Artificial rearing of pigs

7*. Medium chain triglycerides as a dietary source of energy and their effect on live-weight gain, feed:gain ratio, carcass composition and blood lipids

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1. Pigs were weaned at 2 d of age and fed on a milk substitute at hourly intervals. They were slaughtered at 28 d of age.

2. The diets contained 730 g dried skim-milk and 270 g fat/kg dry matter (DM). Three diets were compared in which the fat was supplied as soya-bean oil (SO) (diet A), equal amounts of SO and medium-chain triglyceride (MCT) (diet H), or 246 g MCT and 24 g SO (diet I)/kg DM. In the latter diet, SO ensured that the diet had an adequate content of essential fatty acids.

3. Growth rate (2–28 d of age) was reduced ($P < 0.05$) by the high-MCT diet (diet I) compared with the medium-MCT diet (diet H), but in comparison with diet A, the differences were not significant ($P > 0.05$). The feed:gain ratio (g DM consumed/g live-weight gain) was not affected by the type of dietary lipid.

4. Diet I increased the proportion of crude protein (nitrogen × 6·25) (g/kg wet weight) in the carcass but did not increase N retention (g/d per kg live weight). The proportion of fat in the carcass was reduced, particularly by diet I ($P < 0.001$), and was inversely related to an increase mainly in the water content, and to a lesser extent, in the crude protein content of the carcass. The liver weight (g/kg live wt) was greatly increased by MCT ($P < 0.01$ or $P < 0.001$).

5. Approximately 20, 44 and 80 % of the fatty acids in the carcass of pigs on the SO, diet H and diet I respectively could not have been derived from direct deposition of the dietary fatty acids, but rather by *de novo* synthesis from carbohydrate or elongation of shorter-chain fatty acids.

6. MCT increased the concentrations in the blood, taken 1 h after feeding, of total lipid, phospholipid, cholesterol and cholesterol ester, indicating incomplete oxidation of the caprylic and capric acids in MCT by the liver, and their incorporation, after chain elongation, into plasma lipids.

Medium-chain triglycerides (MCT) are esters of glycerol and saturated fatty acids containing between six and twelve carbon atoms although in most MCT preparations $C_{8:0}$ and $C_{10:0}$fatty acids are the major components. It is well documented that MCT are readily hydrolysed and absorbed from the digestive tract, and transported to the liver via the hepatic portal vein where they are largely oxidized to CO_2 and C_2 molecules (Greenberger & Skillman, 1969; Kalser, 1971; Rothfeld, 1971).

The possibility of reducing the amount of carcass fat, or improving nitrogen utilization in the growing animal, by feeding diets containing MCT has received some attention. In rats, for example, carcass fat has been reduced and N retention or protein deposition increased (Harkins & Sarett, 1968; Aurousseau & Vermorel, 1971; Aurousseau, 1972; Aurousseau & de Groot, 1972). Allee *et al.* (1972) demonstrated in vitro that *de novo* synthesis of fatty acids in adipose tissue from young pigs was reduced when the diet contained MCT. Moreover the reduction in fatty acid synthesis was not counter-balanced by direct deposition of dietary fatty acids in the carcass as happened when tallow, maize oil or coconut oil were included in the diet. Little deposition of $C_{8:0}$ or $C_{10:0}$ fatty acids in the carcass of young pigs after feeding MCT (Baker *et al.* 1970) or little retention in tissues of ^{14}C after injection of [^{14}C]lauric acid (Miller *et al.* 1971) also confirmed rapid catabolism of these medium-chain fatty acids. The greater pancreatic lipase activity for tributyrin than for butter, coconut oil or tallow in young pigs (Frobish *et al.* 1971) indicates that MCT probably will be readily digested.

