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PERSISTENT OBESITY IN RATS FOLLOWING A PERIOD OF CONSUMPTION OF A MIXED, HIGH ENERGY DIET

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SUMMARY

1. Adult male hooded rats which were offered a mixed, high energy diet for 90 days were hyperphagic and became significantly obese compared to chow-fed control rats. Fasting plasma insulin and glucose levels were initially elevated in the experimental rats, but later in the 90 day period were similar to control levels.

2. When the high energy foods were withdrawn after 90 days and just chow was available, the obese rats maintained the elevated body weights. The obese rats were initially hypophagic, but chow intakes rapidly reached control levels. Plasma insulin and glucose levels were similar in both groups, suggesting that the persisting obesity may not be associated with altered insulin resistance.

3. Five weeks after withdrawal of the 'fattening' diet, half of the experimental rats were offered restricted access to chow for 27 days to reduce their weights to control levels. When the rats were again given free access to chow, they returned to the previously elevated weight.

4. Eighteen weeks after withdrawal of the 'fattening' diet, the experimental rats had significantly elevated body weights and fat stores. The elevated body weight was not simply due to increased growth because, although the experimental rats had slightly more lean body mass than the control rats, the increase in fat was not related to body size.

INTRODUCTION

The regulation of energy intake and energy expenditure leads to the maintenance of body composition in relatively stable proportions. Rats can compensate for changes in the energy density of food by complementary changes in the quantity consumed (Snowdon, 1969), and can select the appropriate nutrients from a variety of foods to maintain a balanced diet (Epstein, 1967). Indeed, rats adjust energy intake to changes in energy expenditure by dietary selection; active rats consume proportionally more carbohydrate and fat and proportionally less protein than sedentary rats (Collier, Leshner & Squibb, 1969). However, changes in body composition can be induced in intact rats by manipulating the composition and palatability of the diet over long periods. Rats ingest excess energy and become obese when offered a diet high in either fat (Mickelson, Takahashi & Craig, 1955), or carbohydrate

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(Kanarek & Hirsch, 1977). Provision of a variety of palatable supermarket foods over long periods appears to be a most effective way of inducing overeating, and produces greater weight gains than the use of high fat diets (Sclafani & Springer, 1976) or high carbohydrate diets (B. J. Rolls & E. A. Rowe, unpublished observation). The increase in weight resulting from dietary manipulation reflects an increased storage of fat with only slight increases in lean body mass (Pitts & Bull, 1977; Schemmel, Mickelson & Tolgay, 1969).

In previous studies of dietary obesity withdrawal of the 'fattening' diet led to loss of weight to control levels (Peckham, Entenman & Carroll, 1962; Sclafani & Springer, 1976). This finding has been used to support the hypothesis that body fat storage is maintained at a stable level and that deviations from this level, as in the obese animal, lead to appropriate adjustments of energy intake and energy output (Friedman & Stricker, 1976). This hypothesis originated from an experiment by Cohn & Joseph (1962) in which rats fattened by force feeding stopped eating on termination of the force feeding until they had returned to the weights of control rats. It was noted, however, that although rats kept at 27 °C lost appropriate amounts of weight, the experimental rats had greater proportion of body fat than the control rats. This finding questions the generality of the reversibility of dietary obesity and the regulation of fat stores.

The present study examined the extent to which normal body weight and body composition are reinstated after a 90 day period of consumption of a palatable, high energy, supermarket diet. Energy intake was measured during the development of obesity and after withdrawal of the palatable foods to determine whether the 'fattened' rats showed compensatory hypophagia after withdrawal of the mixed diet with respect to their intakes during the 'fattening' period, and to the intakes of the control animals. When it was found that the obese rats maintained the elevated body weight, a period of forced weight reduction through dietary restriction was imposed to determine whether such dieting would reverse the obesity.

Both insulin and glucose have been implicated in the control of feeding (Friedman & Stricker, 1976; Le Magnen, 1976). Elevated levels of insulin are associated with hyperphagia and obesity in genetically obese animals and in animals rendered obese by lesions in the ventromedial hypothalamus. Resting plasma insulin and glucose levels were measured periodically to determine whether the development of dietary obesity is associated with elevated plasma insulin and glucose levels, and whether differences between the experimental and control rats are eliminated by removal of the mixed diet. At the end of the experiment the carcasses were analysed to determine whether there were persistent differences in the amount of fat storage between the experimental and control rats. Because rats which have grown to a greater size may have greater fat stores than smaller rats (Schemmel, Mickelson & Tolgay, 1969) the relationship between fat free solids and fat was examined in the carcasses of both groups.

