

between daily food intake and energy expenditure. (2) Body-weight can show marked fluctuations from day to day, probably due to a water imbalance. (3) In spite of these two findings over a period of time of a week or more, the food intake and energy expenditure are closely balanced and weight remains relatively constant.

The implications are that the factors controlling appetite are not related to immediate demands but are affected by a longer-lasting stimulus.

In extreme conditions with severe restrictions on intake, energy expenditure is certainly reduced. Nevertheless, the evidence suggests that under more usual conditions, appetite is controlled rather than activity. The nature of this control remains to be elucidated.

REFERENCES

- Adam, J. M., Best, T. W., Edholm, O. G., Fletcher, J. G., Lewis, H. E. & Wolff, H. S. (1958) Report to the Medical Research Council. *M.R.C.* 58/201.
- Adam, J. M., Best, T. W., Edholm, O. G., Goldsmith, R., Gordon, E. F., Lewis, H. E. & Wolff, H. S. (1959). Report to the Medical Research Council. *M.R.C.* 59/819.
- Adam, J. M., Best, T. W., Edholm, O. G. & Wolff, H. S. (1957). Report to the Medical Research Council. *M.R.C.* 57/93.
- Consolazio, C. F., Konishi, F., Ciccolini, R. V., Jamison, J. M., Sheehan, E. J. & Steffen, W. F. (1960). *Metabolism*, **9**, 435.
- Edholm, O. G., Fletcher, J. G., Widdowson, E. M. & McCance, R. A. (1955). *Brit. J. Nutr.* **9**, 286.
- Johnson, R. E. & Kark, R. M. (1947). *Science*, **105**, 378.
- Keys, A. & Brožek, J. (1953). *Physiol. Rev.* **33**, 245.
- LeBlanc, J. A. (1957). *J. appl. Physiol.* **10**, 281.
- Lewis, H. E., Masterton, J. P. & Rosenbaum, S. (1960). *Clin. Sci.* **19**, 551.
- Masterton, J. P., Lewis, H. E. & Widdowson, E. M. (1957). *Brit. J. Nutr.* **11**, 346.
- Passmore, R. & Durnin, J. V. G. A. (1955). *Physiol. Rev.* **35**, 801.
- Rodahl, K. (1954). *J. Nutr.* **53**, 575.
- Welch, B. E., Buskirk, E. R. & Iampietro, P. F. (1958). *Metabolism*, **7**, 141.
- Widdowson, E. M., Edholm, O. G. & McCance, R. A. (1954). *Brit. J. Nutr.* **8**, 147.
- Wilson, O. (1960). *Brit. J. Nutr.* **14**, 391.
- Wolff, H. S. (1958). *Quart. J. exp. Physiol.* **43**, 270.
- Wolff, H. S. (1959). *Ergonomics*, **2**, 354.

Calorie requirements in human pregnancy

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Several professional, national and international organizations have made statements on the requirement or 'recommended allowance' of calories in human pregnancy. Yet, so far as we know, a reasoned account of the matter has never been published. This paper is a preliminary attempt to fill the gap. Our conclusions are provisional and, for reasons of space, we cannot present the sources of information and calculations in detail. We hope to publish a fuller account in due course, after more data have been collected.

Theoretical basis

An increase in the calorie requirement is created during pregnancy in the first place by the growth of the foetus and placenta, and the formation of the liquor

amni. In addition, the mother's uterus and mammary glands increase in size, her blood volume expands and nutrients are stored in her non-reproductive tissues. To the energy represented by these new tissues should be added the energy lost in transporting nutrients from the diet into the tissues. The calorie requirement is further increased by the cost of maintaining the new tissues and by the extra work of the maternal heart and muscles of respiration.

The total energy stored and expended in these ways may be defined as the calorie requirement specific to pregnancy, that is, the additional energy required by a pregnant woman at rest. But a pregnant woman who is up and about may save energy by reducing her activity. Any such saving will be offset to some extent by the extra cost of moving her increased body-weight.

