THE BASAL METABOLIC RATE DURING PREGNANCY IN RELATION TO THE TOTAL ENERGY COST

by

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ABSTRACT

To calculate the energy cost of pregnancy, a group of 61 women were followed longitudinally throughout pregnancy and post-natally. Data are presented on the BMR, weight gain, fat gain and birth weights. From this information the total energy cost of pregnancy is calculated, and the contribution to this made by changes in the BMR. The results are compared to those of other studies, including a multinational study of which this data constitutes a part.

The study was carried out over 4 years, in two two-yearly phases. In the first phase 21 women were measured at 6 weekly intervals, while in the second phase 20 women were measured at 2-weekly intervals and 20 at 4-weekly intervals. The effect of the frequency of BMR measurements is examined. The energy cost of changes in the BMR for the 61 women was found to be 51 MJ, which is lower than previously calculated (Hytten & Chamberlain, 1980), and the figure obtained in a continuation of this study (Durnin 1987). The reasons for this are discussed and recommendations made for future studies.

The mean weight gain of the 61 women from 10 weeks gestation was 11.0 kg, which is comparable to figures previously found. The mean fat gain was calculated and found to be 2.1 kg, which is lower than previous calculations. A decreased fat gain during pregnancy decreases the total energy cost. The mean birth weight was 3.4 kg, comparable to that of Hytten and Chamberlain (1980).

From these components the total energy cost was found to be 196 MJ (47,000 kcal). The BMR data underestimates the cost, and from a continuation of the study a more accurate figure would be 275 MJ (66,000 kcal).

This is still below the previously quoted cost upon which recommended daily allowances for pregnancy are based, and therefore it is considered that there is evidence for revising the current RDAs.

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CHAPTER 1

INTRODUCTION

THE BASAL METABOLIC RATE DURING PREGNANCY IN RELATION TO TOTAL ENERGY COST OF PREGNANCY.

Accurate knowledge of the basal metabolic rate (BMR) during pregnancy is important as BMR data is used to establish energy requirements. Adequate energy intakes during pregnancy have implications not only for the fetus but for the mother as well. Malnutrition is involved in the aetiology of low birth weight babies (LBW), infant mortality and mental retardation (National Academy of Science, 1967). Overweight and overnutrition present their own risks. Obesity in the non pregnant population is associated with an increased risk of heart disease and a shortened life expectancy. In pregnancy there is evidence that obesity leads to an increase in pre-eclampsia, prolonged labour, Caesarian section and perinatal abnormality (Kerr, 1962; Tracey & Miller, 1969). There is also a significant increase in the incidence of gestational diabetes (Gross, Stool & King, 1980). More than 50% of women who develop diabetes during pregnancy are obese (Sutherland & Stowers, 1975).

The effect of pregnancy on the BMR is not fully established despite its importance, and much of the work that exists is contradictory, as will be discussed later. There is therefore a need for a study to provide comprehensive data on the BMR during pregnancy.

Energy balance during pregnancy is unique. The woman gains on average 12.5kg throughout the pregnancy(Hytten & Chamberlain, 1980). The BMR is thought to increase due to the increased oxygen requirements of the fetus and the extra maternal tissues, making up to 50% of the total cost of pregnancy. The remainder is said to be due to the energy cost of producing the products of conception and the amount of fat deposited during pregnancy. This thesis presents results on the BMR, weight and fat gain and infant data from which the total energy cost of pregnancy has been calculated.

It is suggested that the woman meets the energy cost of pregnancy by increasing her energy intake or decreasing her energy expenditure or a combination of the two. Therefore when discussing the BMR and total cost of pregnancy these factors will be considered.

INTRODUCTION

1.1 AN OVERVIEW OF THE BASAL METABOLIC RATE IN MAN

The term basal metabolic rate (BMR) was first adopted by Boothby and Plummer (Du Bois, 1936) and has been defined by Mitchell (1962) as the minimal rate of energy expenditure compatible with life. This is the energy required for maintenance. The energy needed for internal mechanical work such as for heart beat, respiratory muscles, osmotic pumps and the synthesis of proteins. The energy used in this way is given off as heat and is measured in Kilojoules, the unit of measurement previously used was Kilocalories. Both are given in this thesis.

Many of the early studies were interested in the effect of disease on the basal metabolism, such as diabetes (von Pettenkofer & Voit, 1867; Leo, 1891) malaria (Leibermeister, 1871), cardiac patients (Kraus, 1893) and exopthalmic goitre , (Magnus-Levy, 1895). The measurement of the BMR was used clinically in the diagnosis and treatment of diseases of the thyroid gland (Du Bois, 1936). Magnus-Levy was one of the first people to realise the value of studying healthy people, so as to establish normal standards against which the effect of disease could be compared. The advance of medicine means that there are now improved methods of diagnosing such diseases and the BMR is seldom used.

The BMR is measured so that energy requirements of an individual or a population may be calculated. It is estimated that the BMR of a normal sedentary person is equal to two thirds of their total energy expenditure (Ravussin et al, 1982). The BMR is therefore an important factor in the calculation of energy requirements.

Energy requirements of a population are a necessary part of the agricultural planning of a country. They can be used to assess the adequacy of diets and of food supplies. Standards of energy requirements have a role to play in the planning and evaluation of food programmes and in public health nutrition programmes. They are also used in the planning of meals in institutions such as prisons, schools, colleges and the Armed services.

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The Food and Agricultural Organisation (FAO) committee of Calorie Requirements first met in 1949. The report which they issued (FAO, 1950) set out an allowance of calories which would meet the physiological demands for energy of most men and women at all ages. The values are based on a reference man and women, who are 65 Kg and 55 Kg respectively, fit and living in a temperate climate. The man carries out eight hours of work per day and is fairly active, the women spends her day carrying out household duties or is employed in light industry. The total daily energy intake was recommended to be 13MJ, 3200 kcals for men and 9.2MJ, 2300 kcals for women. These figures were calculated using the figures for the BMR as part of the method of calculation. The values used for the BMR in the 1973 report were those of Talbot (1938) and are the result of measurements made over 15 years on 2000 people. These figures are now be recognised as being too high and have been decreased to 12.5MJ (3000 kcal)and 9.2MJ(2200 kcal)(FAO/WHO, 1985). The above values can be modified for body size, age, climate, pregnancy and lactation.

There are reservations about the use of BMR in calculating energy requirements. Results of BMR's may be subject to great variability, even between individuals who appear to be similar. In a population the variability is not important in itself, but must be recognised as a source of error and when combined with other sources of error can assume significance. The minimum rate of energy required depends on nutritional state, absence of disease or infection and body temperature. Other factors which may effect the BMR are sex, age, race, climate and the phase of the menstrual cycle in women. The techniques of measuring the BMR are fraught with difficulties, which are discussed later and methodological problems can increase the variability.

1.1.1 The effect of age on the BMR.

Du Bois (1936), found there was a sudden rise in BMR during the first year of life, which peaked in early childhood. There are several early studies of the metabolism of neonates, (Benedict & Talbot, 1915; Murlin, 1922; Hasselbach, 1904). There was great variation between measurements. This was interpreted as being due to a poor regulation of metabolism during the first few days of life. A crying baby was found to increase its metabolism by 40 per cent. Benedict and Talbot (1915) suggested a formula for the prediction of the metabolic rate in new born babies:

Length in cm x 12.65 x 10.3 3/-Weight 2

After reaching a maximum BMR expressed as surface area (Du Bois, 1936) or per kilogram (Widdowson, 1981) in the first year of life there is a fall to pre-puberty. During puberty there is a slight decrease in the fall,and following puberty a further decrease until about 20 years of age. Du Bois (1916) studying a group of Boy Scouts before the onset of puberty found that their BMRs were 25% above the adult standard, two years later it was found their metabolism had fallen and was only 11% above the adult level (Olmstead, Barr & Du Bois 1918). Two studies on school children in England and New York showed a peak during puberty followed by a fall (Bedale, 1923; MacLeod, 1924). The works reviewed of adult metabolism show essentially similar patterns to each other , that is the BMR declines slowly throughout adult life (Harris &

Benedict, 1919; Boothby & Sandiford, 1922).

Fleisch (1951) compiled measurements from 24 sets of data. The age range covered was from 1 to 80 years. The table showed that by 20 years the BMR per unit of body surface area is 70% of the value of a 1 year old. The decline in the BMR from 20 to 60 years is shown to be another 10%. This decrease is thought to be due to changes in body weight, increases in adipose tissue and a reduction in the muscle mass rather than a direct effect of ageing (Keys et al, 1973; Tzankoff & Norris, 1977; 1978; Shock & Yiengst, 1955; Benedict et al, 1914).

1.1.2 The effect of sex on the BMR

Women have lower metabolic rates than men. This difference appears after early childhood and reaches a maximum of 10% at puberty. This difference falls to 5% during adult life (Benedict & Emmes 1915, Durnin

1981). The lower BMR in women is generally attributed to the increased amount of adipose tissue in women. Changes in the BMR due to the menstrual cycle have been studied but the results are often contradictory. This will be reviewed later.

1.1.3 The effect of ethnic group on the BMR

In early work on metabolism, differences in the BMR were found between different races (de Almeida, 1920; Mantoro,1921; Knipping, 1923; MacLeod, Crofts & Benedict, 1925). All the populations studied in these papers were found to have BMRs below the accepted standards for Americans and Europeans.

A large study of people of different races and ethnic groups was carried out between 1925 and 1937 by the Nutrition Laboratory in Boston. The training and techniques of the investigators were all similar. These studies formed part of a review by Wilson (1945). Low values were found for Asian populations, which was in accordance with previous work, but higher values were given for Central and South American populations which had not been previously found. It is not clear whether these differences are due to racial characteristics or a result of all the variabilities which can effect the BMR.

A study combining all the available data on BMR was analysed for differences due to race (Quenouille et al, 1951). The analysis sub-divides the data into two population groups. People from the United States of America and Northern Europeans and people from India, China and Japan. Some anomalies remain, for example Italians were classed as belonging to the former group, although it was commented that they had higher BMRs. Data from other populations was found to be so variable as to be excluded from the analysis altogether such as that of the Australian aborigines.

More recent work however suggests it is unlikely that ethnic differences have an effect on the BMR (Talaat, Habib & El-Khanagry 1953; Chitre et al, 1959; Kim et al, 1966; Hori et al, 1977).

1.1.4 The effect of climate and season on the BMR

The idea that BMR is effected by the season of the year was not demonstrated in the following studies, (Wilson, 1959b; Elsnet, Andersen & Hermansen, 1960; Malhortra, Ramasaswarmy & Ray 1960) although Gold, Zornitzer and Samueloff, (1969) found that the value of the BMR in winter was 14% higher in a group of 17 men in Israel. The maximum effects of climate are said to be produced by a hot dry day, or a cold wet day (Quenouille et al, 1951).

The effect of people moving to a tropical climate from a temperate climate has been found to be highly individual (Mason & Jacob, 1972). The range was from a 24% decrease in BMR, to no measurable change. In those who demonstrated a decrease, the response was prompt. There was no apparent relationship between the type of response and age, sex or body size. Therefore the evidence for climate exerting an effect on BMR is contradictory. Durnin (1981), concludes that there may be a need for an allowance for climatic factors, but the amount needed will require further investigation.

1.1.5 The effect of nutritional status on the BMR

The plane of nutritional status has an effect when considering undernutrition. The BMR is reduced in undernutrition, (Benedict, 1915b; Benedict et al, 1919; Keys et al, 1950). These workers looked at the effect of fasting, and an energy restricted diet for 4 and 6 months respectively. All three studies showed decreases in the BMR from 16 to 30%.

In calculating the energy requirement of a population, the nutritional state therefore needs to be considered. Measurements of a population may be reduced due to a low nutritional intake. There is speculation that deficiencies of specific nutrients could effect the BMR. Evidence of this comes from animal studies only (Kleiber, 1945, Mitchell, 1962).

1.1.6 The effect of altitude on the BMR

Two early reviews investigating the effect of altidude on the BMR concluded that there was generally an increase in the BMR (Durig, 1911; Loewy, 1932). The review of studies of Hannon & Sudman (1973) lead them to the conclusion that BMR in aclimatised populations falls within the normal range.

1.1.7 Physical fitness in relation to the BMR

The effect of physical fitness on BMR is thought to be negligible when calculating standards for a population, (Durnin, 1981, Benedict & Smith,1915; Harris & Benedict, 1919; Steinhaus, 1928; Schneider & Foster, 1931; Robinson & Harman, 1941; Knehr, Dill & Neufield, 1942; Karpovich, 1953).

There may however be an effect when considering the individual (Karpovich, 1953; Schneider & Foster, 1931) although results are not conclusive.

1.1.8 Standardisation of measurements

To minimise variability when measuring the BMR, measurements are always made under standardised conditions, as stipulated by Benedict (1938). The precise conditions are described in the method section. This means measurements are comparable, and the effect of different factors, such as the effect of age or altitude are more easily identified.

1.1.9 The BMR and Surface Area

The BMR may be expressed as kJ or kcal/square meter of surface area/hour. This was most widely used in the past, as a result of the tables of Voit. When the BMR for different species of animals was expressed by weight the differences between species was enormous, but when surface area was used the difference was plus or minus 20% (Voit, 1901). From this Voit concluded that animals of different body size produce heat at approximately the same rate per square metre of body surface.

Surface area has been used for nearly a 100 years, and most standards of BMR are expressed in kcal/sq m/hr. The use of surface area to express the BMR is not uniformly agreed with, (Brody & Elting, 1926; Kleiber, 1947; Durnin, 1959; 1969) and is used less frequently than previously. This is because surface area was used as a standard for comparing different species, and therefore is not necessarily applicable when considering man only. The theoretical reasons against surface area are firstly the assumption that if surface area determines the heat loss from the body then the BMR is a function of the surface area, whereas BMR is determined by the metabolic activity of the active tissue of the body. Secondly surface area is not measured but is calculated from height and weight using the formula of Du Bois. Mitchell et al, (1971) found the Du Bois formula consistently underestimated the surface area when compared to the true areas as measured by a photometric technique.

Measurements of energy expenditure of 160 men and women were used to compare gross body weight and surface area as standards of reference (Durnin, 1959). A multiple regression analysis showed that both were useful but that surface area gave no greater accuracy than body weight, as had previously been shown (Vogelius, 1945). The BMR can be expressed as per kg of body weight, which means that results from different studies can be compared more easily than comparing results expressed as surface area. This is because there are different standard tables of surface area. Body weight also has the advantage of being one of the easiest and most accurate of biological measurements. Schofield et al (1985) gives 12 equations by age and sex for estimating the BMR by weight alone, and also from height and weight. For quick reference there is also a table of standard BMRs for each sex for weights from 3 to 85kg, although these are not applicable for those over 60.

1.1.10 Calorimetry

The BMR can be measured either by direct calorimetry or indirect calorimetry. Both methods are based on the first law of Thermodynamics, which is energy can not be produced or destroyed.

1.1.11 Direct Calorimetry

Calorimetry is a measurement of the heat emitted from the body . This can be measured directly by putting the subject into a specially constructed calorimeter. Lavoisier was the first to realise the relationship between animal heat and respiration. The original calorimeters were surrounded by ice, with guinea pigs placed inside them. The index of heat production was the amount of ice which melted (Lavoisier & Laplace, 1780).

Atwater built the first human calorimeter at the end of the last century and perfected it over twelve years, a description of the final instrument is given in great detail by Atwater and Benedict (1905). The calorimeter consisted of a copper room in which a person could live for several days, inside there was a bed and an exercise bicycle. Food could be passed in and excreta out through a small hatch.The walls were insulated to prevent heat loss and the heat produced by the subject was taken up by water which circulated in pipes through the chamber thereby measuring the heat output. Oxygen and carbon dioxide were simultaneously measured.

This technique is extremely accurate but has quite considerable drawbacks. The construction and maintenance of the chamber is very expensive, which means that not many human calorimeters exist. The measurments need to be made over several hours, which makes direct calorimetry a very time consuming process, therefore limiting the number of people that can be measured. These disadvantages have been reduced to some extent by the use of gradient layer calorimeters,(Benzinger et al, 1958; Spinnler et al, 1972; Jequier, Pitter & Gygax, 1978), but there are still majar drawbacks when measuring large numbers of individuals, as with water cooled calorimeters (Webb 1972) and heat sink chamber calorimeters (Garrow 1977). As a result of this the most commonly used method of measuring the BMR is indirect calorimetry.

1.1.12 Indirect Calorimetry

This is a measurement of the volume and composition of expired air, from which it is possible to calculate the amount of oxygen used in the body per minute and its energy equivalent expressed in kilojoules or kilocalories. Indirect and direct calorimetry techniques have been compared (Atwater & Benedict 1899; Gephardt & Du Bois 1915). Both sets of workers found agreement between the two methods to within 0.2%. Indirect calorimetry does not measure respiration through the skin but this is counted as a negligible amount (Fitzgerald 1957). The oxygen consumption methods used to measure the BMR are either closed circuit or open circuit.

1.1.13 Closed circuit calorimetry

Regnault and Reiset (1849) described a system of closed circuit equipment which measured the oxygen consumption and carbon dioxide production of animals.

Closed circuit calorimetry for measuring BMR in man was originally proposed by Benedict (1918) and Krogh (1923). In this method the subject is cut off completely from the outside air and breathes through a closed system. A respirometer contains pure oxygen and as the gas is expired by the subject the carbon dioxide is constantly removed as its passes through soda lime. The decrease in the gas volume is related to the rate of the oxygen consumption and from this the metabolic rate can be calculated.

A disadvantage to this method is that it entails an artificial set of circumstances, due to the subject breathing pure oxygen (Durnin, 1972). In some people this may effect their breathing. The pure oxygen may cause a decrease in the volume breathed in, or an increase because of irritation by inspiring a dry gas.

1.1.14 Open circuit calorimetry

Open circuit calorimetry is used more widely than the closed circuit method and is considered to be less prone to errors (Fowler, Blackburn & Helmholz, 1957; Consolazio, Johnson & Pecora, 1963). The subject breathes air from the outside and his expired air is collected. The volume is corrected for standardised conditions and analysed for oxygen consumption and carbon dioxide production. Two such methods are the Douglas bag technique(Douglas 1911) used in this survey and described in full in the methods section,and the ventilated hood method.

Weir (1949) devised a formula for the calculation of the BMR:

Energy = 4.92V/100 (20.93 - 02 expired)

Weir's formula makes it unnecessary to measure carbon dioxide, and therefore the calculation of the respiratory quotient. The error of not measuring the carbon dioxide is calculated to be plus or minus 0.5%.

1.1.15 The Ventilated Hood Method

The ventilated hood method is designed to avoid the problems which mouth pieces and air tight face masks can give rise to if not properly used, such as leaks. The ventilated hood is also more comfortable over long periods of time, than the Douglas bag technique. Benedict (1930) described a helmet originally constructed from a galvanised iron water pail with a celluloid window fitted over the head and sealed at the neck with a bathing cap. A more sophisticated version was used by Ashworth and Wolff (1969) in which the subject can rest comfortably in bed, a paramagnetic oxygen analyser and an infra red carbon dioxide analyser samples the air sucked out. Garrow and Howes (1972) claim " it is possible to obtain both high accuracy and rapid response time ", using the ventilated hood. This method takes into account the cyclic variations which occur in the BMR, (Bailey et al, 1973) which are not measured by the Douglas bag technique due to the short measurment time. The main disadvantage is that it has a tendancy to leaks and needs constant checking (Durnin, 1981). Garrow (1980) however claims that this is not important as the pressure inside the hood is always below atmospheric pressure, provided that the leak is not so great that expired air escapes against the flow of incoming air.

1.2 THE BASAL METABOLIC RATE DURING MENSTRUATION

The effect of the menstrual cycle on the BMR has been investigated and the results from studies differ. Zuntz in 1906 measured the BMR in two women for several months. He reported no consistent variations in the oxygen absorption or the carbon dioxide excretion, before, during or after menstrual periods. There was an increase in the body temperature of 0.36 C during the menstrual period. Other workers found an increase in the BMR one to ten days before menstruation in a sample of ten women, (Snell, Ford & Rowntree, 1920; Wakenham,1923) Wakenham also described the BMR decreasing at the beginning of the menstrual period, which was followed by a gradual return to the normal value within one to ten days.

In a study of five women, the BMR was measured during the pre-menstrual, menstrual and post-menstrual phases. The mean results at each of these phases led the authors to conclude that the variations during the different stages were so small that they could not be said to have a marked effect,(Wiltshire, 1921). This is similar to the conclusion of Blunt and Dye (1921) who reported that the average BMR was 1.6% lower during menstruation, but this was not of significance.

Another study investigating the BMR of seven women found that four of the subjects showed an increase in the metabolism during menstruation. One subject showed a decrease and two showed both an increase and a decrease when measurements were taken during different menstrual periods (Smith and Doolittle, 1925). The review of Benedict and Finn (1928) suggests there is a tendancy for the lowest metabolism to appear a week after the last day of menstruation followed by a rise of 10%.

A more recent paper, (Solomon, Kurzer & Calloway, 1982) investigated the variation in the menstrual cycle of six women. The energy intake and physical activity were held constant under controlled conditions. Using a non linear regression procedure to measure the cyclicity of the BMR they concluded from their data that BMR varied significantly in five of the six subjects. The pattern they described was similar to that reported by Wakenham (1923). The effect was slight and the authors conclude that it may be missed if only the average values are examined. The average difference of the highest value to the lowest was 1.0kJ/min(0.25 kcal/min).

It would appear from the studies reviewed that not all women show the same pattern and that any changes observed are likely to be small. However all studies quoted are on very few women, no more than 10 were studied, and generally for only one menstrual cycle. Any differences observed are unlikely to reach statistical significance on these small numbers. The variations found tend to be no greater than is found when measuring the BMR on consecutive days. It would appear that there is a need for the effect of the menstrual cycle to be investigated more thoroughly in a larger number of women over consecutive menstrual cycles.

INTRODUCTION

1.3 THE BASAL METABOLIC RATE IN PREGNANCY.

Basal metabolism during pregnancy has been investigated since 1868 when Pfluger estimated the energy production of the mammalian fetus (Du Bois, 1936). Pfluger concluded that the gaseous exchange of the fetus when compared with the mother is insignificant. This was supported by work carried out on embryo sheep (Du Bois, 1936). Rubner (1908) stated that the mammalian embryo has very little weight in comparison to the mother until the middle of the gestation period. Other workers failed to find any increase in the oxygen consumption of pregnant women in comparison to non pregnant women, or if there was an increase then this occured only late in gestation (Magnus-Levy, 1904, Du Bois 1936). This view was confirmed by a series of experiments measuring the total energy production of a pregnant dog (Murlin 1910).

Magnus-Levy in a single case study, found an increase in the oxygen absorption during the third month of gestation. The conclusion of Carpenter and Murlin was that the energy production in pregnancy does not rise significantly until half way through the pregnancy. From then on, the total energy increases steadily until parturition (Du Bois, 1936). In the same paper the authors investigated the energy metabolism of the mother and child before and after parturition. They measured the BMR of three women before and after the birth using direct calorimetry. They found that the curve of total energy production of mother and child showed no deflection at birth. The energy production of the pregnant woman per unit weight was seven per cent less than the newly delivered woman, and about four per cent higher than the non-pregnant woman. The increase post-partum is explained as being due to activity of the mammary glands and the dynamic action of protein liberation. A similar increase was found in a study measuring the gaseous exchange and specific dynamic effect of fourteen pregnant women (Knipping, 1922).

Baer in 1921, published the results of a study of forty-four women. The BMR was measured during the last six weeks of pregnancy and the first eleven days following the birth. There were a total of fifty-two measurements prepartum and seventy-five postpartum. The average increase was twenty-six per cent at thirty-six weeks and thirty-three per cent at forty weeks. However this was calculated using the non-pregnant values of surface area equivalent to the pregnant women. As discussed earlier, there are problems in using the standardised tables for surface area. In addition to this the validity of using non-pregnant values for pregnant women makes it difficult to accept the results. Following the birth, the increase in the BMR fell to fifteen per cent at three days parturition and to less than two per cent by the eleventh day. Baer also suggested the use of the BMR to diagnose fetal death or the presence of twins (Baer, 1921). However the BMR in pregnancy was found to be subject to many influences and the results of no practical use in obstetrics for diagnosing abnormal pregnancies (Cornell, 1921). The latter two papers included measurements on pathological pregnancies and in most cases the number of observations per patient was low. Both these factors make interpretation of the results difficult.

In an attempt to overcome such difficulties a study was carried out following a single subject from the fifteenth week of pregnancy to eight weeks after delivery (Root & Root 1923). Measurements were made fortnightly, with the exception of the last three weeks of the pregnancy when they were carried out weekly. A portable Benedict respiration apparatus was used in all measurements. The paper is a very detailed and careful study, but as it is on a single subject no more general conclusions about the BMR in pregnancy can be made. A marked increase was found in the basal metabolism expressed per twenty-four hours and per unit of body weight during the latter months of pregnancy. The heat prodution per unit weight fell during the first three weeks post partum to below the level recorded at four months gestation. The following year another single case study was published (Sandiford & Wheeler, 1924). They followed a subject for a total of seventeen months, from the pre-pregnant state to four months after she had stopped breast feeding and menstruation was established. Frequent measurements were made by indirect calorimetry. There was a variation of less than three per cent in energy production during the first six months of pregnancy. For the last two months of pregnancy an increase in the total heat production was observed. The maximum at term being twenty-five per cent higher than in the non-pregnant state. This increase was thought to be entirely due to the increasing mass of fetal tissues and maternal structures. There was no increase in heat prodution during lactation. When menstruation was re-established there were irregular variations in the

BMR, which were not found to be due to menstruation. A second study on the same subject in a later pregnancy reached the same conclusions (Sandiford, Wheeler & Boothby 1931).

