THE ENERGY REQUIREMENTS OF PREGNANT RURAL THAI WOMEN

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KALLAYA THONGPRASERT, SM

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INSTITUTE OF PHYSIOLOGY
THE UNIVERSITY
GLASGOW G12 8QQ.

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DECLARATION

I hereby declare that this thesis embodies the results of my own work, that was carried out at the Institute of Nutrition, Ubon, Thailand. The training for all the research techniques and the final stages of analysis of the data were performed at the Institute of Physiology, The University of Glasgow.

This thesis has been written and composed by myself. It does not include work forming part of a thesis presented for any other degree in this or any other University.

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SUMMARY

The objective of this study was to investigate the energy requirements of pregnant rural Thai women. Altogether 44 women were followed from about 10 weeks gestation until term. They were all poor farmers who continued their agricultural work until delivery.

The theoretical calculation of the energy cost of pregnancy by Hytten & Leitch (1964) was based on the needs of nonpregnant women with an added amount estimated for the maternal physiological changes and for the growth and development of the fetus. This estimate of the energy cost of pregnancy has been used as a basis for recommendations during the last few decades. (FAO/WHO/UNU, 1985; FAO/WHO,1973; DHSS, 1969, ...etc). The calculation of the energy requirements of pregnancy in this study, however, was conducted by measuring the physiological changes in the mother as a whole, i.e. the changes in the maintenance metabolism (BMR); the changes in body composition, particularly the weight and fat gain; the changes in activity pattern of the mother; and the pregnancy outcome.

In this study the progressive change in BMR was measured throughout pregnancy. The results showed a different pattern of change in BMR in the Thai women compared to the theoretical value. A slight change in early pregnancy was observed and thereafter a marked increase resulted in a total increment from 10 weeks until term at 24,000kcal. Estimates of the BMR of non-pregnant compared to the pregnant women at 10 weeks gestation provided no evidence to support the marked change in BMR during early pregnancy, as demonstrated by Hytten & Leitch (1964).

Weight gain during pregnancy was found to be 8.9 $\pm$ 2.9kg. Fat gain however was estimated by 3 different approaches 1) the changes of the skinfold thickness (biceps, triceps, subscapular and suprailiac); 2) the factorial method and 3) the changes of maternal body weight. The average fat gain by these different methods was found to be 1.2kg.

The energy equivalent of this fat gain and the increment of maintenance energy

resulted in 37,200kcal, plus an assumed energy equivalent of about 10,000kcal from fetal fat and fetal and maternal protein tissues. The energy cost of pregnancy was therefore 47,200kcal which was met by the estimated increase of energy intake of 56,900kcal.

Energy intake was measured serially using the precise weighing method. The observers recorded the food intake for 5 consecutive days in every 6 weeks. The average energy intake was 1932 $\pm$ 358kcal/d at about 10 weeks and showed a rise of 56,900kcal until term. Measurements of total daily energy expenditure were also made on these women simultaneously with the food intake. The average energy expenditure at 10 weeks was 1870 $\pm$ 287kcal and the total increment from 10 weeks until term was 31,600kcal. The difference between the increment of intake and expenditure was found to be similar to the energy needed for the energy deposition in maternal adipose tissue stores and the product of conception.

Changes in total energy expenditure resulted from changes in activity pattern and in the energy costs of individual activities. The women tended to spend more time sitting and less time in agricultural activity particularly in the second half of pregnancy. The daily energy expenditure however increased due to the assumption that the energy cost of activity per unit body weight was constant, which was true for BMR, at least until 33 weeks gestation.

A significant decrease in energy cost of the weight bearing activities, i.e. walking on the treadmill at a fixed speed was observed during the second half of pregnancy. The results indicated an increased mechanical efficiency of the pregnant women. If this was the case for other activities, this would lower the increment of the calculated energy expenditure in this study.

The energy cost of pregnancy in this group of women was 47,200kcal to cover the period of 30 weeks from 10 weeks until term. This was equivalent to an increment of 225kcal daily. The pregnancy outcome of this study was satisfactory taking into account the small stature of the women. These women gave birth to healthy babies with an average birth weight of 2.98 $\pm$ 0.35kg and birth length of 0.48 $\pm$ 0.02m. In order to form a basis for recommending the energy requirements for pregnant rural women, more information is needed particularly from conception to 10 weeks of pregnancy.

CHAPTER 1

1.1 SIGNIFICANCE OF THE STUDY

Pregnant women have long been known as one of the vulnerable groups in all intervention programs. Special care and concern have to be paid to them to ensure the good health of mothers and also the good health and development of the babies. In order to ensure good quality of life, an adequate level of food intake must be available as early as possible and not only after the child is born, when he is already nine months old, but throughout the gestation period too.

Maternal nutrition is not only important for mothers and babies, but also known to be an important issue for public health both in developed and developing countries. Poverty and malnutrition have still not been eradicated in many of the industrialized countries, and low birth weight occur in certain deprived sectors of the popultion (Doyle et al.,1982). At the other extreme, maternal obesity seems to be associated with medical problems during pregnancy and with overweight babies.

In developing countries, particularly in the rural area, the women have poorer nutritional status, and poorer hygienic conditions which lead to more infectous diseases. In addition inadequate food consumption, hard working labour and sometimes food taboos also play a role in the nutritional status.

These factors contribute to the chronic malnutrition of the mother during childhood and adolescence, which results in diminished maternal stature and pre-pregnant weight, both of which are associated with an unfavourable outcome of the pregnancy. This low prepregnant weight and poor weight gain during pregnancy is also associated with an increased incidence of babies with low birth weight (Eastman, 1968; Simpson, et al., 1975) Hence maternal nutritional status is one of the most important factors in a successful pregnancy.

Health conditions of the mother and infant, particularly in developing countries are significant in terms of economic and social importance. The planning of food policy both for production and for the financing of food imports will be much affected by whether or not large extra allowances are included to cover the apparent requirement in pregnant women.

Pregnancy is known as a state of physiological stress to the mother for two reasons, firstly, there is an increase in metabolism, associated with the production of new tissues, i.e. the placenta, fetal membranes, fetus and mammary glands, and secondly in the deposition of maternal fat which can be utilized to meet the increased energy demand during lactation. Hence in order to produce a 3kg baby and to deposit a certain amount of fat it seems logical that the mother needs to consume more food during pregnancy than during the nonpregnant state.

1.2. THEORETICAL CALCULATION

Since 1965, the recommendation of energy requirement during pregnancy was based on the theoretical calculations by Hytten & Leitch (1964). The extra energy needed is the result of two important factors, i.e. the extra energy required for an increase in body maintenance (BMR) and the energy equivalents of the tissue deposition of the products of conception, - the fetus, placenta and amniotic fluid, and the changes in maternal tissues, i.e. the enlargement of the uterus, breast and the increase in blood volume. Hytten & Leitch estimated the caloric requirement specific to pregnancy. They considered the energy equivalent in two categories, i.e. the energy equivalent of protein and fat increment (capital gain), and the energy cost of maintaining the fetus and added maternal tissues (running cost), as follows:-

Hytten & Leitch developed a factorial method for calculating the capital gain of pregnancy, by considering the changes in different organs involved in pregnancy at different stages of pregnancy. During pregnancy the body weight increases as a result of growth of the products of conception, the uterus, the breasts and the increases in the blood and tissue fluid volumes and the storage of fat. Two energy sources, i.e. protein and fat were calculated but not the carbohydrate which contributes only a minute amount to the energy reserved. Hence, the energy equivalents for the cumulative protein and fat in different tissues were estimated as shown in Table 1a. The amount of added protein is 925gm which is equivalent to about 5,000kcal and the added fat is about 3.8kg which is equivalent to 36,000kcal throughout pregnancy (Hytten & Leitch used the factors 5.6kcal/g for protein deposition and 9.5kcal/g for fat deposition).

The accumulation of maternal fat occurs during the first two trimesters. This mechanism is under the control of the feto-placental hormone-progesterone which is the most abundant steroid hormone produced during pregnancy. This hormone appears to exert an anabolic effect which results in the laying down of fat. During the third trimester the oestriole hormone and placental hormone lactogen are released to curtail the fat deposition. This mobilized the stored fat which acts as a major source of energy during this period. Protein is stored in maternal muscles in early pregnancy and is later broken down to augment the supply of amino acids for fetal growth and development. Further more the catabolism of amino acid is suppressed from early pregnancy, thus improving the efficiency of protein utilization (Naismith, 1980).

To calculate the running cost of pregnancy, the oxygen consumption from tissues which required extra energy, were cumulated, i.e. cardiac output, respiration, uterine muscle, placenta, breast, kidney reabsorption and fetus. The energy cost of maintaining the fetus and the added maternal tissues were then calculated. The increase in energy required from conception until term as estimated by this method is 36,000kcal. Details for the calculation will be discussed later in chapter 4. The factorial method was calculated by combining the energy equivalent of the capital gain and the running cost which represented the estimation of extra energy need during pregnancy of 77,234kcal. Hytten & Leitch then added another 10% of the total net energy as the metabolizable energy of 84,957kcal throughout pregnancy as shown in Table 1b.

About 80,000kcal is considered to be a physiological requirement specific

Table 1a Mean daily increments of protein and fat in the fetus and maternal body (Hytten & Leitch 1964).

	Weeks of pregnancy 0-10	10-20	20-30	30-40	Cumulative total
Protein (g)	0.64	1.84	4.76	6.1	925
Fat (g)	5.85	24.80	21.85	3.3	3,825

Note: For the first 10 week period total increment is divided by 56 since pregnancy is dated from the last menstrual period.

Table 1b Cumulative energy cost of pregnancy.

	Weeks of pregnancy 0-10	10-20	20-30	30-40	Cumulative total
Protein	3.6	10.3	26.7	34.2	5,186
Fat	55.6	235.6	207.6	31.3	36,329
O_2 consumption	44.8	99.0	148.2	227.2	35,717
Total net energy	104.0	344.9	382.5	292.7	77,234
Metabolizable energy	114	379	421	322	84,957
(total net energy + 10%)					

to pregnancy which Hytten & Leitch claimed that it is different from total physiological requirements. These total requirements are not necessarily the sum of ordinary nonpregnant requirements and those specific to pregnancy, i.e. the additional energy required during pregnancy may be compensated, in whole or in part, by reduced physical activity.

However, this is purely a theoretical basis of calculation of energy requirements. The model used in this factorial calculation was that the energy needed for nonpregnant women plus the extra energy needed specific for pregnancy might not be the proper way of approach, because these two requirements may not be appropriate to consider separately. The energy requirement of the pregnant women as a whole would be better approach.

1.3 RECOMMENDED ENERGY REQUIREMENT IN PREGNANCY

The health of mother and baby have been receiving great attention since the eighteenth century. Thomson (1959b) reviewed the historical background of diet in pregnancy that in the early eighteenth century the obstetricians were concerned mainly with the problem of difficult delivery and diet was first invoked in the interests of easy labour. Until 1930's, after the difficult labour and puerperal sepsis brought under control, the obstetricians were then more concerned about the survival and well being of the mother.

An early recommended daily allowance of the pregnant women from different countries was reviewed in the WHO Technical Report series no. 302 (1965). Different levels of energy intake were recommended in different countries. For example, in the United Kingdom, the British Medical Association (1950) recommended the increase of 250kcal daily during the period of 1-5 month and 500kcal daily from 6-9 months. In USA, the Food and Nutrition Board (1963) recommended an increase of 200kcal daily at the period from 4-9 months.

FAO (1957) suggested the extra energy needed during pregnancy based on the physiological consideration for the growth of the fetus, the placenta and associated maternal tissues, for the increased cost of the movements of the heavier bodies, and for the increase in basal metabolism at the level of 80,000kcal. The expected weight gain of the women was about 10 $\pm$ 2kg. This extra caloric needs imposed by pregnancy can be carried in two ways, either by increase food intake or in part at least by reduced physical activity. The extent to which each of these two factors contributes to ensuring energy balance during pregnancy depend on social and economic factors. On the basis of some reduction in activity and a modest increase in food intake, an allowance of 40,000kcal was suggested.

On the same basis, NRC (1958) recommended 300kcal during the second half of pregnancy and made no allowance for the first half due to the reduction of activity. Later in 1964, NRC suggested the extra energy needed at the level of 200kcal daily during the second and third trimester. The total increment of extra energy need was about 40,000kcal for both recommendations.

The United Kingdom Department of Health and Social Security (D.H.S.S. 1969) recommended the extra energy needed to be of 200kcal daily during the second and third trimester which was equivalent to 36,000kcal/pregnancy. The reason why there was no extra needs during the first trimester was that the food intake was considered to be slightly reduced, possibly due to nausea. The extra needed was aimed at 40,000kcal because of the reduction of physical activity.

