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EFFECT OF EARLY POSTNATAL NUTRITION IN THE SHEEP, PIG AND RAT ON SUBSEQUENT OBESITY IN THE ADULT

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Summary

From a study of the relationship between total body fat and live weight (LW) in sheep and rats it is concluded that early postnatal nutrition does not affect the fat content of the adult independently of postweaning nutrition. The evidence on pigs is equivocal.

When the adipocyte composition of individual adipose depots of rats is considered, the literature suggests that diet preweaning influences subsequent fatness in the adult. However since the comparisons were made between rats of the same age but differing greatly in LW it is suggested that such conclusions are misleading. Diet preweaning does not affect adipocyte number in pigs compared at the same adult LW.

I. INTRODUCTION

The body fat content of animals post-mortem has been determined by complete dissection (McMeekan 1940a), by chemical extraction of the minced carcass (Haecker 1920) or estimated from similar determinations on some portion of the whole or from various measurements of fat thickness (Hopper 1944). Body fat has also been predicted *in vivo* by various methods which allow repeated estimates to be made on the same individual over its growing period e.g. the chemical composition of the bodies of sheep can be estimated repeatedly *in vivo* by the use of tritiated water (Searle 1970a) and fat determined with an accuracy of *ca.* 0.2 kg (Searle 1970b). Both direct analyses and *in vivo* predictions have been used to provide a description of changes in the body fat content of animals during growth.

The status of body fat has also been described in terms of the number and size of adipocytes in particular adipose depots. Adipocytes are usually estimated by the method of Hirsch and Gallian (1968) which involves the counting of osmium stained cells in a Coulter Counter. Such data are usually presented as mean values for a number of animals of the same age and comparisons made between various ages.

In the present paper, data from both types of experiments are considered in order to assess the effect of early postnatal nutrition on obesity in the adult.

II. FACTORS KNOWN TO AFFECT BODY COMPOSITION

(a) Live Weight

From examination of a wide range of published data on the carcass composition of sheep, cattle and pigs, Tulloh (1963) concluded that composition was mainly dependent on body weight and largely independent of age. He also stated that any comparison of animals may be invalid unless they are compared at the same empty body (LW minus gut contents) or carcass weight. Zucker and Zucker (1963) came to the same conclusion with rats.

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Searle et al. (1972) removed Border Leicester x Merino lambs from the ewe at 2 days of age, bottle-fed them exclusively on milk ad libitum for 3 weeks and then progressively introduced solids which completely replaced the milk after 6 weeks of age. Body fat content was determined in vivo throughout the course of growth using the isotope dilution technique of Searle (1970a). When the relationship between fat and LW for each lamb was examined, 4 phases of growth were distinguished (Fig. 1), namely, a milk-feeding phase, a phase associated with weaning and two postweaning phases referred to as the prefattening and fattening ruminant phases. Body weight gain in successive phases contained 16%, 2%, 27% and 65% fat. The slaughter data of Haecker (1920) for cattle (Fig. 1) follow a similar pattern of fat growth. The relationship between fat and LW postweaning for Lacombe pigs (Doornenbal 1972) is also shown in Fig. 1. Two distinct phases can be distinguished with the transition from one phase to the other occurring at ca. 45 kg. A similar biphasic relationship exists in Sprague-Dawley rats (Fig. 2), the transition point being at ca. 380 g LW. Zucker and Zucker (1963) also demonstrated a phase change in fat at weaning similar to that found with sheep.