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Table 1. *Composition of experimental diets*

	Diet		
	A	H	I
Ingredients (g/kg)			
Dried skim-milk	730	730	730
Soya-bean oil	270	135	24
Medium-chain triglyceride†	0	135	246
Composition by analysis (g/kg)			
Dry matter	972	976	972
Total lipid	250	250	248
Crude protein (nitrogen × 6·25)	286	282	281
Calcium	9·5	10·4	11·2
Phosphorus	7·2	7·4	7·6
Fatty acids:			
6:0	0·0	4·2	7·7
8:0	0·1	62·4	107·3
10:0	0·1	51·2	87·8
12:0	0·4	0·5	0·8
14:0	0·7	0·6	0·5
14:1	0·1	0·1	0·0
16:0	25·5	13·4	3·6
16:1	0·5	0·4	0·3
18:0	10·6	5·5	1·4
18:1	58·5	29·3	7·1
18:2	122·4	55·5	9·8
18:3	15·1	8·0	1·5
20:0	0·7	0·5	0·2
20:1	0·5	0·5	0·0

† Prices Chemicals Ltd, Bromborough, Cheshire.

Previous studies with pigs weaned at 2 d of age showed that although excellent growth and feed:gain ratios were obtained when soya-bean oil replaced butterfat in a milk diet approximately 50% of the carcass dry matter (DM) was lipid at 28 d of age (Braude & Newport, 1973). Although the effect of this high lipid content in the carcass at 28 d of age on carcass quality at pork or bacon weight has not been investigated, a reduction in the lipid content of the young pig may be desirable. The possibility of achieving this, but maintaining similar growth rates, by the substitution of soya-bean oil with MCT in the diet of pigs weaned at 2 d of age has now been studied.

EXPERIMENTAL

Experimental design

Litter-mate 2-d-old pigs were allocated to one of four diets (treatments) described later on the basis of live weight and sex. Pigs on each of the diets were housed in a separate room in semi-isolation from the remainder (Braude *et al.* 1970). Each room contained four pigs. The procedure was repeated three times to give a total of twelve pigs/treatment in the growth experiment, from which eight pigs/treatment (selected from replicates in which no pigs had died) were used for carcass and blood lipid analyses. The pigs were on experiment from 2 to 28 d of age.

Diets and method of feeding

Three diets were prepared by spray-drying mixtures of skim-milk with either soya-bean oil (diet A), or mixtures of soya-bean oil and MCT (diets H and I). A fourth diet was also prepared in which MCT was intended to be the only source of lipid. Unfortunately, analysis of the diet after completing the experiment showed that there were contamination with 10–20 g soya-bean oil/kg diet and therefore the results from this diet were discarded. The conditions of the spray-drying were carefully controlled to prevent denaturation of the whey protein and the non-casein-N content of the diets was 180–200 g/kg total N. All diets contained 14 mg butylated hydroxytoluene/kg as an antioxidant. The composition of the diets is given in Table 1.

Liquid diets were reconstituted from the powders as described by Braude & Newport (1973) and supplemented with 0·6 mg retinol, 5 μg cholecalciferol, 1·65 mg α-tocopherol and 62 μg menapthone per kg DM. The pigs were fed at hourly intervals according to live weight (Braude & Newport, 1973).

Experimental routine, N retention and procedure at slaughter

The same experimental routine as described by Braude *et al.* (1970) was followed except that the feeding equipment was cleaned and refilled with fresh diet once, instead of twice, daily. Faeces were not collected in the study of N retention as faecal N was assumed to be negligible (Braude *et al.* 1976). Urine was collected daily, into 25 ml glacial acetic acid, from pigs, 10–14 d of age. Scouring and spillage of diet into urine limited N retention studies to five or six pigs/treatment. Pigs were killed at 28 d of age, 1 h after a feed, by an intracardiac injection of 10 ml aqueous sodium pentobarbitone (30 mg/ml). Blood (20 ml) was withdrawn immediately into a heparinized tube and centrifuged to separate the plasma. The alimentary tract and the liver were removed, the liver weighed and stored with the carcass at $-20°$. The frozen carcass and liver were minced, and a portion homogenized and freeze-dried as described by Florence & Mitchell (1972).

Analytical methods

DM was determined by heating samples at 100–105° to constant weight, total N by digestion in 3 ml concentrated sulphuric acid, with 0·05 g yellow mercuric oxide as catalyst followed by N concentration estimation with alkaline phenate in an AutoAnalyzer (Technicon Instruments Co. Ltd), non-casein-N by the method of Rowland (1938) and ash as the residue remaining after heating at 540° for 17 h. Samples of the diets were also ashed before determination of calcium by atomic absorption spectroscopy, and phosphorus by colorimetric estimation of the phosphovanadomolybdate complex as described by Cavell (1955).