In contrast to the work of Sandiford and Wheeler, the BMR during pregnancy has been found to be in excess of the increase expected by the increase in weight alone (Rowe, Alcott & Mortimer, 1924). However the weight gain observed in the women were low. There were two groups of women, one from a private hospital, and the other from an institute for unmarried mothers. The average reported weight gains were 3.31Kg and 3.2Kg respectively. No comment is made by the authors concerning this low weight gain, when one considers the average weight gain is generally accepted to be 12.5Kg, it would seem that the low weight gain is an anomaly which invalidates the conclusion of the study.

The review of Harding (1925) summed up the available literature, and was of the opinion that there appeared to be no change in energy exchange during pregnancy, beyond that produced by the products of conception. There are however problems when comparing studies were different methods have been used. Johnson (1938) studying one subject found a rise in the basal metabolism and thought the increase was due to the increased mass, but also concluded that there must be a component of hyperactivity of the pituitary involved. However a previous paper investigated the nutritive state of the same subject (Hummel et al, 1937) . The subject was described as having had a poor nutritional background for the previous six years, and was only eighteen years old. While both these variables may have effected the BMR, the extent of which is not known, they are not discussed.

The majority of papers reviewed so far have found increases in the metabolism during pregnancy. The increases are attributed to the heat production of the fetus and only of significance in the latter months of pregnancy. A paper published in 1932 suggested that this might be a far too simplistic view of what was happening (Rowe & Boyd 1932). They measured the heat production of seventy-seven women throughout the last six months of pregnancy. During the third and fourth months of gestation they recorded a decline in the energy requirement. Thereafter a steady increase in the BMR was reported, which was higher than would be expected by the increase in body weight. The authors do not think that this increase is due primarily to the fetus but to " a complicated and unknown mechanism engendered by the state of pregnancy", and other factors are involved. No evidence or theories are presented to explain the recorded drop in the BMR during the third and fourth months. As with many of the previous papers there is no baseline data with which to compare the recorded increases or decreases in the BMR.

As with many of the workers before him, Teruoka felt that the previous studies had not investigated the metabolism of pregnancy thoroughly, and in particular had not examined what happened in the pregnancies of working women (Teruoka 1933). However despite the former consideration only five women were studied and from the second trimester onwards. The small numbers and lack of baseline data are the main critisms that can be levelled at the previous studies. One woman was a housewife while the other four were factory workers in a cotton mill. The latter group may have had higher energy expenditures than the housewife which compounds the difficulties of such a small group. The BMR was measured at intervals of two to four weeks. In one subject the energy expenditure of walking was measured. There was no increase in the oxygen consumption per unit of body weight, and the rate and depth of respiration remained unchanged as did the body temperature. The pulse rate was found to be higher than for non-pregnant women, although it may not be valid to compare such a small number of women with the non-pregnant average. The total daily heat production increased by twelve to twenty-two per cent by the end of pregnancy.

Widland (1945) measured the oxygen debt after walking up and down stairs in pregnant and non-pregnant women. He found that it was comparable at low and moderate speeds, but ten per cent higher at the greater speeds. Bader et al(1955) looked at the effect of cycling on thirty-five women, who ranged from fourteen to forty weeks pregnant. Oxygen consumption was measured before and after exercise and the increments in consumption were similar for all stages of pregnancy.

Seitchik(1967,a) looked at energy expenditure in pregnant women at rest, cycling and after cycling. The cost of quiet sitting expressed per unit mass was identical in pregnant and non-pregnant women, this was also found for cycling. The most efficient time of pregnancy was given as between twenty-four to thirty-five weeks. This has been shown subsequently (Knuttgen & Emerson, 1974; Pernoll et al, 1975). In contrast to the findings of Seitchik, a study looking at the relationships of red cell mass, oxygen consumption and lean body mass in seventeen pregnant women found that the oxygen consumption per kilogram of body weight did increase (Flanagan, Muldowney & Cannon 1966).

{Dakshani & Ramanamurthy (1964), investigated the BMR of children, adolescents, pregnant and lactating women. The study showed that there was no appreciable difference between non-pregnant women and women in the first trimester of pregnancy. The BMR during the third trimester was found to be raised by twenty-three per cent. It was also found to be eight per cent higher during lactation. A comparative study of energy expenditure at rest and carrying out light work, looked at pregnant and non-pregnant Indian, Chinese and Malay women living in Singapore (Banerjee, Khew & Saha 1971). Increases in the energy expenditure at rest and carrying out activities were shown in the third trimester for all three ethnic groups. For the pregnant women the percentage increase in energy expenditure above the BMR for activities was lower than non-pregnant controls. This would again suggest that pregnant women carry out the tasks in an energetically more efficient way.

Increases in the BMR have been shown to have occured by the third and fourth months of pregnancy (Huen et al, 1970). These are of the magnitude of ten to eleven per cent and decrease to six per cent by the fifth month. There is a total increase in the BMR of twenty four per cent by term. The decrease in the rate of increase, during the middle of pregnancy is thought to be due to hormonal factors, although no data is presented to support this hypothesis. Given the inconclusive nature from the studies on the menstrual cycle this may be unlikely, and any evidence of the effect of hormones on the BMR is not presented.

Measurements were made cross sectionally of the BMR, on a hundred pregnant women and eighty six lactating women using Benedict Roth apparatus (Khan & Belavady, 1973). The results were compared to non-pregnant values. The BMR increased by seven per cent between weeks twelve to twenty four. Weeks twenty four to thirty six showed an increase of fifteen per cent above the non pregnant figure. A significant difference between the two time periods was found.

A paper investigating the BMR in a hundred pregnant and fifty lactating women in Varanasi also found the BMR to be greatest during the third trimester. An increase of five to six per cent was reported (De & Nagchaudhuri, 1975) below the value of Khan and Belvady but similar to Dakshayani and Ramanamurthy (1964). The BMR during lactation was found to be significantly lower than that of pregnancy, but no comparisons are made to pre-pregnant figures.

Blackburn and Calloway (1974) investigated the energy expenditure of pregnant adolescents between the ages of fourteen and nineteen in two groups. One group of fourteen were measured carrying out housework and at rest, while another group kept activity diaries. The energy cost of the activities measured in the former group were used to estimate the energy cost of the latter. The BMR was thirteen per cent higher in the third trimester of pregnancy compared post-natally. The differences were not significant if the values were corrected for weight. This was also found for the activities measured.

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The activity patterns, energy expenditure, energy and protein consumption of mature women were measured by the same group of workers during pregnancy and lactation (Blackburn & Calloway 1976a). The women were not found to be significantly more active than the adolescents, but the range of activities was greater. The BMR increased during pregnancy. There was a small drop of six per cent in the energy expenditure at the end of pregnancy. The total energy expenditure near term is given as 9.2MJ to 9.6MJ (2200 to 2300kcal) per day. The average daily intake reported was 8.2MJ (1960 kcals) per day. The authors question whether it is possible to stay in positive nitrogen balance on this intake. However the question as to whether it is possible to stay in energy balance and produce healthy infants when such discrepancies occur is not discussed. With differences in the energy balance of 1MJ daily (240kcal) a weight loss would be expected. This is not reported, or possibilities as to whether the measured differences are real or not.

In twenty one women studied during the last half of pregnancy and post-natally the BMR was found to increase more than is attributable to the increase in weight. A small fall in the BMR per unit of body mass was observed at term. The data on the lean body mass suggests the fall was not explained by shifts in body water or fat mass.(Blackburn & Calloway, 1976b). The increase in the energy cost of work paralleled the gain in body weight. The net energetic efficiency therefore appeared to be higher for work performed during pregnancy. Only the latter half of pregnancy was investigated, so how the BMR may have changed during the first half is not known. This is of importance for making recommendations as to the energy requirements of pregnancy particulaly when viewed in the light of a following study which compared the BMR in non-pregnant women, early pregnancy and late pregnancy. The women in early pregnancy had a metabolic rate that was thirteen per cent higher than the non pregnant women. When comparing early pregnancy with late it was found that the latter group had BMRs twenty eight per cent higher. When the BMR is expressed as per unit of body weight there are no significant changes during pregnancy. There was an increase in energy expenditure walking at the subjects pace. This was thought to be determined mainly by weight (Nagy & King 1983).

In a group of nineteen Swedish women, at the time of first measurement, which were between sixteen to eighteen weeks gestation, seven showed a decrease in the BMR. For the whole group however, there was an increase from the non pregnant values (Forsum, Sadurskis & Wager, 1985).

A cross-sectional study investigating whole body protein turnover, incorporated measurement of the BMR into the study design (de Benoist, et al, 1985). The subjects were 18 pregnant Jamaican women. Six women were measured per trimester. The BMR was measured using the ventilated hood method. It was found that BMRs were significantly lower in the first trimester compared to the second and third trimesters. When BMR was calculated per unit of body weight, no significant differences were found. There were no significant correlations between the BMR and whole body protein turnover. The authors discuss whether this means that there is a relative saving in energy expenditure related to a decrease in protein turnover as pregnancy progresses. The energy saved would then be used for other metabolic functions. An alternative is that the contribution of rapidly turning over proteins is greatly underestimated in late pregnancy.

In summary from the work reviewed, there would appear to be little doubt that the gross BMR increases during pregnancy and that this is due to the increased oxygen consumption of the fetus and extra maternal tissues. The effect of pregnancy on the BMR per kg of body weight is not so clear. Evidence exists that leads to suggestions of physiological adaptations taking place, so the increase in the BMR may not be as high as calculated previously.

Reports of the point at which the BMR starts to increase and the percentage increase of the BMR during pregnancy vary greatly. This is often as a result of the time during pregnancy when measurements were started. For example if measurements are only made in the third trimester, any increases in the BMR that have already occured will have been missed and the reported increase could be less than a study when measurements were initiated in the first or second trimester of pregnancy. There are problems in interpreting the results of some studies due to study design, for example establishing true pre-pregnant values. If there is great inter-observer variability then cross-sectional studies may not be representative. The numbers in many of the studies quoted above are small. In the larger studies the number of measurements made throughout an individual woman's pregnancy tend only to be one per trimester. This might mean that alterations in the BMR are being missed. There is clearly a need to collect data which can overcome these methodological difficulties. The ideal would be to measure a large enough group of women from the pre-pregnant stage longitudinally throughout pregnancy and during lactation at regular intervals. Without such data the increase in the BMR cannot be accurately assessed, and the energy cost of pregnancy will not be truely reflected. This has implications for the calculations of the increased energy requirements of pregnancy.

1.4 WEIGHT GAIN IN PREGNANCY.

The increase in the BMR may be due in part or in total to the increase in body weight during pregnancy. The range of weight gained during pregnancy is large from

23Kg to a loss of body weight (Hytten & Chamberlain 1980). However while weight is an easy measurement many of the studies have been carried out on pathological pregnancies, or late in pregnancy. Others are effected by dietary manipulation to limit the weight gain. The latter for a variety of reasons such as to make the delivery easier, to prevent pre-eclampsia or simply so that the woman could remain slim (Hytten,1979).

The average figure quoted is 12.5Kg (Hytten & Leitch 1971; Hytten, 1981) , and this was calculated using data from two British studies (Humphries, 1954; Thomson & Billewicz, 1957). Humphreys found that the average weight gain was 11.7Kg. Thomson and Billewicz calculated an increase of 11.4Kg. Chesley (1944) gives the average increase of weight during the first trimester as 1.14Kg. This is based only on the women's reported normal weights before pregnancy which may not be accurate. While the average figure is given as 12.5Kg for primigravidae, there is not a similar estimate for multigravidae. The evidence that exists suggests that the average multigravidae gains 0.9Kg less than a primigravidae (Humphreys, 1954, Sinnathuray & Wong 1972).

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A Japanese study of 2000 women found that the average weight gain was 11.7Kg, and maternal weight gains over 12Kg have no significance for fetal growth (Kawakami et al, 1977). Lower weight gains are reported in Nigeria (Akinkugbe, 1979; Hauck, 1963) India, (Venkatachalam, Shankar & Gopalan, 1960) and Bantu women (Neser, 1963). Low weight gains are related to poor nutrition and an increased incidence of LBW babies (Akinkugbe, 1979). Weight gains in teenage pregnancies have been reported (King, Calloway & Margen, 1973). In ten teenage girls between 14 and 19 the average weight gain was 12.9Kg. When omitting one girl with oedema the average gain is 11.5Kg.

Very low or very high weight gains during pregnancy appear to have only a small influence on the frequency of placental and fetal disorders. However if such a disorder becomes established mortality rates have been found to increase with extremes of weight gain (Naeye, 1979).

High weight gains during pregnancy are associated with an increased risk of pre-eclampsia. However attempts to restrict weight gain during pregnancy in order to prevent pre-eclampsia have been unsuccessful(Baird, Thomson & Hytten, 1962). The incidence of pre-eclampsia was no lower in a group of women who were seen by dietitians and advised on how to prevent gaining extra weight compared to a control group. To manipulate the weight gain so that women do not become progressively heavier following pregnancies is not generally justified (Hytten, 1979). However a study which looked at the weight changes in a group of 50 women who had 5 successive pregnancies found that their weights progressively increased (Beazley & Swinhoe, 1979). These findings support those of Sheldon (1949) and Billewicz & Thomson (1970).

The pre-pregnant weight of women appears to be related to outcome of pregnancy (Peckham & Christianson, 1971; Jacobson, 1975). Toxemia was found to be more frequent in heavier women, and they had longer deliveries. Women who had low pre-pregnant weights had a higher incidence of antepartum bleeding including abortion (Peckham & Christianson, 1971). Underweight women have a higher incidence of LBW babies despite adequate weight gains during pregnancy (Edwards et al, 1979). A study investigating the relationship between maternal body mass indices and the outcome of pregnancy in 44,725 women (Garn &

Pesick, 1982), found that pre-pregnant weight was a better indicator of the size of the neonate than indices using roots or powers of weight and height.

1.4.1 Rate of weight gain in pregnancy.

The rate of weight gain throughout pregnancy differs according to the stage of pregnancy. It is thought to increase at the rate of 0.36Kg per week up to 16 to 18 weeks. It then increases to 0.45Kg per week until 26 to 28 weeks, after which time it slows down to 0.36-0.41Kg per week to term (Hytten & Chamberlain 1980). When weight gain is plotted against time it gives a sigmoid curve. These figures are based on the measurements of 2868 women but are similar to eight other studies where the maximum weight gain was also between 17 to 24 weeks gestation (Hytten & Chamberlain, 1980). A reference table of weight for height by week of pregnancy has been designed based on a twenty per cent increase of the pre-pregnant as the ideal weight gain (Gueri, Jutsum & Sorhaindo, 1982).

Although it has been found to correlate well with birth weight, further testing is necessary before it could become useful.

Fetal distress occurs more commonly in women who fail to gain weight in the last four weeks of pregnancy (Anderson et al, 1973). The onset of abnormal weight gain associated with toxaemia has been found to start as early as the tenth week of pregnancy (Vedra & Parikova, 1969). A rapid weight gain between weeks 13 to 20 has an increased liability of the development of oedema (Thomson, Hytten & Billewicz, 1967). However the incidence of oedema is not always associated with the develoment of pre-eclampsia. It has been found in thirty five to forty per cent of normal pregnancies (Hytten, 1981). Babies born to oedematous mothers are heavier than those born to women without oedema (Hytten, 1981). Hytten proposes that the normal pregnant woman has a physiological oedema due to oestrogens. The difference between this and oedema leading to pre eclampsia is not known.

1.4.2 Components of the weight gain.

The energy cost of pregnancy can be calculated, by looking at the components of the weight gain and the energy needed to lay down the new tissues. The weight gain can be divided into the weight gain due to the fetus and the weight gain due to changes in the maternal body.

1.4.3 The product of conception

The product of conception consists of the fetus, amniotic fluid and placenta. Table 1 shows the weight gain of each of these at 10 weekly intervals throughout pregnancy (Hytten & Chamberlain, 1980).

TABLE 1 - ANALYSIS OF WEIGHT GAIN

Increase in weight (g) Tissues and fluids accounted for and total weight gained	Weeks gestation 10	20	30	40
Fetus	5	300	1500	340
Placenta	20	170	430	650
Amniotic fluid	30	350	750	800
Uterus	140	320	600	970
Mammary glands	45	180	360	405
Blood	100	600	1300	1250
Extracellular extravascular fluid				
No oedema or leg oedema	0	30	80	1680
Generalised oedema	0	500	1526	4897
Total				
No oedema or leg oedema	340	1950	5020	9155
Generalised oedema	340	2420	6466	12372
Total weight gained				
No oedema or leg oedema	650	4000	8500	12500
Generalised oedema	650	4500	10000	14500
Weight not accounted for (maternal stores)				
No oedema or leg oedema	310	2050	3480	3345
Generalised oedema	310	2080	3534	2128

(From Hytten & Chamberlain (1980) p.221)

1.4.4 Increases in the maternal body.

There is an increase in the weight of the uterus, breasts, blood volume and body water as shown in Table 1. The weight of the placenta is linearly related to the fetus (Molteni, Stys, & Battaglia, 1978). The total weight gain of the product of conception and the maternal tissues listed above is below the average weight gain of 12.5 Kg. The discrepancy is thought to be due to an increase of maternal fat and the average woman will gain 3.5Kg of fat during pregnancy (Hytten & Chamberlain, 1980). The amount of fat laid down has a large impact on the energy cost of pregnancy, given that the energy equivalent of 1Kg of fat is 46MJ (11,000kcal) (Keys & Brozek, 1953). It is thought that much of the fat laid down during pregnancy will be deposited subcutaneously (Taggart et al, 1967). Taggart et al measured the skinfolds at seven sites in eighty four women during and after pregnancy. The skinfolds at most sites increased up to thirty weeks, but not at the same rate. There was a greater increase in the central sites compared to the peripheral sites. From thirty weeks to thirty eight weeks changes were variable, but all sites decreased by large amounts from thirty eight weeks to six weeks post partum. This decrease is most likely to have occurred around the time of parturition. Underweight women showed the greatest increase in skinfolds throughout pregnancy. Skinfold thicknesses and fat cell diameters were measured serially during pregnancy in twenty seven women. Total maternal body fat reached a peak at the end of the second trimester before diminishing (Pipe et al, 1979). Problems exist however in interpreting skinfold data during pregnancy due to increases in the body water, and methodological problems in measuring some of the skinfolds as the pregnancy progresses, the most obvious being the supra illiac skinfold.

Skinfold studies of pregnant Nigerian women from a low socio-economic group show a decrease throughout pregnancy. This is thought to be due to inadequate energy intakes for pregnancy. The total weight gains during pregnancy were found to be low when compared with normal healthy Nigerian women with high socio-economic status (Hussain & Akinyele, 1980).

Total body water and total body density during pregnancy have been measured in 126 women (Seitchik, 1967b). The water accumulated is accounted for by the physiological and anatomic adjustments of pregnancy and no evidence was found that storage occurs beyond these requirements. Serial measurements in changes in the body composition during pregnancy in normal and diabetic pregnancies have demonstrated that the fat storage is dependant upon energy intake as in the non pregnant (Emerson, Poindexter & Kothari, 1975). Body cell mass (BCM) accumulation was shown to be independant of food intake except protein. It is concluded that the extra basal energy needs of pregnancy are in relation to the increase in BCM and not total body weight. The conclusions from both these studies seem unsuprising but confirm that pregnancy is a physiological state.

1.4.5 Energy cost of Pregnancy.

The weight gain can be split into three components, fat, water and protein. From this the energy cost of the pregnancy can be calculated. Table 2 shows the increases in these components. The energy cost of

TABLE 2 - WEIGHT GAIN DURING PREGNANY ANALYSED BY COMPONENTS OF WATER, PROTEIN AND FAT

		Increase in weight (g) Weeks gestation			
		10	20	30	40
Fetus	Water	4	264	1184	2414
	Protein	0.3	27	160	440
	Fat	negl.	2	80	440
Placenta	Water	18	153	366	540
	Protein	2	16	60	100
	Fat	negl.	1	3	4
Amniotic fluid	Water	30	346	742	792
	Protein	0	0.5	2	3
	Fat	-	-	-	-
Uterus	Water	116	264	495	800
	Protein	24	55	102	166
	Fat	0.5	1.3	2.4	3.9
Mammary gland	Water	34	135	270	304
	Protein	9	36	72	81
	Fat	1.4	5.4	10.8	12.2
Blood	Water	90	538	1156	1083
	Protein	0	30	102	135
	Plasma fat	0.4	3.9	17.4	19.6
Maternal stores	Fat	326	2052	3480	3345

(From Hytten & Chamberlain (1980)
Tables of Summary p.227-8)

TABLE 3 - CUMULATIVE ENERGY COST OF PREGNANCY

	Equivalent kJ/kcal per day Weeks gestation 0-10		10-20		20-30		30-40		Cumulative Total	
	kJ	kcal	kJ	kcal	kJ	kcal	kJ	kcal	MJ	kcal
Protein	15	3.6	43	10.3	111	26.7	143	34.2	22	5186
Fat	232	55.6	985	235.6	868	207.6	130	31.3	152	36329
Oxygen consumption	187	44.8	414	99.0	619	148.2	949	227.2	149	35717
Total net energy	435	104.0	1443	344.9	1598	382.5	1221	292.7	323	77234
Metabolisable energy (total net plus 10%)	480	114	1585	379	1761	421	1347	322	355	84957

(From Hytten & Chamberlain (1980) p.165) these components plus the extra energy needed to maintain these tissues is shown in Table 3 (from Hytten & Chamberlain 1980). The total energy cost of pregnancy is therefore calculated to be 355MJ (85,000 kcal).

1.5 RECOMMENDED DAILY ALLOWANCE OF ENERGY DURING PREGNANCY

In the previous section it was stated that the theoretical cost of pregnancy is 355MJ (85,000kcal). Accurate knowledge of the energy cost of pregnancy is important because from this the RDAs for pregnancy are calculated. How this cost is met should greatly influence the recommended daily allowances for pregnancy.

RDAs have existed since the 1930s and specify the energy and nutrient requirements of a population. As discussed earlier they are used as standards to compare different populations, and to assess the adequacy of a populations diet. Orr (1937) realised the relationship between food, health and income, and linked this to the need to establish dietary standards which would be based on physiological needs. In 1936 the League of Nations concluded that pregnant and lactating women needed 12.55MJ (3,000kcal), 91g of protein and 1.72g of calcium daily. Since then as more has become known the figures for pregnancy have decreased.

The figures recommended vary from country to country. The WHO/FAO/UNU (1985) figures are for an increase of 1.2MJ/day (290kcal/day) from the pre-pregnant figure of 8.37MJ (2000kcal) throughout pregnancy. The U.K. figures recommend an increase of 1.00MJ (240kcal) in the second and third trimesters, from 9.21MJ (2200kcals) (DHSS, 1987).

These figures are based on the theoretical calculations of the energy cost of pregnancy. The WHO/FAO/UNU figures assume that the total cost of pregnancy is met by an increase in the diet. The UK figures allow for an increase in the diet and for part of the cost to be met by a decrease in the level of energy expenditure.

The RDAs therefore are based on several assumptions which are not necessarily valid when considering women from different cultural and economic backgrounds. Firstly, the assumption is that the pregnant woman is a healthy 55Kg woman in the non pregnant state and consuming a diet which is nutritionally adequate. The woman when she becomes pregnant is well nourished, and her diet during pregnancy maintains this plane of nutrition.

The second assumption is that physical activity has only a slight impact or no impact at all on energy balance in pregnancy. The UK figures allow for a reduction in energy expenditure, whereas many womens activity patterns may be sufficiently sedentary for a further decrease to be unlikely. Equally, some women may be unable to decrease their energy expenditure as they have to continue working. This may be particularly true for women in rural developing countries. There is much conflicting evidence, some workers believe that the requirements are almost completely balanced by a decrease in activity (Norgan, Ferro-Luzzi & Durnin, 1974; Banergee, Khew & Saha, 1971) while others challenge this (Blackburn & Calloway, 1976).

What is apparent however is that the RDAs at the moment are based on limited data, from which assumptions are made. There is clearly a need for more comprehensive data on which recommendations for the increased energy requirements can be made. There needs to be more data to assess if the current figures for the energy cost of pregnancy are accurate, and how this cost is met. This is particularly relevant given the implications accurate data has in nutrition planning programmes and in assessing maternal nutrition.

1.6 ENERGY INTAKE AND PREGNANCY.

Studies of energy intake in pregnancy are often concerned as to whether the RDAs are being met and which members of the of the population form the more vunerable groups (Whitehead et al, 1981; Doyle et al, 1982). If the RDAs are not met, it is not always clear as to whether the reported low intakes are harmful to the mother and fetus or whether the RDAs have been set too high. The latter arguement could be viable if the energy requirements are based on an overestimate of the energy cost of pregnancy, or if the RDAs are based on innaccurate information on how the cost is met.

The mean percentage of LBW infants is significantly higher in mothers who gained little birth weight during pregnancy (Susser & Bergner 1970) and studies undertaken in developing countries have shown that a low energy intake during pregnancy effects the infants weight (Lechtig, Delgado & Lasky, 1975).