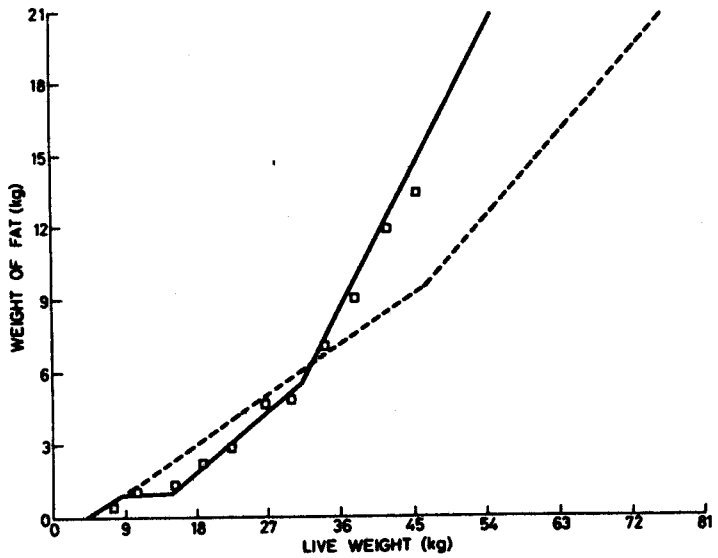

Fig. 1. Relationship between body fat (kg) and LW (kg) for sheep —— (Searle et al. 1972), pigs --- (Doornenbal 1972) and cattle (÷ 12) □ (Haecker 1920).

(b) Diet

When animals are fed diets balanced for all essential nutrients, the amount eaten can influence the fat content of the animal at any given LW e.g. sheep eating half the amount of ad libitum-fed controls (Searle et al. 1972) contained about 10% less fat than the controls.

Diet composition especially the amount and type of protein present can influence fatness. Protein deficiency leads to increased body fat with the interaction between protein and energy influencing the final result (Black 1974).

The effect of a high-fat diet on the body fat content of rats is compared with a grain-based diet in Fig. 6.

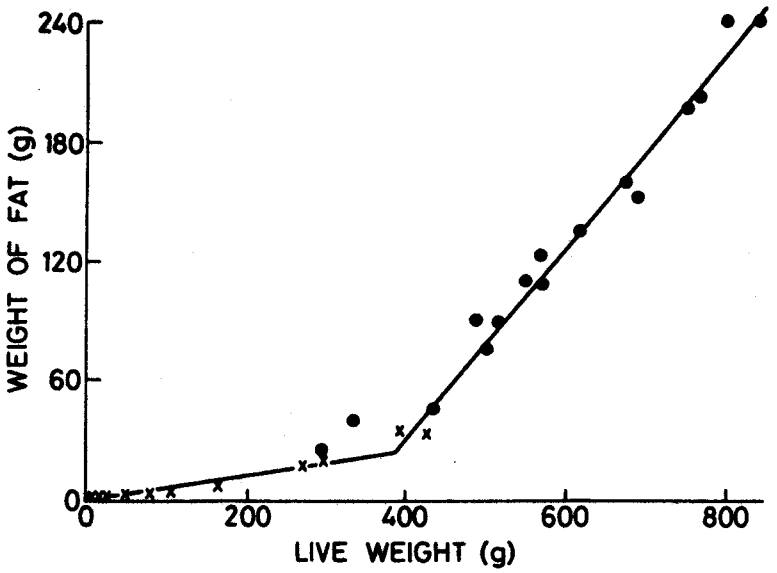

Fig. 2. Relationship between body fat (g) and LW (g) for male Sprague-Dawley rats. Data derived from Zucker and Zucker (1963) (x) and Nolen (1972) (●).

(c) Sex and Breed

Females are fatter than males of the same LW (Searle and Griffiths (1976b). Breeds within a species also differ in fatness. Searle and Griffiths (1976a) examined the course of fat growth in the 2 ruminant phases in Camden Park Merino, Medium Peppin Merino and crossbred (Border Leicester x Merino) sheep, these being breeds of increasing mature size. At any given LW the smaller breeds were fatter and entered the fattening phase of growth at a lower LW than the larger breeds (Fig. 3) e.g. at 36 kg LW the 3 breeds contained 39%, 32% and 25% fat respectively.