Unlike the previous recommendations which provided an average energy requirements, FAO/WHO (1973) suggested the recommendation of energy allowance during pregnancy at the level of 80,000kcal in order to provide a safe level of energy intake to ensure satisfactory nutrition for the fetus and breastfed infant. This allowance required an average increase of 285kcal daily or about 150kcal/d during the first trimester and 350kcal/d in the second and third trimester.

The recent FAO/WHO/UNU (1985) however, recommended the same amount of 80,000kcal throughout pregnancy. As there was little evidence to suggest that the extra energy requirement differs among the three trimesters, the level of energy intake at 285kcal daily was recommended throughout pregnancy for the women who do not reduce their activities. When there is a reduction of the activities in pregnant women, it is considered reasonable to reduce the average additional allowance to 200kcal daily. This reduction in activity may happen towards the end of pregnancy due to the mother's increased weight and size.

In developing countries such as India, the Indian Council of Medical Research (1984) reported in the study of energy expenditure in pregnant Indian women that the women require an extra 120kcal daily during the second and third trimester during normal pregnancy. This level however, would not allow for the deposition of fat, which during lactation is used to meet the additional energy needs. On the basis of the evidence that food supplementation is beneficial not only for the growth of the fetus and the increase in birth weight but also for the subsequent lactation performance, the Indian Council therefore recommended the extra energy intake to be 300kcal/d during the second and third trimester.

1.4 PREVIOUS REPORT OF ENERGY INTAKE DURING PREGNANCY

Many published articles about energy intake, weight gain during pregnancy and baby birth weight were reported by WHO (1965). It was shown that in developed countries the weight gain of the mothers was 10-12kg and the baby birth weight was about 3.3kg, whereas the reports from developing countries was only 5-7kg and the baby birth weight was 3.0kg. Food intake was found to be lower in developing countries (~1500-2000kcal), which most of the data came from poorer section, and the energy intake of pregnant women in developed countries was about 2400-2700kcal.

Despite the recommendation that there is a substantial amount of extra energy needed during pregnancy, dietary intake studies of pregnant women have failed to detect it. Prentice (1981) accumulated the published estimates of energy intake during pregnancy both in developing countries and developed countries.

A wide range of energy intake is observed among different communities. Many studies revealed that the level of energy intake measured in pregnant women did not show much of a difference from that observed in non-pregnant women and substantially less than the amount recommended for pregnant women (English & Hitchcock, 1968; Beal 1971; Smithell et al 1977; Norgan, Ferro-Luzzi & Durnin, 1973; Whitehead et al 1981; Durnin et al., 1985; van Raaj, Peek and Hautvast, 1986). In spite of no substantial increase in caloric intake, pregnant women in developed countries successfully deliver healthy babies of a good weight and size.

Pregnant women in developing countries are also able to deliver babies who are not dramatically smaller than those in developed countries. The baby birth weight, maternal weight, weight gain and energy intake in developed and developing countries are shown in Table 2. Some conclusions can be drawn from this table as follows:

1. Food intake in developing countries were lower than in developed countries, particularly in the unsupplemented group in Taiwan, as demonstrated by both Adair (1984) and McDonald et al, (1981). Surprisingly, mean birth weight of the babies is reasonably acceptable. Another group which showed low food intake was in the Gambian study by Prentice et al. (1981). They demonstrated that during wet season pregnant women had to work hard in the field, and due to the presence of food shortages they consumed less energy than in the dry season. Mean birth weight and weight gain were also lower in the wet season.

2. Only the study of energy intake in Cambridge, U.K. (Whitehead et al. 1981) and in Denver, U.S.A. (Beal, 1971) were carried out longitudinally. Beal conducted the energy intake assessment using the retrospective history and using 24 hour record for cross-check. Unfortunately, both the methods used for energy intake assessment and the cross check method may not be able to provide reliable results, whereas Whitehead, et al., (1981), conducted this study using the weighed inventory method.

Table 2 Comparison of energy intake, prepregnant weight, weight gain and baby birth weight in developed and developing countries.

Source	n	Prepregnant weight (kg)	Weight gain (kg)	Energy intake (kcal/d)	Birth weight (gm)
Developed country					
Sweden (Lunell et al., 1969)	15	59.1	11.9		
1st T				1980	
2nd T				2400	
3rd T				2090	
UK Cambridge					
(Whitehead et al., 1981)	59	56.1	12.6		
NPNL				2030	3310
2nd T				1950	
3rd T				2000	
UK (Darke et al., 1980)	435			2150	
UK, poor community in London	76	-	10.5		
(Doyle, 1982)					
1st T				1610	3020
2nd T				1720	
3rd T				1770	
USA, Denver					
(Beal, 1971)	95	54.4	10.7		3240
NP				1890	
1st T				1900	
2nd T				1930	
3rd T				1850	
Australia, Sydney					
(Ash, Unpublished data)	49	57.8	14.3		3540
1st T				2110	
2nd T				2130	
3rd T				2120	
Australia					
(English & Hitchcock, 1968)	26	-	14.3		3200
2nd T				2150	
3rd T				2030	

Table 2 (con'd)

Source	n	Prepregnant weight (kg)	Weight gain (kg)	Energy intake (kcal/d)	Birth weight (gm)
Developing country					
Gambia, Keneba	156	52.7			
(Prentice, 1984)					
Dry season			ave. 1.35kg/m		2940
1st T				1620	
2nd T				1450	
3rd T				1480	
Wet season			ave. 0.3kg/m		2780
1st T				1440	
2nd T				1460	
3rd T				1380	
Columbia (Mora et al., 1979)					
Unsupplemented group (3rd T)	200			1610	2930
Supplemented group (3rd T)	202			1770	2980
Taiwan, Suilin (Adair, 1984)	225	48.7	7.63		3070
Unsuplemented gr.					
1st T				1220	
2nd T				1240	
3rd T				1140	
Supplemented gr.					
1st T				1610	(160g higher
2nd T				1670	than in
3rd T				1680	unsupp. gr.)
Taiwan, Suilin (McDonald et al., 1981)					
Unsupplemented group	50	48.4	7.51		3050
1st T				1270	
2nd T				1250	
3rd T				1220	
Supplemented group	50	49.0	7.74		3090
1st T				1660	
2nd T				1660	
3rd T				1700	
Ethiopia, Addis Ababa					
(Tafari, et al., 1980)					
Physically active	64	50.3	6.5	1540	3070
Less physically active	10	54.3	9.2	1640	3270

The reliability of this method is much higher than the 24 hour recall or the retrospective history. The results of these two studies, however, did not show any change of energy intake throughout pregnancy.

3. Weight gain during pregnancy in developed countries ranged from 10.3-14.3kg which agrees well with the 12.5kg as recommended by Hytten & Leitch (1964) while weight gain in developing countries is much lower.

4. Even though the prepregnant weight, weight gain of the mother and the baby birth weight of the mother in developed countries agree well with the value suggested by Hytten & Leitch, energy intake of the pregnant women did not differ from the nonpregnant state as shown by Whitehead et al., (1981) and Beal (1971). When body weight of the mother is taken into consideration, energy intakes expressed per unit body mass in developing countries are similar to those in developed countries which was about 35-37kcal/kg/d. (This did not include the data from the unsupplemented group in Taiwan and Gambian women measured in wet season which was about 25-27kcal/kg/d).

It can therefore be demonstrated that energy intake is not substantially increased during pregnancy. Where then does the extra energy responsible for building the new tissues of the baby and the enlargement of maternal tissues come from? Possible explanations might be that:

1. Dietary surveys fail to detect the actual energy intake of the pregnant women. It may be that the methodology used is not accurate enough to pick up the differences in energy intake in pregnant and nonpregnant women. For example some of the studies adopted a 7-day weighed dietary record (Doyle 1982), whereas some other studies adopted a 24-hour dietary recall, (Mora et al. 1979) which is of limited valued. This method is well known for its simplicity and can be used in a large number of subjects but the accuracy is not as good as the food weighing method (Marr, 1971). Some studies did not measure food intake long enough to represent the food intake of that particular period. For example Tafari et al. (1980) conducted a food intake

measurement for only 2 consecutive days at 20-24 weeks and at 36-38 weeks. Although the authors claimed that the food intake in this community was monotonous and therefore a 2 day food record was chosen. This short number of days for food intake measurement might give false results and might not represent the actual food intake of that community due to the inter and intra-individual variation (Widdowson, 1947; Marr 1971; Bingham, 1982).

Not only an accurate and reliable method is needed for food intake measurement but also frequent measurement. Most of the previous studies, reported the caloric intake only once for each trimester. This may not be enough to see the trend of changes in energy intake as pregnancy progresses. In addition, some of the studies made a cross sectional comparison of energy intake in nonpregnant and pregnant group. This is one of the pitfalls of energy intake assessment i.e. there is a tremendous difference in energy intake from person to person and from time to time. Both inter and intra-individual variation in energy intake makes it very difficult for the comparison of energy intakes at different gestation ages during pregnancy in different group of women.

2. Some kind of the metabolic adaptation in response to the physiological stress of pregnancy might have occured. This can be achieved by the reduction of BMR in pregnant women, which may not be as much as calculated by Hytten & Leitch, i.e. the increment of 36,000kcal throughout pregnancy.

3. Less fat may be laid down during pregnancy than 3.5-4.0kg as calculated by Hytten & Leitch. This amount of fat requires the energy equivalent of 36,000kcal for the whole period of pregnancy.

4. There may be some economy of energy output by reducing the time spent in the hard labour activities and/or improving the physical efficiency of different tasks.

In order to test these hypotheses, the study of energy requirement during pregnancy should be done in a large number of subjects in a long term study. The comparison of physiological change and/or food intake change should be done in the same group of women. The measurement of these changes should cover different aspects, i.e. whether or not there are any changes in terms of body composition, changes in the metabolic cost of physical activity, changes in the total daily energy expenditure, changes in activity pattern during pregnancy, adaptation in the fundamental energy metabolism, and changes in the food intake,... etc. For the comparison of energy requirement in pregnancy and in nonpregnancy, baseline information has to be obtained from the prepregnant sate and thereafter followed up throughout pregnancy.

Because of the wide variety of social and cultural factors which may influence energy requirements several types of population needed to be studied. To this end, in 1981 the multicenter study, in 4 different countries and representing a considerable range of developed and developing societies was launched. It was generously sponsored by Nestle Foundation, Switzerland. The study sites were Scotland, Holland, The Gambia and Thailand. And later, a study in the fifth country, the Philippines was carried out (Durnin, 1981).

In Scotland the women are all living in the city of Glasgow or in the immediate urban environment. They are more or less typical housewives without any other paid occupation. In Holland the study was conducted in the urban environment of Wagenningen and because of the economic status of the general cummunity, they are from the socially favoured groups. In the Gambia, the women were all living in the village and engaged in agricultural activity. The same conditions also applied in the Philippines and in Thailand.

The standardised methodology of measuring energy intake, energy expenditure, changes in body composition, changes of BMR, and the metabolic cost of walking on treadmill at fixed speed was carried out. By this method the results from the different countries should be comparable. Considerable effort has been made to ensure that the techniques adopted in the different study sites are identical and are carried out in a uniform manner. All of the senior field workers spent some weeks at Institute of Physiology, University of Glasgow, under the supervision of Prof.J.V.G.A . Durnin for training in these methods. This thesis constitutes the results from the longitudinal study in Thailand. The details of the study site and the protocol will be discussed in the next chapter.