The effect of severe nutritional deficiency has been demonstrated in animal experiments (Hytten & Leitch, 1971). Information about the effect of energy restriction and the outcome of pregnancy in man is available from famines and blockades that occured in the two world wars. During the blockade of Germany the fertility rate of both sexes and the birth rate fell by 50% during 1917 (Starling 1919). War amenorrhoea was common, as it was in the seige of Leningrad 1941-1942 (Hytten & Leitch, 1971). The children born in the first half of 1942 suffered a high mortality and 49% were less than 2500g.

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The famine in Rotterdam during the blocade of October 1944-May 1945 was documented by Smith (1947), who showed that the birth rate fell to about a third of the normal and that 50% of the women were amenorrhoeic. The latter may have been also stress induced and not only due to the low food intakes. Most women gained no more than two kilograms and many lost weight. The energy intake fell to below 4.2MJ (1000kcal), (Stein & Susser 1975). When the famine coincided with the last two trimesters or the last trimester the birth weight was reduced by 350g. However linear growth was not effected, and the infants appeared not to have suffered any permanent stunting of their subsequent growth and intellectual development(Stein et al, 1975), suggesting that the decrease in birth weight is a lack of fetal adipose tissue.

The above conditions are in contrast to Britain during the second world war. McCance et al (1938) had concluded that pregnant and lactating women formed a vunerable group. As a result of the report they were given priority in the rationing system. The still birth rate fell from 38/1000 in 1938 to 28/1000 in 1945. Other workers reported associations between the quality of the pregnant woman's diet and the health of their babies (Ebbs et al 1941, Peoples League of Health 1946). However other workers looking at the energy intakes of pregnant women found that the results did not show any correlations (Thomson, 1959; McGanity et al, 1958).

The effect of supplementation to pregnant women on low calorie diets has been studied in many different parts of the world including Taiwan, Bogata, Guatemala, Gambia, and New York (McDonald et al,1981; Mora, de Paredes & Wanger, 1979; Lectig et al, 1975; Lawrence et al, 1987; Rush, Stein & Susser, 1980). Increases in the birth rates and a decreased incidence of LBW are associated with supplementation. The increases have not always been of the magnitude expected for the supplement given.

Many studies investigating the food intake of pregnant women in the UK have found that their energy intakes do not increase to meet the RDAs for pregnancy. Smithells et al (1977) investigated the nutritional intakes of 195 women in Leeds during the first trimester of pregnancy. They found that two thirds of the sample were having insufficient intakes of energy, iron and cholecalciferol. Low energy intakes were associated with the following factors, maternal age under 20, smoking ten or more cigarettes a day, social groups III, IV and V, and sickness more than three times a week.

Smoking is generally thought to be a factor in decreasing the birth weight of the baby (Butler & Alberman, 1969; Butler, Goldstein & Ross, 1972; Meyer & Tonascia, 1977). While other workers think that women who smoke are also those who are more likely to have other risk factors associated with low birth rate (Hickey, Clelland & Bowers, 1978) there would appear to be little doubt that smoking is a risk factor in pregnancy.

A low intake of energy was found in a group of pregnant women in Hackney, (Doyle et al, 1982). These women were of low economic status and had average intakes of 7.4MJ(1.6) 1770kcal (380). Doyle et al expressed concern about these intakes. Whitehead (1981) reported energy intakes below the recommended RDAs for pregnancy of 8.28MJ (2000kcal) with a standard deviation of 1.46MJ(350kcal) in twenty five women attending a Cambridgeshire hospital. There was no measurable increase in the food intakes during pregnancy, and the mean weight gain and birth weights were normal. Whitehead concludes that the women must have met part of the extra energy needs of pregnancy by changes in their activity or by increased efficiency of metabolism. Other workers have also reported energy intakes below the RDAs (Anderson & Whichelow, 1985; Abraham et al, 1985)

Weigley (1983) suggests that older primigravida, defined as women over the age of thirty-five may have a reduced energy requirement due to a decrease in the BMR with age, and an increased tendancy to hypertension.

Studies in Tanzania, The Gambia and Papua New Guinea have all shown values of energy intakes below the FAO/WHO recommendations (Maletnlema & Bavu, 1974; Prentice, Whitehead, Roberts & Paul, 1981; Norgan, Ferro-Luzzi & Durnin, 1974). Prentice et al with intakes of 6.19 MJ/day (1480kcal) and 5.89 MJ/day (1400kcal) during the dry and wet seasons respectively suggest that long term adaptive mechanisms mean that low intakes of energy do not cause serious impairment during pregnancy. The authors of the two other studies conclude that there is a decrease in physical activity which balances the increased demand of pregnancy. This is supported by the work of Greenfield and Clark (1975) who measured the energy expenditure of pregnant women in the Papua New Guinean highlands. They found that the expenditure was particularly reduced in the last three months of pregnancy.

The available data on food intakes in the UK report energy intakes that are below the RDAs for pregnancy. While in some cases this may be cause for concern where the women investigated come from poor socio-economic groups which have higher incidences of LBW babies (Doyle et al, 1982) in other groups where the women are from the higer socio-economic groups not associated with LBW, then it may seem more likely that the RDAs are set too high. This could be as a result of the energy cost of pregnancy being over estimated.

The data would also suggest that the cost of pregnancy is not being met by a measurable increase in the energy intake. An alternative is that there is a decrease in the energy expenditure but as reported earlier the data is conflicting, so while some groups do find a decrease in the energy expenditure (Greenfield & Clark, 1975) others do not (Blackburn & Calloway, 1974).

1.7 THE FIVE COUNTRY STUDY.

Current knowledge concerning the energy costs and requirements of pregnancy is far from uniform, as the previous review demonstrates. Although theoretical values exist there are gaps in the current knowledge of energy balance during pregnancy. In calculating the cost of pregnancy three main areas are considered. The BMR is thought account for 50% of the total cost, however information on the BMR as discussed earlier is not sufficient, another major component is the amount and cost of laying down extra fat during pregnancy. The figure most often quoted is 3.5Kg based on theoretical calculations only. The third component is the fetus and associated tissues.

How the energy cost of pregnancy is met is more difficult to say from the available data. While it can only be met by an increase in the energy intake or a decrease in the energy expenditure or a combination of these two, the data is often contradictory. Only very few of the papers have tried to measure total energy balance in pregnancy and these have been on limited numbers of women usually in at least the second trimester of pregnancy.

As a result of this, Professor J.V.G.A. Durnin designed a protocol for a study which would provide a more comprehensive data base on energy balance in pregnancy. The study was to be carried out in five countries. This included two developed countries, Scotland and Holland and three developing countries, The Gambia, Thailand and the Philipines. The centres were chosen to give information on women living in a wide variety of circumstances. The women studied in Scotland were a socioeconomically poor and middle classs urban group, while the Dutch women were urban middle class. The women in the developing countries were all from a poor rural background, although only those from the Gambia experienced food shortages.

INTRODUCTION

The study design was to provide longitudinal serial measurements on a group of about fifty women from each centre. They were to be followed from early pregnancy, or where possible pre-pregnant, through to lactation. The variables to be measured were those considered to effect the energy requirement. In practice this entailed measuring the BMR, energy intake, energy expenditure, activity patterns, body weight, body fat and the size of the baby plus placenta. Standardisation of methods between centres was emphasised. The methods used throughout are those described in the method section of this thesis, with exceptions such as the precise weighing method being used for the food intakes in the developing countries rather than the weighed inventory method. There were some differences in the frequency of the measurements between centres. The results of the studies have now been published (Durnin, 1987; Durnin, McKillop, Grant & Fitzgerald, 1987; van Raaj et al, 1987; Lawrence et al, 1987; Thongprasert et al, 1987; Tuazon, van Raaj, Hautvast & Barba 1987). Various differences have been found between centres. The information was analysed separately, looking at each component. The results of the five country study will be reviewed and discussed in the context of the results obtained in this thesis.

CHAPTER 2

STUDY DESIGN AND METHODS

2.1 DESIGN OF THE STUDY

The study is part of a multi-centre project investigating the energy balance of pregnancy. The centres other than Glasgow are the Netherlands and three developing countries, Thailand, the Gambia and the Philipines. In Thailand both rural and urban groups are being studied. In the Gambia and the Phillipines the populations studied are rural.

The intention is to study energy balance in pregnant women in differing societies and therefore of differing needs. The Glasgow study reported here was carried out over a period of four years and was split into two, two yearly blocks. Work was carried out by two post-graduate field workers and supervised by a post-doctoral worker. Overall supervision of the project was by Professor Durnin. The project was divided into two halves;

1. Work examining the energy cost of pregnancy

2. How the cost could be met.

Results on the energy cost of pregnancy are presented here. Results of the energy intakes during pregnancy and changes in the energy expenditure are the subject of the other field worker's thesis, although the results will be discussed in the light of the results obtained and presented here.

2.1.1 Phase I

A group of pregnant women meeting the selected criteria were followed at six weekly intervals. The following measurements were made:

1. The BMR
2. A standardised activity, walking on a treadmill at a fixed speed.
3. Anthropometric measurements of body fat, circumferences, diameters, body weight and height.
4. Body density.

5. Food intake for five days

6. Activity patterns for five days

7. Energy expenditure measurements of the major activities.

The last three measurements were carried out by the subject in their home. The former in the laboratory of the Physiology department of Glasgow University. After the birth of the babies all the above measurements were carried out monthly with the addition of forty-eight hours test weighing each month and anthropometric measurements being made on the baby.

2.1.2 Phase II

At the end of the first two years the results were analysed and the design of the project evaluated. As a consequence of this the design was changed so that women were measured more regularly but for less parameters. This meant that the Phase II group consisted of several sub-groups, they were:

1. A group who had fortnightly BMRs and recorded their food intake for five days monthly.

2. Monthly BMRs and monthly five day food intakes.

3. Monthly BMRs and monthly five day activity diaries.

4. Food intake and activity diaries each for five days monthly.

5. Fortnightly three day food intakes.

STUDY DESIGN AND METHODS

2.2 AIMS OF THESIS

1. To calculate the energy cost of changes in the BMR during pregnancy.

2. To calculate the total energy cost of pregnancy.

3. To discuss whether the energy cost of pregnancy as calculated here, is similar to previous calculations, and any implications this may have for the RDA for energy during pregnancy.

To achieve this the following data was collected:

1. Measurements of the BMR on a group of 61 women throughout pregnancy.

2. Measurements of body weight on a group of 61 women throughout pregnancy and after parturition.

3. Measurements of body fat on a group of 61 women throughout pregnancy and after parturition.

4. Recorded birth weights and placental weights.

2.3 SELECTION CRITERIA

Women entering the study had to fulfil the following criteria:

1. They were aged between twenty and thirty years. Subjects younger than twenty could still be growing and this would increase the cost of metabolism.

2. The pregnancy studied should be their second or third pregnancy. Primigravidae were excluded as many women in their first pregnancy are working until eleven weeks before the birth. This would introduce an artificial change which could effect their activity patterns and eating habits.

3. The fat mass of the subjects should be no greater than thirty-five per cent as measured by skinfolds, on their original visit to the laboratory.

4. They should have no marked or unusual nutritional prejudices which would effect their eating patterns and or their weight.

5. The woman should be in the early stages of pregnancy, preferably between eight to twelve weeks pregnant but no later than fourteen weeks or should be intending to become pregnant in the near future.

6. They had sucessfully breast fed their last infant for three to four months and intend to breast feed their next baby for the same period.

7. They had a normal medical and reproductive history.

The above factors were chosen to give as homogenus group of women as possible.

2.4 METHOD OF RECRUITING SUBJECTS

The criteria listed above meant that recruiting subjects was a long and arduous process. The intention was to recruit women from the lower socio-economic groups. Methods used included articles about the project appearing in the local papers. Local radio and television programmes broadcast information about the project and asked for volunteers. Posters giving details of the study were put in general practicioners waiting rooms, local shops, libraries and mother-toddler groups. Permission was obtained from GPs and consultants for the research workers to attend ante-natal clinics and a consulting room was made available. When a woman presented who fitted the criteria, the doctor would explain the project briefly to her. Interested women could then discuss the project in more detail with the researcher and decide whether or not to become involved.

Other women who heard of the project through the media exposure contacted the university and appointments were made to visit them at home to discuss the details of the project.

When discussing the study with potential volunteers the protocol was explained to them in great detail, so that they were aware of the amount of commitment that was required. Frequently, the women would want to then discuss whether they took part or not with their husbands and would wait to do so before making their final decision.

The area from which the women were to be recruited from was originally intended to be areas within easy access to the university, so that traveling both for the subjects and for the research workers was kept to a minimum. Recruiting women from the lower socio-economic groups proved difficult, and the area from which recruitment was to take place was expanded considerably to include the whole Glasgow area.

2.5 METHOD OF MEASURING THE BASAL METABOLIC RATE.

The BMR was measured by indirect calorimetry using the Douglas bag technique, (Douglas, 1911). This is a plastic bag, usually of 100 litres for the BMR measurements, which by means of inspiratory and expiratory valves collects all the air breathed out by the subject during the timed interval. The subject is fitted with a rubber mouth piece attached to a Rudolph valve. The valve is T shaped, made of perspex, and has an inspiratory side and an expiratory side. It is joined to a piece of plastic tubing which connects via a three way tap to the Douglas bag. The subject wears a nose clip so that no air escapes through the nose.

The technique is essentially straight forward, but great care must be taken that there are no leaks in the circuit. The valves are checked to ensure that they are completely dry. This is because the mica discs can stick, either open causing leaks, or shut so that the subject finds difficulty breathing. The tubing and the seams of the Douglas bag are examined for leaks. It is ensured that the sample tube from the Douglas bag is firmly clamped.

2.5.1 Standardisation of BMR measurements

Prior to the measurement taking place there are several conditions which must be imposed to ensure standardisation. Measurements made are therefore comparable if the following conditions are met (Benedict 1938).

1. The subject must be in the post absorbtive state, so that digestion is not effecting the metabolism. The subjects arrived at the laboratory in the morning between nine and ten o clock, not having eaten for the last twelve hours and only having drunk water.

2. There must be an absence of gross muscular activity, and the subject in a state of complete muscular relaxation. To achieve this the subject lies down on a bed for thirty minutes before the measurement is made and is asked to lie as still as possible.

3. The room in which the measurements take place is thermo-neutral and the lighting is subdued.

4. While the subject should be relaxed under these conditions she should not be allowed to fall asleep, as sleep has been shown to depress the BMR by 10% (Mason & Benedict, 1934; Buskirk et al, 1960).

After the thirty minutes lying down the subject places the mouth piece in her mouth, and puts on the nose clip, checking that no air can escape from either source. She is then given a five minute run in period to accustom her to the apparatus. During this time the three way tap is turned so that expired air passes into the atmosphere. At the end of the five minutes the tap is turned and the expired air passes into the Douglas bag. The subject's pulse is taken at the start and end of each measurement, to obtain independant information about the state of relaxation of each woman.

The first measurement is for fifteen minutes, at the end of this period the three way tap is turned back to its former position when the subject is allowed to remove the mouthpiece. The Douglas bag is taken away for analysis and the procedure is repeated.

The two samples should give results within 3% of each other. If they are not then a third sample is taken. The mean of the results of the samples is taken.

2.5.2 Gas analysis and calculation.

The contents of the Douglas bag are analysed by attaching it via the sample tube to an infra red carbon dioxide analyser (P.K. Morgan, infra red type 101 mark2). The output of this analyser is linked to a Paramagnetic Taylor Servomex oxygen analyser (type OA272). The expired air is first pumped through the carbon dioxide analyser and then the oxygen analyser. Both analysers should be calibrated daily with great care and test gases put through between measurements to check the accuracy of the analysers.

Once the gases have been analysed, the volume of the expired air is measured, by connecting the three way tap to a Parkinson Cowan dry meter. The air is pulled through the meter by the use of a Zenith Variable transformer (type V8 HM) at a rate no higher than one hundred and seventy five litres per minute. Half a litre is added to the volume as an allowance for the air used during the gas analysis. Calculations of the oxygen consumption and the BMR kJ/minute (kcal/minute) are made using Weir's formula (Weir 1949).

$$E(kJ/min,kcal/min)= 4.92V/100(20.93 - O2e)$$

Where V is equal to the volume of expired air in litres/minute at STP. O2e is the oxygen content of expired air expressed as a percentage.

2.6 METHOD OF MEASURING ENERGY EXPENDITURE.

During Phase one of the survey, total daily energy expenditure was measured concurrently with the five day food intake every six weeks, using the factorial method. That is to say that each subject kept a detailed record of the time spent per day on different activities and the metabolic cost of the most common activities measured using either the Douglas bag technique or the Max Planck respirometer.

The energy expenditure is then calculated by:

1. Energy expenditure = time spent in each activity(min)x metabolic cost of activity (kJ/min, kcal/min).

It is impossible to measure every activity and therefore only activities which contribute significantly to the total daily energy metabolism are measured. The average person spends eight hours a day sleeping. Measured values of the BMR were used for this, for while the BMR is said to drop during sleep, it is not constant throughout the night. The rate of energy expenditure when someone first goes to bed is higher due to digestion of the evening meal. During the early hours of the morning it falls to the lowest level and then rises again (Durnin & Passmore, 1967). Therefore although during eight hours of sleep there are periods when the amount of energy expended is lower or higher than the BMR, it is likely to average out. For this reason the results of the BMR measured in the laboratory are thought to be acceptable.

Sitting and sitting activities which usually occupy several hours of the day were measured in the women's homes using Douglas bags. Other activities such as housework, kitchen work and walking were measured using Max Planck respirometers. This is a small dry gas meter weighing 3 kilograms. It is worn on the back like a rucksack. The subject breathes through an expiratory valve and the expired air is passed through the meter. A small sample of air is diverted into a rubber bladder. Careful calibration of the respirometers is needed and a full description of the technique is given by Durnin and Passmore(1967) and Consolazio (1963).

It is essential to measure the activities which were carried out regularly and for long periods of time, such as the aforementioned, on each individual and at each experimental period. The measurements are made in a normal representative fashion.

For relatively unimportant activities lasting only a ort time or occurring infrequently appropriate values were taken from published tables and adjusted for body weight (Durnin & Passmore 1967). Activities such as shopping are calculated as being 50% walking and 50% standing while personal necessities are taken to be 1.8 x sitting.

2.6.1 Activity Diaries.

The activity diaries consist of small booklets with each page representing three hours, starting from 6a.m. and going through to 6 a.m. the next morning. Each block is further divided up into minutes and the subject, using the codes given, marks down the exact time when they change their activity. The diaries have to be meticulously kept and this is emphasised to the subjects. To aid them the subjects are provided with digital watches which gives the precise minute that they change activitites. The subject's recordings are checked regularly and by careful questioning any possible inaccuracies can be corrected. The codes given are:

1. B = Bed, time spent sleeping or lying down resting.

2. S = Sitting quietly such as reading or watching television.

3. SA = Sitting activities such as knitting, sewing, eating, driving and some child care.

4. ST = Standing, queuing.

5. STA= Standing activities such as ironing, child care, hanging out washing, light gardening.

6. KW = Kitchen work, cooking, washing dishes, preparing food, tidying up.

7. HW = Housework including hoovering and dusting, polishing, sweeping making beds.

8. W = Walking

9. WS = Walking slowly with a child

10. WP = Walking pushing a pram or pushchair.

11. SH = Shopping, excluding time spent going to and from the shops.

12. SW = Swimming.

13. PN = Personal necessities, washing, bathing, toilet necessities.

When there is no applicable code the subject is asked to invent one and to note it down, most activities however fall into one of the above categories.

2.6.2 Standardised Exercise.

The standardised exercise was measured in Phase one of the study only. It was designed to see the effect of pregnancy on a fixed workload. It has been suggested that women are energetically more efficient during pregnancy (Banerjee, Khew & Saha, 1971; Blackburn & Calloway, 1976). The women were measured walking on a treadmill at 4 kilometers/hour,(2.4 m.p.h), at each of the laboratory visits.

The measurements are made in the post absorbtive state. A standardised breakfast of two bread rolls plus tea or coffee is provided after the BMR measurements. Energy expenditure during walking is measured using the Douglas bag technique and two ten minute samples collected after a three minute run in period to ensure the body is in a steady state. The energy expended is calculated as for the BMR, using Weirs formula.

2.7 MEASUREMENT OF ENERGY INTAKE

The food intake of the subjects is measured using the weighed inventory technique (Widdowson 1937). The subject weighs every item of food and drink consumed, with the exception of water. This is recorded in a booklet which is provided, with the time at which food or drink was consumed, an accurate description of the food or drink, the amount and any leftovers. All food is weighed in the cooked state. A record is kept in the booklet provided. For Phase I of the study Pelouze dietary scales were used, and in the second phase Soehlne electrical dietary scales. The former are accurate to within five grams, while the latter are accurate to within two grams, and have a digital readout.

All the subjects are carefully instructed in the use of the scales and the method of recording food and drink. They must weigh and record everything, giving as accurate a description as possible. The method of cooking must be given, e.g. fried, boiled or roasted. The type of food is recorded, that is to say they record if it is white or brown bread, whole milk or skimmed. Brand names should be given where possible. At the back of every food intake record is a questionnaire asking which vitamin and mineral supplements the subjects take and any health problems that they may have during the recording period.

In the first phase of the study intakes were recorded for five days, Wednesday to Sunday every six weeks. In Phase II there were two groups, a group who weighed their food for five days every four weeks, and a group who weighed their food for three days every fortnight. The latter group alternated from Thursday to Saturday and Sunday to Tuesday, ensuring that a weekend day was included in every measurement. This was felt to be important as many people's food habits change at the weekend as does their activity pattern.

2.7.1 Food analysis

The food intakes were coded and analysed by computer using a food dictionary based on the food composition tables of McCance and Widdowson (1978) but extended to cover a greater variety of foods, such as manufactured products and foods that are particular to Glasgow. Information for the former was supplied by the manufacturers.

The diets were analysed for protein, fat, carbohydrate, calcium, iron and energy.

2.8 BODY COMPOSITION

In a longitudinal study of energy cost in pregnancy changes in the body fat are of great importance. The percentage body fat was measured in two ways. In all the subjects skinfolds were measured and in a group of women the body density was measured by under water weighing.

2.8.1 Method of measuring skinfolds

The skinfold is picked up between the thumb and forefinger and the skinfold caliper (Holtain caliper) is placed on the identified site. The measurement is taken after two seconds so that the full pressure is applied to the skinfold, but no longer otherwise the calipers will compress the skinfold. Three readings per site were taken and averaged. The sites are those described by Weiner & Lowry (1981). The skinfolds measured were:

1. Biceps skinfold, this is picked up on the front of the arm, directly above the centre of the cubital fossa, at the same level as that at which the triceps skinfold is measured.

2. The triceps skinfold is picked up at the back of the arm, half way between the inferior border of the acromion process and the tip of the olecranon process with the arm flexed to a right angle.

3. The subscapular skinfold is picked up under the inferior angle of the left scapula. The fold should be vertical or slightly inclined downward and laterally.

4. The supra-illiac skinfold is picked up 1cm above and 2cm medial to the anterior superior iliac spine.

5. The costal skinfold is picked up at the mid axillary line at the level of the lowest rib.

6. Thigh skinfold is picked up on the anterior aspect of the thigh, halfway between the mid-inguinal point and the upper border of the patella.

2.8.2 Calculation of body fat from skinfold measurements

The percentage body fat is calculated from the biceps, triceps, subscapular and suprailliac skinfolds using regression equations (Durnin & Rahaman, 1967; Durnin & Womersley 1974). The logarithm of the sum of the four skinfolds is calculated and the formula for women in this sample is:

$$Y = 1.1599 - 0.0717X$$

were Y is the predicted body density, and X is the log of the sum of the four skinfolds. The estimated standard error for females is plus or minus 4.5% (Durnin & Womersley 1974). The costal and thigh skinfolds were measured as it was thought that these sites might show deposition of fat as the pregnancy progressed.

2.8.3 Densitometry

The percentage fat was measured by densitometry using the under water weighing technique (Brozek & Keys, 1950; Durnin & Rahaman, 1967). The equation to calculate the body density into percentage body fat was that of Siri (1956). In Phase I of the study this was carried out on all women at six weekly intervals. In Phase II a smaller number were measured each trimester.

2.9 DIAMETERS AND CIRCUMFERENCES

2.9.1 Diameters

The following diameters were measured at the subject's original laboratory visit. The sites are those identified by Weiner and Lowry (1981).

1. Wrist breadth is measured across the styloid processes with pressure to compress the tissues.

2. Bicondylar femur is measured by the subject sitting on a table or bench with knees bent to a right angle. The width across the outermost part of the lower end of the femur is measured and pressure exerted to compress the tissues.

3. Biacromial diameter is measured with the subject standing with shoulders relaxed. The investigator stands behind the subject and

feels for the outside edge of the acromion process of the shoulder blade. The anthropometer is then placed with one arm along the lateral border of the acromion process and the other arm is brought inwards until it rests on the lateral border of the opposite acromion process. Gentle pressure is applied and the reading taken.

4. The biiliocristal diameter is measured with the subject standing with heels together and their back facing the investigator. The anthropometer arms are placed on the iliac crests at the widest diameter. Pressure is applied to ensure that fat covering the bone is not included in the measurement.

In the first two of the above measurements a sliding caliper is used and for the latter two a Harpenden anthropometer. Height was also measured on the original visit using a Holtain stadiometer.

2.9.2 Circumferences

At each laboratory visit the following circumferences were measured using a steel tape.

1. Upper arm circumference is measured with the subjects arm hanging relaxed just away from their side, the circumference is taken horizontally at the marked level, as for triceps skinfold .