Our present knowledge of each of these components of the calorie requirement in pregnancy—storage of nutrients, increased metabolism, and altered activity—is far from complete. Fortunately, the validity of the conclusions can be tested in several ways. The weights of materials stored must agree with measured changes in body-weight. The amount of water in maternal body fluids and in the product of conception should be consistent with measurements of total body water. Estimates of each item contributing to increased metabolism should give a total corresponding to the observed increase in basal metabolism. The theoretical pattern should be consistent with observations of health and behaviour; in particular, the estimated calorie cost per day at various stages of pregnancy should conform with measurements of the calorie value of diets taken by pregnant women. Finally, conclusions as to human pregnancy may be supported by comparing them with the results of experiments on animals.

Normal pregnancy

It is by no means easy to define what is meant by normal physiological pregnancy. For example, the amount of weight that should be gained is much disputed. Rather than fit our data to an arbitrary standard, we have used a statistical model: the characteristics of the average healthy primigravida as calculated from our hospital records. This average woman is aged 24 years, is 158 cm in height and weighs about 54 kg before pregnancy. During pregnancy, which proceeds without significant abnormality, she is allowed to eat to appetite and gains 12.5 kg in weight. She produces a healthy baby weighing 3.3 kg at birth, with a placenta weighing 650 g. Recently, we have made many measurements, by dilution methods, of changes in body-fluid volumes, using Evans Blue for plasma, ⁵¹Cr for red blood cells and deuterium oxide for total body water. Our values are consistent with those published by others. The literature has also been used to supply estimates which we cannot provide from our own records.

The weight gained by our average healthy woman corresponds to a rate of gain of about 1 lb/week (0.45 kg/week) during the second half of pregnancy. In a large, representative sample of all primigravidae whose diets were not being restricted, this rate of gain was associated with the most favourable clinical experience

(Thomson & Billewicz, 1957). With higher rates of gain, the incidence of pre-eclampsia rose steeply; and at both low and high rates of gain there were raised prematurity and perinatal death rates.

Weight gained during normal pregnancy

Fig. 1 illustrates the gain in body-weight during pregnancy. Of the total gain, 12.5 kg, about half is accounted for by the growth of the uterus and its contents, and of the mammary glands. The other half represents increase in the maternal body fluids and non-reproductive tissues.

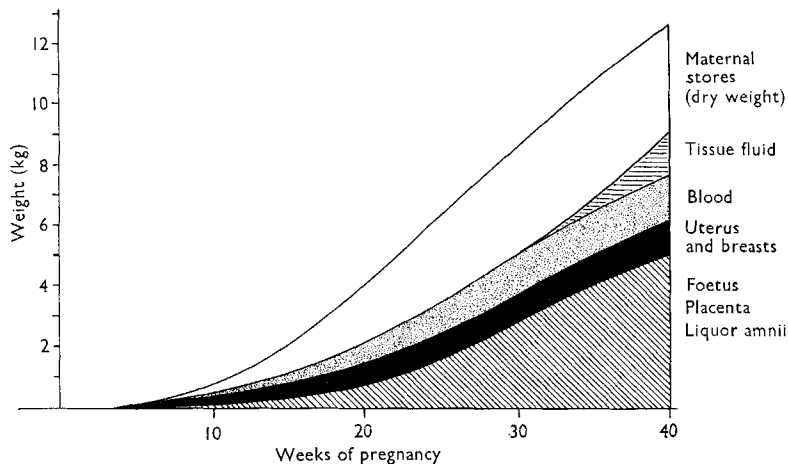


Fig. 1. Weight gained by an average normal primigravida.

Up to the 30th week of pregnancy the measured increase in total body water seems to be wholly accounted for by the growth of the uterus and its contents and by increased maternal blood volume. At term, there is an excess of body water which, in Fig. 1, is labelled 'tissue fluid'. We think that the excess is extracellular water. This view is consistent with the fact that slight oedema of the lower limbs often appears during the last few weeks of pregnancy in women who are otherwise perfectly normal. It has not been confirmed directly because, unfortunately, the usual methods of measuring extracellular water seem to give misleading results in pregnancy.