CHAPTER 2

2.1 GENERAL DESCRIPTION OF THE STUDY SITE

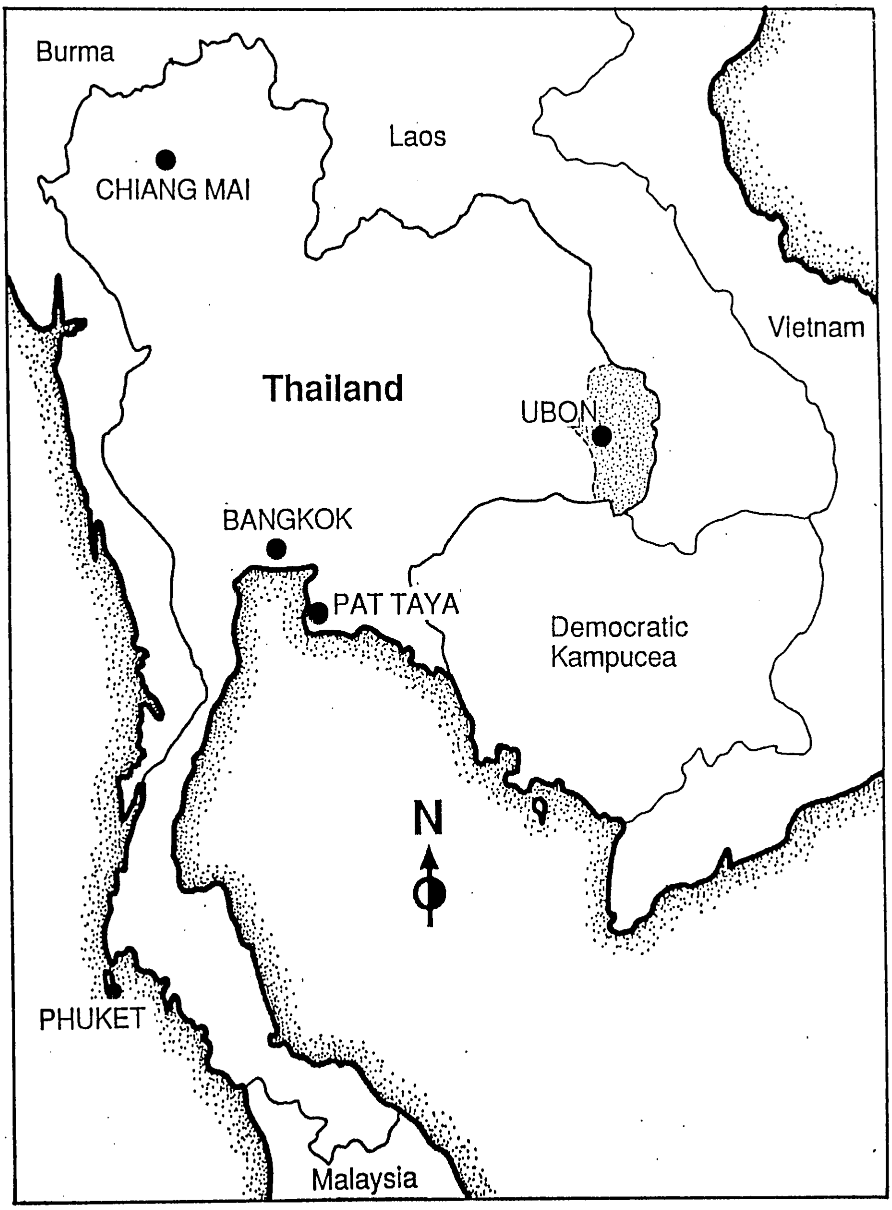
2.1.1 Geography and climate

Thailand is an agricultural country. It shares its borders with Burma & Laos in the north, Malaysia in the south, Burma in the west, and Laos and Kampuchea in the east as shown in Figure 1. The population is 50 million with the rate of growth 1.9% per year. The study on the energy requirements in pregnancy was conducted in Ubon which is about 650km from Bangkok and located in the north eastern part of the country. It is the second biggest city with a population of 1.6 million. 85% of the surrounding area being utilized for rice plantation. Ubon was selected as the study area for various reasons. Firstly, it is one of the poor cities of Thailand. About 89% of its population earn their living from agriculture, animal husbandry, forestry work and fishing. Secondly, there is a field station of the Institute of Nutrition that can provide good facilities, such as air-conditioned lab and rooms for the BMR measurement. Thirdly, there have been nutritional studies by the research center of Ramathibodi Hospital in Bangkok and from the Institute of Nutrition in Ubon for the last four decades. We therefore know about the location of the villages, the cultures, food habits, agricultural cycle, the life styles, ... etc. This information is very useful for this current research on pregnancy because this involves the study of the habitual food intake, energy expenditure and energy requirements.

Climate: There are three distinct seasons in Thailand, the rainy season, the cool season and the hot season. The rainy season lasts from mid-May to the end of October and has a bimodal type of distribution with the first peak in May-June and the second peak in August-September. Although the amount of rainfall varies from year to year as a result of monsoons, on average the amount of rain during the study period (1982-1985) was 1,800 mm/yr.

The cool season starts at the end of November and lasts until February. The lowest temperature is about 12^{o}C in December. Rain may occur during this period but

Fig. 1 Map of Thailand



contributes only a small amount compared to the total annual rainfall.

The dry and hot season starts at the end of February and lasts until mid-May. The highest temperature reaches 38-40^{o}C in March and April. The general climatic record, the pattern of rainfall and the average temperature during the study period is shown in Figure 2.

2.1.2 Agricultural cycle in the village

The annual agricultural cycle in the village is shown in Table 3. Rice is the principal food for people throughout the country. The rice planting season usually begins in May or June. Shortly after the planting is completed, the annual monsoons arrive and are useful for the farmland. By October or November, rice in the field is ripe enough to be harvested. The harvesting season lasts about one to two months. Rice is grown once a year in this region because most of the land is not well irrigated and rice plantation reflect very largely on adequate rainfall. For about 5-6 months, the farmers are invovled in the rice plantation and for the rest of the year they grow cassava, peanuts, chilli, jute or vegetables. These activities are optional whereas rice plantation is the compulsory activity in the village.

The land for plantation is either near the village or sometimes located quite far away from the village. During work on the rice plantation, a family which might stay far from the rice field, moves to stay in a temporary field shelter near the rice field until the work is finished, when they return back to the village.

At the beginning of the rice plantation period (May or June), men use the water buffalo to draw cart in order to prepare the rice field and the women help the men by clearing the field and breaking the hard soil. After the land preparation is finished, the rice grain is spread over a small piece of land. While the farmers wait for the rice plant to grow and be ready for replanting, they prepare the land and make it suitable for this. The women help the men to transfer the small rice plants to the paddy field. They normally start the planting early in the morning and work until about noon. They take a

Fig.2 Average amount of rainfall and temperature in 1982-1985.

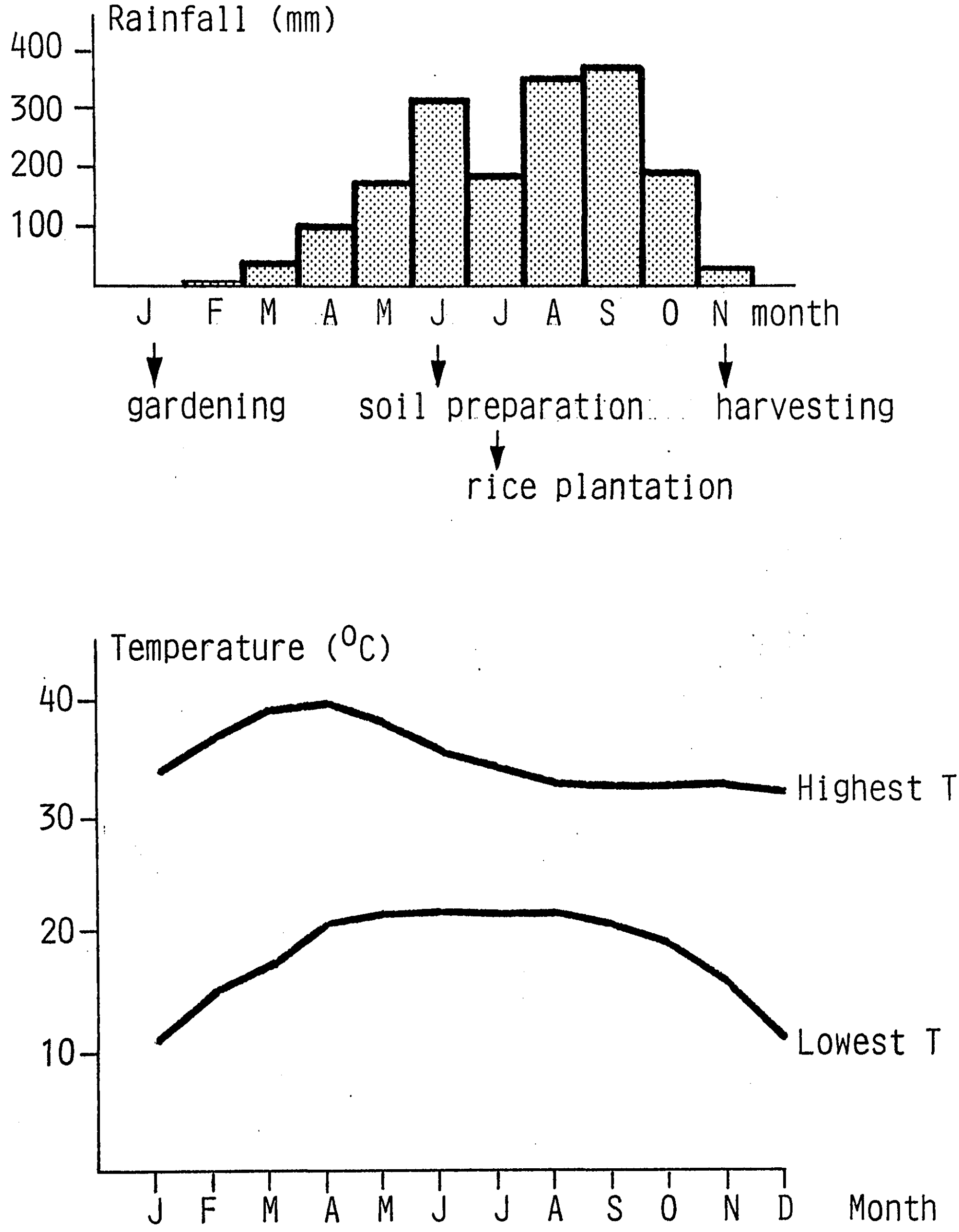
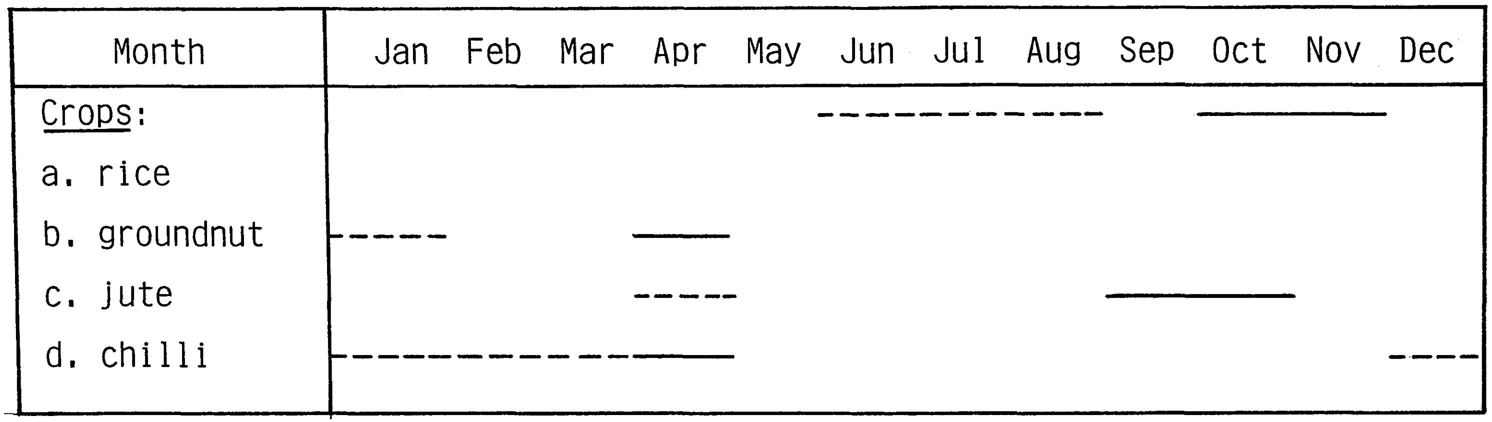


Table 3 Annual agricultural cycle in the village



----- plantation, ——— harvesting

a. compulsory activity

b,c,d optional activity

rest in the afternoon because of the strong sun and in the late afternoon they continue their work, take out and bundle rice plants ready to put in the paddy field the next morning.

During the harvesting season which occurs about two months after planting, the women help the men in rice harvesting until the work is finished. Later bundles of rice will be threshed and winnowed. The harvesting season lasts about one or two months depending on how large the rice field is.

In December, after the harvesting season is finished, the family move back to the village. They spend more time resting, working on activities which have been neglected during the harvesting season, such as building, repairing tools and fences, etc. During this resting period before the starting of the next rice plantation, men go to the big city, looking for temporary job to earn some money and they come back to the village for the next rice plantation. Women normally stay at home and do some gardening or grow cassava, corn, jut, groundnut, etc.

The role of the women in the rural community is not only helping the men in agricultural work, but also taking care of the family and doing the housework, such as cooking, tidying the house, washing clothes, carrying water from quite a distance ... etc. When the women get pregnant, their activities are still the same as nonpregnant women. They continue their agricultural work until delivery. After giving birth, they stay near an open fire for a number of days, ranging from 7-14 days as they believe that the uterus will be speedily involuted. At that time, some of them restrict their food by having only rice and salt. It normally takes about 3-4 weeks after parturition for the recovery period and then they resume their work.