2. Buttock circumference is measured with the subject standing with their legs together. The tape is passed around the hips horizontally from the subjects side.

3. Upper thigh circumference is measured with the subject standing with legs slightly apart and the weight distributed evenly on both feet. The tape is passed horizontally round the thigh with the top edge just under the gluteal fold.
4. The maximum calf circumference is measured with the subject sitting on a table with the leg hanging freely.

The maximum circumference is found by passing the tape up and down the leg and is taken horizontally.

2.10 BODY WEIGHT

Body weight was measured at every laboratory visit using an Avery beam balance. In Phase I each woman was supplied with a set of Seca bathroom scales, and was asked to weigh herself weekly first thing in the morning after emptying her bladder and to wear as little as possible. The weight was recorded on charts provided.

In Phase II the women were issued with Salter battery operated digital scales. They weighed themselves daily in order to assess the fluctuations in weight due to changes in fluid balence. Both types of scales are accurate to 0.5Kg. Phase I and Phase II women continued to weigh themselves for several months after the birth of the baby

2.11 RECORDING BIRTH DATA

The weight and length the baby at birth were recorded by nursing staff after the birth of each baby. Placental weight was also recorded. This data was collected from the hospital as soon after the birth as possible.

CHAPTER 3

RESULTS OF THE BMR MEASUREMENTS

3.1 INITIAL CHARACTERISTICS OF THE WOMEN ON THE STUDY.

A total of sixty one women took part in the study. At the time of their first visit to the laboratory fifty-three were pregnant and eight were non-pregnant.

RESULTS OF THE BMR MEASUREMENTS

Four women whose data is not included here were recruited but subsequently were unable to continue with the study due to ill health.

In the first phase of the study twenty-one women took part at six weekly intervals. In the second phase there were two groups of women followed. One group of twenty women had their BMRs measured at four weekly intervals. Another twenty women were measured fortnightly.

Table 4 shows the initial characteristics of the women. The mean age of the pregnant and pre-pregnant groups was 27.7 years. The mean height of the pregnant group was 162.2 cm (7) compared with 166.8cm (6.6) in the non pregnant group, and the mean weight in the pregnant group at a mean of 10 weeks gestation was 56.85kg (9) compared to a mean weight of 59.9kg (9) in the non-pregnant group. The non-pregnant women had a lower percentage fat as measured by skinfolds than the pregnant women, 24.7% (4.5) {compared with 24.7% (4.5).

TABLE 4 - GENERAL DATA ON WOMEN WHO VISITED THE LABORATORY

	Mean (s.d) Pregnant (N = 53)	Mean (s.d) Non-Pregnant (N = 8)
Age (years)	27.7 ± 2	27.7 ± 1.3
Height (cm)	162.2 ± 7	166.8 ± 6.6
Weight (kg)	56.85 ± 9	59.9 ± 9
% Fat	26.4 ± 4.5	24.7 ± 4.5
Week gestation	10.4 ± 2.9	-

TABLE 5 - SOCIAL GROUP OF WOMEN

Social Group	I	II	III	IV
No. of Women	33	6	16	4

TABLE 6 - PARITY OF SUBJECTS

Parity	0	1	2
No. of women	5	50	6

RESULTS OF THE BMR MEASUREMENTS

Table 5 shows the distribution of socio-economic groups in the study. The majority of women are from socio-economic group I, a total of 33 women, with 6,16 and 4 in social groups II, III, and IV respectively. The parity of the pregnancies studied is shown in Table 6. As was intended by the selection criteria the majority of the women are in their second or third pregnancy, while for five of the women, the pregnancy studied was their first.

For analysis of the BMR during pregnancy, the period of gestation was divided into twelve time periods. These are shown in Table 7. Table 8 and Figure 1 show the number of observations made at each stage of pregnancy, divided into three weekly intervals. The degree of cooperation was high with most women attending at the required intervals, reasons which prevented attendance were ill-health in the mother or her child. The most common illnesses experienced were colds or 'flu. In the winter bad weather meant that some women were reluctant to attend.

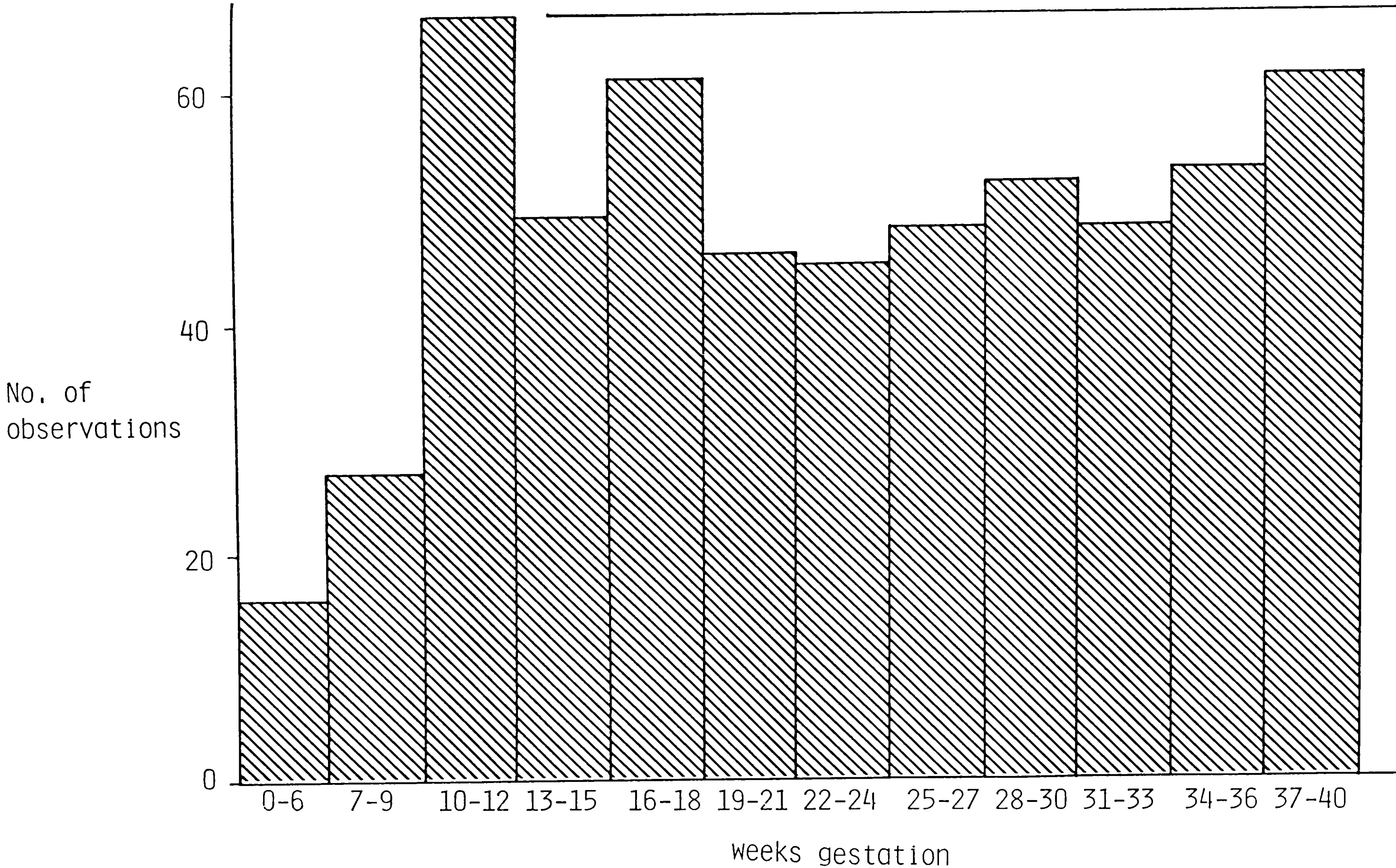
TABLE 7 - THE GESTATIONAL PERIOD DIVIDED FOR STATISTICAL ANALYSIS

Week of Gestation	0-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	29-31	32-34	35-37	37-40
Time Period	1	2	3	4	5	6	7	7	8	10	11	12

TABLE 8 - NUMBER OF OBSERVATIONS AT EACH GESTATIONAL STATE FOR THE 61 WOMEN

Weeks of Gestation	0-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36	37-40
Number of Observatns	16	27	67	49	61	46	45	48	52	48	53	61

FIGURE 1: NO. OF OBSERVATIONS AT EACH GESTATIONAL STAGE FOR THE 61 WOMEN



RESULTS OF THE BMR MEASUREMENTS

3.2 REPRODUCIBILITY AND VARIATION IN THE BMR MEASUREMENT.

To investigate the reproducibility and variation of the BMR a sub-group of twenty three women were asked to attend the laboratory on two consecutve days. BMR measurements were made on both visits. The means of each days measurements were then compared. A students t test was carried out to see if there was a significant difference between the two days. The results are presented in Table 9. The women were on average nine weeks pregnant and the mean difference between days one and two was found to be two per cent lower. This was not significant, t=0.573.

3.3 DISCUSSION

A total of 61 women were recruited to take part in the study. There were differences in the means between the women who were pregnant at the time of the first measurement and those who were not. However there were

TABLE 9 - THE DIFFERENCE BETWEEN BMR MEASUREMENTS ON TWO CONSECUTIVE DAYS

Subject	BMR/Min Day 1 kJ	kcals	BMR/Min Day 2 kJ	kcals	% Difference	Weeks gestation
1	3.97	0.95	4.05	0.97	+ 2	9
2	3.18	0.76	3.18	0.76	+ 0.7	5
3	4.69	1.12	3.68	0.88	- 21	11
4	2.89	0.69	3.18	0.76	+ 8	4
5	4.85	1.16	4.56	1.09	- 6	7
6	4.02	0.96	3.89	0.93	- 4	8
7	4.56	1.09	4.30	1.03	- 5	8
8	3.72	0.89	4.18	0.91	+ 1	8
9	3.47	0.83	3.51	0.84	+ 1	11
10	4.18	0.82	3.39	0.81	- 2	12
11	4.35	1.04	4.59	0.97	- 7	12
12	3.93	0.94	4.02	0.96	- 4	7
13	3.89	0.93	3.51	0.84	- 10	10
14	3.39	0.81	3.39	0.81	0	11
15	3.56	0.85	3.93	0.94	+ 6	12
16	4.35	1.04	3.97	0.95	- 8	12
17	3.72	0.89	3.60	0.86	- 3	11
18	4.27	1.02	4.30	1.03	+ 0.1	11
19	4.02	0.96	4.27	1.02	+ 6	8
20	4.68	1.12	4.64	1.11	- 1.0	12
21	4.1	0.98	4.27	1.02	+ 4	8
22	4.14	0.99	3.72	0.89	+ 10	4
23	3.30	0.79	3.39	0.81	+ 3	11
Mean (s.d)	3.93 ±0.5	0.94 (±0.12)	3.82 ±0.4	0.92 (±0.1)	-2	9±

only 8 in the latter group compared with 53 in the former so no conclusions should be drawn from this.

The majority of the women fitted all the required criteria. However there were difficulties in recruiting women due to the limitations of the criteria. An example of this is the uneven distribution among the socio-economic groups. This was mainly due to difficulties in finding women from the lower socio-economic groups who intended to breast feed. This phenomena has been reported elsewhere (DHSS, 1988). There were 5 primigravidae who took part in the study, although initially women in their first pregnancies were to be excluded. Their inclusion is again due to the problems experienced in recruiting women. The 5 primigravidaes were thought to be suitable as they fulfilled all the other criteria and were keen to be part of the study.

The degree of cooperation was high in all women taking part and subjectively most women seemed to enjoy their visits to the laboratory, although not necessarily all the techniques. There appeared to be the feeling that they liked being part of a research project.

RESULTS OF THE BMR MEASUREMENTS

The gestation period was divided into 12 time periods to give as even a distribution of the measurements as possible. The least number of measurements were in the first six weeks of gestation, this was again due to problems of recruiting people early enough, however by 10 to 12 weeks gestation onwards the number of measurements per time period although not identical were more equal.

The first time a woman visits the laboratory she may feel anxious because of the lack of familiarity of her surroundings and the techniques used. This could effect her BMR (Young & Donaldson, 1946). To ensure that the measurements made were representative and to prevent measuring a practice effect, data was collected on twenty three of the women on consecutive days. The standardised conditions prevent variability due to digestion, temperature, diurnal cycles, muscular and mental activity. No significant differences between the means were found, which shows that any variation between day to day is small on a group level. However the differences within a few individuals was large, for example subject 3 showed a difference of 21% between the two days. This is indicative of variations which can occur within the

BMR even when the conditions are standardised. Factors can effect the BMR which one may not be aware of. It may be that this subject was particularly apprehensive. However differences of this magnitude demonstrate the difficulties of BMR measurement. Also in some measurements the more used to the technique a subject becomes may alter the results of the measurement. The results obtained here on a group level were not significantly different on consecutive days which would suggest that there was not a measurable practice effect on the results.

3.4 RESULTS OF THE PRE-PREGNANT DATA

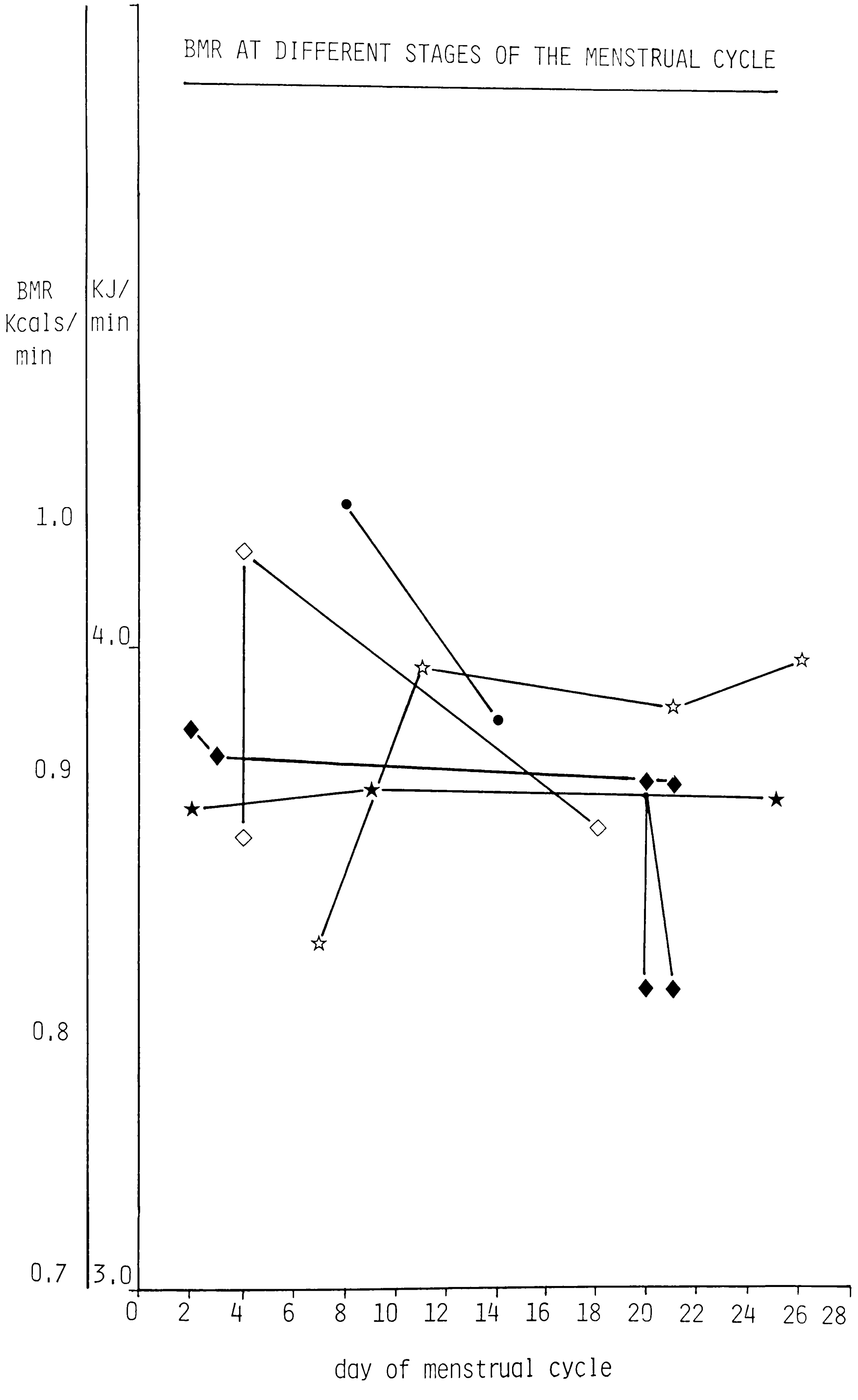
Data was collected on eight women in the pre-pregnant state. The intention was to follow them at each stage of the menstrual cycle and as soon as they became pregnant. Some of the women became pregnant far sooner than they anticipated which meant that the number of measurements is less than was planned. Table 10 shows

TABLE 10 - BMR/MIN DURING THE MENSTRUAL CYCLE

Subject	Day of cycle	BMR kJ/min	BMR kcals/min
1	7	3.51	0.84
1	11	3.93	0.94
1	21	3.89	0.93
1	26	3.97	0.95
2	7	4.44	1.06
2	14	3.84	0.92
3	2	3.68	0.88
3	9	3.76	0.90
3	25	3.72	0.89
4	2	3.84	0.92
4	3	3.80	0.91
4	20	3.77	0.90
4	21	3.43	0.82
5	4	4.14	0.99
5	4	3.68	0.88
5	18	3.68	0.88
6	1	4.76	1.14
7	15	4.56	1.09
7	26	4.22	1.01
8	14	3.26	0.78
8	14	3.51	0.84
8	28	3.14	0.75

FIGURE 2:

BMR AT DIFFERENT STAGES OF THE MENSTRUAL CYCLE



the results of the BMR at different times in the menstrual cycle for the eight women. The number of measurements per woman is small, with only two of the eight having four measurements made and in the case of subject six, only one measurement was made. To see if there appeared to be any trends in the data the results were plotted graphically, see Figure 2. Two women showed a marked decrease in the BMR/min from the first to the second week of the menstrual cycle, while one showed an increase. Two others seemed to show no marked increase or decrease throughout the cycle. The variability between measurements at different times of the menstrual cycle ranged from 0.8% to 13%.

3.5 COMPARISON OF PRE-PREGNANT DATA WITH EARLY PREGNANCY.

The average pre-pregnant figure was calculated for each of the eight subjects and compared with their first measurement in pregnancy. Table 11 shows the BMR expressed as kJ & kcal/minute pre-pregnant and

TABLE 11 - COMPARISON OF THE AVERAGE NON-PREGNANT BMR/MIN WITH THE FIRST MEASUREMENT OF THE BMR/MIN IN PREGNANCY (kJ and kcal/min)

Subject	Non-pregnant Mean BMR kJ	Non-pregnant Mean BMR kcals	Pregnant BMR kJ	Pregnant BMR kcals	Wks.gestation	% difference
1	3.82	0.91	3.87	0.92	6	1
2	4.15	0.99	4.33	1.03	4	4
3	3.72	0.89	3.36	0.80	2	8
4	3.71	0.89	3.60	0.86	15	3
5	3.83	0.91	4.58	1.09	12	19
6	4.4	1.05	4.36	1.04	2	1
7	3.3	0.78	3.43	0.82	3	5
8	4.78	1.14	4.56	1.09	6	4
Mean	3.85	0.92	4.01	0.96	6	4
(s.d)	(0.35)	(0.08)	(0.5)	(0.11)	(4)	

TABLE 12 - COMPARISON OF THE AVERAGE NON-PREGNANT BMR/kg WITH THE FIRST MEASUREMENT OF THE BMR/kg IN PREGNANCY (J and cals/kg)

Subject	Non-pregnant Mean BMR J/kg	Non-pregnant Mean BMR cals/kg	Pregnant BMR J/kg	Pregnant BMR cals/kg	Wks. gestation	% difference
1	75	18.1	77.4	18.5	6	3
2	61.5	14.7	64.4	15.4	4	4
3	64	15.3	58.6	14.0	2	5
4	70.7	16.9	65.2	15.6	15	8
5	59	14.1	72.8	17.4	12	22
6	92	22.0	92.0	22.0	2	0
7	66.9	16.0	63.6	15.2	3	5
8	64.9	15.5	67.8	16.2	6	4
Mean	69.2	16.5	70.2	16.7	6	1
(s.d)	(10)	(2.4)	(10.5)	(2.5)	(4)	

TABLE 13 - COMPARISON OF THE AVERAGE OF NON-PREGNANT BMR/24hrs. WITH THE FIRST MEASUREMENT IN PREGNANCY (MJ and kcals)

Subject	Non-pregnant Mean BMR/24hrs		Pregnant BMR/24 hrs		Wks. gestation	% difference
	MJ	kcals	MJ	kcals		
1	5.50	1310	5.57	1330	6	1
2	5.98	1430	6.23	1490	4	4
3	5.36	1280	4.84	1160	2	8
4	5.34	1280	5.18	1240	15	3
5	5.52	1320	6.6	1580	12	19
6	6.33	1500	6.28	1500	2	1
7	4.75	1140	4.93	1180	3	5
8	6.88	1650	6.57	1570	6	4
Mean	5.7	1360	5.77	1380	4	1
(s.d)	(0.66)	(150)	(0.73)	(170)		

pregnant. The average stage of pregnancy was seven weeks. The mean pre-pregnant BMR was 3.96kJ/minute (0.4) 0.95kcal/minute(0.09) and the mean of the pregnancy measurements was 4.0kJ/minute(0.5), 0.96kcal (0.1). There is a mean increase of two per cent which is not significant, (t=0.188).

When the BMR is expressed per kilogram, see Table 12, there is also a two per cent increase but again this is not significant using the student's t-test, t=0.169.

When the mean pre-pregnant BMR is calculated per twenty four hours it is equal to 5.7MJ, 1360kcal. The mean value of the first measurement in pregnancy is 5.77MJ, 1380kcal, see Table 13. A difference of 0.07MJ, 20kcal. This difference is not statistically significant.

3.6 DISCUSSION

The results have been presented on a sub-group of 8 women who were non-pregnant at the time of entry to the study. The intention was to follow them through the different stages of the menstrual cycle and as soon as they became pregnant. From this data would be collected on the effect of the menstrual cycle on the BMR and it would be possible to see the effects of early pregnancy on the BMR. However only eight women were recruited in the non-pregnant state and the data is far from complete. Several of these women became pregnant sooner than they had anticipated and so it was not possible to collect data at all the stages of the menstrual cycle. The net result is that the data from the pre-pregnant stage is insufficient and it is not possible to draw any conclusions from it.

As a result of this in a further stage of the study, the results of which are not presented in this thesis, information was collected on a group of 25 women. Two or three measurements were made at each of the different stages of the menstrual cycle. When measurements in the post ovulatory phase were compared with those in the pre-ovulatory phase no significant differences were found (Durnin et al, 1987). Twenty subsequently became pregnant. This work is continuing and the intention is to have measurements on 150 women in the pre-pregnant state. However from the current available data it would appear that the effect of the menstrual cycle on the BMR is not of significance, although one study has found significant differences (Solomon, Curzor & Calloway, 1982).

The mean BMRs from the eight women in the non pregnant state have been compared with the first BMR measurement in pregnancy at a mean of seven weeks. From the data it would appear that there is no significant difference in the BMR in early pregnancy compared to the non-pregnant state. This has been observed in the final study were the BMR did not show significant changes until week 18 of pregnancy (Durnin et al, 1987).

In summary from the data presented here and from further stages of the study it would appear that the menstrual cycle does not have a significant effect on the BMR, and that changes in the BMR from pre-pregnancy to pregnancy are not of significance in the early weeks.

RESULTS OF THE BMR MEASUREMENTS

3.7 RESULTS OF THE BMR IN PREGNANCY.

The BMR during pregnancy has been analysed as kJ/minute, kcal/minute, per Kg of body weight and per twenty-four hours. The data is presented mainly as the results of the 61 women combined. It has however also been analysed for each of the three groups separately and where appropriate is presented on the individual groups. The gestational period has been divided up into 12 time periods for the analysis.

3.8 INITIAL CHARACTERISTICS

Table 14 shows the initial characteristics of the 61 women and for each group at the first measurement in pregnancy. It can be seen that women in Phase I were on average 11 weeks pregnant compared to 8 weeks in the 2 weekly group and 10 weeks in the monthly group. The mean gestation at entry to the study for the whole group was 10 weeks. All three groups were comparable

TABLE 14 - **MEAN** (s.d) INITIAL CHARACTERISTICS OF 61 PREGNANT WOMEN

	Combined Data	2 wkly group	4 wkly group	6 wkly group
Weeks gestation	10 (3.5)	8 (3)	10 (4)	11 (2)
Age (years)	28 (3)	27 (3)	28 (2)	27 (7)
Height (cm)	162.6 (6.9)	162 (7.7)	163.4 (6)	162.7 (65)
Weight (kg)	57.17 (7.2)	56.19 (7)	56.6 (5.3)	58.4 (6.4)
% fat (skin folds)	26 (5)	26 (5)	24 (4)	29 (4)
Av. BMR (kJ)	3.85 (0.42)	3.74 (0.4)	4.09 (0.4)	3.78 (0.4)
Av. BMR (kcals)	0.92 (0.1)	0.89 (0.1)	0.98 (0.1)	0.9 (0.07)
N	61	20	20	21

for age, although the 6 weekly group had the lowest mean of 26 years (7). The mean height for the 61 women was 162.6cm (6.9)and the mean weight was 57.17Kg (7.2). The heaviest group was the 6 weekly group and they had the highest % fat as measured by skinfolds, 29% (4) compared with 26% for the group as a whole. The mean BMR at time of first measurement in pregnancy was 3.85kJ/min (0.42), 0.92kcal(0.1).