If the measurements of total body water are reliable, about 25% of the total weight gain, more than 3 kg, remains to be accounted for. It must be dry weight of nutrients stored in the maternal non-reproductive tissues, and in Fig. 1 is labelled 'maternal stores'. The amount is similar to the net gain of weight during pregnancy, i.e. the additional weight remaining after the losses at parturition and during the puerperium.

The main increase in weight of the uterine contents takes place during the second half of pregnancy; in fact, the foetus puts on about half its final weight during the last 10 weeks. By contrast, 'maternal stores' accumulate rapidly between the 10th

and the 30th weeks and during the last 10 weeks there is little further storage. This differential pattern resembles that described in laboratory animals, experiments with which have shown that storage in the maternal tissues depends on the presence of the placenta, but not of the foetus (Kosterlitz & Campbell, 1957).

Storage of nutrients and their calorie value

The weight gained during pregnancy may be assumed to consist almost entirely of protein, fat and water. The weights of carbohydrate, salts and other substances stored are very small by comparison. Estimates can be made of the composition of the foetus and placenta at different stages of gestation, from the analyses of Widdowson & Spray (1951), Kelly, Sloan, Hoffman & Saunders (1951) and others. Similar estimates, some involving an element of guesswork, can be made for the composition of the uterus, liquor amnii, mammary glandular tissue, maternal blood and tissue fluids.

The main difficulty arises in deciding the composition of 'maternal stores'. From these calculations, they weigh more than 3 kg as dry matter, at term. Not much can be protein, because dry protein must be associated with about four times its weight of water, and there is no evidence that a sufficient quantity of water is stored. From similar reasoning, Morrison (1956) concluded that, in rats, 'the gain in maternal weight has been largely made up of energy-yielding materials, mainly fat'. Spray (1950) claimed that carcass analysis of rats showed an increased protein content of maternal non-reproductive tissues, but this was not confirmed by the more detailed analyses of Boyne, Chalmers & Cuthbertson (1953). We ourselves have suggested (Thomson & Hytten, 1960) that, in women, the 'maternal stores' consist mainly of fat, and since then we have obtained by means of skinfold measurements evidence of considerable fat storage. Sandiford, Wheeler & Boothby (1931) concluded that nitrogen retention in the woman they studied was entirely due to the growth of the product of conception and of the maternal reproductive organs. For present purposes, we have assumed that the 'maternal stores' consist entirely of fat. Even if this assumption is not wholly correct, it makes little difference to the final computation of the calorie requirement. Errors in the assessment of quantity are, from this point of view, much more important than those in the assessment of composition.

Adding up the amounts of protein and fat in the various components of increased body-weight, we estimate that a total of about 800 g protein is added during pregnancy, and nearly 4 kg fat. Most of the protein is in the uterus and its contents, and most of the fat in the maternal non-reproductive tissues.

The heats of combustion of stored protein and fat have been taken as 5.65 and 9.5 kcal/g, respectively. Losses during digestion, absorption and intermediary metabolism may be allowed for by using the Atwater coefficients 'in reverse'. Thus, for example, the total cost of storing 1 g protein is 5.65 ($5.65/4.0$) = 7.98 kcal.