2.2 RECRUITING THE VOLUNTEERS AND THE PROTOCOL

The criteria for recruiting the volunteers were as follows:-

- Healthy pregnant women aged 20-30 years in her second or third pregnancy and not more than 18 weeks pregnant.

- They had normal medical and reproductive histories with no previous abortions.
- They were farmers who lead normal lives and stayed in a village which was not more than 25 kilometers from the research center.
- They had no intention of moving out from the village during the study period.
- Above all, they were willing to take part in the study.

The protocol of the study is shown in Table 4.

The energy requirement study was carried out in two phases. In the first phase (August 1982-January 1984) the women were recruited from the ANC (Ante Natal Clinic) in the provincial hospital and in the military hospital where a large number of pregnant women registered their pregnancies. However, the number of women reporting to the ANC in early pregnancy was rather small and normally they reported at about 4-6 months gestation. Therefore in the second phase which was carried out from January 1984-July 1985, a more efficient method of recruiting volunteers at an earlier stage was proposed.

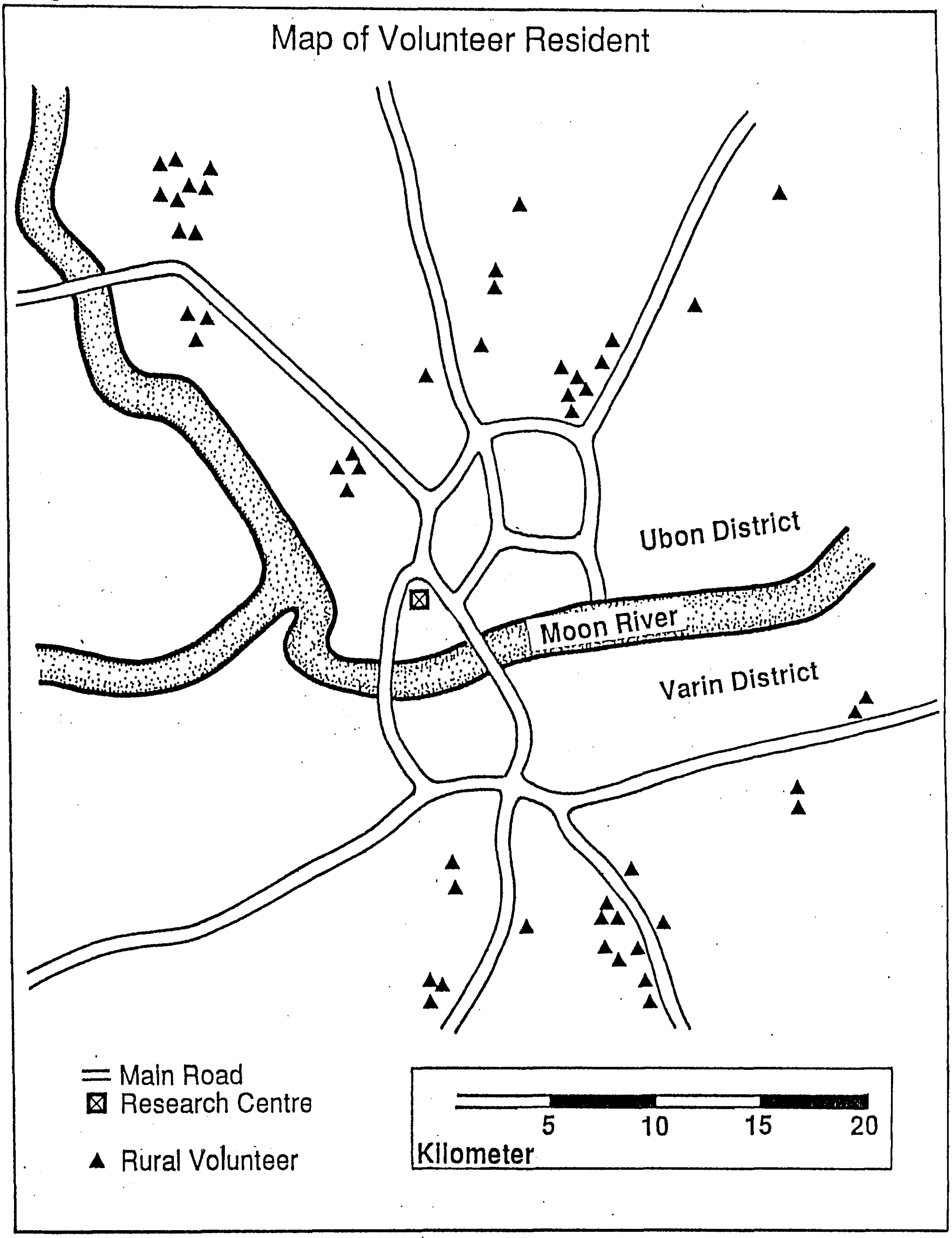
The women were recruited from 12 villages around Ubon as shown in Figure 3. Some of these villages are accessible to the town whereas some are quite remote. By making a list of women in these villages who were likely to become pregnant and intended to participate in this study, these women were followed up regularly and checked for pregnancy. Immediately after the pregnancy was confirmed by a pregnancy test, these women were informed about the procedure of the measurements and the study was started. By this approach, the pregnancy was detected at an earlier stage than in the first phase.

The success of the study relied on the cooperation of the volunteers, hence an incentive was quite important for maintaining their cooperation. In this study the medical service for the pregnant women and the family was provided. The nurse visited

Table 4 Protocol of the study

	Pregnancy						Postpartum
Week gestation	7-12	13-18	19-24	25-30	31-36	37-40	4
Mother						Delivery	
- Food intake (5 consecutive days: precise food weighing method)	✓	✓	✓	✓	✓	✓ ✓	✓
- Energy expenditure (5 consecutive days: activity-diary record)	✓	✓	✓	✓	✓	✓ ✓	✓
- Standard energy expenditure							
BMR	✓	✓	✓	✓	✓	✓ ✓	✓
Walking on treadmill at 3.0km/h	✓	✓	✓	✓	✓	✓ ✓	✓
- Anthropometry							
Body weight recorded at home	Weekly record						
Body weight	✓	✓	✓	✓	✓✓✓✓	✓ ✓	✓
Body height	✓	✓					
Skinfold thickness, circumference, skeletal diameter	✓	✓	✓	✓	✓✓✓✓	✓ ✓	✓
- Placenta weight						at birth	
Baby							
- Body weight, length, skinfold and circumference.						at birth	

Fig. 3


Map of Volunteer Resident
Ubon District
Moon River
Varin District
Main Road
Research Centre
Rural Volunteer
5
10
15
20
Kilometer

the villages twice a month. If the women had any simple medical problems, they were treated by the health personel of the staff, and if the problems were quite serious, they were referred to see the doctors at the provincial hospital.

The medical service was also included the medical care and the fee for delivering small gift of necessary things for the new born was presented. And when the study was completed, another gift consisting of things necessary for the family and a certificate conveying the appreciation of their participation in the study were given.

2.3. GENERAL CHARACTERISTICS OF THE VOLUNTEERS

The women who were recruited in this study were all farmers who had low socioeconomic status. Table 5 shows the number of recruited volunteers in two phases. Altogether 60 volunteers were recruited at different gestational ages. 31 were recruited during early pregnancy (less than 12 weeks gestation) and the rest of the women were recruited from 13-18 weeks. 15 women were recruited during the pre-pregnant period but only 3 women were conceived and were followed up throughout pregnancy.

After completion of the first phase, 10 women out of 13 were studied at about 15-24 months after parturition, this being the time when they might often again become pregnant - i.e. a time corresponding to the pre-pregnant period. Two of the other three were already pregnant and one did not want to continue in this project.

4 women dropped out from the study for various reasons. There were 2 cases who had miscarriages, one volunteer found it inconvenient to only breath by mouth while performing the expired gas collection using noseclip and mouthpiece, and another volunteer moved out of the village. The results in this study are therefore based on the measurements of 44 pregnant women.

Table 6 shows the general characteristics of the pregnant women and the outcome of pregnancy. The women were of small stature with an average weight of 47.6 $\pm$ 5.7 kg and an average height of 152.2 $\pm$ 5.0 cm. Though the investigators tried to recruit the pregnant woman at as early a stage as possible, on average the initial

Table 5 Number of recruited volunteers

	Phase I	Phase II	Total
Nonpregnancy	-	3	3
Prepregnancy	-	25	25[a]
Pregnancy	13	35	44[b]
Dropped-out	-	4	4

[a] 10 volunteers' were from the first phase who were observed at 15-24 months after their deliveries.

[b] One volunteer gave birth to the premature baby at 27 weeks gestation. Baby birth weight was excluded.

Table 6 Maternal characteristics at 10 weeks pregnancy and baby characteristics at birth.

	Characteristics	$\bar{X} \pm SD$
Mother:	Age (y)	23.0 ± 1.4
	Weight at 10 wk (kg)	47.6 ± 5.7
	Height (m)	1.52 ± 0.05
	Initial gestation wk (at 10 wk)	10.1 ± 3.9
	Length of gestation (wk)	38.9 ± 1.6
	Weight at term (kg)	56.5 ± 6.3
	Weight gain (kg)	8.9 ± 2.9
	Placenta weight (kg)	0.53 ± 0.09
Baby:	(male = 18, female = 25)	
	Mean birth weight (kg)	2.98 ± 0.35
	Length (m)	0.48 ± 0.02
	Birth weight (kg): ⩽2.5	12%
	⩽3.0	40%
	>3.0	48%

[a] weight gain is weight at term minus weight at 10 weeks gestation.

Table 7 Characteristics of the 25 nonpregnant women.

	$\bar{X} \pm$ S.D.
Age (y)	26.4 $\pm$ 2.6
Weight (kg)	49.0 $\pm$ 4.7
Height (m)	1.52 $\pm$ 0.05
BMI	21.3 $\pm$ 2.2
% body fat	25.1 $\pm$ 4.5

gestational age was about 10 weeks.

There were 18 male and 25 female babies and there was a significant difference ($p<0.05$) between the male and female birth weight (3.07 ± 0.32kg in male and 2.87 ± 0.34kg in female babies). The average birth weight was 2.98kg and the birth length was 0.48m. This birth weight and the incidence of low birth weight were similar to the birth weight previously reported in this region which were 3.0kg in Ubon provincial hospital and 2.8kg from Ubon village (Tontisirin and Winichagool 1982).

According to the Aberdeen Fetal Growth Standard (Thompson & Billiwicz + Hytten, 1968), babies born from mothers who had a similar stature as Thai rural women had their birthweights of 3.38kg. By applying the correcting factor in accordance with maternal height (1.52m) and mid pregnancy weight (50.4kg), the expected baby birth weight in this study was 3.19kg which was about 95% of the standard. And by taking into consideration that there was a racial difference of the Indian and West Indian babies who tend to be smaller than caucasians (Grundy & Hood, 1978), the baby birth weight in the study was found to be satisfactory.

In order to be able to get the baseline information at the prepregnant state, 25 nonpregnant women were recruited during the second phase. The characteristics of the nonpregnant women is shown in Table 7. Out of 25 women, 10 of them were taken part in the phase I study and were measured again at about 15-24 months after parturition.

Their weights were higher than the pregnant weight at 10 weeks. Energy intake was as well higher than at 10 weeks pregnancy. The reason might be that some of the women still breast fed and therefore consumed more food to provide for the breastmilkproduction. It is the common practice in the rural community that the women continue their breastfeeding for about 1-2 years or more. They normally wean the baby when they know that they have become pregnant again. Therefore, this is one of the constraints to recruiting nonpregnant nonlactating women in this community.

2.4. EFFECT OF THE SEASONAL VARIATION

In general, a seasonal variation factor was always considered in the nutritional study. This is due to the fact that there is some limitation of food intake and/or the agricultural cycle makes the person work harder at certain periods of the year. Hence the level of food intake and work output normally varied during the year. In these circumstances, seasonal variation was usually taken into consideration, because these two factors influence the nutritional status of the person.

Maternal nutritional status would be also affected by seasonal variation in terms of the weight gain, baby birthweight and child growth. The effect of seasonal variation was clearly shown in nonpregnant, pregnant and lactating women in Gambia (Lawrence et a., 1986; Prentice et al, 1981) and in nonpregnant women in Bangladesh (Huffman, Wolff & Lowell, 1985).