A short report on this subject, but in a different group of rats, has been presented to the Physiological Society (Rolls & Rowe, 1977).

METHODS

Subjects

Twenty-three male hooded Lister rats, 10–12 weeks of age, were matched for body weight and allocated to the experimental group (n = 13, 267–342 g) which received the palatable diet for a 'fattening' period, and the control group which received only chow (n = 10, 236–364 g). Later both the experimental and control groups were allocated to a period of restricted or normal access to chow, in sub-groups matched for body weight (experimental normal access, 488–588 g, n = 7; experimental restricted access, 508–618 g, n = 6; control normal access, 377–538, n = 6; control restricted access, 452–556 g, n = 4).

TABLE 1. Energy content and gross composition of foods in the mixed diet

	Digestible energy (kJ/g)	% composition (gross)		
		Protein	Carbohydrate	Fat
Potato crisps	23·4	5·9	50·0	38·0
Chocolate chip cookies	20·3	4·8	63·6	25·2
Cheese crackers	22·6	10·9	50·6	32·6
Chow	16·3	15·8	51·4	2·0

Procedure

The rats were individually housed in small metal cages (34 × 15 × 13·5 cm) in conditions of controlled lighting (12 hr light, 12 hr dark) and temperature (24 ± 1·5 °C.) All animals received free access to water, and access to chow according to the conditions imposed. Groups of animals were subject to successive periods of dietary manipulation. For the first 90 days the rats received either free access to chow plus a palatable energy-rich diet or only chow (Dixons FFG (M)). The palatable diet included three supermarket foods (plain salted potato crisps (Golden Wonder), chocolate chip cookies (Maryland Cookies, Lyons), and cheese crackers (Crawford's)). All of the foods were scattered on the floor of the cage. The approximate energy contents and compositions of the foods are shown in Table 1.

After 90 days the palatable diet was withdrawn and both the experimental and control animals received free access to chow. Thirty-one days after the palatable diet was withdrawn, the experimental and control groups were each divided into two subgroups, which either continued to receive free access to chow, or were restricted to 15 g chow each day for a period of 27 days. Then all animals were again offered free access to chow for 66 days when the experiment was terminated.

Body weights were recorded regularly throughout the experiment. Growth was estimated at the beginning and end of the experiment by measurements of skeletal size. Rats were lightly anaesthetized with ether and the naso-anal lengths were measured on a calibrated platform (Hughes & Tanner, 1970). It is possible, however, that the values for naso-anal length do not accurately reflect skeletal length in obese animals because accumulated fat around the base of the tail may cause a falsely extended measurement on the platform (Schemmel, Mickelson & Tolgay, 1969). Girths were also measured.

Food intake measurements

Energy intakes over 24 hr were estimated by measuring the amount of each food consumed. Food intakes were corrected for spillage which was collected by suspending a paper trap beneath each cage. After drying, the amounts of spillage of each food were determined. Determinations were made before the beginning, and then 2, 5, and 8 weeks after the beginning of the 'fattening' period, and on the 6 successive days immediately before the end of this period. Then intakes of chow were measured daily for 12 days immediately after withdrawing the mixed diet; over 1 day immediately before the dietary restriction period; for 1 week after dietary restriction; and over 1 day at the end of the experiment.

Insulin and glucose determinations

Fasting plasma levels of insulin and glucose were determined from blood collected from the tails of unanaesthetized rats at 3·15–4·15 p.m. after 7 hr of food deprivation. Blood samples were collected before the beginning of the 'fattening' period; 3, 6, 9 and 11 weeks after the beginning of this period; 2 weeks after the mixed diet was withdrawn; during the latter part of dietary restriction when the rats' weights were stable; and at the end of the experiment. Plasma glucose was measured manually using glucose-oxidase (Boehringer, GOD-period), and plasma insulin using charcoal phase separation (Albano, Ekins, Maritz & Turner, 1972) with Wellcome anti-insulin serum and Novo rat immunoreactive insulin standard. Haemolysis gives spuriously low values, and haemolysed samples were not assayed.

Estimation of body composition

Body composition was estimated at the end of the experiment by determining the water content of the carcasses by oven drying at 95 °C for 6–9 days until constant weight was reached. Then the fat content was determined by successive extractions with petroleum ether at room temperature until constant weight was reached (Han & Young, 1964).