The lower part of Fig. 2 shows the cumulative calorie value of nutrients stored during pregnancy, including the cost of transporting them from food. The total is about 45 000 kcal, of which about 15% is due to storage of protein and 85% to storage of fat. Put another way, 21% of the energy stored is accounted for by the

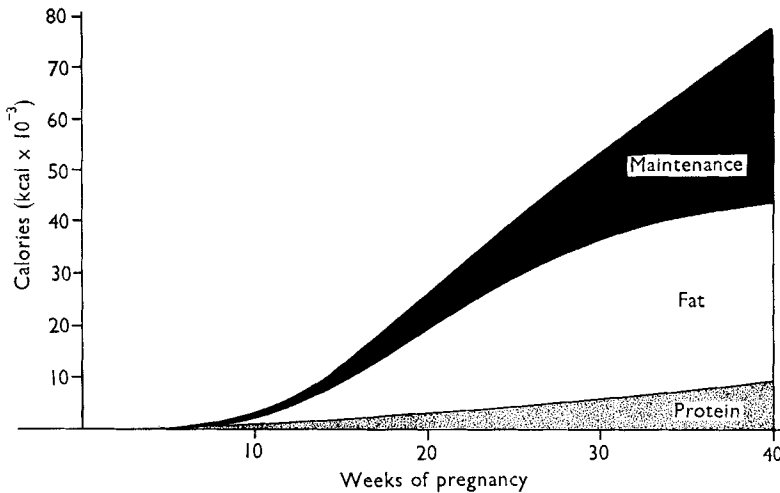


Fig. 2. Cumulative calorie requirement of an average normal primigravida, for storage of protein and fat and for maintenance.

growth of the uterus and its contents and 76% by the accumulation of reserves in the maternal non-reproductive tissues, the remainder being due to increase of the mammary glands and the maternal body fluids which, of course, contain some protein and fat.

Maintenance costs

We have estimated the cost of maintenance from the oxygen uptake of the uterus and contents (Romney, Reid, Metcalfe & Burwell, 1955), the increased maternal cardiac and respiratory work and the additions to basal metabolism attributable to weight of new tissue in the maternal body. The totals indicate a gradual rise of heat output, reaching a peak at term amounting to about 270 kcal/day. This figure, which is about 20% of the calculated basal metabolic rate of our representative woman before pregnancy, agrees well with direct measurements of the rise of basal metabolism that occurs during pregnancy (Burwell, 1954).

From estimates of the daily cost of maintenance at 10, 20, 30 and 40 weeks, we drew a smoothed curve, from which the cumulative costs were deduced. The total cost of maintenance is estimated to be about 35 000 kcal. In Fig. 2, maintenance costs have been added to those of storing protein and fat.

Physiological calorie requirement in pregnancy

Adding the costs of building new tissues to those of maintenance, we estimate the total cumulative costs of pregnancy at 10, 20, 30 and 40 weeks, to be about 3000, 25 000, 54 000 and 78 000 kcal, respectively.

Fig. 3 shows the mean daily requirement in each of the four quarters of pregnancy, obtained by dividing the increment at the end of each quarter by the number of days in each period. It is assumed that the first quarter lasts 56 days (14 days being allowed from the beginning of the last menstrual period to conception) and the

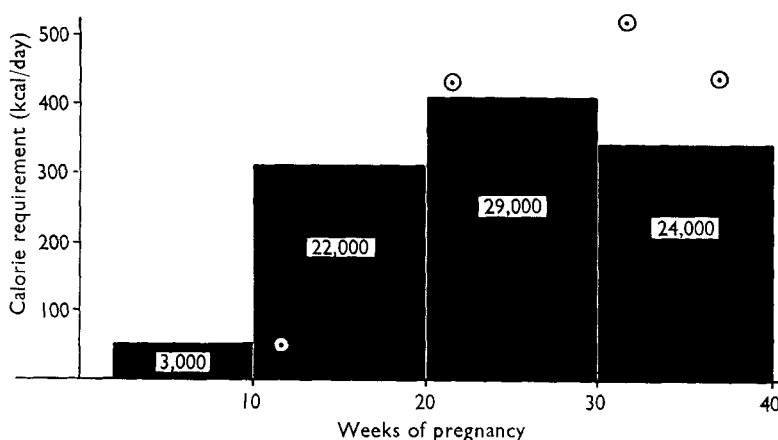


Fig. 3. Mean additional daily calorie requirements of a normal primigravida during the four quarters of pregnancy. The figures in each 'block' show the calorie increment (kcal) in each period. The points show the observed intakes of one primigravida after deduction of 2000 kcal/day.

remaining quarters 70 days each. In general, the picture is consistent with experience. Many women say that there is an increase of appetite fairly early in pregnancy and that appetite then remains fairly steady or declines slightly in late pregnancy (Taggart, 1961). Our figures indicate that the additional calorie demand rises sharply to more than 400 kcal/day about the middle of pregnancy and then falls slightly.