The effect of seasonal variation on food intake is very unlikely in this study due to the fact that the farmers grows enough rice for consumption throughout the whole year. No food shortage, particularly rice, was observed in this community. Seasonal variation, however, might be expected to play some role in the energy expenditure of this group of volunteers. This is because most of the women grow rice as a compulsory activity for the period of 5-6 months and for the rest of the years, they grow chilli, jute, cassava and groundnut or vegetables as the optional activities.

Nevertheless when the pregnant volunteers were divided into two groups according to the time of delivery, i.e., the group of women who gave birth at the time of the year when they were all involved in the rice plantation from June-November (n=21) and the group of women who gave birth at the other times of the year (n=22), it was found that there was no difference in either weight gain of the mother (8.8 $\pm$ 2.8 vs 8.9 $\pm$ 3.0kg) or baby birth weight (3.03 $\pm$ 0.36 vs 2.93 $\pm$ 0.35kg). These findings along with the fact that the number of babies born was evenly distributed throughout the year, show that the effect of seasonal variation for this group of women, if any, was minimal.

CHAPTER 3

3.1 THE SIGNIFICANCE OF WEIGHT GAIN AND FAT GAIN DURING PREGNANCY

Two of the most important measures of the physiological changes during pregnancy are weight and fat gain. Weight gain is the combination of the increase in weight of the fetus, amniotic fluid and placenta, (for the product of conception); and the enlargement of the uterus, breasts and body volume (of the mother). Increase in water content as well as fat in these tissues contribute in various amounts to the increase in weight during pregnancy (Hytten & Leitch, 1971).

Weight gain during pregnancy is of clinical importance for both the mother and the baby, and regular weight records provide useful information. For example, continuous weight loss might be the result of prolonged morning sickness whereas rapid weight gain might be the result of oedema, and these excessive gains in weight are correlated with certain complications of pregnancy, especially with preeclampsia and eclampsia. Information about body weight is primarily for the doctor to diagnose the problems.

There was some evidence to indicate that the mothers who gained more weight during pregnancy produced heavier babies than the mothers who gained less weight. In addition, the percent of low birth weight was lower in the higher weight gain group (Eastman, 1968). Hence weight gain of the mother is a significant factor in the pregnancy outcome.

Weight change during pregnancy varies widely from an actual loss of weight to a gain of 23kg or more (Hytten & Chamberlain 1980). This wide range is still compatible with normal pregnancy and a normal outcome. It is therefore difficult to define what is physiologically acceptable since the amount of weight gain recommended is much disputed. Hytten & Chamberlain stated that "the incidence of clinical complication rises at the extremes of the range, but a normal outcome is possible throughout".

During the first 30 weeks of pregnancy, fat is laid down as a store to be drawn upon during late pregnancy when fetal growth is maximal. In addition, the fat that is laid down is used during lactation. Such deposition of fat may be extremely important in areas of the world where food supplies are inadequate at certain periods of the year and breast feeding being a common practice in most developing countries.

Another variable component of weight gain in pregnancy is water. This component is definitely important and contributes to the growth of the fetus, amniotic fluid, placenta, uterus, breasts and obviously, to the expansion of the blood volume. Measurement of the total baby water in pregnancy has been made Hytten, Thomson & Taggart (1966) who measured the total body water using a deuterium oxide dilution technique in 93 normal pregnant women and found that the total body water was markedly increased in generalized oedema by about 2kg at 20 weeks and by 8.5kg at term, but the range of increase was very wide.

Weight gain during pregnancy

Weight gain during pregnancy was calculated to be 12.5kg in healthy primigravidae (Hytten & Leitch, 1964). This figure is based on the work of Humphreys (1954) and Thompson & Billiwiez (1957) who measured the weight gain of the primigravidae from 12 or 13 weeks gestation until term. The mean increase in both studies was about 11.5kg. To estimate weight gain from conception until about 12 weeks, Hytten & Leitch used the data of Chesley (1944) who reviewed the study of weight gain of about 9,000 cases and found that the mean weight gain was 1.14kg for the first trimester. Weight gain during pregnancy, however was later confirmed by Hytten & Leitch (1971) in a selected group of Aberdeen women with clinically normal pregnancies. The study showed that weight gain during the last half of pregnancy was comparable well to that calculated by Thomson & Billiwicz (1954).

In addition, Hytten & Leitch state that for multigravidae, the weight gain could be about 0.9kg less than for primigravidae. The reference value for weight gain, however, is 12.5kg for all pregnancies.

The average weight gain of 12.5kg is equivalent to a rate of gain of 450g/wk in the last half of pregnancy. This optimal increase in weight was shown to be related to an acceptable reproductive performance, i.e. this rate of weight gain corresponded with the lowest incidence of three major obstetric complications, i.e. perinatal death, preeclamsia and prematurity (Thomson & Billiwicz 1957). Of the total gain, about half was accounted for by the growth of the uterus and its content and the mammary glands. And the other half represented the increase in the maternal body fluid and the maternal fat stores.

<u>Fat gain during pregnancy</u>

In order to provide the optimal fetal growth and development while preserving maternal maintenance, pregnant women need either to eat more or to expend less energy than usual to spare energy for tissue synthesis and to lay down fat.

Fat is laid down in two parts during pregnancy, i.e. fetal fat and maternal fat, which requires about 4,000kcal and 32,000kcal respectively. The energy equivalent of the maternal fat laid down is about half the energy cost of pregnancy. The purpose of fat being laid down is as a protective mechanism. Its function is usually to protect mother and fetus against food shortages and to draw upon during lactation.

The amount of fat gain was calculated by substracting the weight of the fetus, placenta, uterus, amniotic fluid and extracellular extravascular fluid from total weight gain (Hytten & Leitch 1964). They demonstrated that 3.5-4.0kg of fat was deposited in healthy pregnant women. Fat is accumulated during the first and second trimester. This considerable amount of fat may be later used as an energy source for fetal growth in the third trimester and the subsequent baby development.

In pregnant women all the measured increase in water could be accounted for in known sites until the last four weeks of pregnancy. In the absence of clinical oedema and surplus water was fairly small. The extra weight gain was therefore deduced to be dry matter. Not much of this can be protein, because protein must be associated with some water. Thomson & Hytten (1961) and Hytten, Thomson & Taggart (1966) concluded that the extra weight gain could therefore only be due to the accumulation of fat. They substantiated this conclusion by referrring to the study in pregnant rat by Morrison (1956) who showed that the gain in maternal weight was largely made up of energy-yielding materials, mainly fat.

Whether or not the changes in body composition and laying down of fat during pregnancy follows the pattern of similar changes in nonpregnant women when they gain weight is still not clear. There was an evidence cited by Hytten & Chamberlain (1980) of the study by Edwards (1950) who demonstrated a proportional decrease of the skinfold thickness all over the body in nonpregnant obese women. Whereas Taggart et al., (1967) demonstrated that in pregnant women there was a selective deposition of fat at difference sites. They measured the changes in the thickness of skinfolds at 7 sites (biceps, triceps, subscapular, suprailiac, costal, midthigh and knee) and found that these skinfolds increased up to 30 weeks of pregnancy. Thereafter the pattern of increase was variable, i.e. the mid thigh skinfolds continued to increase, costal and tricep skinfolds started to decrease, but the other sites showed a little change. After paturition, there was an abrupt change in skinfold thicknesses between 38 weeks gestation and about one week after delivery.

The total body water mesurement is known as one of the most widely used methods for fat estimation. This is based on the assumption that lean body mass contains 72 percent of water. However, the measurement of total body water in pregnancy may not be an applicable method due to the change in composition of lean body mass. There is evidence from Seitchik's study (1967)about the changes in water content of fat free mass during pregnancy was demonstrated. By measuring the body density and total body water in 126 pregnant, nonpregnant and postpartum women, he found that fat free mass showed a progressive increase in hydration. The quantity of water gained during pregnancy and the lack of changes in total body density indicated that the quantity of water and fat free solids accumulated, are accounted for by the fetus, the amniotic fluid, the placenta and membrane and the known physiological and anatomical adjustment of pregnancy.

Unfortunately, this study was a cross-sectional study and the comparison of each parameter was not within the same group. The conclusion that possibly can be drawn from this study was that there was a progessive increase in the amount of water presented in the fat free mass during pregnancy.

Another evidence was obtained from Pipe et al., (1979) who conducted a longitudinal study of 27 normal pregnant women. They measured that pattern of change of 4 skinfold (biceps, triceps, subscapular and suprailiac sites) and applied the equation to transform total skinfold to body fat (Durnin & Rahaman, 1967). They also measured body fat by using total body water and total body potassium by considering the difference between the total body water and the expected amount of water present in the fat free mass which was estimated by total body potassium. This difference was considered to be the excess water in pregnancy. The two estimations of fat by measuring skinfold thickness and by measuring total body water were in agreement up to 24-28 weeks gestation but thereafter skinfolds continued to increase whereas the estimation of fat by total body water decreased. The results suggested not only the fat free mass hydration during pregnancy but also demonstrated an accumulation of fat reserve during the second trimester. Thereafter there was no further net accumulation of fat during the third trimester.

3.2 MEASUREMENT OF CHANGES IN BODY WEIGHT

Changes in body energy may be seen as changes in weight but changes in the body weight of human subjects do not necessarily reflect changes in energy balance or energy stores. This is because the fluctuation in body weight from day to day may be as much as a kilogramme, due to changes in body water, and daily changes of 0.5kg body weight are quite common. Khosla & Hytten (1963) demonstrated daily fluctuations in body weight in healthy pregnant women. The standard deviation of dailly weight change was about 0.5% of the mean. For example, when the subject weighs 50kg, the fluctuation of body weight can be about 0.5kg (two standard deviations).

Body weight can be simply and accurately measured using weighing scales. The scale is preferable the beam balance scale which provides an accurate measurement. Bathroom scales can also be used but they need to be regularly checked by a standard weight. Body weight measurement is normally done early in the morning after emptying the bladder and the subject wearing light clothing.

3.3 MEASUREMENT OF BODY FAT

3.3.1 Direct methods

The only way to determine accurately an individual's fat content is to carry out a cadaver analysis, either by chemical or anatomical means. Garrow (1974) reviewed that at that period only 6 adult cadavers were analysed chemically (Mitchell et al., 1945, Widdowson, McCance and Spray 1951; Forbes, Cooper and Mitchell, 1953; Forbes, Mitchell and Cooper, 1956). This method, though not practical, has been used to help standardize other methods, since it provides estimates of the whole body composition.

An important point that emerges from the data derived by the direct method is that the body may roughly be regarded as consisting of two components, i.e. the fat mass and the fat free mass, the fat free mass consists of all the other parts of the body except fat. The composition of the fat free mass is fairly constant in terms of water, protein and minerals. On average water makes up 72.5% and protein 20.5% of the weight. Of the remaining 7%, most of it consists of bone mineral.

There is a slight difference between fat and adipose tissue that adipase tissue composed of fat plus fluid and cellular component of adipose tissue. Lohman et al.

(1981) reviewed the measurement of skinfolds, body density and body fatness and stated that:-

body weight	=	fat + fat free mass (FFM)
	=	(storage fat + essential fat) + FFM
storage fat	=	the combination of subcutaneous fat, intermuscular fat, intramuscular fat and fat surrounding the organs and gastrointestinal tract of the body.
essential fat	=	lipid of bone marrow, central nervous system, mammary gland, wall of erythrocyte, cell membrane and other organs.

3.3.2 Indirect methods

In order to study living individuals, indirect methods for measuring body composition and fat content have been developed and validited where possible against the cadaver analysis. There is not absolute measure of fat mass in living animals or people; all methods involve assumptions. The commonly used "standard methods" are based on:-

- body density
- total body water
- skinfold thickness

3.3.2.1 <u>The estimation of body density</u>

Behnke, Feen & Welham (1942) were the first group to suggest that the body is composed of two parts, i.e. lean body mass (LBM) and fat component, each with relatively constant density, and they also to suggestedusing this principle to assess body fat content from measured total body density. Brozek & Keys (1951) studied 133 college men and developed the equations for prediction of specific gravity (and the corresponding percentage of body fat) from skinfold thicknesses, and stated that in living man, the percentage of the body represented by fat, estimated on the basis of specific gravity of the body, appears to be the best single method of characterizng the individual's leanness-fatness.

The assumptions in this method are that fat mass has a density 0.90 whereas the density of the fat free mass, which can not be accurately determined, and may vary (Lohman, 1981), is generally close to 1.10.

According to Siri's equation (1961)

$$\% \text{ fat} = \frac{495}{\text{body density}} - 450$$

Since body density = $\dfrac{\text{body mass}}{\text{body volume}}$,

body volume estimation will allow the calculation of body density and body fat. To obtain the volume of the body, a correction has to be made for the residual air in the lungs at the moment the underwater weight is recorded. It is impossible to measure the gas in the gastrointestinal tract, but the amount is usually small and can be neglected, therefore:-

$$V_{body} = \frac{\text{Wt in air - Wt under water}}{D_{water}} - V_{\text{air in lungs}}$$

The under water weighing technique is used to determine the body volume and hence body density, and the percentage of fat in the body can then be obtained using Siri's equation.