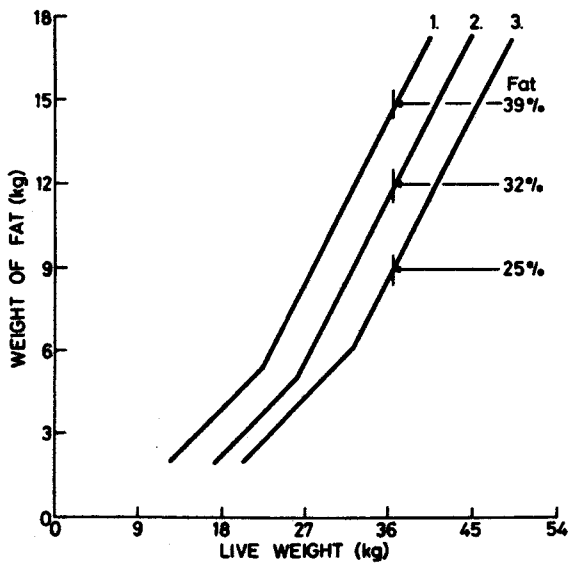

Fig. 3. Relationship between body fat (kg) and LW (kg) for (1) Camden Park Merino (2) Medium Peppin Merino and (3) Border Leicester x Merino sheep (Searle and Griffiths 1976a). The proportion of fat in each breed at 36 kg LW is indicated.

III. EFFECTS OF EARLY POSTNATAL NUTRITION ON THE FAT CONTENT OF THE ADULT

(a) Sheep

Early postnatal nutrition can exert a large effect on body fatness but ultimately sheep on the same diet postweaning attain a similar fat content. Searle and Griffiths (1976b) examined the course of fat growth in male and female sheep during extended milk feeding and also described the effect of weaning at various LW's on the fat content of the adult. Lambs fed milk ad libitum for up to 18 weeks were fatter than early-weaned ruminant lambs, the maximum difference being 5 kg of fat at 30 kg LW. In the final fattening phase of growth however, sheep of the same sex had similar body composition irrespective of early nutrition. Typical results are summarised in Fig. 4.

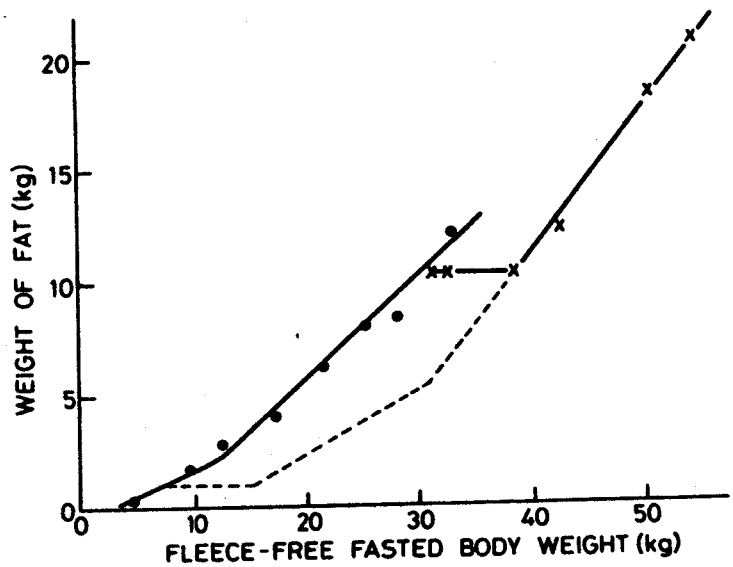

Fig. 4. Relationship between body fat (kg) and LW (kg) for an individual male sheep during milk feeding (●) and when fed roughage (x). The dotted line is for early-weaned wether sheep (Searle et al. 1972). From Searle and Griffiths (1976b).

(b) Rats

Changes in the neonatal nutrition of rat pups can be achieved either by varying litter size or by altering the diet of the mother and hence affecting the composition of the milk. Widdowson and McCance (1960) allowed rats to suckle in litters of 3 or 15-20. Following weaning at 3 weeks all rats were fed ad libitum on the same stock diet. As shown in Fig. 5 the better-fed rats had more body fat during milk feeding than the restricted rats, but after ca. 180 g LW body fat contents were similar.

Schemmel et al. (1973) allowed Osborne-Mendel rats to suckle at 8 per litter but influenced milk composition of the dam by dietary means. Pups suckled on dams fed a high-fat ration were heavier and fatter at weaning than those suckled on grain-fed dams. Postweaning, half the rats in each group were fed the fat ration and half the grain ration. When compared at the same empty body weight (Fig. 6) the rats on the high-fat diet were fatter than those on the grain diet, the body composition of the adult being influenced by the postweaning diet irrespective of the preweaning diet or body fatness.