Calorie cost of pregnancy in practice

None of the above calculations has taken account of altered activity or of the altered cost of activity during pregnancy. Our representative primigravida probably continues to lead an ordinary life, with not much restriction of activity, during the first half of pregnancy at least, though there may be a phase of lassitude during the first trimester. During the last trimester, she certainly rests more. Unfortunately, data from which we can estimate, for pregnant women, the effect on total energy expenditure of altered activity, and of the altered cost of a given activity, apparently do not exist. On the whole, we are inclined to think that the net effect in primigravidae is fairly small, and that the physiological energy requirement is not greatly reduced. A multipara who has to look after young children may find it difficult to reduce her activity very much, and any saving that she achieves may be outweighed by the increased cost of movement.

In Fig. 3, we have plotted the observed calorie intakes of one primigravida who measured her diet at 11, 21, 31 and 36 weeks, and who kept a diary of her activities. The points have been placed on the assumption that she took 2000 kcal/day before pregnancy. The trends of these observations agree quite well with the theoretical trends, even though the latter take no account of activity. Fairly good agreement is also given by the trend in the calorie intakes of one woman observed by Sandiford *et al.* (1931). Our own subject reduced the time spent in walking from

over $1\frac{1}{2}$ h/day in the first half of pregnancy to about 20 min/day at 36 weeks. The hour saved was spent resting in bed. Time spent in light housework and in sitting activities did not change much, nor apparently did the extent of more strenuous activities (such as bed-making and washing). She was not doing paid work at any stage.

Discussion

Our estimate of the physiological calorie requirement specific to pregnancy, nearly 80 000 kcal, is almost identical with that of FAO: Second Committee on Calorie Requirements (1957). But the FAO Committee thought that in practice the supply of 40 000 kcal would usually suffice, the difference being accounted for by diminished activity. 'A poor woman who already has several children to care for will be unable to decrease her activity much and will therefore need extra food, whereas a well-to-do primipara with few domestic responsibilities may achieve energy balance by cutting down physical activities and so not require many additional calories from food.' The (U.S.A.) National Research Council: Food and Nutrition Board (1958) proposed an allowance of 300 kcal/day during the second half of pregnancy, which agrees closely with the FAO practical allowance. Such a supply, it says, is appropriate 'for the active, young, and immature woman undergoing first pregnancy. Other women, however, may so reduce physical activity during this period that the extra demands for calories may be largely compensated for without addition of food calories.' As stated already, we doubt if sufficiently great reductions of activity usually take place to eliminate, or even to halve, the physiological calorie requirement, especially when the extra cost of a given activity is taken into account. But quantitative data are lacking.

Though further research may invalidate the reason given by the committees for reducing the calorie allowance in practice, other reasons can be adduced. Both committees say that the desirable average gain of weight during pregnancy is about 10 kg. Recalculation of our data to a gain of 10 instead of 12.5 kg, on the assumption that the reduction takes place entirely at the expense of maternal stores (fat), shows that the physiological requirement is reduced to about 55 000 kcal. Many obstetricians insist on pregnant women limiting the amount of weight gained during pregnancy, with the main object of preventing pre-eclampsia. When necessary, they prescribe a low-calorie diet. The patient may find that it needs considerable will power to restrict her diet sufficiently. This raises again the vexed question of defining the normal and the physiological.