3.3.2.2. Total body water

This method is based on the dilution principle. If a known amount of tracer substance is introduced into an unknown volume of body water and mixedthoroughly, the final tracer concentration provides a measure of the total volume. The final concentration is reached when complete mixing has taken place and after a correction has been made for the elimination of a tracer from the body after injection. A sample of body fluid, the blood or urine, is taken for the tracer analysis.

Tritiated water has been used for total body water measurement (Pace et al. 1947), but is not widely used because of its radioactivity. Deuterium oxide was first introduced by von Havesy and Hofer (1934). This method was shown to be satisfactory method but the cost of measurement is rather high. McCance & Widdowson (1951) demonstrated that a urea method can be used and it also appears to give good agreement with the deuterium method.

As mentioned earlier that, the body is composed of two components: fat, and fat free mass which has a fairly constant composition. It was found that each kilogram of fat free mass contained about 725g water, 205g protein and 69mmole potassium, but that there was considerable variation between individuals.

Fat mass can therefore be estimated by measuring total body water by the above mentioned method and then by applying the equation.

$$\text{Fat mass} = \text{body mass} - \frac{\text{total body water}}{72.5} \times 100$$

Since total body potassium is almost entirely located in the fat free mass, with a relatively constant concentration in normal subjects, the measurement of total body potassium by a sensitive whole body counter can also be used to calculate fat mass, using this equation.

$$\text{Fat mass} = \text{body mass} - \frac{\text{total body potassium}}{69}$$

3.3.2.3. Skinfold thickness

Sophisticated methods of assessing body composition, i.e. body density, total body water and total body potassium methods are time consuming, require considerable equipment and are, in general, less available. These methods are apparently not appropriate for the field study. Efforts have been made to find more practical ways of assessing body fat on a more easily obtained anthropometric and skinfold measurement.

Many investigators have developed the assessment of subcutaneous fat by measuring the skinfold thickness. A different number of skinfold thickness sites were proposed (Brozek and Keys 1951, Edward 1950, Pascale et al. 1956). Durnin & Rahaman (1967) proposed 4 skinfold thickness as a good prediction of body density and then used Siri's equation (1956) to predict body fat.

The study of Durnin & Rahaman (1967) was carried out in about 200 adolescent males and females. For each sex and age group, there was one equation to predict body density from the equation of sum of the 4 skinfolds. Log transformations were used because the skinfolds and density were related in a curvilinear relationship as opposed to rectilinear. Therefore the logarithm of skinfold measurement has a linear relationship with body density.

Later the relationship of body density and sum of the 4 skinfold was successfully confirmed in a group of several hundred subjects in a wide age range (17-72 years) of both sexes (Durnin & Womersley 1974). In this study, they compared the measurement of body density by underwater weighing technique and the skinfold. Then using Siri's equation, they made regression equations for each sex and age group.

Durnin & Womersley (1974) also demonstrated that there was no advantage in accurary of deduction of the skin layers for each measurement of skinfold thickness, which was about 1.8mm or when the multiple regression analysis incorporated height and weight, or including limb circumferences.

There were some studied indicated an improvement in skinfolds measurement by measured other parameter. For example, Lohman et al. (1975) predicted the fat in boys by using regression equations of skinfold thickness as well as weight. They claimed that this method gave a better estimation of fatmass than skinfold thickness alone.

Dugdale and Griffiths (1979) also pointed out in the study of boys and girls aged under 19 years that the surface area in addition to skinfold thickness give a good prediction of body fat. This regression equation has a smaller error in the estimation. But this relationship may not hold true in other age groups.

Nevertheless, it would appear that the inclusion of some other parameters with skinfolds is of relatively minor importance as long as a prediction equation takes into account the more important factors of age, sex and the standard measurement of the skinfold thickness. In addition the less parameters involved in the measurement, the less time consumed and the less error involved in the actual measurement.

Anthropometric measurement have been conducted using the regression equation for predicting body density from skinfold thickness in pregnant women (Pipe et al., 1981; Adair 1984). This method is widely used particularly in the field situation and some other clinical practices, without involving the complicated and time consuming procedures like other available methods. Therefore the only caution of this method is that, the skinfold measurement need highly skilled and well trained observers. The standard procedure is also required, i.e. the exact point of the skinfolds measurement and the type of the caliper used.

3.4 SELECTED METHOD OF BODY COMPOSITION IN THIS STUDY

The main concerns in the body composition of the pregnant women are the weight and fat gain during pregnancy. These can be obtained by the difference of the body weight and fat at term and at conception. These measurements at term were easy to obtain before the women delivered in the hospital, whereas the measurement at conception was rather difficult, because in this study the recruiting of the pregnant woman was done after the conception period. In the first phase of this study, it was planned to recruit the pregnant women as soon as possible. During the second phase, however, some of the women were recruited in the prepregnant period in order to get the baseline information at conception.

Weight measurement, though it is very simple to measure, need to be as accurate as possible. In this study the calibrated beam balance was used to measure the body weight when the women came to the lab. A weekly weight record of the women was also needed. Nevertheless, it was not practical to measure the body weight of the women either by bringing them to the lab in the morning or carrying the beam balance scale to the villages, because the scale required calibration every time it was set up. Hence bathroom scales were used for the weekly weight record. These scales need frequent calibrations and need to be put in the stable or firm ground to get a reliable reading.

For the fat estimation, total body density and total body water were not appropriate methods to use in the field situation. The reasons are that these methods require considerable equipment, and high cost to set up the lab. Hence skinfold thickness is considered to be the most appropriate method to use in this study, because of its simplicity. Nevertheless, skinfold thickness measurement to estimate fat during pregnancy, particularly near term might not be an ideal method. This is because the tissue hydration might affect the density of fat free mass. Also there is a selective deposition of fat particularly at the central site of the body. These problems can be overcome by considering the change of maternal fat store after delivery in stead of at term. This method will be discussed later in the thesis.

3.5 BODY COMPOSITION MEASUREMENT

The body composition measurement of pregnant women was serially measured in the laboratory at 6 weekly intervals according to the protocol. Some of the pregnant women were measured more often near term in order to get the measurement as close as possible to the delivery period. The same investigator was responsible for the body composition measurement in the same women throughout the study.

The details of body composition measurement are as follows:

3.5.1 Body weight/height

The woman were asked to empty their bladders prior to being weighed on the accurate weighing scale (Brash Model 424: a portable pillar scale with movable weights and a capacity of 100kg and a minimum reading is 50g). They were weighed with their clothes on and later the weight was corrected by weighing their cloths and subtracting this from the initial weight obtained. Readings were taken to the nearest 0.1kg.

At home, they also weighed themselves using the provided calibrated bathroom scales. Light cloth was also given for them to wear for weighing purposes. This weighing procedure was done in the morning after they woke up and emptied their bladders. Food or drinks were not allowed before the measurement. The scales were put on a thick piece of wood which was laid on the floor as stable as possible because their house floors were sometimes uneven. The scales were regularly checked with the standard weight.

Body height

The woman was asked to stand on a horizontal platform with her heels together, stretching upward to the fullest extent. The anthropometer was used for the measurement. Her back was as straight as possible against the vertical bar and the horizontal arm of the anthropometer was in contact with the women's head. The reading was read to the nearest mm.

3.5.2 Skinfold thickness

Different sites of skinfold thickness was measured. In general the skinfolds were picked up between the thumb and the index fingers of the left hand and lifted up, ensuring that no underlying muscle tissue was included. The thickness, which represents the thickness of the skin plus subcutaneous fat, was determined by a pair of calipers. In this study, Harpender caliper (Holtain Ltd., Brybearian, Crymych, Pembrokeshire) was used throughout. The calipers were placed about 1cm below thfinger, holding the skinfold lightly and allowing the pressure of the caliper alone to be applied to the skinfold. The measurement was read 2 seconds after the full pressure of the caliper was applied to the skinfold; If a longer interval was allowed the jaws may 'creep' and give an inaccurate reading (Weiner & Lourie, 1969).

The measurement was done in triplicate and the mean reading represented that particular skinfold thickness. The exact position of the sites of skinfold thickness is as follows:-

Biceps: The skinfold was picked up on the front of the relaxed arm at the midpoint of the belly of the muscle.

Triceps: The skinfold was taken at the back of the relaxed arm, at the mid point between the acromial process and the olecranon process. The measurement was taken at this midpoint, and directly in line with the two processes.

Subscapular: The skinfold was picked up under the angle of the scapular, just below the top of the inferior angle of the scapular, at an angle of about 45^{o} to vertical, and with the finger touching the bone.

Suprailliac: This measurement was taken just above the iliac crest, on the mid-auxillary line.

Costal: This measurement was taken at the level of the front lowest rib.

Thigh: The skinfold was picked up on the anterior aspect of the thigh, halfway between the mid-inguinal point and the upper border of the pattella (with knee flexed at 90^{o}).

3.5.3 Body circumferences and diameters

The circumferences were measured using a metal flexible tape, (3m x 1mm), the bone diameters by the anthropometer, (range 50 x 570mm). The standard techniques were performed as described by Weiner & Lourie (1969) as follows:

-Upper arm circumference

The subject's arm hung relaxed, just away from her side, and the circumference was taken horizontally at the middle way of the acromial process and the tip of the olecrenon process.

-Upper thigh circumference

The subject stood with her feet slightly apart and her weight evenly distributed on both feet. The tape was placed round the thigh horizontally with its top edge just under the gluteal fold.

-Buttock circumference

The subject stood with her feet together. The maximum buttock horizontal circumference was measured.

-Calf circumference

The subject sat on a table with her leg hanging freely. Maximum calf circumference was taken horizontally.

<u>Diameter</u>

-Biacromial diameter

To give maximum shoulder width, the subject stood with her shoulders relaxed to the point of slumping forward. Standing behind the subject, the measurer felt for the outside edge of the acromial process of the shoulder blade which could be felt as a ridge just above the shoulder joint. The measurer then placed the edge of one arm of the anthropometer along the external border of one acromial process and brought the other arm of the anthropometer inwards until its edge rests on the opposite acromial external boarder.

-Biiliac diameter

The subject stood with her heels together and the anthropometer arms were brought into contact with the iliac crests at the place which gave the maximum diameter. Strong pressure was applied to the anthropometer blades to put aside any fat covering the bone. This measurement was more easily taken with the measurer standing behind the subject.

3.6 RESULTS AND DISCUSSION

3.6.1 Weight gain during pregnancy

The comparison of mean weight gain during 10 weeks gestation until term in the Thai's study and theoretical weight gain from Hytten & Leitch is shown in Figure 4. A parallel increment of weight gain was observed, with a lower rate of weight gain in this study. Rate of weight gain was fairly uniform with the rate of increase 0.3kg/wk whereas the rate of increment in Hytten & Leitch was 0.4kg/wk.

The average weight gain of the women was 8.9 ± 2.9kg, compared to the theoretical weight gain of European women at 11.8kg. (This weight gain was calculated by subtracting the estimated weight gain from conception to 10 weeks gestation which was 0.7kg from the theoretical weight gain of 12.5kg.) The weight gain of the women in this study was found to be satisfactory for women with a smaller stature compared to European women.

In this study there were quite a few women whose weight was measured from preconception, but no conclusion of total weight gain at conception until term could be drawn from this basis. However, although the average weight gain was 8.9kg, a wide range of weight gain from 3.5-15kg was observed.

Theoretical weight gain in developed countries is 12.5kg. This has been confirmed by many studies as shown in Table 8. There was a difference in prepregnant weight and weight gain during pregnancy in developed and in developing countries. On average the prepregnant weight of the mother in developed country was about 57kg and the weight gain was about 12kg. For the women in developing countries, they have smaller stature and the average weight was 49kg with the weight gain of about 7.7kg.

The only way to make the comparison of the weight gain in these two groups is to consider the percentage of weight increase compared to a prepregnant weight. On average, the percentage of weight gain is less in developing countries than in developed countries. In this study the percentage of weight gain compared to initial

Fig.4 Mean weight gain during pregnancy (from 10 weeks until term) compared to Hytten & Leitch (1964).