Statistics

Weekly measurements of body weight were analysed by an analysis of variance with dietary condition, dietary restriction, and time (weeks) as factors, separate analyses being conducted for the 'fattening' period and after the withdrawal of the high energy foods. Group comparisons were made using the appropriate error term from the analysis of variance. Rates of weight gain were examined by analysis of variance of the regression coefficients (with time). Energy intakes and plasma insulin and glucose levels were similarly analysed. Regression coefficients between the amounts of fat-free solids and fat in the carcasses were determined by the method of least squares.

Single comparisons between groups for body measurements and body composition were made using the Student's t test (two-tailed).

RESULTS

Body weights

The mean body weights are shown weekly for the experimental and control groups (Fig. 1*B*). The animals receiving the mixed diet became significantly heavier than the controls during the 'fattening' period ($F = 19{\cdot}7$; 1, 22; $P < 0{\cdot}01$). At the end of the 'fattening' period the experimental rats weighed a mean of 95 g more than the control rats ($t = 5{\cdot}7$, 21, $P < 0{\cdot}001$), and the body weights of the experimental rats had increased by 60–108 % compared to their weights when the mixed diet was introduced, while the control rats increased by 42–80 % in the same period. Only one of the experimental rats failed to gain more weight than the control rats during the 'fattening' period.

After withdrawal of the mixed diet, individual animals exhibited small gains or losses of weight which are reflected in the slight reduction in the experimental group mean. This stabilized after 2 weeks (Fig. 2). Changes in body weight during this period were not related to the body weights or percentage weight gains of the experimental rats at the end of the 'fattening' period ($r = 0{\cdot}14$, n.s.). The control rats continued to increase in weight in the period before the dietary restriction experiment, reducing the difference in weight between the experimental and control groups to a mean of 65 g. However, after 5 weeks the experimental animals receiving free access to chow began to increase in weight, and at the end of the experiment,