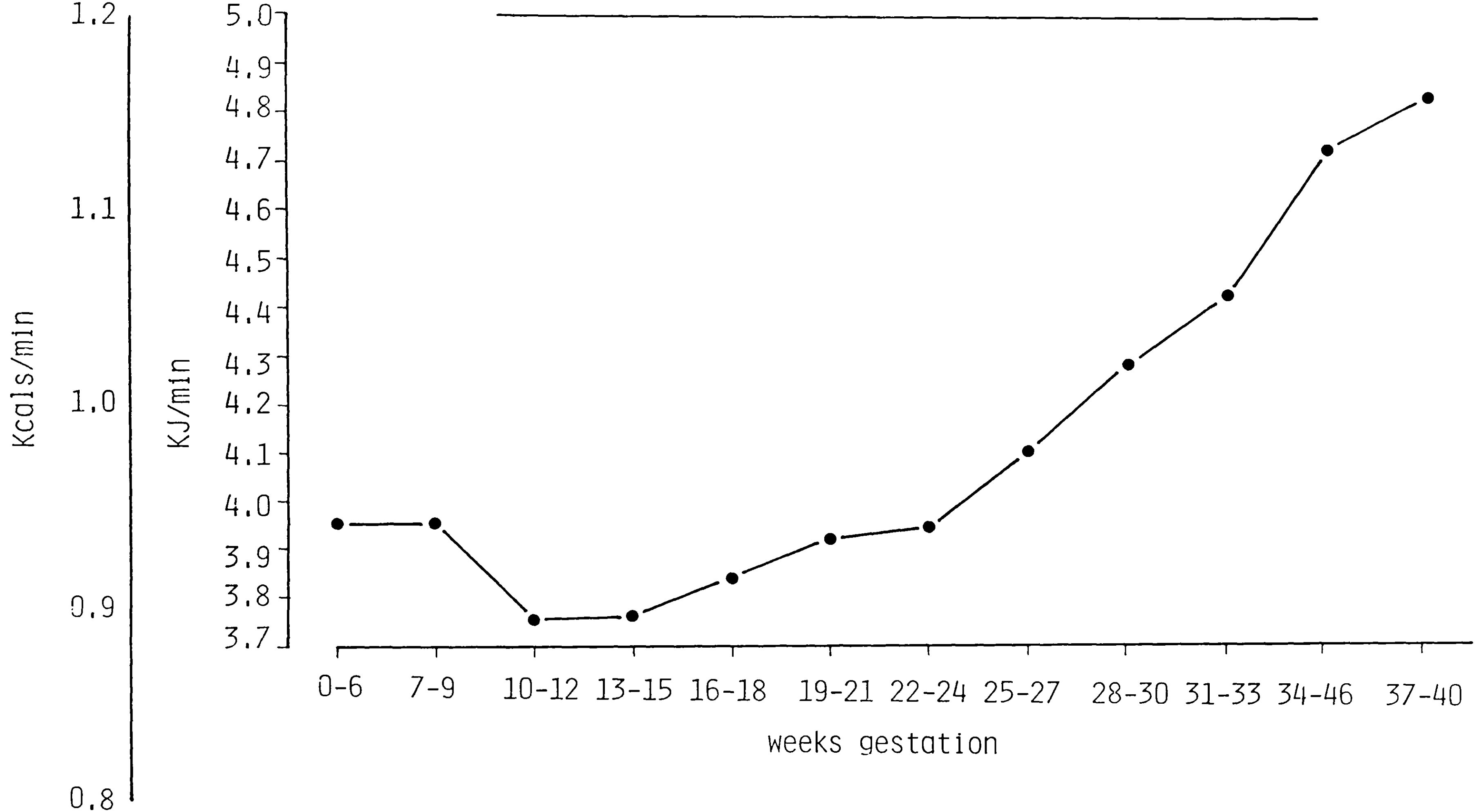
3.8.1 Results of the BMR kJ/minute (kcal/minute)

The results of the BMR kJ/min and kcal/min are shown in Table 15 and Figure 3. At 0 to 6 weeks the mean BMR is 3.95kJ/min(0.5) 0.94kcal/min(0.12) and remains at this level until weeks 10 to 12 when it drops to 3.78kJ/min(0.5) 0.9kcal/min(0.12). There is a slight decrease at weeks 13 to 15 and this is the lowest level that is recorded. Thereafter the BMR is shown to have increased at each time period, the final value being 4.82kJ/min(0.6) 1.15kcal/min(0.14) at 37 to 40 weeks.

TABLE 15 - THE MEAN BMR/MIN (s.d) FOR THE 61 WOMEN

Weeks gestation	Mean BMR (± s.d) kJ/min		kcals/min		N
0-6	3.95	(0.55)	0.943	(0.132)	16
7-9	3.95	(0.53)	0.944	(0.127)	27
10-12	3.78	(0.48)	0.904	(0.114)	67
13-15	3.76	(0.41)	0.899	(0.100)	49
16-18	3.84	(0.41)	0.920	(0.100)	61
19-21	3.92	(0.53)	0.937	(0.126)	46
22-24	3.94	(0.45)	0.942	(0.108)	45
25-27	4.10	(0.49)	0.979	(0.117)	48
28-30	4.28	(0.54)	1.023	(0.129)	52
31-33	4.42	(0.6)	1.056	(0.144)	44
34-36	4.72	(0.51)	1.129	(0.122)	49
37-40	4.82	(0.6)	1.153	(0.143)	57

FIGURE 3: THE MEAN BMR/min OF THE 61 WOMEN THROUGHOUT PREGNANCY



RESULTS OF THE BMR MEASUREMENTS

Differences were observed in the results of the three individual groups when analysed separately, see Table 16. In the six weekly group no measurements were made between weeks 0-6. Three women were measured at 7-9 weeks of pregnancy. The mean value for the latter was 3.76kJ/min 0.9kcal and this figure had increased by the next time interval to 3.8 kJ/min (0.3) 0.91kcal (0.07). In contrast to the results from the combined data the mean BMR fell for the next three time periods i.e. between weeks 13 to 21. The lowest figure was at 19-21 weeks, with a mean BMR kJ/min of 3.64 (0.3) 0.87kcal(0.07). The BMR increased after that by 1.6% and continued to increase to 31-33 weeks when it fell by 7% to 3.75 kJ/min(0.10), 0.9kcal(0.02) after which it continued to increase to term. The mean value for 37-40 weeks being 4.41 kJ/min (0.6), 1.05kcal(0.14). Nine women were measured between 0 and 6 weeks in the women who had their BMRs measured monthly. The mean BMR was 4.28kJ(0.3), 1.02kcal(0.07). This value was shown to decrease over the following weeks until it reached the minimum level of 3.96kJ/min(0.5), 0.95kcal(0.12), at 13 to 15 weeks gestation, which is the same as the combined data. Thereafter the BMR/min increases progressively until term reaching a maximum value of 5.23kJ/min (0.5), 1.25kcal(0.12) at 37 to 40 weeks.

TABLE 16 - THE MEANS AND STANDARD DEVIATIONS OF THE BMR/MIN IN THE THREE GROUPS (kJ and kcals)

	BMR/minute (s,d)								
Weeks gestation	2 weekly			4 weekly			6 weekly		
	kJ	kcals	N	kJ	kcals	N	kJ	kcals	N
0-6	3,49 (0,3)	0,834 (0,082)	7	4,28 (0,33)	1,022 (0,83)	9		-	-
7-9	4,14 (0,6)	0,909 (0,144)	15	4,25 (0,25)	1,016 (0,068)	9	3,76 (0,4)	0,899 (0,101)	3
10-12	3,53 (0,5)	0,844 (0,108)	32	4,12 (0,36)	0,984 (0,087)	23	3,8 (0,3)	0,909 (0,073)	12
13-15	3,67 (0,4)	0,877 (0,095)	28	3,96 (0, 9)	0,945 (0,117)	12	3,73 (0,3)	0,893 (0,077)	9
16-18	3,74 (0,4)	0,893 (0,092)	29	4,11 (0, 5)	0,983 (0,107)	19	3,71 (0,28)	0,887 (0,068)	13
19-21	3,78 (0,5)	0,903 (0,126)	24	4,28 (0, 3)	1,022 (0,103)	15	3,65 (0,3)	0,872 (0,072)	7
22-24	3,86 (0,4)	0,922 (0,095)	23	4,29 (0,47)	1,026 (0,112)	15	3,70 (0,3)	0,886 (0,077)	10
25-27	4,00 (0,4)	0,957 (0,106)	23	4,50 (0,36)	1,076 (0,087)	13	3,82 (0,43)	0,914 (0,103)	12
28-30	4,19 (0,5)	1,002 (0,117)	26	4,56 (0,48)	1,098 (0,114)	15	4,05 (0,62)	0,969 (0,747)	11
31-33	4,43 (0,5)	1,059 (0,119)	22	4,85 (0,46)	1,160 (0,109)	13	3,75 (0,44)	0,897 (0,104)	9
34-36	4,68 (0,5)	1,119 (0,111)	25	5,01 (0,51)	1,197 (0,123)	15	4,37 (0,39)	1,046 (0,094)	9
37-40	4,88 (0,5)	1,166 (0,115)	26	5,23 (0,47)	1,251 (0,109)	14	4,41 (0,62)	1,055 (0,150)	17

RESULTS OF THE BMR MEASUREMENTS

In the two weekly group seven women were measured between 0 to 6 weeks of pregnancy. The mean BMR kJ per minute was 3.49kJ (0.3), 0.83kcal(0.07). At 7 to 9 weeks gestation there was an increase in the mean BMR to 4.14kJ/min, 0.99kcal with a standard deviation of 0.6kJ, 0.14kcal. This value fell for the next time period, but for the subsequent measurements there was a steady increase throughout pregnancy. The final value at 37 to 40 weeks was 4.88kJ(0.5), 1.17kcal(0.12).

3.8.2 Percentage and cumulative difference in the BMR

Table 17 shows the % increase between measurements. For the whole group there is initially a drop of 4% between periods 2 and 3 and a further drop of 1% between the next two periods. The BMR then starts to increase by 1% for the following three intervals, until weeks 25 to 27

TABLE 17 - THE % DIFFERENCES BETWEEN THE MEAN BMRs FOR EACH TIME PERIOD

Time period	Whole group	6 weekly	4 weekly	2 weekly
1-2	0	-	-0.5	9
2-3	-5	1	-3	-7
3-4	-1	-1.8	-4	4
4-5	2	-0.7	4	1.8
5-6	2	-1.7	4	1.1
6-7	0.5	1.6	0.4	2
7-8	4	2.8	5	3.8
8-9	4	6	2	4.7
9-10	3	-7	6	5.7
10-11	7	15.6	3	5.6
11-12	2	1	5	4.2

TABLE 18 - THE CUMULATIVE % DIFFERENCES BETWEEN THE MEAN BMRs

Time period	Whole group	6 weekly	4 weekly	2 weekly
1-2	0	-	-0.5	9
1-3	-5	1	-3.5	2
1-4	-6	-0.8	-7.5	6
1-5	-4	-1.5	-3.5	7.8
1-6	-2	-3.2	0.5	8.9
1-7	-1.5	-1.6	0.9	10.9
1-8	2.5	1.2	5.9	14.7
1-9	6.5	7.2	7.9	19.4
1-10	9.5	0.2	13.9	25.1
1-11	16.5	16.8	16.9	30.7
1-12	18.5	17.8	21.9	34.9

when it increases by 4% for the next two time periods. The highest increase is between weeks 31-33 and 34-36, when the BMR increases 7%. The % increase from 34-36 weeks to term is 2%. When the changes are expressed cumulatively the total % increase is 18%, if however the total increase is calculated from the first measurement to term then there is an increase of 22%.

As differences were found when the three groups were analysed separately so the percent changes through pregnancy show different trends and cumulative increases. In the women measured in Phase I the greatest rise is 16.6% following the recorded drop at 31-33 weeks. The largest decrease is 7% . The general pattern other than those two measurements is for the BMR to remain steady until thirteen weeks when it starts to drop below the initial value, to the lowest level at 19-21 weeks. There is then a marked increase and the BMR rises at each subsequent time period. The rate of increase declines for the last three weeks of pregnancy.

Table 18 shows the cumulative increase in the mean BMR/min. The total increase in the BMR from the initial measurements at 7-9 weeks compared with the mean BMR kJ/min at 37-40 weeks is 17.4%. This is similar to the results of the four weekly group, although the rise above the initial measurement occurs earlier at 19 to 21 weeks. This group of women show a total increase of 22%

The women measured at two weekly intervals show a differing trend. The largest changes are between the first and second time periods and the third and fourth. The changes observed in the second trimester are of the magnitude of 1 to 2 per cent between measurements. However between periods 7 and 8 the rate of change in the BMR starts to increase. The maximum increases are between 28 to 36 weeks, with percentage differences between time periods of 6% There is a slight decline in this rate of increase at 37 to 40 weeks of 4%. The cumulative increase for this group is 35%, or if calculated from the first measurement to term 40%.

The results of the BMR/min were analysed using a statistical package, (Scott,1979). This is a generalised linear modeling package. When looking at all the values across time the F ratio is equal to 5.75 p0.00. Therefore there are significant differences in the means. To analyse at which point in time the means were significantly different from one another a multiple comparison procedure, with an overall significance level of 5% was carried out. Statistically significant differences are found between weeks 0 to 21 and 25 to 40, and between weeks 22 to 24 and 28 to 40.

No significant differences were found in the two and four weekly groups but in the six weekly group the mean BMR/min at 10 to twelve weeks of pregnancy is significantly different from the mean BMR at 37 to 40 weeks of pregnancy. The mean BMR /min at weeks 19 to 27 is also found to be significantly different from weeks 37 to 40. The mean BMR at weeks 13 to 18 is significantly different from the mean BMR at 34 to 40 weeks, which is indicative of a decrease in the BMR, followed by an increase in the last six weeks of pregnancy.

3.8.3 The BMR/24 hours.

The BMR/24 hours is calculated by:

the BMR kJ(kcal)/minute x 1440

Where 1440 is equivalent to the number of minutes per twenty four hours. The BMR/24 hours is expressed in mega joules (MJ)and Kilocalories (kcal).

The BMR/24 hours at the different times in pregnancy are presented in Table 19 and Figure 4. The trends are the same as those described for the BMR/min. The mean BMR/24 hours at 0 to 6 weeks is 5.69MJ(0.8), 1360kcal(190) and the value at term is 6.95MJ(0.9),1660kcal (215). This represents a total increase in the energy requirements due to the BMR of 22%, this does not account for the decreases in the BMR observed.

As with the results of the BMR/min differences were found between the three groups of women analysed separately, see Table 20. For the six weekly group the increase in MJ from 7 to 9 weeks to term was

TABLE 19 - THE MEAN (s,d) BMR/24hrs FOR 61 WOMEN (MJ and kcals)

Weeks gestation	BMR/24 hrs. MJ	kcals	N
0-6	5.69 (0.79)	1360 (190)	16
7-9	5.69 (0.77)	1360 (183)	27
10-12	5.44 (0.65)	1300 (163)	67
13-15	5.40 (0.6)	1290 (144)	49
16-18	5.56 (0.6)	1330 (144)	61
19-21	5.65 (0.76)	1350 (181)	46
22-24	5.69 (0.65)	1360 (156)	45
25-27	5.90 (0.7)	1410 (167)	48
28-30	6.1 (0.73)	1470 (186)	52
31-33	6.36 (0.87)	1520 (207)	44
34-36	6.81 (0.74)	1630 (176)	49
37-40	6.95 (0.86)	1660 (206)	57

FIGURE 4: THE MEAN BMR/24HRS FOR THE 61 WOMEN THROUGHOUT PREGNANCY

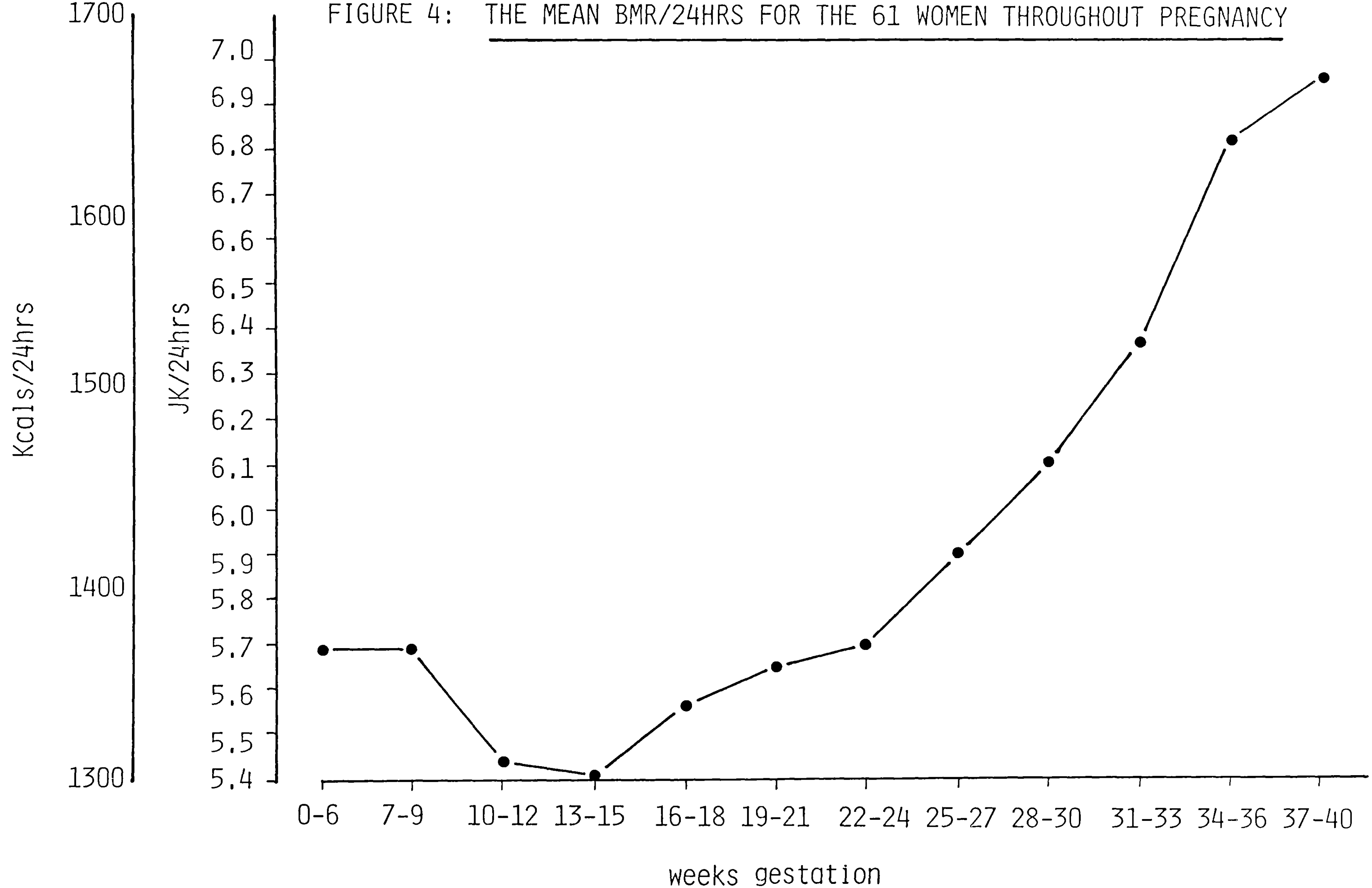


TABLE 20 - THE MEANS AND STANDARD DEVIATIONS OF THE BMR/24hrs IN THE THREE GROUPS (MJ and kcals)

Weeks gestation	BMR/24hrs (± s,d) 2 weekly			4 weekly			6 weekly		
	MJ	kcals	N	MJ	kcals	N	MJ	kcals	N
0-6	5,02 (0,49)	1200 (118)	7	6,19 (0,57)	1480 (138)	9	-	-	-
7-9	5,48 (0,86)	1310 (207)	15	6,10 (0,41)	1560 (97)	9	5,40 (0,62)	1290 (150)	3
10-12	5,10 (0,65)	1220 (155)	32	5,94 (0,52)	1420 (125)	23	5,48 (0,44)	1310 (104)	12
13-15	5,27 (0,57)	1260 (136)	28	5,69 (0,71	1360 (169)	12	5,40 (0,46)	1290 (111)	9
16-18	5,40 (0,55)	1290 (132)	29	5,94 (0,64)	1420 (154)	19	5,36 (0,41)	1280 (97)	13
19-21	5,44 (0,76)	1300 (181)	24	6,15 (0,62)	1470 (149)	15	5,27 (0,43)	1280 (103)	7
22-24	5,56 (0,57)	1330 (136)	23	6,19 (0,67)	1480 (161)	12	5,36 (0,46)	1280 (111)	10
25-27	5,77 (0,42)	1380 (153)	23	6,49 (0,52)	1550 (124)	13	5,52 (0,62)	1320 (147)	12
28-30	6,02 (0,69)	1440 (164)	26	6,61 (0,68)	1580 (163)	15	5,85 (0,89)	1400 212)	11
31-33	6,40 (0,72)	1530 (171)	22	6,99 (0,66)	1670 (157)	13	5,40 (0,62)	1290 (149)	9
34-36	6,74 (0,67)	1610 (161)	25	7,20 (0,74)	1720 (176)	15	6,32 (0,56)	1510 (136)	9
37-40	7,00 (0,69)	1695 (165)	26	7,53 (0,65)	1800 (156)	14	6,36 (0,90)	1520 (216)	17

0.96MJ, 230kcals. A total increase of 18%, if the measurements of 7-9 weeks are accepted. They are however only a mean of three women and may not be representative of the whole group. If the increase in BMR is calculated from 10-12 weeks it is equal to 16%, but whether the BMR has increased before that time is not known. The four weekly group show a total increase of 1.34MJ/day, 320kcal, an increase of 22%. For the two weekly group the value reported at 0 to 6 weeks is 5.02MJ (0.5), 1200kcal (120). At 37 to 40 weeks the mean BMR per twenty four hours is 7.0MJ (0.7MJ), 1670kcals(170), an increase of 1.98MJ/day, 470kcal, which is equal to 39%.

When the results are analysed using the linear modeling package (Scott, 1979), significant differences are found at different times in gestation. For the whole group these are found to be significant at the 5% level. Weeks 10 to 12 are significantly different from weeks 19 to 40, and weeks 13 to 18 from 25 to 40. This is indicative of the fall in the BMR during the first and second trimester followed by an increase in the third. The multiple comparison procedure shows significant differences between mean BMRs/24 hours at different stages in pregnancy. The differences are at the same stages as the BMR expressed per minute.

The three groups analysed separately all show significant changes in the BMR across time. These are not at exactly the same time periods, but not disimilar, for example in comparison to the combined data, in the four weekly group the value at 0 to 21 weeks is significantly different from 28 to 40 weeks, while 22 to 30 weeks are significantly different from 34 to 40 weeks. The mean BMR at 31 to 33 weeks is significantly different from 37 to 40 weeks.