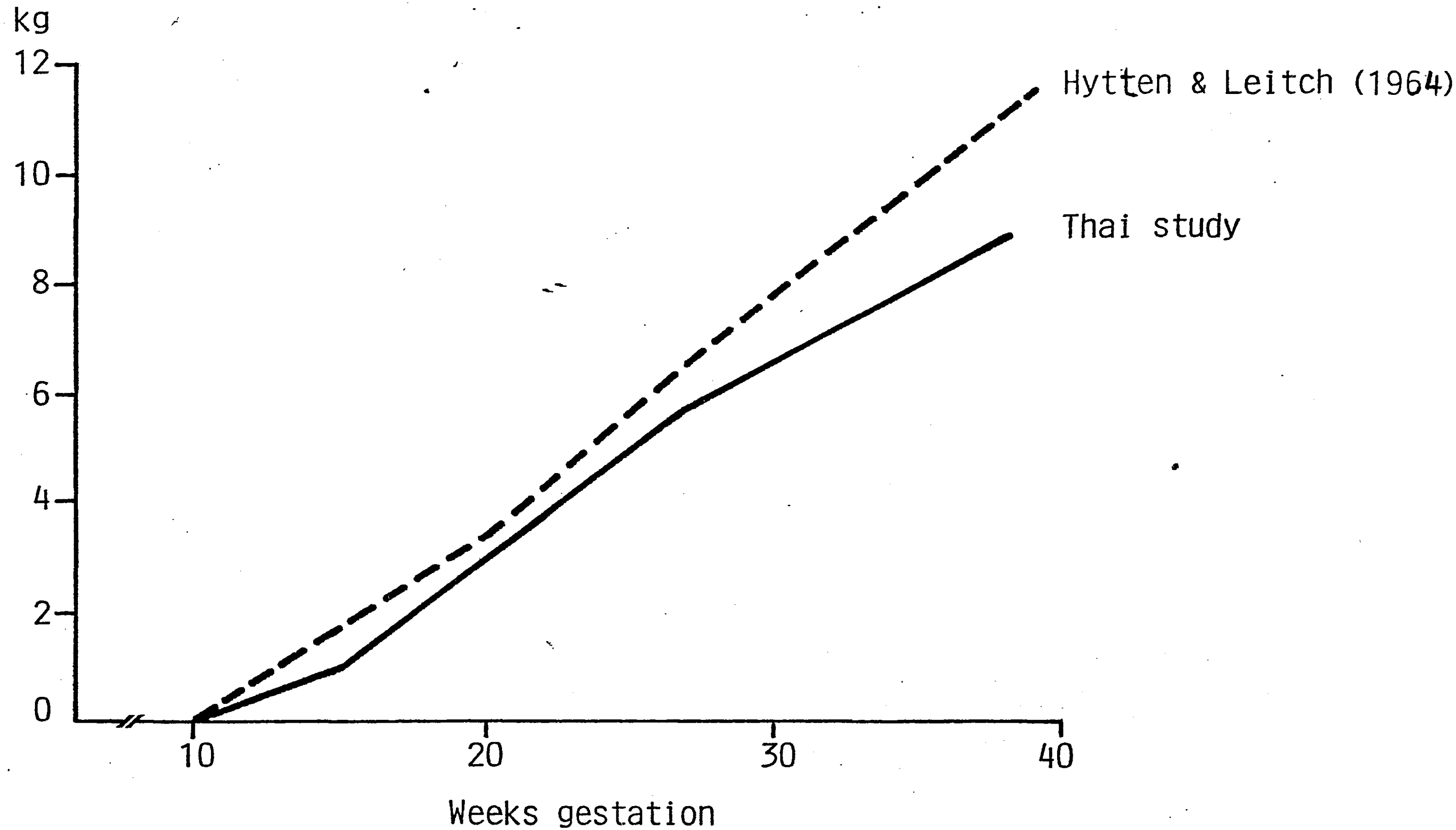


Table 8 Maternal initial weight and weight gain in the developed and developing countries.

	Initial wt. (kg)	Wt. gain (kg)	% wt gain
Developed countries			
UK, Thomson & Billiwiez (1957)	53.7	11.2	21
Humphreys (1954)	54.1	11.2	21
Whitehead et al (1981)	56.1	12.6	22
Durnin et al (1985)	57.5	11.7	20
Lunell et al (1965)	59.1	11.2	20
Forsum et al (1985)	60.2	13.9	23
Netherland, van Raaj et al (1986)	62.5	10.6	17
USA, Beal (1971)	54.4	10.7	20
Australia, English & Hitchcock (1968)	53.8	10.3	19
Ash (unpublished data)	57.8	14.3	25
Developing countries			
India, Venkatachalam et al (1960)	48.0	6.0	13
Gambia, Lawrence et al (1984)	51.4	7.3	14
Taiwan, Adair (1984)	48.7	7.6	16
McDonald et al (1981)	48.6	7.6	16
Ethiopia, Tafari et al 1980)			
Less active	54.3	9.2	17
Active	50.0	6.5	13
Philippines (Barba & Tauzon, 1986)	44.4	8.5	19
Thailand (This study)	47.6	8.9	19

weight was 19% which was quite similar to that in developed countries. The weight gain of these women in this study was found to be quite satisfactory. The Gambian women (Lawrence et al 1984) and the Ethiopian active women (Tafari, Naeye and Gabezie 1980) showed a low percentage of weight gain which was about 13-14%. These women though weighed more than the women in this study, they gained less weight not because of their involvements in hard labour works but also the effect of food famine that occured at some period during the year.

3.6.2 Fat gain estimation

In this study, the skinfold thickness measurement method was adopted. Nevertheless, there were some problems attached to this method in that the estimation of fat at term might not be accurate enough. This is due to the problem of tissue hydration that would alter the density of the fat free mass and therefore affect the calculation of the body fat. This is because the method of body density measurement is based on an assumed constant density of fat mass and fat free mass. This change in the density of fat free mass would alter the estimation of body fat. For example, if the body fat is 20% of a person whose weight is 50kg and later 55kg. Suppose this latter weight includes an extra weight of 5kg water. The calculation of fat would be 10 and 11kg respectively. The difference of one kg which is mistaken as fat would require 11,000kcal extra energy to lay down that amount of fat.

In addition to the problem of tissue hydration near term, there was also the problem of measuring the skinfold (SKF), particularly at suprailiac site. This problem can be solved by either measuring only 3 skinfolds, i.e. biceps, triceps and subscapular skinfold thickness and use the equation of estimating body fat from 3 SKF (Durnin & Rahaman 1967), or measuring 3/4 SKF after delivery period. In this study the first skinfold measurement was performed 2 days after delivery and later at 4-6 weeks. The fat gain was estimated based on these measurements as follows:

3.6.2.1 <u>SKF estimation at 2 days after delivery</u>

This method could be used provided the skinfolds were measured within a few days of delivery. At this period, fat mobilisation for breastmilk production would be very small or even not changed. In addition, the weight of the mother would not include the weight of the fetus, placenta, amniotic fluid or possibly some extracellular extravascular fluid which were lost at delivery and during the subsequent days. This method, however is still prone to the problem of tissue hydration due to pregnancy.

The comparison of 3 SKF/4 SKF measured at the last lab measurement (at 38 weeks), at term (about 39 weeks) and at 2 days postpartum was done in this study as shown in Table 9. It was found that there was no difference in skinfolds measured in these different periods for the 3 SKF whereas there was a significant decrease in the 4 SKF after delivery ($p<0.001$). This change in the sum of 4 SKF was mainly due to the difficulty in picking up the skinfold at suprailiac site which possibly resulted in an overestimated value at or near term. This measurement of SKF at term and at about 2 days postpartum was not expected to change because the measurement was done more or less within the same week. No fat loss would have occured in that short period of time.

The amount of fat gain was calculated using the estimation of the final fat at term and at 2 days postpartum and the initial for at 10 weeks gestation. The average fat gain of the fat at term - initial fat by using 3/4 SKF was 2.96 and 3.50kg respectively. Whereas the average fat gain of the fat at 2 days post partum - initial fat by using 3/4 SKF was 0.89 and 1.01kg.

The difference in the estimated fat laid down was about 2kg. The higher estimated fat gain by the first method was partly due to the higher weight of the mother (which included fetal weight, placenta, amniotic fluid, ..etc.) and the higher sum of the skinfold. However, it is more appropriate to consider the fat gain by the second method because there was no influence of the reproductive outcome weight and no difficulty in measuring the skinfolds after delivery.

By this method the amount of fat gain from 10 weeks until term was about 0.9-1.0kg. The calculation was based on the assumption that the water retention did

Table 9 Estimation of fat gain during pregnancy by 3 SKF[a]/4 SKF[b], measurement ($\bar{X} \pm SD$).

Sum of the skinfold thickness (mm)	38 weeks	at term	2 days postpartum
3 SKF	33 ± 9	33 ± 8	32 ± 9
4 SKF	49 ± 12	50 ± 12	46 ± 12[c]

Fat gain estimated at 2 days postpartum (kg)	1. at term-initial fat mass	2. at 2 days postpartum-initial fat mass
n	24	28
3 SKF	2.96 ± 0.35	0.89 ± 0.38
4 SKF	3.50 ± 0.37	1.01 ± 0.40

Fat gain estimated at 4-6 weeks postpartum (kg)	
Final fat mass (at 4-6 weeks postpartum)	12.14 ± 2.50
Initial fat mass (at 10 weeks gestation)	11.02 ± 2.14
Fat gain	1.12 ± 1.02

[a] 3 SKF (biceps, triceps, subscapular skinfolds)

[b] 4 SKF (biceps, triceps, subscapular and suprailiac skinfolds)

[c] significant difference at $p<0.0001$

not have much influence after delivery period.

3.6.2.2 Fat gain estimated from 4-6 weeks postpartum and initial fat

In order to avoid the problems of the alterations in the body density of the fat free mass as the result of increasing water retention, and the different pattern of deposition of fat during pregnancy, fat gain was estimated by the difference in fat at 4-6 weeks postpartum and the initial fat at 10 weeks gestation. At this time, the extra fluid and other repreoductive tissues would have returned to the nonpregnant level. The calculation of fat at this stage assumed the body density of fat and fat free mass were constant and the fat estimated at this puerperium period would represent the final fat laid down in pregnancy. This calculation is based on the assumption that during the first 4-6 weeks after delivery, little or no change of maternal fat is occured.

In this study, the result showed that the mother lost 5.1kg after delivery and thereafter they reduced weight from the pre-delivery level by 6.2, 6.5, 6.6 and 6.7kg for the subsequent weeks in their first months. Thereafter, they tended to gain weight. During the first 4 weeks of lactation period, whether or not the loss of body weight was accompanied by the loss of body fat was still not clear. However, the evidence from this study demonstrated the marked increase of energy intake after delivery (about 700kcal extra compared to the energy intake at 10 weeks gestation). This extra energy intake might be used as the energy source for breastmilk production without metabolizing the reserved maternal fat.

Table 9 also demonstrates the fat gain by calculating the fat mass from the difference of fat at 4-6 weeks postpartum and the initial fat at 10 weeks. The fat gain was 1.1kg which was similar to the fat gain obtained by the skinfold measured at 2 days after delivery either by the 3 SKF or 4 SKF.

It seems as if there was no change or a slight increse of fat mass at one month compared to at 2 days postpartum. But the difference was so small that the accuracy of the estimation of fat mass by the skinfold measurement might not be able to detect it. Therefore, the results of fat gain estimated either at 2 days or at about one month after delivery gave the same result, i.e. about 1kg fat was gained during pregnancy.

3.6.2.3 Factorial method

Another method of estimating fat gain during pregnancy is the factorial method. In this study, the total weight gain, the fetal weight, and the placenta weight were carefully and accurately measured. However, some other tissues which contributed in the weight gain of pregnancy were not measured, i.e. amniotic fluid, uterus, mammary gland, blood, extracellular extravascular fluid. These unmeasured fluids and tissues can be estimated from the theoretical values from Hytten & Leitch (1971) and would provide an approximate weight which would be important for the calculation of the material fat deposition.

Table 10 shows the factorial calculation of maternal fat stored from 10 weeks until term. The calculation of unmeasured tissues and fluids were based on the assumption that the increase weight of unmeasured tissues would be in the same proportion as the increase weight of other reproduction products, i.e. fetus and placenta. In this study the average fetal weight and placenta weight at birth were 2.98 and 0.53kg respectively whereas the theoretical values were 3.40 and 0.63kg. The theoretical weight of amniotic fluid, uterus, mammary gland, blood, extracellular extravascular fluid was 4.79kg. The unmeasured tissues were therefore:-

$$\frac{2.98 + 0.53}{3.40 + 0.63} \times 4.79 = 4.17\text{kg}$$

Also it can be assumed that the unmeasured fluid and tissues can be estimated based on the initial weight of the mother. Mean maternal weight at 10 weeks in this study was 47.6kg whereas the theoretical maternal weight at conception was 56kg. With the weight gain of 0.7kg from conception to 10 weeks, the theoretical weight at the same gestation age would be 56.7kg. Therefore the unmeasured weight of fluid and tissues were $\frac{47.6}{56.7} \times 4.79 = 4.02$kg. The average unmeasured tissues and fluid by these two methods were therefore 4.10kg.