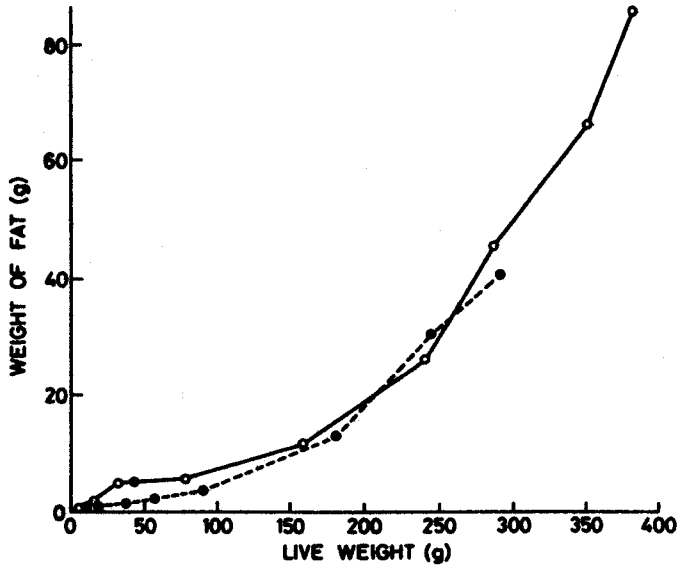

Fig. 5. Relationship between body fat (g) and LW (g) for rats suckled 3 (O) or 15-20 (●) per litter prior to weaning (O) and then fed ad libitum on the same diet. (Widdowson and McCance 1960).

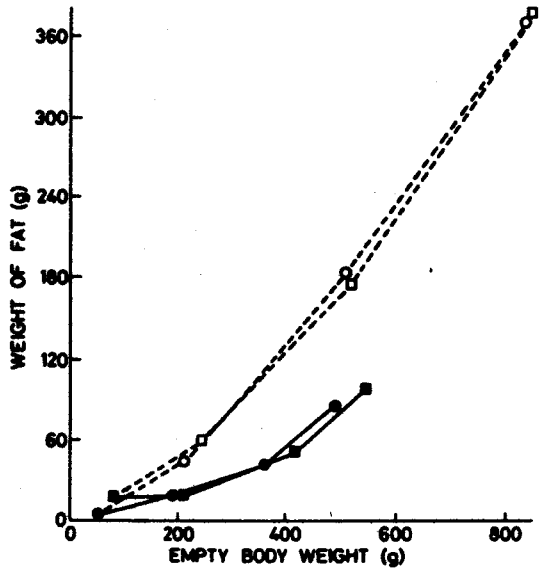

Fig. 6. Relationship between body fat (g) and LW (g) for male Osborne-Mendel rats. O,□, --- high-fat diet; ●,■, —— grain diet. The first point is at weaning and also refers to the preweaning diet of the mother. (Schemmel et al. 1973).

(c) Pigs

Information on the effect of feed intake of the young pig on subsequent fatness in the adult is rather scanty.

In a literature review Young and Sharma (1973) concluded that pigs on restricted feeding during early postnatal growth followed by liberal (but not ad libitum) feeding may produce carcasses with less fat than pigs fed liberally throughout. This conclusion seems hard to justify in view of the equivocal nature of the evidence. For example, McMeekan (1940a, b, c), Lucas et al. (1959) and Elsley (1963) compared the effects of different growth patterns before 22.5 kg on the carcass fat at ca. 90 kg LW. After 22.5 kg all pigs were fed at a predetermined

scale of feeding (less than ad libitum) depending on LW. Feed quality was also changed at predetermined intervals. McMeekan found that early restriction produced carcasses fatter than sow-reared controls, Lucas et al. found no difference and Elsley concluded that the slowest growing pigs had least fat at 90 kg. These experiments differed in the period of restriction, diet composition and growth rates of the pigs. It is suggested that the final result reflects the total treatment and not simply the effect of early nutrition.

Ad libitum feeding following early restriction has been used by Lee et al. (1973b) to study fat growth. When both controls and restricted pigs were compared at the same LW (80 kg) there was no difference in total fat, subcutaneous fat, visceral and bone fat. Intramuscular fat was less in the restricted pigs but as it was only 12% of the whole this difference was not apparent in total fat. Thus where the pig can express its full potential for growth postweaning with unrestricted feeding, the effect of neonatal nutrition on the fat content of the adult is negligible.