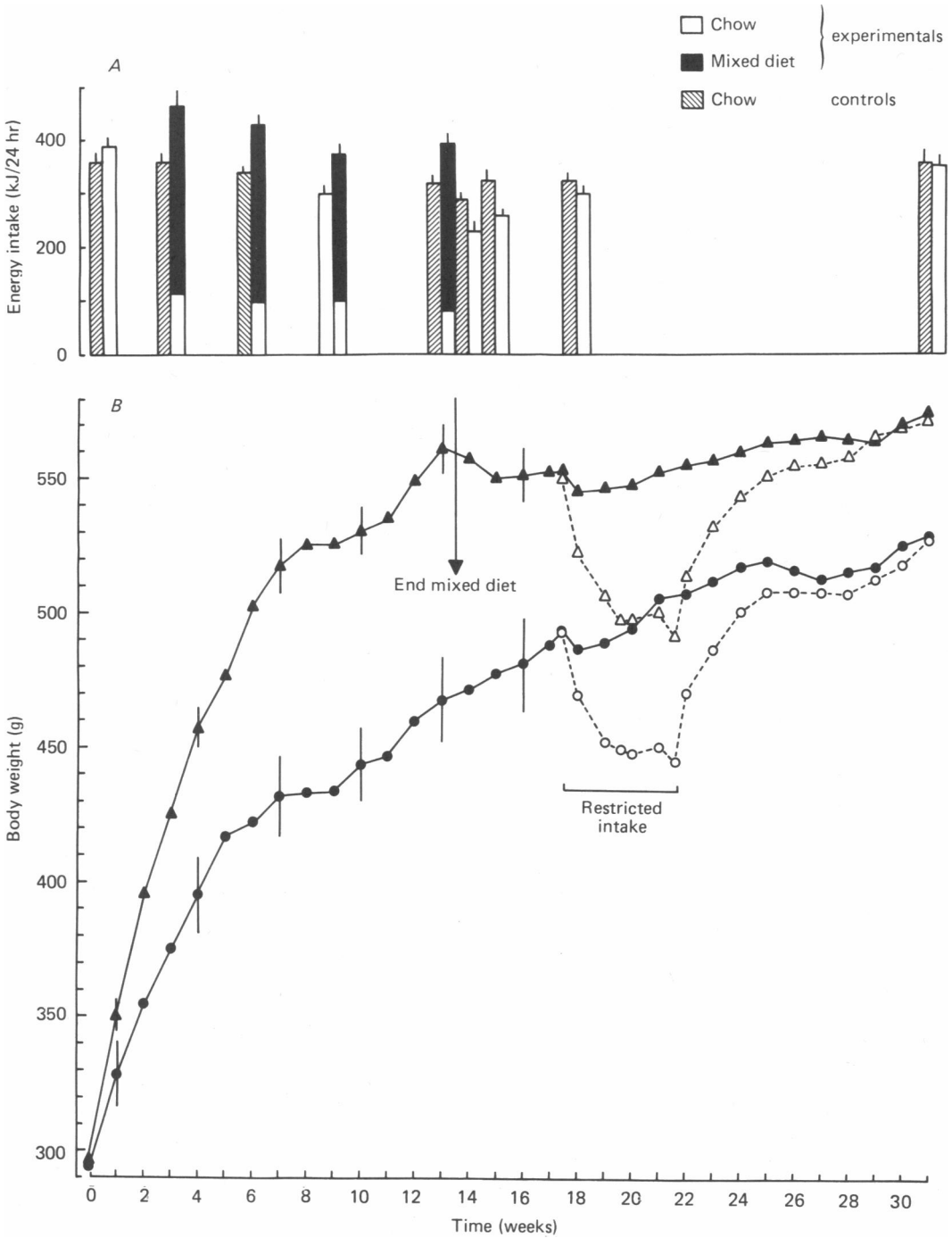

Fig. 1. *A*, mean energy intakes for the experimental (n = 13) and control groups (n = 10) before the mixed diet was offered, while the mixed diet was offered, and after the mixed diet was withdrawn. Vertical bars indicate the standard error of the mean. *B*, mean body weights for the experimental (▲, n = 13) and control groups (●, n = 10) while the mixed diet was offered, after the mixed diet was withdrawn, and in response to dietary restriction. The open symbols (△, ○) indicate the sub-groups which were subject to dietary restriction. Vertical bars indicate the standard error of the mean.

eighteen weeks after withdrawal of the mixed diet, the experimental animals remained significantly heavier than the controls ($t = 2{\cdot}2$, 21, $P < 0{\cdot}05$).

The animals which were allocated to restricted and unrestricted access to chow had similar energy intakes and weight gains both during the 'fattening' period and when both experimental and control groups were on free access to chow alone. During

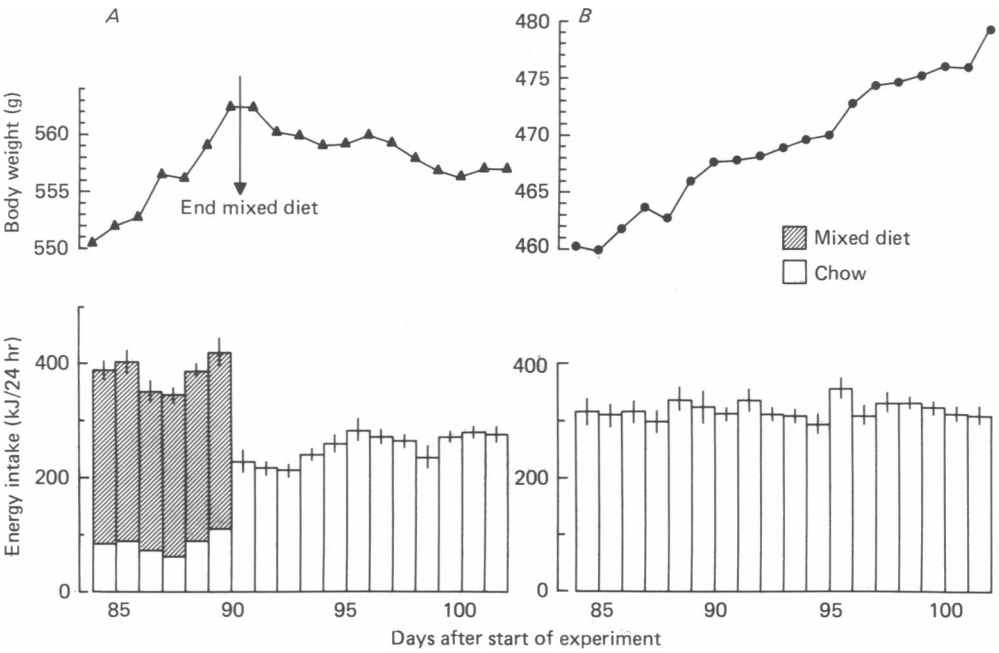

Fig. 2. Mean daily body weights (above) and food intakes (mean ± S.E., below) for the 6 days before the mixed diet was withdrawn, and for the subsequent 12 days, for the experimental group (*A*) and control group (*B*).

dietary restriction, the body weights of the experimental restricted-food subgroup were reduced to the weights of the unrestricted control rats over 16 days, and then kept at this level for a further 11 days (Fig. 1*B*) even while eating 15 g of chow per day. When the restricted subgroups were allowed free access to chow, they rapidly regained their lost weight and both experimental and control animals reached their pre-restriction weights in 5 weeks and then their body weights continued to be similar to their relevant subgroups which had not had a period of dietary restriction.

