization this must be allowed for by including essential amino acids in rather higher proportions than are eventually incorporated.

There is information in the literature on the daily amino acid requirements for maintenance of several species and it is of interest to compare these (Table 6). Between pig, rat and man there is a broad measure of concordance in the rankings of the requirements for the different amino acids. For the fowl the pattern does seem to be different. Leveille *et al.* (1960) reported, however, that their estimates were highly correlated with the amino acid composition of feather protein and it may be that these keratins make an even greater contribution to the maintenance of the fowl than skin and hair do in the cases of man or the growing rat or pig.

In the presence of dietary cystine the daily methionine requirement was estimated to be 12 mg/kg $W^{0.75}$ per d (Expt 2) and 9 mg/kg $W^{0.75}$ per d (Expt 3), whereas when the diet contained no cystine, so that the requirements for both amino acids had to be met by methionine, the requirement was increased to 49–56 mg/kg $W^{0.75}$ per d. This implies that cyst(e)ine can supply 79–82% of the total S amino acid needed for maintenance. For accretion, on the other hand (Expt 2), the total S amino acid requirement was 36 mg/g which included 19 mg methionine. It appeared, therefore, that for accretion, cyst(e)ine could supply only 47% of the total S amino acid needed. This observation, that cyst(e)ine can make a much greater contribution to S amino acid needs for maintenance than it can for tissue growth, is in accord with a number of previous reports (Rose & Wixom, 1955; Baker *et al.* 1966c; Said & Hegsted, 1970).

To maintain N equilibrium in the absence of dietary tyrosine 47 mg (Expt 2) or 37 mg

Table 6. *Estimates of the maintenance requirements for amino acids (mg/kg body-weight (W)^{0.75} per d) of several species from the literature*

	Pig (present study)	Pig (Baker <i>et al.</i> 1966 <i>a, b, c</i> ; Baker & Allee, 1970)	Rat (Dreyer, 1975)	Rat (Said & Hegsted, 1970)	Fowl (Leveille <i>et al.</i> 1960)	Man (Rose, 1957)
Threonine	53	39	26	46	82	21
Valine	20	21	16	47	82	33
Methionine + cystine	49	26	24	43	58	46
Methionine	9	—	nd	11	22	—
Isoleucine	16	30	11	47	73	29
Leucine	23	—	1	44	81	46
Phenylalanine + tyrosine	37	—	14	53	57	46
Phenylalanine	18	21	nd	31	19	—
Lysine	36	25	10	34	0	33
Histidine	nd	—	3	22	0	nd
Arginine	nd	—	nd	nd	81	nd
Tryptophan	11	5	4	10	10	10

nd, not determined.

(Expt 3) phenylalanine were estimated to be required per kg $W^{0.75}$ per d, but when tyrosine was supplied this requirement was reduced to 24 or 18 mg/kg $W^{0.75}$ per d, indicating that tyrosine can spare 49–51 % of the phenylalanine needed for maintenance. For tissue protein accretion the percentage was similar, 51. In the adult rat, Said & Hegsted (1970) found the replacement value of tyrosine to be 42 % for maintenance, and for the adult fowl Leveille *et al.* (1960) reported 67 %.

Considering the total needs of the growing pig for both maintenance and tissue protein accretion the two estimates given here can be recombined for any given rate of protein accretion. For the present purposes it is useful to compare the combined estimates with those in a previous study (Wang & Fuller, 1989). In that work, the final pattern was derived from the third experiment in which animals were retaining 1 g N/kg $W^{0.75}$ per d. The present results have been recalculated by adding the requirement per 1 g increase in body protein accretion to the requirement for maintenance (Expt 2). The resulting estimates are given in Table 7, together with those suggested by the Agricultural Research Council (1981). It is evident that the three patterns are broadly similar, but there are discrepancies of up to 15 % amongst them.

Concerning the extent to which cyst(e)ine can substitute for methionine in supplying total S amino acid needs, the combined estimates suggest a value of 54 %, very similar to the value of 56 % reported by Baker *et al.* (1966*c*). Mitchell *et al.* (1968) reported that maximum growth rates were maintained with diets in which cystine supplied 57 and 61 % of total S amino acid needs, though they interpreted their findings to suggest that cystine can replace at least 70 % of the methionine need.

The estimate of the total phenylalanine requirement was 3.5 g/16 g N, which amounts to 49 % of the total need for the two aromatic amino acids. This estimate is very close to the value of 51 % found for young pigs by Robbins & Baker (1977), but these percentages are higher than that which tyrosine forms of total aromatic amino acids in body tissue, 42–43 % (Aumaitre & Duee, 1974; Zhang *et al.* 1986).

Table 7. Estimates of the amino acid composition of 'ideal protein' (mg/g) made in this and the previous experiments (Wang & Fuller, 1989) compared with those proposed by the Agricultural Research Council (ARC) (1981). The estimates from the present experiment are for a rate of N accretion of 1 g/kg body-weight (W)^{0.75} per d

	Present estimate	Wang & Fuller (1989)	ARC (1981)
Threonine	44	47	42
Valine	44	49	49
Methionine + cystine	35	41	35
Methionine	16	nd	nd
Isoleucine	36	39	38
Leucine	65	72	70
Phenylalanine + tyrosine	72	78	69
Phenylalanine	35	nd	nd
Lysine	59	65	70
Tryptophan	11	12	10

nd, not determined.

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