IV. ADIPOCYTES AND GROWTH

(a) Rats

Hirsch and Han (1969) studied the size, number and rate of formation of adipocytes in several adipose sites in Sprague-Dawley rats raised without dietary restriction. They concluded that early growth of these depots was the result of an increase in both cell number and cell size. Growth after 15 weeks of age was exclusively the result of cell enlargement. Weight loss caused a reduction in cell size but no change in cell number. The mean LW of rats at 15 weeks was ca. 350 g and from Fig. 2 it can be seen that this is in the region of transition between the 2 phases. Thus it would appear that adipose tissue growth is by both hyperplasia and hypertrophy in the prefattening phase and exclusively by hypertrophy thereafter.

The effect of early postnatal feeding was studied by Knittle and Hirsch (1968) who allowed rats to be suckled in litters of either 4 or 22 prior to weaning at 21 days when all rats received stock diet ad libitum. They examined epididymal fat pads at 5, 10, 15 and 20 weeks of age and found more and larger cells in the group suckled in small litters and concluded that this was the result of preweaning nutrition. No account was taken of the large differences in LW between the 2 groups. Knittle (1972) examined epididymal fat pads at 8 and 12 weeks of age of rats raised to weaning in litters of 12 on mothers suffering either caloric or protein restriction. When compared with controls it was concluded that caloric restriction produced transient effects while protein restriction resulted in a permanent reduction in cell number. At 12 weeks of age the protein-restricted group were the same LW as the controls at 8 weeks (ca. 275 g) and if they are compared at this weight there is a significant difference in cell size but not cell number. The protein-restricted group had larger cells. Johnson et al. (1973) found that early overfeeding increased adipocyte number in both obese and non-obese rats while early under-feeding reduced adipocyte number only in the non-obese. Comparisons were made over the LW range 634-752 g and 379-505 g in obese and non-obese rats respectively.

Greenwood and Hirsch (1974) used tritiated thymidine to study DNA synthesis in normal rats and concluded that a large number of pre-adipocytes were synthesised in the 2nd and 3rd postnatal weeks.

The experiments described above imply that early postnatal nutrition affects this synthesis. However, since cells < 25 μm diameter are not counted in the method of Hirsch and Gallian (1968) and since the early-restricted rats were not grown to the same LW as the controls it is possible that some adipocytes may have been too small to count. Examination of rats at the same LW would probably remove the disparity that exists between conclusions from studies of total body fat and studies of adipocytes in isolated fat depots.

(b) Pigs

Adipocyte development has been studied by Lee et al. (1973a) in pigs removed from the sow 18 hours after birth and artificially fed to grow only about 700 g in 4 weeks. Following this severe restriction they were fed ad libitum on the same diet as control pigs fully suckled by the sow for 28 days. When compared with controls slaughtered at the same age (24 weeks) the undernourished animals had less total fat, smaller fat cells, similar cell numbers in subcutaneous adipose tissue but fewer cells in intramuscular and omental fat depots. They weighed 82 and 52 kg respectively. In a subsequent experiment of similar design (Lee et al. 1973b) where the 2 groups were compared at the same LW of 80 kg there was no difference in total fat or in the number of adipocytes.

(c) Sheep

Haugebak et al. (1974) reported an increase in both cell number and volume in crossbred lambs growing from 24 to 40 kg LW but only an increase in volume subsequently. Burton et al. (1974) found an increase in size but no change in number of adipocytes in the adipose tissue of Suffolk sheep growing from 50 to 70 kg LW. Weight loss resulted in a decrease in size but no change in cell numbers. As with rats this would place the upper limit for hyperplasia at LW's around the transition point. The influence of preweaning nutrition on the growth of adipocytes has not been reported.

V. CONCLUSIONS

The broad conclusions of this review are:

(a) Body weight is the major correlate of fatness but breed and sex modify the relationship. Thus the effect of nutrition on fatness can be correctly assessed only when comparisons are made at the same LW.

(b) Body fat content can be altered by nutritional level and diet composition but some time must elapse after a change in diet before the ultimate composition is attained.

(c) There is no evidence of a permanent effect of early nutrition on the fatness of the adult. Conclusions to the contrary derived from studies of adipocyte growth are misleading since comparisons were made on the basis of age and not LW.

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