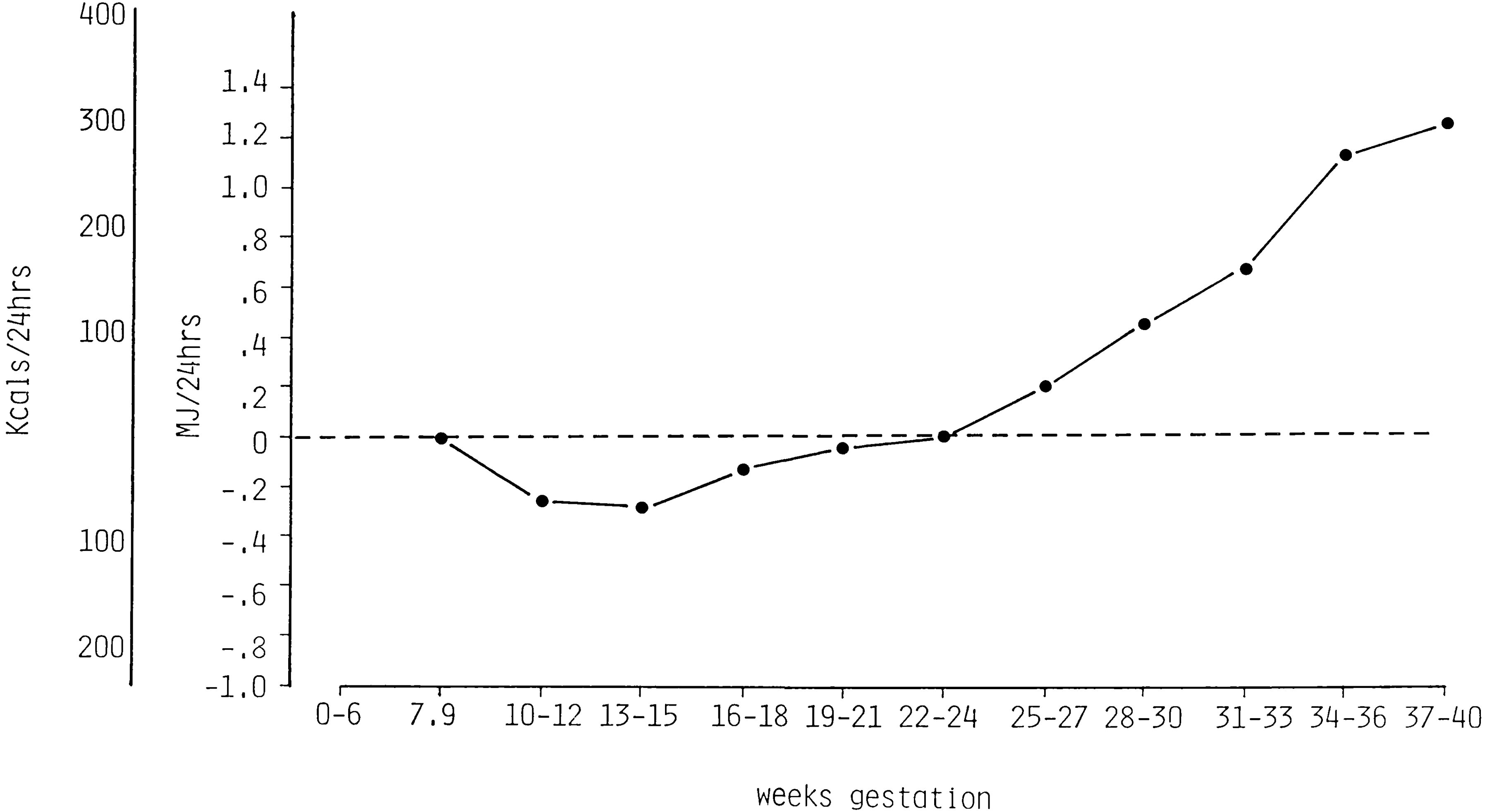
3.8.4 Calculation of the increased energy costs

The total change in the energy requirement for the BMR/24 hours is calculated by measuring the area under the curve in Figure 5, expressing the cumulative changes in the BMR across time, see also Table 21. The decrease in the BMR is equivalent to a saving of 15MJ, 3600kcal, which for the time it is recorded over

TABLE 21 - THE CUMULATIVE DIFFERENCE IN BMR/24hrs (MJ & kcals)

Time Period	Whole group MJ	Whole group kcals	2 weekly MJ	2 weekly kcals	4 weekly MJ	4 weekly kcals	6 weekly MJ	6 weekly kcals
1-2	0	0	0.46	110	-0.080	-20	-	-
1-3	-0.25	-60	0.08	20	-0.251	-60	0.08	20
1-4	-0.29	-70	0.25	60	-0.5	-120	0	0
1-5	-0.13	-30	0.37	90	-0.25	-60	-0.04	-10
1-6	-0.04	-10	0.41	100	-0.4	-10	-0.13	-30
1-7	0	0	0.54	130	0	0	-0.04	-10
1-8	0.21	50	0.75	180	0.29	70	0.13	30
1-9	0.46	110	0.92	220	0.42	100	0.46	110
1-10	0.67	160	1.38	330	0.80	190	0	0
1-11	1.13	270	1.72	410	1.0	240	0.92	220
1-12	1.26	300	1.99	4.75	1.34	320	0.96	230

FIGURE 5: THE CUMMULATIVE CHANGE IN THE MEAN BMR/24HRS FOR THE 61 WOMEN



is 150kJ/day or 40kcal. The increase from weeks 22 to term is equal to 66MJ, 16,000kcal. Therefore the increase in cost is 51MJ, 12,200kcal, because of the saving in the early part of pregnancy. If this cost is spread evenly throughout pregnancy it is equal to an extra 180kJ/day or 40kcal.

The results for the separate groups have been analysed in the same way and give differing results. The results of the four weekly and six weekly are similar with a total increase in the cost of the BMR of 44MJ and 55MJ or 10,500kcal and 13,200kcal respectively. When this cost is spread over the whole of pregnancy then the equal to an extra 160kJ (40kcal) and 200kJ/day (50kcal). These values are not disimilar to the value obtained for the whole group.

For the two weekly group, there is a steady increase in the mean BMR from 10 weeks onwards. Between weeks 0 to 10 there is a sharp increase followed by a fall to the initial value. Calculation of the total increase in energy requirement due to changes in the BMR in pregnancy have been made including and excluding the first 10 weeks. The former gives a result of a total increase of 180MJ, 43,000kcal, while the latter is equivalent to 165MJ (39,400kcal).

On a daily basis, if the increased cost is spread equally throughout pregnancy, the former figure is equal to an extra 640kJ/day or 150kcal and the latter 590kJ/day or 140kcal.

3.8.5 Results of the BMR/kg of body weight

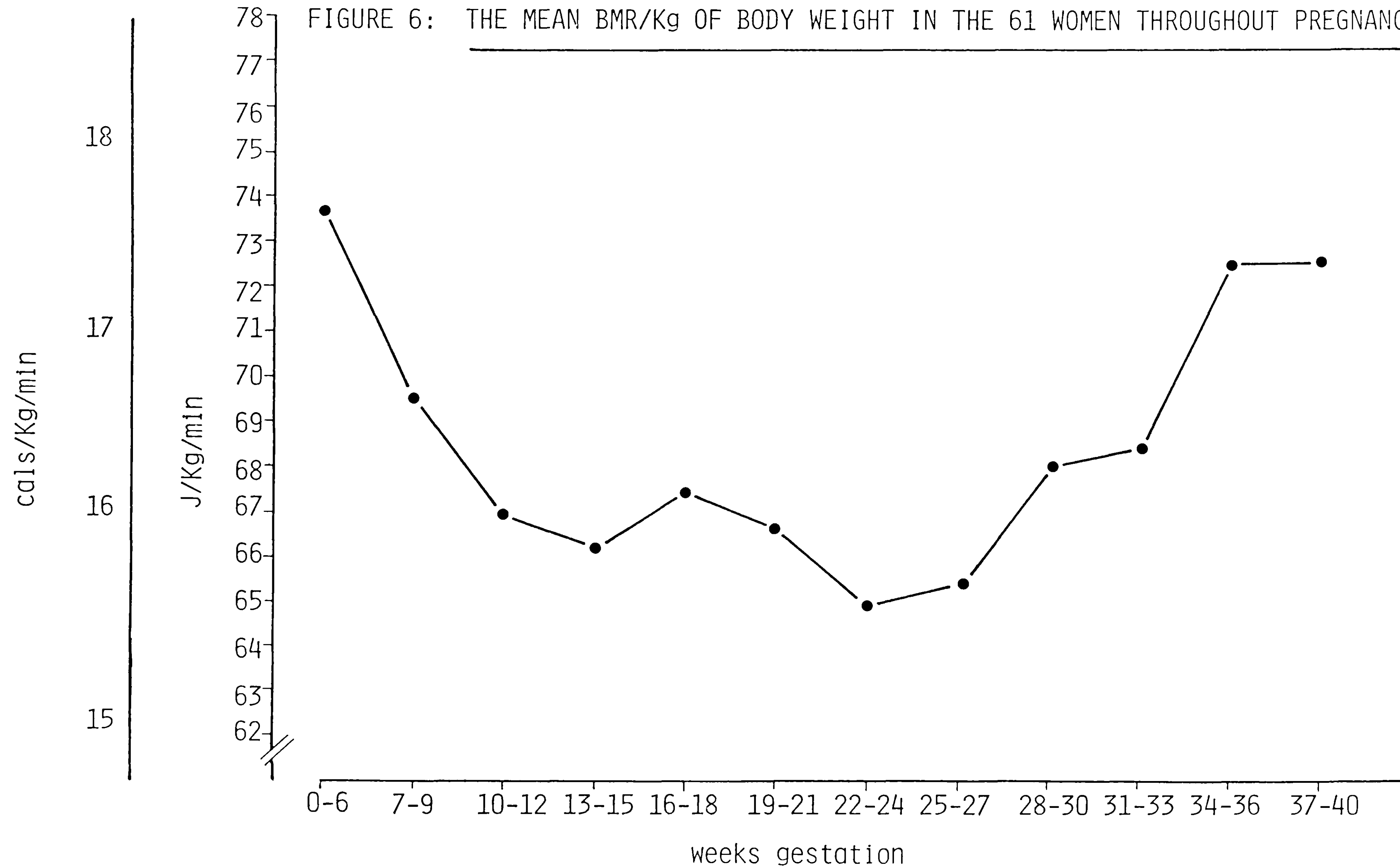
The results of the BMR for each woman were calculated as the BMR/kg. The BMR is measured in kJ or kcal per minute. When that figure is divided by the woman's body weight then the value in joules and calories per unit of weight is found.

The mean BMR/kg at the different stages of pregnancy for the 61 women are shown in table 22 and figure 6 . From weeks 0 to 15 there is a fall at each subsequent time interval. The initial mean measurement is 73.6J/Kg(8) 17.6 cals (1.9) and falls to 66.1J/kg(7),

TABLE 22 - THE MEAN (s.d) OF THE BMR/kg BODY WEIGHT OF THE 61 WOMEN

Weeks gestation	BMR/kg J		cals		N
0-6	73.6	(8.2)	17.6	(2)	16
7-9	69.5	(8.2)	16.6	(2)	27
10-12	66.9	(8.2)	16.0	(2)	67
13-15	66.1	(7.1)	15.8	(1.7)	49
16-18	67.4	(7.1)	16.1	(1.8)	61
19-21	66.5	(7.9)	15.9	(1.9)	46
22-24	64.8	(7.1)	15.5	(1.7)	45
25-27	65.2	(7.1)	15.6	(1.7)	48
28-30	67.8	(7.1)	16.2	(1.7)	52
31-33	68.2	(9.2)	16.3	(2.2)	44
34-36	72.4	(6.7)	17.3	(1.6)	49
37-40	72.5	(7.1)	17.1	(1.7)	57

FIGURE 6: THE MEAN BMR/Kg OF BODY WEIGHT IN THE 61 WOMEN THROUGHOUT PREGNANCY



15.8cals (1.7). This rises slightly at weeks 16 to 18 but falls again by the next time period and reaches the lowest value at 22 to 24 weeks, 64.8J/kg(7.1), 15.5cal/kg (1.7). The BMR/kg is then shown to increase at subsequent time intervals reaching a maximum at term of 72.5J/kg(7), 17.3cal/kg (1.7). This figure is still below the mean of the measurement at 0 to 6 weeks. Using the linear modelling programme to analyse the changes during pregnancy in the BMR/kg significant differences are found. Weeks 10 to 30 are shown to be statistically significantly different from weeks 34 to 40 weeks at the 5% level. The monthly group also show significant differences with time. The results of the BMR/kg are shown in table 23. The values fluctuate between time intervals, but between weeks 0 to 24 there is no consistent trend upwards or downwards. Between weeks 25 to 30 the BMR/kg remains static at 71J/kg, 17cal/kg. Thereafter the BMR/kg increases progressively at each time period, to a maximum value of 77J/kg, 18.4cal at term. Weeks 10 to 15 and 25 to 30 were significantly different from weeks 37 to 40 at the 5% level. Weeks 16 to 24 were significantly different from weeks 34 to 40.

For the six weekly group the initial value is 70.7J/kg

TABLE 23 - THE MEANS AND STANDARD DEVIATIONS OF THE BMR/kg FOR THE THREE GROUPS (J and cals)

	BMR/24hrs (± sd)								
Weeks gestation	2 weekly			4 weekly			6 weekly		
	J	cals	N	J	cals	N	J	cals	N
0-6	73,2 (8,7)	17,5 (2,09)	7	74,0 (8,2)	17,7 (2,0)	9	-	-	-
7-9	65,3 (8,4)	15,6 (2)	15	76,1 (8,2)	18,2 (2,0)	9	70,7 (7,9)	16,9 (1,9)	3
10-12	65,3 (8,7)	15,6 (2,09)	32	69,8 (8,2	16,7 (2,0)	23	66,5 (7,5)	15,9 (1,8)	12
13-15	66,1 (7,2)	15,8 (1,72)	28	69,8 (5,8)	16,7 (1,4)	12	61,5 (6,7)	14,7 (1,6)	9
16-18	66,9 (6,3)	16,0 (1,51)	29	70,2 (7,1)	16,8 (1,7)	19	62,3 (8,0)	14,9 (20)	13
19-21	65,9 (7,5)	15,7 (1,8)	24	71,0 (6,0)	17,0 (1,5)	15	59,8 (7,5)	14,3 (1,8)	7
22-24	64,9 (7,1)	15,5 (1,7)	23	68,6 (5,0	16,4 (1,2)	12	60,7 (6,7)	14,5 (1,6)	10
25-27	65,3 (5,9)	15,6 (1,4)	23	71,0 (5,8)	17,0 (1,4)	13	58,5 (4,6)	14,0 (1,1)	12
28-30	66,9 (6,7)	16,0 (1,3)	27	71,0 (5,8)	17,0 (1,4)	15	61,9 (6,7)	14,8 (1,6)	11
31-33	70,2 (5,4)	16,8 (1,3)	22	73,2 (7,1)	17,5 (1,7)	13	56,1 (9,6)	13,4 (2,3)	9
34-36	72,4 (5,4)	17,3 (1,3)	25	76,1 (6,7)	18,2 (1,6)	15	65,7 (5,0)	15,7 (1,2)	9
37-40	74,1 (5,9)	17,7 (1,4)	26	77,4 (5,7)	18,5 (1,4)	14	63,2 (10,4)	15,1 (2,5)	17

(8.0), 16.9cal(1.9). This figure falls to 66.5J/kg (7.5), 15.9cal (1.8), at 10-12 weeks and remains below the value recorded at 7 to 9 weeks throughout pregnancy. No significant differences were found across time.

The mean BMR expressed as per kg of body weight for the two weekly group shows differing trends to the other groups. The mean value of 73.2J/kg, 17.5cal, at 0 to 6 weeks falls to 65.3J/kg (8.4), 15.6cal (2) at 7 to 9 weeks. The number of measurements made are different however. The mean value for the next time period is the same as for 7-9 weeks. It remains constant between 65 to 66 J, 15.5 to 15.8cal until weeks 31 to 33. The BMR increases to 70.2J/kg (5.4), 15.5cal and 15.8cal, and increases at each subsequent time period. At 37 to 40 weeks a maximum value of 74.1J/kg (5.9), 17.7cal (1.4) is reached. No significant differences were shown across time.

3.9 DISCUSSION OF THE BMR RESULTS

3.9.1 BMR/min

The results of the BMR expressed per minute for the whole group showed a decrease from 10 to 15 weeks, followed by increases to term. This differs from previous work suggesting that the BMR increases progressively to term (Hytten & Leitch, 1971).

The results were also analysed for each group as defined by the frequency of measurement to investigate whether differences existed between the groups and also in an attempt to ascertain how frequently measurements of the BMR needed to be made to ensure that possible changes in the BMR were not missed. This was partly as a result of evaluating the Phase I data where women were only measured at six weekly intervals.

When the data was analysed group wise, the six weekly group and the four weekly group also showed a decrease in the BMR from the initial measurements. The time of the decreases were not identical on a weekly basis, but occured in the second trimester. In the six weekly group the BMR falls between weeks 13 to 21. This would suggest that instead of the BMR increasing there is a saving in the amount of energy required. In the 4 weekly group the BMR does not increase above the values recorded in early pregnancy, until weeks 19 to 21. This would again suggest that there is an energy saving mechanism during pregnancy. Other workers have shown similar results, (Rowe & Boyd,1932; Huen et al, 1970; Lawrence et al, 1984, 1987). In contrast to this the 2 weekly group, showed an increase from 10 weeks gestation onwards, which is similar to that of Hytten and Leitch.

There are three factors which may be effecting the results as presented here. The first is the lack of data from the pre-pregnant state. It is not possible from this data to say whether the BMR changed during early pregnancy. The 8 women measured in the pre-pregnant state in this study showed no significant difference in the BMR from being non-pregnant to the first measurement made when pregnant, which was at a mean of 7 weeks. The data presented here in the non pregnant state was on too few women, and the number of measurements on this group was insufficient. The results however illustrate how difficult it is to know if any changes in the BMR have occured without accurate knowledge of the BMR before pregnancy.

However, other studies have shown that the BMR has already increased very early in pregnancy (Durnin et al,1987; van Raaij et al, 1987). The final results from the Glasgow study are calculated from the pre-pregnant value of 20 women and extrapolated to the whole group. They showed that there was an upward trend from 6 weeks of pregnancy onwards, which did not reach significance until 18 weeks (Durnin et al, 1987). This work is continuing and the intention is to collect data on 150 women. The Dutch group found at 6 weeks gestation the BMR was significantly different from the non pregnant state in a sub-group of 21 women, (van Raaij, Peek, & Hautvast, 1986).

Difficulty also arises in interpreting the data not only because of the lack of pre-pregnant data but because of the difficulty experienced in recruiting women early in pregnancy. As a result of this the number of measurements made in the first trimester are small. Only 16 women of the 61 were measured between 0 to 6 weeks and 27 between weeks 7 to 9. The values at both these times are identical, but the mean at 10 to 12 weeks is of 67 women and the value drops. From the data of the final Glasgow study where the results of the 20 women are extrapolated to the whole group an upward trend is observed from 6 weeks onwards. The early measurements in the group followed here may not be representative of the whole group, and the observed decrease could then be an artifact due to the small numbers. In the 2 weekly group there is a sharp rise and then fall in the BMR between consecutive measurements. This seems unlikely to be the case and is more likely to be due to the small numbers of women measured at that stage. Therefore there are difficulties in observing how the BMR changes from the pre-pregnant state but the effect of early pregnancy is not clear either due to the small numbers. The later study carried out in Glasgow clarified this. The data collected on the 20 non-pregnant women and following them through pregnancy made it possible to extrapolate the results to the whole group and to get a statistically representative information as to the changes in the BMR from the non-pregnant state to the pregnant state.

The lack of a baseline data may not completely explain the decreases in the BMR observed. As noted before previous workers have measured decreases, although these could also be due to the fact there is a lack of data on a sufficient number of women. From the final analysis of the Glasgow and Dutch study it would appear that there is an increase in the BMR from very early in pregnancy, so that the decreases in the BMR observed in this study may not represent decreases below the non pregnant BMR but may still be real. For example, the Dutch study measured a decrease in the BMR from 10 to 16 weeks in a sub group of 19 women (van Raaij, Peek & Hautvast, 1986). Forsum (1985) showed a decrease in the BMR of 7 out of 19 women at 16 to 18 weeks gestation, while the group of women as a whole showed an increase. Huen et al (1970), showed a decrease in the percentage increase of the BMR at 20 weeks. No discussion of why this may occur is given except by Huen et al who think that hormonal factors may be effecting the BMR.

Another factor to consider is the length of time between measurements. The Phase I data was collected at 6 weekly intervals, and from the analysis carried out at the end of this phase it became clear that 6 weeks was too long a time gap. There are various reasons for this. Firstly, it is not possible to recruit everyone at the same stage of pregnancy, therefore when analysing the data the subjects are rarely at the same time point. In a group of 21 women measured 6 weekly the number of women at a given time point is therefore small. The three weekly intervals used in the analysis were chosen to give as even a distribution of measurements as possible. With individual women being measured at longer time intervals, it means that the number of measurements as well as being small could be weighted by one or two women in that group, who may have had higher or lower BMRs than the rest of the group. A 6 weekly measurement means also that it is not possible to get more than 6 measurements throughout pregnancy, less depending on the time of first measurement. This did not seem to be enough to get an accurate impression of what was happening throughout pregnancy, and between measurements.

In Phase II therefore it was decided to see if 4 weekly intervals gave sufficient information or if 2 weekly intervals between measurements were necessary to provide an accurate picture of changes in the BMR during pregnancy. When one compares the data (Tables 15 & 16) it would appear with the more frequent measurements it is possible to see what happens to the BMR more easily. This can be illustrated if the results are compared to the 4 weekly group were the value at 10 to 12 weeks is higher than both the previous measurement and the subsequent measurement. For the four weekly group any calculations are made even more difficult because of this.

Therefore, it would appear that on groups of small numbers such as 20, the more frequent the measurement is, the more accurate the information. This does have to be balanced against the degree of cooperation that is required from the individual mother, and fortnightly visits to the laboratory, are time consuming and demand a lot of commitment to the study. With a larger group than 20 women it is possible to get representative data on the BMR as demonstrated by the results of the Glasgow and Dutch study, especially when the pre-pregnant values have been established on at least a sub-set of women. The decreases observed in all the studies (van Raaij, Peek & Hautvast, 1986; Huen et al, 1970; Forsum, 1985) and the data presented here are all shown to be at the end of the first trimester and the begining of the second. Other studies have found the BMR during the first trimester to be significantly different from the second and third (Khan & Belavdy, 1973; Nagy & King, 1983; Jackson, 1985).

RESULTS OF THE BMR MEASUREMENTS

The Thai group reported slight increases in the BMR to 16 weeks after which time it increased progressively (Thongprasert et al, 1987). The Phillipines showed that the BMR increased steadily throughout pregnancy, but the values recorded at 11 to 16 weeks were significantly different from later stages of pregnancy (Tuazon et al, 1987)

All the data reviewed here would lead to the suggestion that while increases in the BMR are recorded from 6 weeks gestation, it is not until the second trimester that the increases begin to assume significance,for example in the Glasgow study it was 18 weeks. The reported decreases in the BMR after an initial increase remain unexplained, it is not clear whether they are a function of small numbers, insufficient measurements or too long a gap between measurements. The fact that the Glasgow study did not find such a decrease while the Dutch study did report a decrease in a sub-group of women is puzzling. The Gambian study found that the BMR decreased from pre-pregnant values during the first three months of pregnancy in both the supplemented and unsupplemented women, it is speculated that such decreases are a physiological adaptation to food shortages (Lawrence et al, 1987).

RESULTS OF THE BMR MEASUREMENTS

The findings of this study would emphasise the need to have accurate pre- pregnant and early pregnancy data. The time between measurements would seem to give more accurate data the shorter it is, however if the number of subjects being observed is large and the former two conditions are accounted for then monthly measurements are probably sufficient. If the group is small, such as the individual groups followed here then it is suggested that fortnightly or three weekly would be more appropriate.

The data of the 61 women when analysed shows significant differences in the BMR/min after week 25, this is later than the final Glasgow study by 7 weeks. However in the 6 weekly group it is not until weeks 37 to 40 that the BMR is significantly different from the measurements in early pregnancy, while weeks 13 to 18 are significantly different from weeks 34 to 40. This is indicatve of the decrease in the BMR shown by the data in this group. The two weekly group and the four weekly group do not show any significant differences across time.

RESULTS OF THE BMR MEASUREMENTS

The results from the final analysis of the Glasgow study show significant differences in the BMR after week 18, the Dutch study did not find any significant differences until week 36 and the Philipines found significant differences after week 16. The Dutch group also recorded the drop in the BMR which might explain why the increase in the BMR does not reach significance until week 36, while the Glasgow and Philipino studies show an increase much earlier. The data from the 2 weekly group, the final Glasgw study, Thailand and the Phillipines all show the BMR to increase steadily and the shape of the curves are very different from the hypotheses of Hytten and Leitch. They thought that the BMR increased most during the second and third quarters of pregnancy, due to the increased needs of the fetus.

The percentage increase in the BMR/min from the initial measurement to the final measurement at term was 17%, 22%, 40% & 22% for the 6 weekly, 4 weekly, 2 weekly and the whole group respectively. The value for the 6 weekly group is the lowest and this is thought to be due to the fact that the first measurements for this group were later than the other groups, the increase in the 2 weekly group is nearly 2 fold that of the other groups.

Other workers report increases of between 15 and 33% (Baer, 1921; Sandiford & Wheeler; Dakshani & Ramanamurthy, 1964;Huen et al, 1970; Khan & Belvady, 1973; Nagy & King, 1983). The increases recorded here therefore fall within this previously recorded range with the exception of the 2 weekly group. The increases reported in the five country study are as follows: the Dutch study showed an increase of 14%, 7%, and 11% for each sub-groups 1, 2 and 3. Only the first of these has pre-pregnant data and when the increase is calculated from this the percentage increase is 21%. The latter two groups do not record data past 35 weeks when the BMR is likely to be still increasing. The Philipino data shows an 18% increase from 11 weeks gestation to 35 to 40 weeks.

From all the available data the increase of 40% seems higher than previously reported in other studies. The 2 weekly group however have lower values in early pregnancy, and increase above the values of the other groups. This again may be a function of the small numbers.

3.9.2 BMR/kg

No significant differences are found across time in the 2 weekly and the 6 weekly groups in the BMR expressed per kg of body weight, while the 4 weekly and the whole group do. In latter group, weeks 10 to 30 are significantly different from weeks 34 to 40.

All groups whether the changes assumed significance or not showed a bell-shaped curve for the BMR/kg across time. Carpenter & Murlin (1911) found that the energy production of the pregnant women decreased by 7% per unit of body weight, while others have found it to increase(Root & Root, 1923). These two studies were on single subjects, others studies on groups of women have shown that the BMR per kg does not show any significant changes throughout pregnancy (Nagy & King, 1983; Jackson, 1985).

The Glasgow study recorded an increase in the BMR/kg from 70J (16.6cal) to 75J (17.9cal) at term. The Dutch study recorded significant changes in the BMR/kg, from the pre-pregnant state to 6 weeks gestation, the value per kg decreased to its lowest value at 23 weeks, this decrease was significant at the 5% level. The Philipino study did not show any significant change in the BMR per unit of body weight. The value for the BMR/kg therefore does not remain constant throughout pregnancy, but decreases and then increases. The changes observed do not always reach significance.