Food intakes

The energy consumed by the experimental and control groups during the 'fattening' period is shown in Fig. 1*A*. Both groups consumed the same weight of food but because the mixed diet was more energy dense (Table 1), the experimental rats had a greater energy intake (Figs. 1*A* and 2) ($F = 12{\cdot}4$; 1, 22; $P < 0{\cdot}01$). This is consistent with their greater weight gain. The food with the highest carbohydrate content (chocolate chip cookies) accounted for approximately 60% of the supermarket food

consumed, the remaining 40% being the foods with the highest fat content (potato crisps and cheese crackers). The approximate nutrient intakes during the 'fattening' period as a percentage of total intake by weight were: experimental rats (protein 9%, carbohydrate 58%, fat 21%); control rats (protein 16%, carbohydrate 51%, fat 2%). The approximate nutrient intakes during the 'fattening' period as a percentage of energy intake were: experimental rats (protein 10·5%, carbohydrate 47·5%, fat 42%); control rats (protein 29·1%, carbohydrate 64·7%, fat 6·2%).

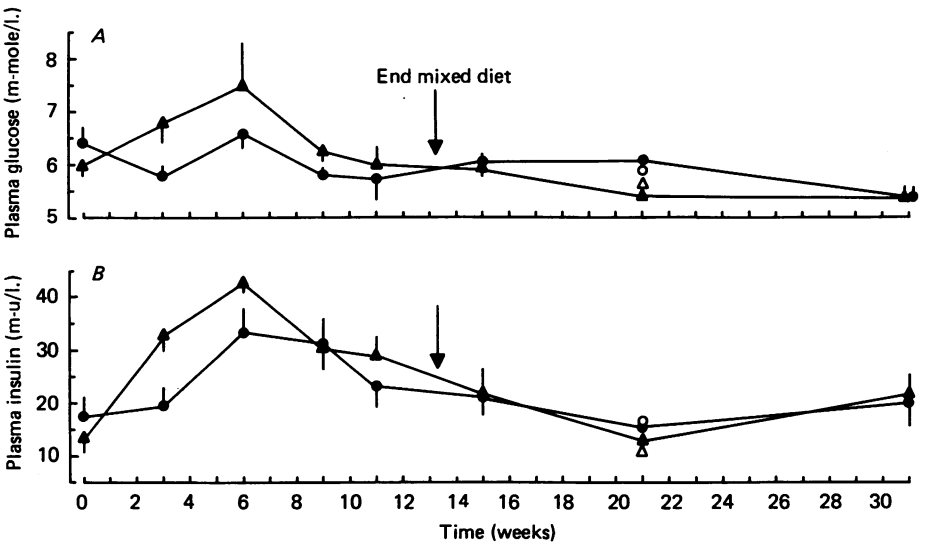

Fig. 3. *A*, mean (± S.E.) plasma glucose concentrations for the experimental (▲, $n = 13$) and control (●, $n = 10$) groups before the mixed diet was offered, while the mixed diet was offered, and after the mixed diet was withdrawn. *B*, mean (± S.E.) plasma insulin concentrations for the experimental (▲, $n = 13$) and control (●, $n = 10$) groups before the mixed diet was offered, while the mixed diet was offered, and after the mixed diet was withdrawn.

The energy intakes of the experimental, obese rats, fell significantly when the mixed diet was withdrawn ($P < 0·02$) to a level below the intake of the control group (Fig. 2). The intakes of the experimental group then progressively increased over the first 12 days after the withdrawal of the mixed diet, and comparisons of the daily group means revealed that on days 5, 7 and 10, and thereafter there were no significant differences between the intakes of the experimental and control groups. The food intakes of the experimental and control rats were also similar at the end of the experiment.

On the first day after the termination of the dietary restriction, the restricted experimental and control subgroups consumed significantly more chow than the non-restricted subgroups ($P < 0·001$) and they continued to consume slightly but not significantly more than the non-restricted subgroups during the next 6 days. There were no significant differences between the intakes of the two restricted subgroups.