Total lipid in blood plasma, freeze-dried carcass samples and diets was extracted in chloroform-methanol (2:1, v/v), followed by washing the extract with 8·8 g potassium chloride/l water (Brumby *et al.* 1972) and weighing the dried extract finally recovered from the chloroform layer. Plasma lipid composition was determined by thin-layer chromatography and chemical determination (Tuckley & Storry, 1974; Brumby *et al.* 1975).

Compositions of carcass and dietary fatty acids were determined by gas-liquid chromatography (Hewlett Packard Model 7620 A) of methyl esters. The following conditions were used to determine carcass fatty acids. A known weight of $C_{17:0}$ fatty acid was added to a known weight of extracted lipid and the mixture saponified with 20 g potassium hydroxide/l water–propan-2-ol–ethanol (5:47·5:47·5, by vol) for 90 min at 90°. After drying the saponified mixture under N_2 at 60°, 3 ml water was added and the mixture washed twice with 10 ml pentane. Concentrated hydrochloric acid (0·5 ml) was then added to the washed

Table 2. *Live-weight gain (g/d), feed:gain ratio (kg dry matter consumed/kg gain) and N retention (g/d per kg live weight) of pigs given a milk substitute containing soya-bean oil or mixtures of soya-bean oil and medium-chain triglycerides (MCT)*

(Mean values for twelve pigs/treatment)

	Diet†			SEM	df	Statistical significance of differences between diets
	A	H	I			
MCT (g/kg diet) ...	—	135	246	—	—	—
Soya-bean oil (g/kg diet)	270	135	24	—	—	—
2–7 d of age						
Live-weight gain	169	177	144	12·0	20	NS
Feed:gain	0·73	0·64	0·78	0·064	20	NS
2–28 d of age						
Live-weight gain	328	342	311	8·5	19	H > I*
Feed:gain	0·87	0·83	0·85	0·018	19	NS
N retention‡	2·20±0·262	2·02±0·272	2·17±0·050	—	—	NS

Two pigs given diet A died before 7 d of age, and one pig given diet I died after 7 d of age. Missing values were calculated.

NS, not significant ($P > 0.05$).

* $P < 0.05$.

† For details of diet composition, see Table 1.

‡ Values for six (diets A and H) or five (diet I) pigs.

solution of fatty acid salts and the released fatty acids extracted by shaking with 10 ml diethyl ether. Approximately 90 % of the diethyl ether extract was then transferred to a freeze-drying ampoule, evaporated under N_2 at 30° until just dry and 1 ml methanol containing 2 ml HCl/l was added. After cooling in ice for 3 min the ampoule was sealed and heated at 100° for 20 min. The gas–liquid chromatography of prepared methyl esters was carried out using 100 g Silar 5CP/kg (Field Instruments Ltd, Twickenham, Middlesex), 100–120 mesh Diatomite C (J.J.'s Chromatography Ltd, King's Lynn, Norfolk) and temperature programming over the range 100–210°.

For determinations of dietary fatty acids the following double methylation and gas–liquid chromatography procedures were used. Approximately 40 mg of the total lipid extract (shown by thin-layer chromatography to be virtually all triglyceride) was heated in a sealed ampoule at 100° for 60 min with 1 ml 0·025 M-sodium methoxide. The ampoule was then opened, 0·1 ml methanol containing 35 ml HCl/l added, and the ampoule resealed and reheated for 20 min at 100°. The methyl esters were separated using 200 g polyethylene glycol adipate/kg stationary phase and temperature programming from 80–200°.

RESULTS

Live-weight gain, feed:gain ratio and N retention

Replacing half the soya-bean oil in the diet by MCT did not affect growth rate during the experiment from 2 to 28 d of age, but when 90 % of dietary lipid was supplied by MCT (diet I) there was a significant ($P < 0.05$) reduction in growth rate (Table 2). Up to 7 d of age, growth rate was reduced and feed:gain ratio was worse in pigs given diet I, but the differences were not significant ($P > 0.05$) in comparison with the other two diets. Up to 28 d of age, the feed:gain ratio was not affected by any of the diets. There was no significant effect ($P > 0.05$) of diet on N retention (g/d per kg live-weight) estimated at 12 d of age.