3.9.3. The BMR/24 hours

The percentage increase in the BMR/24 hours is the same as for the BMR/min. The BMR/24 hours is different for each group, although it is only the 2 weekly group that is substantially different to the others with an increase from the time of first measurement of 1.98MJ (470kcal). The 6 weekly, 4 weekly and combined data having increases from time of first measurement to term of 0.96MJ (230kcal) , 1.34MJ (320kcal) and 1.26MJ (300kcal) respectively. If a baseline is set as of 10 weeks, then for the 6 weekly group, the mean increases to 5.48MJ/day (1300kcal/day) to give an overall increase of 0.88MJ, (210kcal). The 2 weekly group increases to 5.1MJ/day, (1220kcal/day) at 10 weeks. The 4 weekly group and the group as a whole have decreased means at 10 weeks, the overall increase that they demonstrate is then 1.59MJ, (380kcal) and 1.51MJ, (360kcal) respectively.

The 2 weekly group has the lowest mean BMR/24 hours at 5.1MJ, (1220kcal), at 10 weeks, but increases the most to 7.0MJ, (1670kcal) at term, while the 4 weekly group has the highest value at 10 weeks of 5.94MJ (1420kcal). There is no apparent reason as to why the value of the 2 weekly group is lower than the rest or why it should be higher at term and is probably a function of the small numbers.

The BMR at term in the final Glasgow group is 1.7MJ (400kcal) higher than the pre-pregnant baseline, and again the value of pre-pregnant data is demonstrated. The Dutch study shows an increase of 0.32MJ/day (80kcal/day) from the non-pregnant state to 6 weeks gestation and increases a further 0.92MJ, (220kcal) to term, a total of 1.24MJ (300kcal) a day compared to the non-pregnant figure. A sub-group of women measured at 10 weeks show an increase of 0.53MJ, 130kcal at 35 weeks, while another sub-group, measured initially at 11 weeks show an increase of 0.77MJ/day, 180kcal/day by 35 weeks. The women followed in the Gambia show an increase of less than 0.4MJ/day, (100kcal/day) throughout the whole of pregnancy. The Thai study demonstrated an increase of 1.2MJ/day (290kcal/day) from week 10. The Philipino workers measured two sub-groups of women who showed increases of 0.96MJ/day, (230kcal/day) and 0.91MJ/day, (220kcal/day) from 11 to 16 weeks gestation to term. The values of the BMR/24 hours in the three developing countries are lower than those reported here, for example the mean BMR/24 hours at 11 to 16 weeks is 4.99MJ (1200kcal), while the figures for the Dutch study are higher, 6.37MJ/24 hours (1520kcal/24 hours) at 6 weeks in one of the sub-groups. The increased BMR could be related to body weight and will be discussed in a further section.

3.9.4 The energy cost of the increase in the BMR

The total cost of the BMR was calculated as the area under the curve of the changes in the BMR throughout pregnancy. The values obtained in the different groups differed by over 400%, with the lowest value being that in the 4 weekly group of 44MJ (10,500kcal), and the highest in the 2 weekly group of 180MJ (43,000kcal). The results combined gave a cost of 51MJ (12,200kcal) and the 6 weekly group had a total cost of 57MJ (13,600kcal).

The increased cost of the BMR in pregnancy is calculated by Hytten and Leitch to be 150MJ, 36,000kcal, so the group which is nearest this is the 2 weekly group, when the cost is calculated for the other 2 groups and the combined data the total cost is about one third of the estimated value.

The results obtained by both the Glasgow and Dutch study using measurements from pre-pregnant baseline showed increases which were nearer to the calculations of Hytten and Leitch. The former study showed an increase of 125MJ (30,000kcal) and the latter 145MJ (35,000kcal) The values obtained in the Thai and Phillipino studies were 100MJ (24,000kcal) and 89MJ (21,000kcal) respectively from the end of the first trimester. The Gambian study demonstrated an overall saving of 46MJ (11,000kcal) while the supplemented group were only seen to have a total increase of 4MJ (1000kcal) throughout the whole of pregnancy.

It would appear from the results of the completed Glasgow study that the decreases in the BMR as measured have a large effect when calculating the total cost of the increased BMR during pregnancy, and are likely to be due to a mixture of factors, such as the lack of baseline data, both in the pre-pregnant state and sufficient measurements during the first trimester. The small numbers in each of the groups may also be a factor, and it is likely that the more frequently the measurements are made the more accurate the calculations. This latter point is particulary relevant when the calculation of the cost is from the cumulative increase in the cost between each measurements.

In summary it would appear that the magnitude of the cost of the increase in the BMR was greatly underestimated in the data presented here. This is thought to be due to a combination of factors, the most important being the lack of the pre-pregnant data, and insufficient data in the first 10 weeks gestation. Other factors such as the number of women and frequency of measurement can be overcome if the former two considerations are met, as demonstrated by the final results of the Glasgow study.

CHAPTER 4

RESULTS OF THE WEIGHT GAIN DURING PREGNANCY

The results of the measurement of body weight on the visits to the laboratory are presented here. The mean weights during the first 6 weeks post-partum are also presented. As for the BMR the data was analysed for the group of 61 women and for the separate groups. However the same trends were shown throughout, unlike the BMR data and to avoid repetition data is presented only on the whole group and not for the groups separately. The means at the twelve time periods during pregnancy have been calculated and analysed for statistical differences across time using the linear modelling package as before(Scott, 1979).

4.1 WEIGHT GAIN IN THE WHOLE GROUP

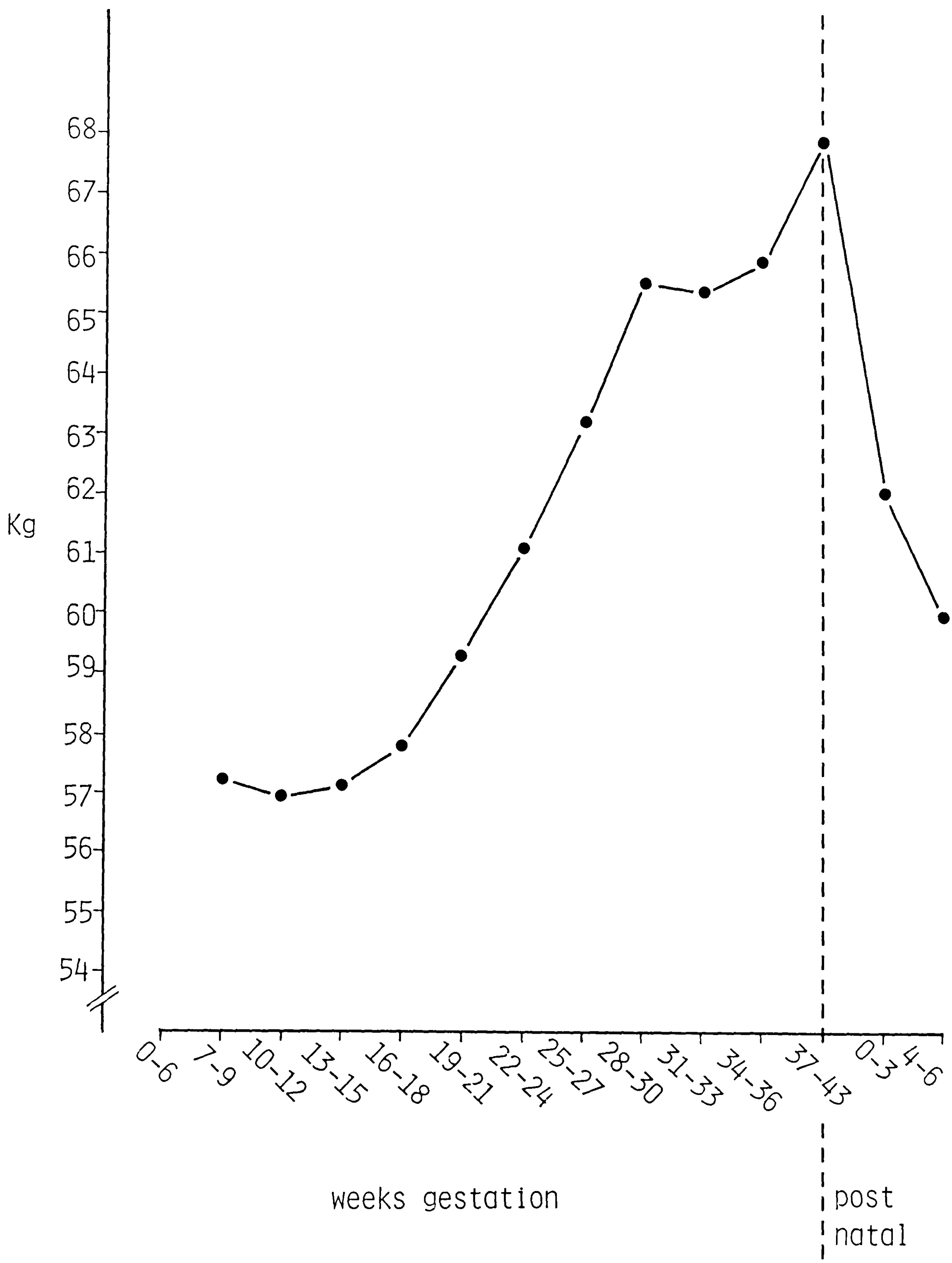
The mean body weights and standard deviations at the 12 times in pregnancy are presented in Table 24, Figure 7 expresses these means graphically. Between weeks 0 to 10 there is an increase followed by a decrease. The number of measurements at these two times is small even with all the data combined. The value at 10 weeks is 56.9kg(8), and this rises successively until weeks 31 to 33, when there is a small decrease in the mean weight from 65.52kg(8.6) to 65.37 kg(9.0). Thereafter the mean body weight continues to increase to term, where a mean weight of 67.9kg(8.5) is recorded.

When the weight gain is calculated from week 10 to

TABLE 24 - THE **MEAN** (s.d) BODY **WEIGHT** IN THE 61 **WOMEN MEASURED** (kg)

Weeks gestation	Weight (kg)		N
0-6	54.05	(9.7)	16
7-9	57.19	(7.3)	27
10-12	56.9	(8)	67
13-15	57.07	(6.8)	49
16-18	57.75	(7.3)	61
19-21	59.28	(7.7)	46
22-24	61.09	(7.7)	45
25-27	63.23	(8.4)	48
28-30	65.52	(8.6)	52
31-33	65.37	(9.0)	44
34-36	65.82	(9)	44
37-40	67.9	(8.5)	57
Post-natal			
0-3	62.02	(9.1)	57
4-6	59.88	(8.6)	55

FIGURE 7: THE MEAN BODY WEIGHT(Kg) THROUGHOUT PREGNANCY AND POST NATALLY



term there is a mean weight gain of 11.0kg. This is an increase of 19% in body weight. There is not sufficient data available to know if there was any change in weight during the first 10 weeks of pregnancy.

There is a decrease of 5.88kg in the first three weeks following the birth, to 62.02kg (8.5). By 4 to 6 weeks post-partum there is a further decrease to 59.88(8.6), a decrease of 2.14kg. This weight is 2.98kg above the mean weight at 10 weeks gestation.

4.2 WEEKLY AND CUMULATIVE WEIGHT GAIN

Table 25 shows the weight gain calculated on a weekly basis. Between weeks 10 to 15 the weight gain is small, a mean gain of 0.05kg per week. From weeks 16 to 18 the rate of the gain increases to 0.2kg per week. The maximum rate of weight gain is observed between weeks 19 to 30, with increases of 0.5kg a week to 0.8kg per week. The rate of gain slows down between weeks 30 to 33 and there is a slight weight loss, the

TABLE 25 - CUMULATIVE AND WEEKLY WEIGHT GAIN FOR THE 61 WOMEN (kg)

Weeks gestation	Cumulative weight gain (kg)	Weekly weight gain (kg)	Weeks
10-15	0.17	0.05	10-15
10-18	0.85	0.2	16-18
10-21	2.38	0.5	19-21
10-24	4.19	0.6	22-24
10-27	6.33	0.7	25-27
10-30	8.62	0.8	28-30
10-33	8.47	0.05	31-33
10-36	8.92	0.2	34-36
10-40	11.0	0.7	37-40

weight then increases a further 0.2kg weeks 34 to 36 and there is a final increase in the mean weekly weights of 0.7kg from weeks 37 to term. The cumulative weight gain from 10 weeks to term is shown in Table 25.

Significant differences across time were seen when the data was analysed using the linear modelling package as before. The significant differences at the 5% level were as follows:

1. 10 to 15 weeks and 16 to 40 weeks

2. 16 to 18 weeks and 19 to 40 weeks

3. Thereafter the mean weight at each time was significantly different from the subsequent time.

4.3 CORRELATION WITH THE BMR DATA

The results of the weight gain during pregnancy were correlated with the results of the BMR. No significant correlations were found.

4.4 DISCUSSION OF WEIGHT GAIN RESULTS

The increase in the weight of the pregnant women has been calculated from 10 weeks gestation to term. The results as presented before that were not thought to be representative of the whole group as the numbers of women involved were small. Data is only presented for the whole group as the separate groups not unsurprisingly showed very similar trends in the pattern of weight gain. This differs from the data presented on the BMR, in which the separate groups showed differing trends. The similar trends in the weight gain data in the three groups of women suggests that the differing trends shown in the BMR data are heavily influenced by the methodological considerations as discussed, rather than real differences between the groups of women.

The overall increase in the body weight of the pregnant women as been calculated from 10 weeks gestation to term was 11kg. The most often quoted figure for weight gain during pregnancy is 12.5kg (Hytten & Chamberlain, 1980). This figure is calculated from data of primigravidae, and it is thought that the gain of multigravidae is 0.9kg less. All but five of the women observed in this study were multigravidae. The mean weight gains recorded in this study were therefore similar to previously reported means on large numbers of women.

The weight gain for the first 10 weeks of pregnancy cannot be calculated from the data collected in this study as there is insufficient data. It is thought that the average increase during the first trimester is 1.14kg (Chesley, 1944). As with the BMR data, to be aware of the weight gain from conception to term there needs to be accurate data on the women in the pre-pregnant state and sufficient women weighed during the first 10 weeks of pregnancy. The final analysis of the Glasgow study showed a weight gain of 11.7kg from 10 to 40 weeks. In the 20 women who were followed from pre- pregnancy there was a weight gain of 0.5kg. The Dutch study showed an increase of 10.7kg from 10 weeks to term, but on a sub-set of 19 women there was an increase of 1.28kg by 12 weeks gestation. It therefore seems likely that for the 61 women followed here there was a weight gain of between 0.5kg and 1kg during the first 10 weeks of pregnancy.

The Thai and Phillipino women gained comparable amounts of weight of 8.9kg and 8.5kg respectively from 10 weeks to term and the women studied in the Gambia had the lowest increase in body weight, of 7.3kg.

The results of the Dutch and Scottish study are comparable with the results obtained here. The results of the weight gains from the Philipines, Thailand and the Gambia are lower, and similar to weights recorded in Nigerian, Indian and Bantu women (Akinkugbe, 1979; Hauck, 1963; Neser, 1963).

The weight gain as a percentage of the initial body weight was found to be similar in the centres in the five country study, (Durnin, 1987), with the exception of the Gambia the increase was 19 or 20%. In the results reported here the increase in the body weight was 19% for the group as a whole. The results are therefore compatible with those of the other studies.

The weekly weight was calculated from the recorded weights for the different times of pregnancy. The largest rate of increase was between weeks 19 to 27. There was a decrease in the mean weight at 30 to 33 weeks of 0.15kg. This may represent a slowing down in the rate of weight gain at the end of the third quarter of pregnancy. This was followed by a spurt in the weight gain for the last three weeks of pregnancy. The increase was 0.7kg per week. The weekly weight gains given by Hytten & Chamberlain differ from those recorded here. They found that the weekly rate of increase was 0.36kg until 16 to 18 weeks when it increased to 0.45kg until 26 to 28 weeks, and then the average increase was between 0.36kg to 0.41kg to term. In the Glasgow study a sub-set of 35 women measured themselves weekly from 10 weeks to term. In this group of women the rate of weight gain was found to be a constant 0.4kg/week. The results from the Philipines record a constant increase in weight of 0.33 to 0.37 between weeks 17 to 29. The Hytten and Chamberlain figures are far more uniform than those recorded in this study, this may be because much larger numbers were being examined, nearly 3000 as opposed to 61. However the general trend observed in this data and the data of Hytten and Leitch is for the maximum weight gain to be between the middle two quarters of pregnancy. This is in contrast to the steady weight gain observed throughout pregnancy in the final Glasgow study.

Significant differences between weights were found as pregnancy progressed. This is indicative of the increase in body weight throughout pregnancy. No correlation was found between the BMR data and the increase in weight. From this data it would appear that increases in the BMR are not directly related to increases in the body weight.

The recorded weight loss after the birth was 5.88kg, which meant that the women immediately after delivery were 5.12kg heavier than at 10 weeks gestation. However by 4 to 6 weeks post-partum this value had fallen to 2.98kg above the mean weight at 10 weeks. This is comparable to the data of Hytten and Chamberlain who claim that on average any weight gained above 8.6kg during pregnancy is retained post-natally. The expected figure for a weight gain of 11kg would therefore be 2.4kg. This group show an increase of 2.96kg.

In summary, the weight gains recorded are lower than the average 12.5kg quoted for primigravidae, but comparable to the recorded lower weight for multigravidae. The results are also comparable with the final results from the Glasgow study and those from the Dutch study. The weight gain was greatest during the second trimester, the weekly weight gains did not match those recorded by Hytten and Leitch, but the sample of women studied here was much smaller.

CHAPTER 5

RESULTS OF THE INCREASE IN BODY FAT DURING PREGNANCY.

5.0.1 Body fat as calculated from skinfolds

The results of the 4 skinfold measurements are presented in Table 26. The mean percentage fat at each of the twelve time periods through pregnancy has been calculated for each group and for all the data combined. The trends in all groups were similar and as with the results of the weight changes during pregnancy data is presented on the whole group only.

TABLE 26 - **MEAN (s.d) PERCENTAGE FAT AS MEASURED BY SKINFOLDS IN THE 61 WOMEN**

Weeks gestation	% fat		N
0-6	23.4	(0.05)	16
7-9	27.4	(4.85)	27
10-12	26.4	(5.63)	67
13-15	28.2	(5.9)	49
16-18	28.0	(5.4)	61
19-21	28.1	(4.8)	46
22-24	28.5	(5.3)	45
25-27	28.9	(5.5)	48
28-30	29.5	(4.55)	52
31-33	30.5	(5.01)	44
34-36	29.0	(5.12)	49
37-40	29.4	(4.79)	57

Results of the increase in body fat during pregnancy

Data is also presented on the percentage fat during the first 6 weeks post-partum. Other methods have also been used to calculate the change in fat. This is because the weight gain in pregnancy is due to the fetus, placenta and increase in fluid volumes as well as the increase in the uterus, breasts and maternal fat. These changes mean that in the later stages of pregnancy there is a change in the body density of the pregnant woman. Because of this the equations which the calculations of the skinfolds are based are no longer valid (Durnin & McKillop, 1987).

The percentage body fat as calculated by skinfolds throughout pregnancy is shown in Table 26. The value at 10 weeks is 26.4% after which time it increased progressively to 33% when it fell slightly to term. If the percentage fat was accepted using these figures it would give an increase in the fat mass of 4.94kg, with an energy equivalent of 227MJ (54,300kcal).

To calculate the changes in body fat during pregnancy a further three methods of calculation were used.

Results of the increase in body fat during pregnancy.

5.0.2 Fat mass at entry to study and post-nataly

By calculating the fat mass at entry to the study using skinfold equations, and calculating the fat mass at 4 to 6 weeks post partum in the same way. At 4 to 6 weeks it is assumed that the mother's body has returned to normal, i.e. it has lost the extra fluids which may effect the skinfold equations. Any body fat which may have been lost by then is assumed to be very small (Durnin & McKillop, 1987).

The mean fat mass at 10 weeks is 15.14kg(4.3). At 4 to 6 weeks post-partum the fat mass as calculated from skinfolds is 16.54kg(4.98). The mean increase in the fat mass is 2.14kg(1.52). The energy cost of which is 124MJ (29,600kcal).

5.0.3 Mean body weight at 10 weeks and post-nataly

Calculation of the fat mass can be made from the mean body weight at 10 weeks and the mean body weight at 4 to 6 weeks post-partum. Differences in weight are thought to be due to an increase in breast tissue and in adipose tissue. From the calculated increase in adipose tissue the increase in fat can be calculated.

The mean weight at 10 weeks is 57.17kg(7.2), after the birth of the babies the mean weight is 59.88kg. The mean difference is 4.0kg (3.2), minus the amount calculated for the increase in breast tissue is 3.6kg of adipose tissue, which gives an increase of 2.88kg of fat equivalent to 132MJ (31,500kcal).

5.0.4 The factorial method

The factorial method of Hytten & Leitch(1971) calculates the increase in the fat mass from the known weight gains of the fetus and placenta, and the calculated gains of the amniotic fluid, increased blood volume and extracellular fluid and increased mass of the uterus and breasts. Any remaining weight gain is assumed to be increased fat mass.

The mean weight gain at 10 weeks for the 61 women is 11kg, which after all the other components have been accounted for leaves 2.19kg, which is assumed to be adipose tissue with a fat content of 1.75kg. This is the energy equivalent of 80MJ (19,100kcal).

5.1 DISCUSSION OF FAT GAIN RESULTS

The original intention of the study was to monitor the changes in the fat throughout pregnancy using the equation of Durnin and Womersly (1974). From this it was thought it would be possible to see at which times during gestation maternal fat was deposited and what effect this had on the energy requirements of different times in pregnancy. In the study of Taggart et al (1967), which measured the skinfolds at eight different sites, they found that the skinfolds increased up to thirty weeks. Other workers measured skinfold thickness and fat cell diameter in 27 pregnant women and reported that total maternal body fat reached a peak at the end of the second trimester (Pipe et al, 1979).

The skinfold measurements are based on regression equations using figures from body density studies. The density of the pregnant women changes throughout pregnancy, particularly in late pregnancy, and therefore the regression equations which are from non-pregnant individuals are not valid when considering late pregnancy. There are other difficulties in this method. Taking the skinfolds at the supra illiac site becomes more difficult as the woman progresses in her pregnancy and because of this the accuracy of this measurement is likely to be effected. The inaccuracy of the skinfold method for serial measurements during pregnancy was demonstrated in this study. The calculated increase in fat mass from 10 weeks to term was 4.94kg. The total weight gain was 11kg, the increase in the fat mass would then be equal to 45% of the total weight gain, leaving a weight gain of only 6.06kg for all the other components of the weight gain such as the products of conception and the increases in fluid. In contrast to this the factorial method estimates a fat gain of 2.19kg after the known weights of the fetus and placenta, and the calculated gains of the amniotic fluid, increased blood volume and increased mass of the uterus and breasts have been accounted for. From this it would appear that using the skinfold equations throughout pregnancy gives an over estimate of the total amount of fat gained.

Fat gains and fat losses were observed between measurements using the skinfold technique which would mean large changes in the energy balance. There is no evidence to suggest that such large fluctuations would occur and would appear to further support the discussion that skinfold measurements are not a valid way of estimating changes in the fat mass during pregnancy. It may also be argued that the skinfold method is not a sensitive enough measurement to use serially in this way, even without changes in the body density and methodological problems of taking the measurements. As a result of this three other methods for calculating the amount of fat gained during pregnancy were devised (Durnin & McKillop, 1987).

The three methods devised gave a figure for the total fat gained during pregnancy but it was therefore not possible to tell at which stages during pregnancy the fat was laid down. The available evidence suggests that the majority of fat has been laid down by the end of the second trimester (Hytten & Leitch, 1970). It is suggested that this means there is a supply of energy for breast feeding and also for the last trimester when fetal growth is fastest. From the data presented here it is not possible to speculate further.

When the data was combined the amount of fat gained as calculated by the three methods was 2.14kg, 2.88kg and 1.75kg. This compares with 4.94kg as calculated by skinfolds at 10 and 40 weeks gestation. There was less than a kilo difference using the three methods. There is therefore quite close agreement between the three methods of calculation. The calculated energy cost of these gains is 98MJ (23,400kcal), 132MJ (31,500kcal) and 80MJ (19,100kcal) respectively.

The theoretical increase in maternal body fat during pregnancy is 3.5kg. All three methods of calculation in all the groups give lower values than this. In the final analysis of the data from the groups of women in the five countries investigated the fat gain was calculated from skinfolds at 10 weeks gestation and at

4 to 6 weeks post-partum. The fat gains calculated in this way showed an increase of 2.3kg (0.3) in the Scottish group and 2.0kg (0.3) in the Dutch group. The Thai and Phillipino results gave similar results to each other with calculated fat gains of 1.4kg and 1.3kg. The Gambian group reported an increase of 0.6kg.

The results presented here are therefore comparable with the results of the two developed countries but lower than the theoretical value of 3.5kg. A possible argument is that the women in this study and the Dutch study were deliberately controling their weight gains during pregnancy. However the total weight gains were comparable with those reported on large numbers of women. If this group were controlling their weight gains then one would expect the total weight gain to be correspondingly lower. All women were selected for the study after questioning of their eating habits and attitude to body weight. No women displaying signs of abnormal eating patterns were invited to take part on the study. The food intakes recorded are comparable with those reported in other studies and will be discussed later. Energy intakes therefore do not demonstrate decreased intakes associated with weight restriction. Overall the more probable explaination would appear to be that theoretical fat gain of 3.5kg is an over estimate.