Plasma insulin and glucose

The mean plasma levels of insulin and glucose are shown in Fig. 3*B* and *A*. Before the experiment there were no significant differences between the experimental and control rats in insulin or glucose levels. Three and 6 weeks after the beginning of the 'fattening' period, the experimental animals had significantly higher insulin levels than the control animals ($t = 2{\cdot}9$, 21, $P < 0{\cdot}01$; $t = 2{\cdot}2$, 21, $P < 0{\cdot}05$, respectively), but there was no significant difference at the two subsequent time points in the 'fattening' period. Although at individual time points there was no difference in plasma glucose concentrations, over the entire 'fattening' period, the glucose levels were greater in the experimental than the control rats ($F = 4{\cdot}3$; 1,18; $P < 0{\cdot}05$).

Two weeks after withdrawing the mixed diet there were no significant differences in the plasma insulin or glucose levels of the experimental and control rats. Because some samples taken during the dietary restriction period were haemolysed, no comparisons have been made for this period. At the end of the experiment there were no differences in the plasma levels of insulin or glucose between the experimental and control rats.

Body measurements and body composition

Body measurements taken before the mixed diet was offered showed that there was no significant difference in naso-anal length or girth between the experimental and control rats. At the end of the experiment, 18 weeks after the mixed diet was withdrawn, the experimental rats had significantly greater girths than the control rats ($t = 2{\cdot}5$, 21, $P < 0{\cdot}01$) (Table 2), whereas the naso-anal lengths were slightly, but not significantly, greater than the naso-anal lengths of the control rats. This difference in length may simply reflect the greater amount of subcutaneous fat in the experimental rats (see Methods section). There was a slight, but insignificant, increase in the amount of fat free solids and water. However, the experimental rats had significantly greater amounts of fat ($t = 2{\cdot}7$, 21, $P < 0{\cdot}02$) and significantly more fat as a percentage of body weight than the control rats ($t = 2{\cdot}5$, 21, $P < 0{\cdot}02$) (Table 2). The disproportionate increase in fat to lean body mass in the experimental rats compared to the control rats is demonstrated by the ratio of fat to fat free solids and water for the experimental rats ($0{\cdot}308 \pm 0{\cdot}015$) and for the control rats ($0{\cdot}248 \pm 0{\cdot}017$) ($t = 2{\cdot}7$, 21, $P < 0{\cdot}02$), an increase in the experimental rats of 20%. Furthermore, if the greater fat content of the experimental rats was attributable to increased growth, both groups should have a similar relationship between the amounts of fat free solids (FFS) and fat. However the coefficients of the linear regression equation between the experimental and control rats were significantly different ($t = 2{\cdot}2$, 19, $P < 0{\cdot}05$) (linear regression equation ± S.D. of the mean for the experimental group: $FAT = 143{\cdot}9\ (\pm 90{\cdot}4) - FFS \times 0{\cdot}12\ (\pm 0{\cdot}70)$; for the control group: $FAT = -123{\cdot}3\ (\pm 62{\cdot}6) + FFS \times 1{\cdot}85\ (\pm 0{\cdot}51)$. Also the amount of fat estimated from the regression lines for the same amount of fat free solids (for example 120 g) was significantly greater in the experimental rats ($129{\cdot}4 \pm 4{\cdot}8$ g) than in the control rats ($99{\cdot}1 \pm 7{\cdot}1$ g) ($t = 3{\cdot}3$, 21, $P < 0{\cdot}01$).

There were no significant differences in carcass composition between the restricted and unrestricted experimental rats or between the restricted and unrestricted control

rats. Also the non-restricted experimental rats had significantly more fat (133·6 ± 9·5 g) and a greater percentage of fat (24·1 ± 1·2 %) than the non-restricted control rats (103·7 ± 13·0 g; 20·1 ± 1·9 %) ($P < 0·05$), and the restricted experimental rats had significantly more fat (122·5 ± 7·0 g) and a greater percentage of fat (22·5 ± 1·2 %) than the restricted control rats (97·3 ± 9·5; 19·3 ± 1·1 %) ($P < 0·05$).