Table 3. *Weight and composition of carcass, and weight of liver of pigs given a milk substitute containing soya-bean oil, or mixtures of soya-bean oil and medium-chain triglycerides (MCT)*

(Mean values for eight pigs/treatment)

	Diet†			SEM	Statistical significances of
	A	H	I	(14 df)	differences between diets
MCT (g/kg diet) ...	—	135	246	—	—
Soya-bean oil (g/kg diet)	270	135	24	—	—
Carcass weight (kg)	9·67	9·76	8·74	0·219	A, H > I**
Water (g/kg)	636·7	645·7	678·3	4·44	I > A, H***
Fat (g/kg)	145·3	137·4	109·1	5·94	A > I***; H > I**
Crude protein (nitrogen × 6·25) (g/kg)	142·2	145·5	150·3	2·07	I > A*
Ash (g/kg)	34·7	35·2	33·2	0·88	NS
Liver weight (g/kg live weight)	37·4	43·3	54·4	1·30	I > A, H***; H > A**

NS, not significant ($P > 0.05$).
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.
† For details of diet composition, see Table 1.

Carcass composition and liver weight

The weight of carcasses and livers, and the chemical composition of the carcasses are given in Table 3. The effect of diet on carcass weight was similar to the effect on live-weight gain, and the carcass weight of the pigs given diet I (high-MCT) was lower ($P < 0.01$) than that of pigs receiving the other two diets. The weight of liver from pigs given the diets containing MCT (diets H and I) were all significantly greater ($P < 0.01$ or $P < 0.001$) than those from pigs given soya-bean oil alone (diet A). Pigs receiving diet I had significantly greater liver weights than pigs receiving only 50 % of the dietary lipid as MCT (diet H).

Carcass composition was influenced by dietary treatment, and there were major changes in the lipid and water components which varied inversely with each other. Carcasses of pigs receiving diet I had significantly ($P < 0.001$) lower lipid and higher water contents than those from pigs receiving diet H and diet A. There was also a small increase in the proportion of crude protein (N × 6·25) in the carcasses of pigs given diet I.

The amount of total and individual fatty acids in the carcass is shown in Table 4. The composition of the dietary lipid did not affect the total amounts of fatty acids in the carcass, the majority of which were accounted for by $C_{16:0}$, $C_{18:0}$ and $C_{18:1}$. The amount of $C_{18:0}$ was increased ($P < 0.01$ or $P < 0.001$) when the diet contained MCT, but the amounts of $C_{16:0}$ and $C_{18:1}$ were not affected by the composition of the dietary lipid. Although the total intakes of $C_{8:0}$ and $C_{10:0}$ were considerable in the pigs given the diets containing MCT (Table 5), little of these two fatty acids were found in the carcass. The amount of $C_{10:0}$ was, however, greater ($P < 0.001$) in pigs fed on diets containing MCT.

Concentrations of plasma lipids

The concentrations in blood plasma of total lipid, triglyceride, free fatty acids, cholesterol, cholesteryl ester and phospholipid are given in Table 6. Apart from the statistically significant differences between treatments indicated there appeared to be some over-all trends in the concentration of the various lipid fractions in association with the level of MCT in the diet. Total lipid, cholesteryl, cholesterol ester and phospholipid increased progressively with increased dietary level of MCT. The concentration of plasma free fatty acids was reduced when the diet contained MCT. There was no consistent effect of dietary MCT on plasma

Table 4. *Total (g) and major individual fatty acids (g) in the carcass of 28-d-old pigs given a milk substitute containing soya-bean oil, or mixtures of soya-bean oil and medium-chain triglycerides (MCT)*

(Mean values for eight pigs/treatment)