There is no doubt that storage of nutrients in the maternal tissues is normal, and that it takes place mainly before the period of greatest foetal growth. If, at a later stage, the mother has to maintain her habitual level of activity, or is obliged to reduce her food intake, foetal growth can apparently be maintained at the expense of these reserves. Our average normal primigravida did not deplete her reserves during late pregnancy, but there was little additional storage. At the end of pregnancy she had a surplus of more than 3 kg reserve stores, probably mainly or all fat. This increment can plausibly be explained as a reserve for use during lactation. Utilized with 100%

efficiency at the rate of 200 kcal/day, it would last for about 5 months. The loss in body-weight by lactating women confirms that such utilization of reserves does, in fact, occur (Hyttén & Thomson, 1961). But breast-feeding is becoming the exception rather than the rule in Western society and, if it is not removed by lactation or exercise, the surplus of fat may represent the beginnings of obesity. We may therefore have to revise our ideas of 'normality' in the light of the customs in modern urban society.

REFERENCES

- Boyne, A. W., Chalmers, M. I. & Cuthbertson, D. P. (1953). *Hoppe-Seyl. Z.* **295**, 424.
 Burwell, C. S. (1954). *Johns Hopk. Hosp. Bull.* **95**, 115.
 FAO: Second Committee on Calorie Requirements. (1957). *FAO nutr. Stud.* no. 15.
 Hyttén, F. E. & Thomson, A. M. (1961). In *Milk: the Mammary Gland and its Secretion*, Vol. 2, Ch. 13. [S. K. Kon and A. T. Cowie, editors.] New York and London: Academic Press Inc.
 Kelly, H. J., Sloan, R. E., Hoffman, W. & Saunders, C. (1951). *Hum. Biol.* **23**, 61.
 Kosterlitz, H. W. & Campbell, R. M. (1957). *Ann. Nutr. Aliment.* **11**, A 85.
 Morrison, S. D. (1956). *J. Physiol.* **134**, 650.
 National Research Council: Food and Nutrition Board. (1958). *Publ. nat. Res. Coun., Wash.*, no. 589.
 Romney, S. L., Reid, D. E., Metcalfe, J. & Burwell, C. S. (1955). *Amer. J. Obstet. Gynec.* **70**, 791.
 Sandiford, I., Wheeler, T. & Boothby, W. M. (1931). *Amer. J. Physiol.* **96**, 191.
 Spray, C. M. (1950). *Brit. J. Nutr.* **4**, 354.
 Taggart, N. R. (1961). *Proc. Nutr. Soc.* **20**, 35.
 Thomson, A. M. & Billewicz, W. Z. (1957). *Brit. med. J.* **i**, 243.
 Thomson, A. M. & Hyttén, F. E. (1960). *Proc. Nutr. Soc.* **19**, 5.
 Widdowson, E. M. & Spray, C. M. (1951). *Arch. Dis. Childh.* **26**, 205.

Energy balance in early life

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When a baby has safely come through the strenuous hazards of being born, starvation immediately confronts it for anything up to 5 days. While in the uterus the foetus receives a constant supply of food materials from its mother through the placenta, but as soon as the cord is tied this supply of nourishment is suddenly cut off. In many mammals suckling begins almost immediately, but not so in man. If the baby is the firstborn there is rarely any significant amount of colostrum for at least 24 h, and if the baby is premature, or if birth has been difficult and the baby is distressed, it is likely to be kept without food for a much longer time. We all start life in negative energy balance. The baby katabolizes some of its own body tissue to provide the energy it requires, and it consequently loses weight. The loss of weight is partly of water, partly of solid matter; how much solid matter is lost per day depends upon the metabolic rate and upon the proportions of protein, fat and carbohydrate that are being oxidized.

Many mammals are born with a high concentration of glycogen in their livers and sometimes also in their skeletal muscles (Goldwater & Stetten, 1947; McCance & Widdowson, 1959; Shelley, 1960). There seems to be no information about the baby at term, but the human foetus at the 20th week of gestation already has 4% of