In conclusion, there are methodological problems in measuring the increase in the fat content of the maternal body during pregnancy, due to changes in the body density as pregnancy progresses. Various calculations have been used to estimate the increase in the body fat. From these calculations it would appear that the amount of fat laid down during pregnancy, theoretically as a buffer for the increased energy requirements of the last trimester and lactation, is less than previously thought of 3.5kg. A buffer for the increased energy requirements of the last trimester and for lactation may not be necessary in populations such as those studied here, when food shortages are generally not experienced. The cost of laying down 2.14kg of fat as compared with 3.5kg is 98MJ (23,000kcal) and 160MJ (38,000kcal) respectively. This is a large difference when calculating the energy cost of pregnancy, and will lower the theoretical cost accordingly. This has important implications when calculating the energy requirements of pregnancy. A decrease in the energy cost of pregnancy of 60MJ

Results of the increase in body fat during pregnancy.

(14,000kcal) is equal to a decrease of over 214kJ (50kcals) spread throughout pregnancy and is a reduction of 20% in the FAO/WHO figures.

CHAPTER 6

RESULTS OF THE INFANT DATA

All the women investigated delivered sucessfully and all babies were healthy. Table 27 shows the mean gestational age, birth weight, placental weight and birth length of the infants born to the 61 women.

The means of the birth weight, placental weight and birth length between the groups are very close. The means for the whole group are 3.39kg (0.45), 0.65kg

TABLE 27 - MEAN (s.d) GESTATIONAL AGE, PLACENTAL WEIGHT, BIRTH WEIGHT AND BIRTH LENGTH OF INFANTS

	Mean	(s.d)
Gestational age (wks)	39.7	(1.0)
Placental weight (kg)	0.65	(0.14)
Birth weight (kg)	3.39	(0.45)
Birth length (cm)	52.39	(2.41)
N	59	

(0.14) and 52.39 cm (2.83) respectively.

6.1 THE CALCULATED ENERGY COST OF THE PRODUCTS OF CONCEPTION

The energy cost of the products of conception can be calculated from the estimated amount of fat and protein in the fetus, placenta, uterus, blood volume, amniotic fluid, extracellular fluid and breast tissue. The energy equivalent of the fat and protein content can then be calculated.

This has been done using the figures of Hytten and Leitch (1971) see Table 28. The mean total energy cost is 47MJ (11,200kcal).

TABLE 28 - MEAN ENERGY COST OF FETUS, PLACENTA AND MATERNAL COMPONENTS

		Energy Equivalent MJ	kcals
Birth weight			
Fetus (kg)	3.39		
Fat (kg)	0.44	20.3	4800
Protein (kg)	0.41	12.0	2900
Placenta (g)	650		
Fat (g)	3.8	0.16	40
Protein (g)	97.5	2.86	700
Maternal components excluding body fat (g)	4800		
Fat (g)	34	1.5	400
Protein (g)	360	10.5	2500
Total Energy Cost		47.32	11340

TABLE 29 - INFANT DATA ANALYSED BY SOCIAL CLASS

	Social Class I	II	III	IV
Mean Birth weight (kgs)	3.5	3.72	3.07	3.07
(s.d)	(0.34)	(0.6)	(0.37)	(0.34)
Mean Placental weight (kgs)	0.66	0.77	0.60	0.64
(s.d)	(0.12)	(0.22)	(0.14)	(0.17)
Mean Birth length (cms)	53.12	51.7	51.02	52.53
(s.d)	(2.58)	(2.74)	(2.82)	(4.5)
Mean Mother's height (cms)	163.47	159.7	161.6	158.9
(s.d)	(6.25)	(11.12)	(6.5)	(8.3)
N	33	6	16	4

Results of the Infant data

6.2 BIRTH WEIGHT BY SOCIAL CLASS

The mean birth weights for each of the three groups were close to the reported average birth weight of 3.4kg. The range of birth weights was 2.25kg to 4.86kg, so some of the babies although healthy would classify as low birth weight babies.

The birth weight, placental weight, birth length and mother's height were analysed by social class, see Table 29. Significant differences were found between social classes I and II and social classes III and IV. The birth weights were significantly different at the $p=0.007$ level despite the small numbers. There was no significant difference between the placental weights or the mothers heights, but significant differences were shown in the birth lengths. ($p=0.0124$).

6.3 DISCUSSION OF THE INFANT DATA

"Fetal growth is ultimately the best measure of the quality of pregnancy" (Hytten & Chamberlain, 1980). All the women observed delivered at term as defined by

Results of the Infant data

Neligan (1970) and all babies were healthy. The mean birth weight for the whole group was 3.39kg (0.45) which is nearly identical to the mean birth weight of Hytten & Chamberlain of 3.4kg. The mean placental weight was 650g (140) and this is the same as the figure quoted by Hytten and Leitch (1970) and McKeown and Record (1953) on much larger studies of women.

The results obtained here are similar to the final results of the Glasgow study of 3.37kg (0.4) with a placental weight of 641g (107) (Durnin et al, 1987). The Dutch study recorded a mean birth weight of 3.46kg with a mean placental weight of 657g (114). The mean birth weights for the three developing countries were lower than those recorded in Scotland and Holland, with a mean birth weight of 2.98kg (.32) in the Gambia, 2.98kg (.35) in Thailand and 2.89kg (.39) in the Philipines. The mean recorded placental weights were 500g (90), 530g (90) and 526g (62) respectively (Durnin, 1987). Lower birth weights recorded in developing countries could be due to inadequate food intakes, maternal stature and maternal ethnic origin (Hytten & Chamberlain, 1980).

The energy cost of producing a fetus calculated here is similar for the calculations for the Scottish and Dutch study and the figures of Hytten and Chamberlain upon which the calculations are based and therfore comparable.

Differences were observed between the social classes as has been previously reported (OPCS, 1986). These may be due to enviromental factors or to differences in the food intakes but this has not been investigated in this study and is presented as an interesting observation only.

In summary, the mean birth weights recorded are in line with the average birth weight for a developed country, as are the placental weights. This would suggest that the women studied here were a representative sample of pregnant women. The energy cost of producing a fetus, placenta and expanded maternal tissues is calculated for the whole group to be 47MJ (11,200kcals).

CHAPTER 7

TOTAL ENERGY COST OF PREGNANCY IN RELATION TO THE BMR

DISCUSSION AND CONCLUSIONS

The cost of pregnancy is divided into three components, the increase in the BMR, the cost of the fat laid down during pregnancy, and the fetus, placenta and expanded maternal tissue. Table 30 shows the overall energy cost of pregnancy as calculated for the 61 women investigated in this study. The theoretical cost of pregnancy has been calculated by

TABLE 30 - THE TOTAL ENERGY COST OF PREGNANCY

Component	Whole group MJ	Whole group kcals	2 weekly MJ	2 weekly kcals	4 weekly MJ	4 weekly kcals	6 weekly MJ	6 weekly kcals
BMR	51	12200	180	43200	44	10500	57	13600
Fetus	32.3	7700	33.8	8000	32.3	7700	30.7	7300
Maternal tissues	15	3600	15	3600	15	3600	15	3600
Fat	98	23400	112	27000	89	21000	93	22300
Total	196	47000	340	81000	180	43000	196	47000
N	61		20		20		21	

Hytten and Leitch to be 355MJ (85,000kcal) of which about half is thought to be due to the increase in the BMR. The cost calculated for the whole group is 196MJ (47,000kcal) a value that is only 51% of the Hytten and Leitch figure. The overall cost calculated separately for each of the three groups of women is 196MJ (47,000kcal), 180MJ (43,000kcal), 340MJ (81,000kcal) for the 6 weekly, 4 weekly and 2 weekly groups respectively. Only the calculated cost for the 2 weekly group is close to the theoretical value of 355MJ (85,000kcal) , but much higher than the figures for the other groups and the combined data.

As can be seen from Table 30, it is the calculated costs of the increase in the BMR that cause the differences between the combined data and separate groups. The 2 weekly group showed a much larger increase in the BMR during pregnancy, a total increase of 180MJ (43,000kcal). This is 20% higher than the values of Hytten and Leitch who estimate an increase of 150MJ (36,000kcal) and also higher than the cost calculated in the final analysis of the Glasgow study and the Dutch study. These were 126MJ (30,000kcal) and 144MJ (34,000kcal) respectively.

The 6 week group and 4 week group have much lower values of 57MJ (13,600kcal) and 44MJ (10,500kcal). This is below the theoretical value due to a combination of factors already discussed, and would appear to be an under estimate. One factor is the lack of pre-pregnant data, from which an accurate baseline can be established, this was achieved in the continuation of the Glasgow study and in the Dutch study. They showed increases of 170 to 340 kJ/day (40 to 80kcal), from before conception to 10 to 13 weeks. However, in the women observed in the 2 groups measured here they both showed a decrease in the BMR, in the 6 weekly group the BMR was lower between weeks 13 to 21 and in the 4 weekly group the BMR did not increase above the early measurements until weeks 19 to 21. In contrast to this the 2 weekly group showed increases from 10 weeks gestation onwards.

The combination of the lack of baseline data and the observed decreases in the 6 weekly and 4 weekly group therefore would appear to explain why the calculated increase in the BMR is lower than that measured in the final analysis of the five country study. The results of the Thai and Philipino study show higher costs in the BMR than those calculated here with the exception of the 2 weekly group. Only the Gambia showed increases in the BMR below the figures calculated here, with an energy cost of only 7.9MJ (1900kcal). This is thought to be an adaptation to severe nutritional stress (Durnin,1987) and not a factor effecting the women in this study.

The increase of the 2 weekly group although higher than that observed in the Glasgow and Dutch studies, showed a similar trend in that it increased from 10 weeks onwards. The lack of sufficient data before 10 weeks means that the final figure could be higher. The difference in the trend in the data from the other 2 groups observed here is probably due to the more frequent measurements made. It is possible that as the data was analysed using three week blocks of time that some women with higher metabolic rates may have influenced the data, as they could be included twice in a three week period. The data from the continuation of the Glasgow study contained accurate pre-pregnant data on 20 women, from which it was possible to extrapolate the likely pre-pregnant BMRs on all the women measured. Without this it would be possible to grossly underestimate the contribution of the BMR to the total energy cost of pregnancy. In the 6 weekly group it is 29% of the total cost, 24% of the 4 weekly, 53% of the 2 weekly and 26% for all the groups combined. In the final analysis of the Scottish study the calculated increase in the BMR was 126MJ (30,000kcal), 45% of the total cost of pregnancy. In the Dutch study the increase in the BMR was 144MJ (34,400kcal) 50% of the total cost. The Thai and Philipino studies had increases of 100MJ (24,000kcal) and 79MJ (19,000kcal) contributing 48% and 44% of the total extra energy required during pregnancy. In the latter 2 studies it is thought that the total increase in the BMR may be higher as the BMR is measured from 13 weeks onwards (Durnin, 1987). It would therefore appear that the increase in the BMR during pregnancy contributes about 50% of the energy cost of pregnancy. Hytten and Leitch estimated the cost of the BMR to be 50%, but that the overall cost was higher, 150MJ (36,000kcal), whereas only the Dutch study show an increase approaching this.

The increase in body fat during pregnancy is a large component in the total energy cost of pregnancy. Problems in measuring the change in body fat during pregnancy have been discussed earlier, and various methods were used to calculate the gain in fat. The results obtained by skinfolds at 10 weeks gestation and 4 to 6 weeks post-partum are used in Table 30 for the calculation of the total energy cost. This is so that the results are homogenus to those presented in the final results of the five country study.

The estimated fat gain during pregnancy for the combined data on the 61 women was 2.14kg. This has an energy cost of 98MJ (23,000kcal) The estimated fat gain in the Scottish study was 2.3kg and in the Dutch study was 2kg, with energy costs of 106MJ (25,000kcal) and 92MJ (22,000kcal) respectively. These results are similar to the ones reported here. The theoretical fat gain during pregnancy is 3.5kg (Hytten & Leitch, 1970). This was calculated using the factorial method and would appear to be an over estimate which increases the cost of pregnancy quite considerably as the energy cost of depositing 3.5kg of fat is 160MJ (38,000kcal). This increases the cost of the fat component by 60%. The value obtained in this study is calculated from measurements of the fat mass at 10 weeks gestation and post-partum, whereas the factorial method assumes that any weight left over after the other components have been subtracted is fat. In the light of this it is suggested that the former method is more accurate and that 3.5kg is an over estimate.

The results of the fat gains in the three developing countries are lower than those reported in the Scottish and Dutch studies. Lower weight gains are reported in developing countries (Akinkugbe,1979; Hauck, 1963; Venkatachalam, Sankar & Gopalan, 1960) and are associated with lower fat gains or even losses of fat during pregnancy (Hussain & Akinyele, 1980). The women in the Gambian study gained the least fat with a mean increase of 0.6kg, and an energy cost of 27.6MJ (6,500kcal) The women in the Thai study gained on average 1.4kg of fat with a cost of 64.4MJ (15,000kcal) and the women in the Philipino study had a mean increase of 1.3kg equivalent to 59.8MJ (14,000kcal). There are therefore quite substantial differences in the amount of fat gained in developed countries and in developing countries during pregnancy, and this will obviously effect the energy requirements of pregnancy. It is not known however as to whether there is an optimum fat gain upon which energy requirements should be based, the women in the Gambia, who had the lowest fat gain were still able to breast feed their babies successfully, and all three studies reported mean birth weights above 2.5kg.

However if the fat gain is taken to be in the region of 2kg rather than 3.5kg, this decreases the overall energy cost of pregnancy by 60MJ (14,000kcal). On a daily basis throughout pregnancy this would decrease the cost by 200kJ (50kcal).

The results of the birth weights, and placental weights reported in this study are similar to those of Hytten and Leitch, the Dutch study and final figures for the Scottish study. The energy costs are therefore also very similar. The costs of the expanded maternal tissues are calculated using the figures from Hytten and Chamberlain. The total energy cost of the fetus, placenta and maternal tissues for the combined data is 47.3MJ (11,300kcal). This is similar to the calculated costs from Scotland and the Netherlands, but higher than those from the three developing countries, who recorded lower birth weights of between 400g and 500g.

The total energy cost of pregnancy is calculated from the three components discussed above. From the results reported in this thesis, the total cost of pregnancy is underestimated because of the low increase in the BMR compared to the final analysis. It seems probable that this under estimate is in the region of 70MJ (17,000kcal), as the cost of the increase in the BMR calculated from the pre-pregnant data in the continuation of the Scottish study was 126MJ (30,000kcal). The final study reported values 24MJ (6,000kcal) below the theoretical value. This represents a decrease of 80kJ/day (20kcal/day) if the lower cost were to be spread throughout pregnancy. The calculated fat gains both in this study and in the final study are lower than the previous theoretical value by 60MJ (14,000kcal). Only the calculated costs of the products of conception give similar results. From the data presented here and the final study it would appear that the total energy cost of pregnancy is 80MJ (19,000kcal)lower than the much quoted theoretical value of 355MJ (85,000kcal) with a total cost of 275MJ (66,000kcal). The daily cost of this if spread evenly throughout pregnancy is 1MJ/day (240kcal/day), a decrease of 20% compared to the theoretical value. The cost of pregnancy is thought to be met by increases in the energy intake of the pregnant woman and a decrease in the amount of energy expended during pregnancy. The current FAO/WHO figures are based on the total requirement of 355MJ (85,000kcal) being met by increased energy intake, recommending an increased intake of 1.2MJ/day (300kcal) throughout pregnancy (WHO, 1985). The UK figures assume that there is some energy saving during pregnancy and advise on an extra 1.0MJ/day (240kcal) (DHSS,1987). in the second and third trimesters, a total increase of 180MJ (43,000kcal). This implies that the reduction in energy expenditure is of the magnitude of 175MJ (42,000kcal) and accounts for half the cost of pregnancy.

The energy cost of pregnancy when calculated as an increased cost daily throughout gestation for the data presented here is 700kJ/day (170kcal/day). However this is thought to be an underestimate for the reasons already discussed. The energy cost as calculated by the final analysis of the Glasgow study is equal to an increase of 1MJ/day (240kcal/day).

The increased requirement during pregnancy could be met either by an increase in the energy intake, a decrease in the energy expenditure or a combination of these two factors. The energy intake was measured in all the five countries studied. In the Scottish and Dutch studies the weighed inventory method was used. In the Glasgow study energy intake was measured on 71 women. All the women in Phase I of the project had their food intakes measured at six weekly intervals. In Phase II one group of women measured their food intake for five days every month and another for three days every fortnight. The intention was to investigate how frequently food intakes need to be measured in pregnancy, as with the BMR data presented here. This is the subject of another thesis by a co-worker on the Glasgow study. The results of the food intakes are discussed here as part of the discussion on the overall cost of pregnancy and how this cost could be met. The women in Phase II who measured their food intakes were not necessarily those who had their BMR measured. This is because after Phase I, a decision was made to increase the frequency of the measurements. The increased frequency of the measurements meant it was felt to be too demanding to ask a woman to measure her food intake, keep activity records and visit the laboratory for BMR measurements. Therefore some kept activity diaries and food records and another group recorded their food intake every two weeks and another group had their BMR and food intakes measured. Pre-pregnant data was obtained on 17 of the 71 women. No significant change was observed in the energy intake, although there was an upward trend from week

18 onwards reaching a maximum of 0.6MJ (140kcal) per day above the pre-pregnant baseline of 8.8MJ/day (2100kcal/day). The amount of variation within individuals and between individuals was large. The total increase in the energy intake was estimated to be 88MJ (21,000kcal). The Dutch study showed an increase in the energy intakes during the third trimester, although again the increase did not reach significance, and the total estimated increase for the whole of pregnancy was 22MJ (5,300kcal). The Philipino study did not show any increase in the energy intake while the Thai study reported a total increase of 238MJ (57,000kcal) and was the only group of women who appeared to meet the energy requirements from an increased energy intake. In the Gambia the food intakes recorded were so low that they would have been equivalent to a decrease of 1kg of body weight per week when matched up to recorded energy expenditures. As these two studies gave such disparate results further research is necessary in these two populations.

Therefore although trends were observed in the Glaswegian and Dutch studies suggesting that there is an increase in the food intake they appear to account for only a small part of the energy cost. Regression analysis of the Glasgow data was carried out on the assumption that any alterations in intake during pregnancy were equal. There were problems analysing the data in this way, as the 17 women on whom there was pre-pregnant data appeared to show different results to the group as a whole. This is thought to be due to the large inter and intra observer variability. A decrease in the energy intake was shown in early pregnancy followed by a rise at 12 weeks and it is speculated that this is due to a decrease in appetite caused by morning sickness followed by a compensatory increase in appetite. However by analysing the data in this way an increase is demonstrated throughout pregnancy, which is equivalent to 310kJ/day (75kcal/day). This is equivalent to 87MJ (21,000kcal) over the whole of pregnancy.

Whether these are true increases or not is open to speculation as no significant differences were found. This is a problem when carrying out serial measurements using this technique. The weighed inventory method is said to be accurate to within 10% (Durnin & Passmore, 1967). This is despite every care being taken to ensure accuracy. The women on the study were impressed to record everything as accuractely as possible, and not to change their eating patterns while carrying out the weighed intake. Frequent checking of the records was carried out.

Energy intakes below the RDAs have been shown in other groups of pregnant women (Whitehead, 1981; Anderson & Whichelow; Abraham et al, 1985) Assuming the cost of pregnancy is met by increases in the food intake only, means increases of 1MJ (240kcal)/ day would be observed. This was not shown, and it therefore seems likely that the total cost of pregnancy is not met by increases in the energy intake alone. Part of the cost could however be met by increasing the energy intake but the method for measuring the food intakes is not accurate enough. That is to say if half the cost of pregnancy were met by an increase in food intakes then there would be an increase of 0.5MJ/day (120kcal/day). The standard deviations of the energy intakes are greater than that and it is therefore unlikely that changes such as these would reach significance because of the limitations of the methods and the level of variation between subjects and within subjects.

Decreases in the amount of energy expended could achieved by the pregnant woman becoming mechanically more efficient, or by decreasing the time spent on physical activities, or by some activities becoming less energy intensive (Durnin, 1987). To see if the former happened a standardised activity was carried out. In the the Glasgow women there was no change in the energy expended other than that which could be accounted for by the increase in body weight (Durnin et al, 1986). This has been found by previous workers (Seitchik, 1967; Blackburn & Calloway, 1976; Nagy & King, 1983). In contrast the findings of the Dutch study indicate that net energetic efficiency for work performance in pregnancy is higher than before or after pregnancy as has also been previously suggested (Bannerjee, Khew & Saha, 1971).

The Gambian study showed a decrease in the energy expended of 10% for the standardised exercise during the first trimester of pregnancy. After which time it increased to a value not significantly different from the expenditure at conception. Lawrence et al think this may indicate an adaptive reduction in energy expenditure during exercise in the early part of pregnancy. Supplementation had no effect on the energy cost of activity.

Activity diaries were kept to investigate whether changes in patterns of activity resulted in decreased energy expenditure. In the Glasgow study small differences were found between gestational periods. By the end of pregnancy more time was spent sitting and less time spent walking. It is possible to save about 420kJ per day (100kcal/day) in this way (Durnin, 1987). The Philipino study (Tuazon et al, 1987), found that time spent on light activities and light housework increased throughout pregnancy, and that time spent on moderate to heavy housework decreased. The Dutch study suggests that energy savings may made to the order of 500kJ (120kcal), 730kJ (170kcal), and 270kJ (65kcal) for each of the trimesters.

Subjectively, it would appear that the intensity with which physical activities are carried out decreases in late pregnancy, (Durnin et al, 1986). This is very difficult to measure. A small group of women on the Dutch study were measured walking on the treadmill at a self-selected pace. This was found to be 25% lower at the end of pregnancy compared to 6 weeks gestation ($p < 0.01$). The Dutch workers also suggest that there is a higher efficiency of work performance, as do results from the Thai study. However results from the Thai study suggest an increase in energy expenditure from 10 weeks to term of 132MJ (31,500kcal) which is met by the increase in food intake. Overall the results of the energy expenditure do no more than to suggest that there may be decreases, but the methods used are not sufficiently accurate to measure changes which may small. As with the energy intake data the method for measuring energy expenditure is accurate only to within 10% at best. A difficultly with energy expenditure measurements is that they are made for 10 minutes at a time only, and the results multiplied for total time spent in these activities. Any inaccuracies are therefore magnified. For example the total time spent sitting and in sitting activities can amount to one third of the day or more. If for example, the average figure for siting in one particular woman for the whole of pregnancy is averaged to give a single figure of 6kJ/min (1.5kcal), and she spends eight hours sitting, on a daily basis this accounts for 3MJ (700kcal). If this is an overestimate of for example, 10% then it means on a daily basis that the energy expenditure is overestimated by 0.3MJ (70kcal). Over the whole of pregnancy this could lead to discrepancies of up to 84MJ (20,000kcal). Measurements were made at different times during pregnancy in Phase I of the study at six weekly interval, any changes in between would be missed, and the BMR data demonstrates that this can have a large impact on the final calculations. Another possible area for concern is that the BMR is used as the value for time spent sleeping. However it is known that the BMR rises and falls during sleep, and although for the purpose of most studies this is thought to even out, when small changes are being looked for this may mask them. Activities which do not take up significant amounts of time are calculated from standard values corrected for body weight. In other studies of energy expenditure the discrepancies that this could lead to are not a cause for concern (Durnin & Passmore,1967). However in this study it could mean that small changes in energy balance are missed. Therefore while this method is suitable for gaining information on an individual's energy expenditure at a given time point it is not accurate enough to pick up small changes in expenditure across time. It is suggested that new methods of measuring energy expenditure such as the use of doubly labelled water may provide more accurate data.

The results from the energy intakes are also not conclusive and more research is needed using more accurate methods. For both the energy intakes and expenditure it is important as with the BMR data that accurate pre-pregnant figures are obtained. This is currently being carried out in Glasgow on 150 to 200 women.

However trends were shown that suggest changes in the energy intake and expenditure did occur which may meet the cost of pregnancy. The data collected here and in the final Glasgow study mean that the overall energy cost of pregnancy is lower than previously thought by 80MJ (19,000kcal). This gives a total increase on a daily basis of 1MJ (240kcal) which is not shown to be met by an increase in food intakes alone. It would appear from the available information that the current RDAs are too high and that there is a need for them to be revised in the light of the information obtained from this study and from the results of other workers who have reported food intakes below the RDAs (Anderson & Whichelow, 1985; Abraham et al, 1985;

Whitehead, 1981). There would appear to be sufficient data to suggest that at least part of this cost is met by a decrease in the energy expenditure and any new recommendations should be made in the light of this. It is not possible from the available data to estimate the magnitude of the decrease and what proportion it contributes to the overall cost of pregnancy. As figures for the RDAs during pregnancy have large implications for public health, new figures would have to be carefully discussed.

In summary the overall cost of pregnancy is calculated to be 275MJ (66,000kcal) of which the BMR contributes about half of the cost. To get accurate BMR information pre-pregnant data is needed, otherwise as with the results presented in this thesis it is possible to grossly underestimate the cost of the changes in the BMR, by fifty per cent or more.

How the energy cost of pregnancy is accounted for is not apparent from the current data available on the food intakes and energy expenditure. This is partly due to the lack of pre-pregnant data and to the fact that the methods used are not sufficiently accurate to measure the presumably small daily changes involved.

Further work is needed and is ongoing. The information available does however suggest that the current recommendations for food intakes particularly in the developed countries need revising and are too high. It would also seem likely that different recommendations should be made for different populations to reflect diverse lifestyles and needs.

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