	Diet†			SEM (14 df)	Statistical significance of differences between diets
	A	H	I		
MCT (g/kg diet) ...	—	135	246	—	—
Soya-bean oil (g/kg diet)	270	135	24	—	—
Fatty acids:					
6:0	4·3	1·0	0·0	0·503	A > H, I***
8:0	1·1	1·5	0·3	0·369	H > I*
10:0	3·6	19·3	18·6	2·192	A < H, I***
12:0	1·6	5·4	6·4	0·552	A < H, I***
14:0	12·7	20·9	26·5	1·754	A < H**, I***; H < I*
14:1	4·7	1·8	0·6	0·909	A > H*, I**
16:0	268·2	286·9	258·6	17·958	NS
16:1	12·8	15·9	18·6	1·949	A < I*
18:0	112·5	171·7	189·9	14·426	A < H**, I***
18:1	154·9	181·5	156·2	17·901	NS
18:2	6·3	7·8	4·5	2·063	NS
18:3	2·0	1·8	0·2	0·461	A > I**; H > I*
20:0	7·5	7·3	5·1	0·678	I < A, H*
20:1	11·3	10·4	8·8	0·716	A > I*
Total	712·2	827·5	714·7	55·396	NS

NS, not significant ($P > 0.05$).
* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.
† For details of diet composition, see Table 1.

Table 5. *Total intakes of fatty acids (g) of pigs during a 26 d experiment when they were given a milk substitute containing soya-bean oil, or mixtures of soya-bean oil and medium-chain triglycerides (MCT)*

	Diet†		
	A	H	I
MCT (g/kg diet) ...	—	135	246
Soya-bean oil (g/kg diet)	270	135	24
Fatty acids			
6:0	0·0	31·1	53·4
8:0	6·0	462·2	740·0
10:0	0·8	379·3	608·3
12:0	3·0	3·7	5·5
14:0	5·3	4·4	3·5
14:1	0·8	0·7	0·0
16:0	191·3	99·3	24·9
16:1	3·8	3·0	2·0
18:0	79·5	40·8	9·7
18:1	438·8	217·1	49·1
18:2	918·0	411·1	67·9
18:3	113·3	55·5	10·4
20:0	5·3	3·7	1·4
20:1	3·8	3·7	0·0
Total	1858·9	1719·4	1615·4

† For details of diet composition, see Table 1.

Table 6. *Blood plasma concentrations of total lipid, triglyceride, free fatty acids, cholesterol, cholesteryl ester and phospholipid of pigs given diets containing soya-bean oil or mixtures of soya-bean oil and MCT*

(Mean values for eight pigs/treatment)

	Diet†			SEM	Statistical significance of
	A	H	I	(14 df)	differences between diets
MCT (g/kg diet) ...	—	135	246	—	—
Soya-bean oil (g/kg diet)	270	135	24	—	—
Total lipid (g/l)	4·44	4·74	5·29	0·209	I > H*; I > A**
Triglyceride (g/l)	0·66	0·58	0·74	0·045	I > H**
Free fatty acid (mg/l)	81	59	62	7·0	A > H**, I*
Cholesterol (g/l)	0·29	0·36	0·44	0·017	I > A, H***; H > A***
Cholesteryl ester (g/l)	1·68	1·94	2·07	0·072	H > A**; I > A***
Phospholipid (g/l)	1·57	1·85	2·27	0·090	I > A***, H**; H > A*

* $P < 0·05$, ** $P < 0·01$, *** $P < 0·001$.
† For details of diet composition, see Table 1.

triglyceride concentrations, although higher values ($P < 0·01$) were obtained from diet I compared with the diet H.

DISCUSSION

Growth rate was reduced when 90 % of the lipid was supplied by MCT. The effect of diet I (high-MCT) could not have been due to a deficiency of essential fatty acids as the soya-bean oil in the diet would have met the requirement (Hill *et al.* 1961; Leat, 1962, 1963).

The efficiency of N retention was not improved when MCT replaced soya-bean oil in the diet (diets I and H), and although the proportion of crude protein in the carcass was significantly ($P < 0·05$) increased by diet I, this increase was quite small. These results do not support those for rats (Aurosseau & Vermorel, 1971; Aurousseau, 1972; Aurosseau & de Groot, 1972) where MCT was found to improve the efficiency of N retention estimated by balance studies or carcass analysis and may reflect differences between species or experimental conditions in that in their experiments MCT replaced starch rather than long-chain fatty acids in the diet. Although the high-MCT diet reduced the total lipid content of the carcass there was no statistically significant effect on the content of total fatty acids. This probably indicated that the carcasses of pigs on the diet I (high-MCT) contained less of the complex lipids such as phospholipids, cholesteryl esters or free cholesterol.