TABLE 2. Mean (± S.E. of mean) body weights, measurements, and composition 18 weeks after withdrawal of the mixed diet. (* $P < 0·05$; ** $P < 0·02$)

	Body weight (g)	Naso-anal length (cm)	Girth (cm)	Fat (g)	% fat	Fat free solids (g)	Body water (g)
Experimental ($n = 13$)	571·7 ± 9·4*	25·8 ± 0·3	23·8 ± 0·3**	128·5 ± 6·0**	23·3 ± 0·8**	127·6 ± 2·6	291·9 ± 5·1
Control ($n = 10$)	528·4 ± 16·0	25·4 ± 0·3	22·3 ± 0·6	101·1 ± 8·3	19·8 ± 1·1	121·1 ± 3·5	281·6 ± 8·8

DISCUSSION

Providing male hooded rats with a mixed, palatable diet of 'supermarket' foods in addition to chow is an effective means of inducing hyperphagia and obesity. During the development of the obesity daily energy intakes were elevated by twenty to thirty percent. The experimental rats preferentially selected the supermarket foods (Fig. 1*A*) but continued to consume significant quantities of chow. The mixed aspect of the diet may have influenced the degree of obesity produced. In short experiments (2 hr) rats ate significantly more if offered four different supermarket foods than if offered just one (Rolls, 1979; B. Rolls, E. Rowe & E. Rolls, in preparation). Furthermore, in long-term studies rats gained significantly more weight if the available supermarket foods were varied each day rather than remaining the same as in the present study (B. J. Rolls and E. A. Rowe, unpublished). Sclafani & Springer (1976) noted that the over-consumption of the mixed diet reflected an increased meal size, with the rats sampling many of the foods during a meal.

In previous reports on dietary obesity, when the dietary manipulation was terminated, the animals rapidly lost weight until they reached control weights (Sclafani & Springer, 1976). This is usually achieved by hypophagia (Cohn & Joseph, 1962), although one report shows that increased energy expenditure by thermogenesis may be predominantly responsible for the weight loss (Rothwell & Stock, 1978). In the present study prolonged hypophagia (below control levels) was not observed. The rats showed only a transient loss of weight and reduction of food intake on withdrawal of the mixed diet. The transient decrease in food intake may partly reflect a response to the contrast between the varied and palatable supermarket diet and the monotony and lower palatability of laboratory chow.

The persistence of the obesity is a particularly interesting aspect of the present study. More than four months after withdrawing the mixed diet, the experimental rats were still significantly heavier than the control rats, and had significantly more body fat. It appears that within the period of investigation (18 weeks after with-

drawing the mixed diet) the experimental rats were 'permanently' obese. After a period of dietary restriction which lasted 27 days and brought the obese rats down to control weights in 16 days and kept them down for 11 days, the rats returned to the former elevated body weight. Thus the obese rats not only maintain but also appear to 'defend' the elevated body weight. In a similar study using female hooded Lister rats, persistent obesity was observed after the mixed diet was removed, and the elevated body weight of these obese females was also 'defended' after a period of dietary restriction. Persistent obesity has also been observed in another group of obese females and in three additional groups of male rats (Rolls & Rowe, 1977; Rolls & Rolls, 1977; Rolls & Rowe, 1979*a*, *b*). Thus, despite some individual variation between rats in weight gain and response to dietary restriction, persistent obesity is a reproducible phenomenon.

That the increase in body weight reflected an increase in body fat and not increased growth was indicated by the carcass analysis done 18 weeks after the supermarket foods had been withdrawn. The experimental rats were found to have a significantly greater percentage of body fat than the control rats. This increased fat could simply be related to increased growth since it is known that normal rats which have more fat have greater amounts of fat free solids (Schemmel *et al.* 1969). The increased percentage of body fat in the experimental rats does not, however, appear to be attributable to increased growth induced by the mixed diet. Although the obese rats had slightly more fat free solids than the control rats in this experiment, the relationship between fat free solids and fat was significantly different in the experimental rats compared to the control rats. It was found that even the period of dietary restriction did not eliminate the significant elevation of body fat in the experimental rats.