The smaller amount of total fatty acids in the carcasses compared with the amounts ingested indicate that at least half the dietary fatty acids were catabolized irrespective of the source of dietary fat. Virtually no $C_{8:0}$ and $C_{10:0}$ acids from the MCT were deposited directly in the carcass, thus confirming findings of Baker *et al.* (1970). A notable feature was that the amounts of $C_{14:0}$, $C_{16:0}$, $C_{18:0}$, $C_{20:0}$ and $C_{20:1}$ fatty acids in the carcasses of pigs on all diets exceeded their corresponding dietary intakes and this applied also for $C_{18:1}$ in the carcasses of pigs receiving diet I. This excess over dietary intake of particular fatty acids in the carcasses must have resulted from *de novo* synthesis of fatty acids from dietary carbohydrate (lactose) or from elongation of shorter-chain acids from the MCT or soya-bean oil.

The marked increase in liver weight, of up to 46 %, when soya-bean oil was replaced by MCT, indicates an increased liver metabolism of pigs receiving the MCT diet. Since there was little difference between diets in the over-all amounts of fatty acid catabolized it seems unlikely that fatty acid oxidation would be contributing to an increased liver metabolism,

unless sites for long-and short-chain fatty acid oxidation differed. More likely contributory metabolic processes are the *de novo* synthesis and chain elongation of fatty acids and synthesis of plasma lipids. If the amounts of each individual fatty acid consumed (Table 5) and deposited in the carcass (Table 4) are compared, then approximately 140 (20 %), 360 (44 %) and 570 g (80 %) of the fatty acids in the carcasses of pigs receiving diets A, H and I respectively could not be accounted for directly from dietary fatty acids as there was more deposited in the carcass than consumed. Also, increased levels of plasma lipids, particularly cholesterol, cholesteryl esters and phospholipids were observed. Consistent effects of MCT on liver weight have not been found in studies with rats. For example Saxena *et al.* (1972) reported an increase of 10 %, whereas Harkins & Sarett (1968) found no effect. It is of interest in relation to the present experiments that increased energy and N contents in livers of rats given $C_{10:0}$ have also recently been observed (Chenat *et al.* 1976).

The effects of the various diets on blood lipid concentrations need considering in relation to certain aspects of the absorption and hepatic metabolism of MCT and the types of dietary lipid used in the present experiment. First the diets ranged from wholly polyunsaturated soya-bean oil on the one hand to mainly saturated MCT on the other, and all the diets contained virtually no cholesterol. Secondly blood samples were taken 1 h after feeding when there would be more rapid absorption and hepatic uptake of medium rather than long-chain fatty acids (Babayan, 1974). Although it has been shown that the liver oxidizes medium-chain saturated and long-chain unsaturated fatty acids more rapidly than long-chain saturated fatty acids (Kohout *et al.* 1971) it is possible that in the present experiment the uptake of fatty acids by liver on the MCT diets exceeded its capacity for catabolism thus resulting in their elongation to long-chain fatty acids. The need to transport these synthesized long-chain saturated fatty acids as lipoproteins from the liver would require increased biosynthesis and secretion of cholesterol and phospholipids (Kohout *et al.* 1971). Such a hypothesis is consistent with the increased levels of blood lipids observed during the present experiment in pigs receiving the diet I (high-MCT). More detailed metabolic studies with sequential blood sampling and a range of MCT intakes are required to substantiate these possibilities.

In conclusion it would appear that, although there is a reduction in the proportion of lipid in the carcass, substitution of MCT for soya-bean oil in the diet offers little possibility of improving performance or N retention. The effect of the amount of lipid in the carcass of the very young pig on the proportion of fat in the carcass at pork or bacon weight remains to be studied. A further possibility remains in that the diets used in this experiment may have contained energy in excess of the requirement of the pig, and that in a diet with a marginal energy content the inclusion of MCT might improve performance and N retention.

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