Because the experimental rats are maintaining excess weight above the control rats, despite eating the same amount of chow after the mixed diet is withdrawn, it is possible that the obese rats have undergone a long-lasting endocrine or metabolic change during the 'fattening' period. During the period of rapid weight gain, the experimental rats had raised fasting plasma insulin concentrations. In man this is associated with increased insulin resistance (Olefsky & Reaven, 1977), and in these obese rats the accompanying raised fasting plasma glucose levels also suggest increased insulin resistance. This appears to be secondary to the hyperphagia rather than the obesity *per se*, for the raised fasting plasma insulin and glucose levels of the rats on the supermarket diet became more similar to control rats towards the end of the 'fattening' period when the rate of increase in weight of the two groups was less disparate. When both groups were later given free access to chow, their plasma glucose and insulin concentrations continued to be similar to the end of the experiment, even though the experimental group continued to be significantly more obese. Thus the presistent obesity does not appear to be accompanied by a marked increase in insulin secretion or insulin resistance. This data is thus different from the obesity induced by bilateral lesions of the ventromedial nucleus of the hypothalamus, which is characterized by increased insulin secretion (Inoue, Campfield & Bray, 1977), which might play an integral part in the development of the obesity (Inoue, Bray & Mullen, 1977). Obesity induced by a high fat diet (Inoue *et al.* 1977) was not associated with the same increased insulin secretion we observed with a diet high in fat and relatively high in carbohydrate. This may relate to a high fat diet producing lower plasma insulin levels than a high carbohydrate diet (Grey & Kipniss, 1971).

The lack of persistent abnormal insulin concentrations in the experimental rats suggests that abnormally increased insulin resistance is not a factor which is maintaining obesity in this study.

Many factors may contribute to the persistence of the obesity. In this study young adult hooded Lister rats were maintained in conditions under which they had little opportunity to expend energy voluntarily or through thermoregulation. The age at which the mixed diet is introduced may influence subsequent growth rate and the deposition of fat. Weanling rats exposed to a high fat diet exhibited significant increases in fat free solids and fat over a 20 week period (Pitts & Bull, 1977). In older rats, as used in the present study, fat was the main component of the increased weight (Schemmel *et al.* 1969). Faust, Johnson, Stern & Hirsch (1978) claim that providing adult rats with a high fat diet can lead to a permanent increase in the number of adipocytes, but in view of the methodological problems in determining fat cell number this still remains an open issue (Gurr & Kirtland, 1978; Kirtland & Gurr, 1979).

The strain of rat affects the development of obesity resulting from the consumption of a high fat diet (Schemmel *et al.* 1970). Also, there are differences between strains in the rate and partition of energy expenditure and the relationship with energy intake, and the responses to dietary dilution and other regulatory challenges (Morrison, 1973). Typically albino rats have been used in studies of reversible obesity (Rothwell & Stock, 1978; Sclafani & Springer, 1976; Sclafani & Gorman, 1977). It is possible that hooded rats are different from other strains in energy utilization and in response to regulatory challenges which are related to persistent obesity.

The duration of the 'fattening' period may influence the establishment of metabolic changes which may be related to the persistence of obesity. Reversible obesity induced in albino rats over a short period (20 days) was accompanied by a pronounced increase in energy expenditure by thermogenesis when the 'fattening' foods were withdrawn (Rothwell & Stock, 1978). It remains to be determined whether in persistent obesity levels of oxygen consumption remain normal when the mixed diet is withdrawn. This subject is at present under investigation.

Voluntary energy expenditure through exercise affects both the development and the persistence of dietary obesity. Exercising males failed to develop obesity, while exercising females developed obesity but lost weight to control levels when the mixed diet was withdrawn, although females housed in sedentary conditions exhibited persistent obesity (Rolls & Rowe, 1979*a*).

As originally indicated by the findings of Cohn & Joseph (1962) the environmental temperature may affect the persistence of obesity. The rats were maintained at close to the thermoneutral range in the present study, whereas in other studies lower temperatures have been used, for example, 21° C (Sclafani & Gorman, 1977). In a study (Rolls & Rowe, 1979*b*) of the effects of temperature on obesity, male hooded rats developed the same degree of obesity whether housed at 20 or 27 °C. The rats housed at the lower temperature lost slightly more weight than those at the higher temperature when the mixed diet was withdrawn. At the higher temperature the persistently elevated weight was accounted for almost entirely by fat; at the lower temperature, although there was a persistent increase in body weight and body fat, much of the surplus weight was attributable to an increase in lean body mass.

Thus over-consumption of a high-energy diet leads to obesity in hooded rats which

persists after the diet is replaced by laboratory chow. The maintenance of the elevated weight is associated with normal levels of food intake. The obesity is 'defended' in that the elevated weight is reinstated after enforced weight reduction by dietary restriction. It is proposed that persistent obesity in hooded rats is a suitable model for investigations of obesity. Because the method of inducing obesity, that is, by an over-consumption of palatable foods, is similar to a common cause of obesity in man, it may be particularly relevant to human obesity.

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