Table 10 Factorial calculation of maternal fat stored from 10 weeks until term.

Weight (kg)	Hytten & Leitch		Thai's study	
Total weight gain		11.80		8.90
Fetus	3.40		2.98	
Placenta	0.63		0.53	
Amniotic fluid	0.77			
Uterus	0.83			
Mammary gland	0.36	4.79		4.10[a]
Blood	1.15			
Extracellular Extravascular fluid	1.68			
Weight unaccounted for		2.98		1.29

[a]Average estimated value of unmeasured tissues and fluid.

The factorial method showed that the weight unaccounted for during pregnancy from 10 weeks until term in Thai's study was about 1.3kg which was lower than that of estimated by Hytten & Leitch.

It was assumed that the components of weight gain consist almost entirely of protein, fat and water. Other components such as carbohydrates or other substances were stored in relatively small amounts and not used for the theoretical calculation of caloric cost of pregnancy. When the total body water and protein compartments were calculated, the remainder of the dry matter was therefore fat or adipose tissue. Not much can be protein, because in order to lay down protein tissue, water must be associated. Hytten & Leitch (1971) therefore assumed that the maternal store consisted entirely of fat. Whether or not the maternal store is entirely fat or adipose tissue, is still a controversy, i.e. the woman could store energy in terms of adipose tissue, but this consists mainly fat. However it might not make much difference in the final caloric computation of the requirement. In addition to that this maternal store varies from one individual to another. The error from the above assumption may not contribute a significant proportion compared to the variation.

3.6.2.4 Estimation of fat gain by weight change

Another possibility of estimating the fat gain during pregnancy is by looking at the weight change at 10 weeks and at puerperium state. As mentioned earlier, the water retention as well as the extra blood volume might not go back to the nonpregnant state until 4-6 weeks of lactation. Therefore, the difference in weight in these two periods could represent the gain in adipose tissue. By taking into account the increase in mammary gland (about 0.4kg according to Hytten & Leitch 1971). The extra weight is assumed to be adipose tissue. The maternal fat can therefore be calculated by multiplying factor 0.8 to the weight of adipose tissue (adipose tissue contains about 80% fat).

In this study, the difference of weight at 4-6 weeks postpartum and at 10 weeks was 2.4kg. By taking into account the increase in breast volume according to

Hytten & Leitch, this left about 2.0kg for adipose tissue, hence the maternal fat store was 1.6kg.

This estimation of maternal fat gain is obviously based on the assumption that there is no change in maternal fat due to utilizing some fat for milk production and an increase in reserved fat due to an increase in food intake. In this study, it was shown that at one month lactation the amount of food intake of the women was further increase to about 700kcal/d whereas energy expenditure decreased by about 100kcal/d compared to the baseline data at 10 weeks. The difference in energy intake and expenditure, therefore was 800kcal for the first month of lactation. This reserved energy is needed to synthesis the breastmilk if fat has not been utilized. With 80% efficiency of converting the dietary energy to breastmilk production, (Thomson, Hytten & Billiwicz, 1970) the result demonstrated that the breastmilk production was 800kcal/d x 0.8 = 640g/d. This amount of breastmilk production is similar to the breastmilk value obtained by the test weighing method of the lactating women (n=25) which was 690g/d. Therefore, the changes of maternal fat store during pregnancy if any, might be minimal.

Estimated fat gain by four different methods is shown in Table 11. The average fat gain was therefore 1.2kg during pregnancy. The extra energy needed for this amount of fat deposition was 13,200kcal.

3.6.3 Comparison of a low birth weight and a high birth weight group

In this study 5 out of 44 pregnant women delivered low birth weight babies. The comparison of the characteristics of the mother who gave birth to the low birth weight baby and the same number of mothers who gave birth to the high birth weight baby is shown in Table 12. The results indicated that there was a significant difference in the gestational weeks at term of these two groups ($p<0.05$). The high birth weight group gave birth at full term (40 ± 1 wk) whereas the low birth weight group gave birth at about 37 wks (ranged from 35-38 wks). This is not a surprising finding because the gestational age of the baby at birth is one of the factors which

Table 11 Estimations of fat gain in this study.

	Method of estimation	Fat gain
1.	Skinfold thickness.	
	-2 days postpartum fat - 10 weeks gestation fat	
	Biceps, Triceps & Subscapular (3SKF)	0.9
	Biceps, Triceps, Subscapular & Suprailiac (4SKF)	1.0
	-4-6 weeks postpartum fat - 10 weeks gestation fat by 4SKF.	1.1
2.	Factorial method	1.3
3.	Estimation by weight change	1.6
	The average fat gain	1.2kg

Table 12 Comparison of various parameters in a low birth weight group and a high birth weight group.

No.	Sex	Birth weight (kg)	Gestational wk at term	Maternal wt at 10 wk	Weight gain (kg)	Fat gain (kg)
Low birth weight group						
213	F	2.40	37	45.5	5.5	0.03
220	F	2.50	38	41.0	4.5	-0.11
231	M	2.45	35	41.5	8.5	0.43
238	F	2.25	36	48.0	7.0	-
246	M	2.25	38	43.5	3.5	-
	$\bar{X}$	2.37	36.8	43.9	5.8	0.12
	SD	$\pm$0.12	$\pm$ 1.3	$\pm$ 2.9	$\pm$2.0	$\pm$0.28
High birth weight group						
214	M	3.80	40	54.5	15.0	2.31
217	F	3.32	41	54.0	5.5	-0.59
223	M	3.40	41	48.0	11.0	2.44
229	F	3.40	39	47.0	11.0	3.26
237	F	3.35	39	39.0	6.5	-
	$\bar{X}$	3.45[a]	40.0[a]	48.5[a]	9.8[b]	1.86[b]
	SD	$\pm$0.20	$\pm$ 1.0	$\pm$ 6.3	$\pm$3.8	$\pm$1.68

Significant difference at [a] ($p<0.001$), [b] ($p<0.05$).

influence the baby's weight.

A significant difference in the weight gain in these two groups was observed ($p<0.05$). The low birth weight group had an average weight gain of 5.8 + 2.0 (SD) kg ranging from 3.5-8.5kg. Volunteer #231 had the highest weight gain in this group at 8.5kg but due to the gestational age of the baby being only 35 weeks at birth, this resulted in the low weight of the baby. However #220 who gained about 4kg less than subject #231 (i.e. 4.5kg) but gave birth at full term (38 wks) produced a baby of similar weight at birth.

The weight gain in the high birth weight group also varied widely, from 5.5-15kg. The average weight gain of this group was 9.8 + 3.9kg. Volunteer #217 gained only 5.5kg and produced a 3.32kg baby. This woman did not reserve fat during pregnancy but lost about 0.6kg. Unfortunately no data was available on volunteer #237 who gained only 6.5kg and produced a baby weighing 3.35kg.

A stepwise multiple regression analysis was performed on the total 43 women in this study (this excluded one woman who delivered the baby at 27 weeks). A significant correlation between the birth weight and the weight gain of the mother ($r=0.42$ $p<0.005$) was found. Among many parameters that played role in the baby birthweight, weight gain of the woman was considered to be the best predictor. The linear regression equation was

$$\text{birth weight (kg)} = 0.048 \times \text{weight gain (kg)} + 2.53$$

For example in this study the average weight gain was 8.9kg and the baby birth weight was 2.98kg. By applying the actual measured weight gain of 8.9kg in this equation, the predicted baby birth weight would be 2.96kg which was similar to the actual measured birth weight. If the weight gain was assumed to be 10.6kg using the theoretical value of 12.5kg adjusted for the smaller stature of the Thai pregnant women of weight 47.6kg as opposed to 56.7kg European women), the predicted baby birth weight would be 3.04kg which is similar to the value obtained in this study (2.98kg). The birth weight of the babies in this study are therefore satisfactory.

A small change in maternal fat store during pregnancy in low birth weight group (gain of 0.12 ± 0.28kg) was observed in this study. The fat gain in the high birth weight group was significantly higher than the low birth weight group (gain of 1.86 ± 1.68kg) ($p<0.001$) even though one volunteer (# 217) in the high birthweight group seemed to loose fat. A significant coefficient correlation was demonstrated in a group of 24 women whose fat gain during pregnancy was estimated. The correlation coefficient of birth weight and fat gain was $r=0.50$, $p<0.01$.

In terms of energy intake and energy expenditure the high birth weight group consumed a higher caloric intake and expended more energy than the other group (2,304 ± 334kcal/d vs 2120 ± 108kcal/d for energy intake; and 1,973 ± 302 kcal/d vs 1882 ± 189kcal/d for energy expenditure respectively). No significant difference between these two groups was found. This could be due to the wide variation both in inter and intra-individual in energy intake and inter-individual variation in energy expenditure. These estimated values of these two parameters might not be sensitive enough to show up their small effect on birthweight.

3.6.4 Changes in skinfold and circumference during pregnancy

Skinfold measurement at different gestation periods was compared to the initial value of 10 weeks. The pattern of the different skinfolds did not show the same trend of changes, i.e., the increasein skinfolds is not proportional to the original thickness of the skinfold at each site. Figure 5a showed that the increase in these 6 SKF was clearly shown to be of different magnitude. For instance at the peripheral site, the percentage increase in biceps or triceps, the peripheral site was only 2-3% whereas at the central site the percentage increase in suprailiac costal or thigh was about 15-20%. The highest percentage of increase was clearly demonstrated at suprailiac site which was about 40%.

This finding is similar to that of Taggart et al (1967) who measured the changes of skinfold at different sites in 84 subjects. Taggart found that the proportional change was greater in suprailliac than other skinfold sites.

One should bear in mind the technical error in skinfold measurement and that the suprailliac site measurement, particularly near term, is very difficult to measure due to the stretching of the tissue. So the increase of skinfold thickness at the suprailliac site might be as well subject to error.

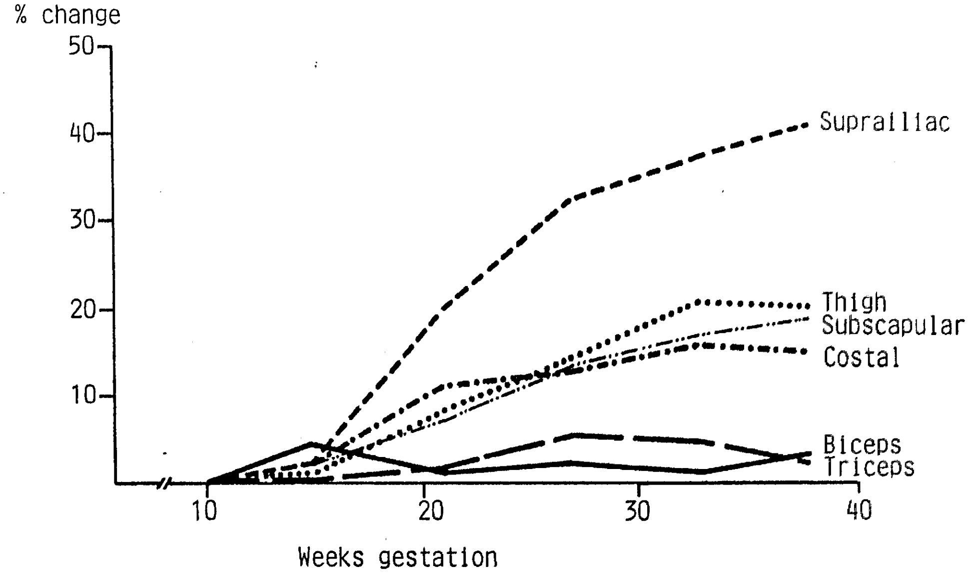
The changes of circumferences during pregnancy is shown in Figure 5b. Buttock circumference showed the highest increase which was about 5% increase compared to the initial value at 10 weeks. Whereas upper thigh circumference showed a comparable increase as buttock except at the few weeks before delivery there was a slight drop of the increment. Calf circumference also showed a comparable increase to buttock but to a less extent. Upper arm circumference showed a slight drop at 10-20 weeks and then slightly increased therefore showed no change of upper arm circumference over the whole period.

The result of changes of skinfold and circumference during pregnancy indicated that there was not much change in any other parts but the central part of the body, i.e. the changes can be found in the circumference of calf, upper thigh, buttock and the skinfold of thigh, subscapula and costal, but no change in the upper arm circumference along with the biceps and triceps skinfolds. The results indicated the preferential of fat deposition in the central part that might possibly be easy to draw upon for energy utilization.

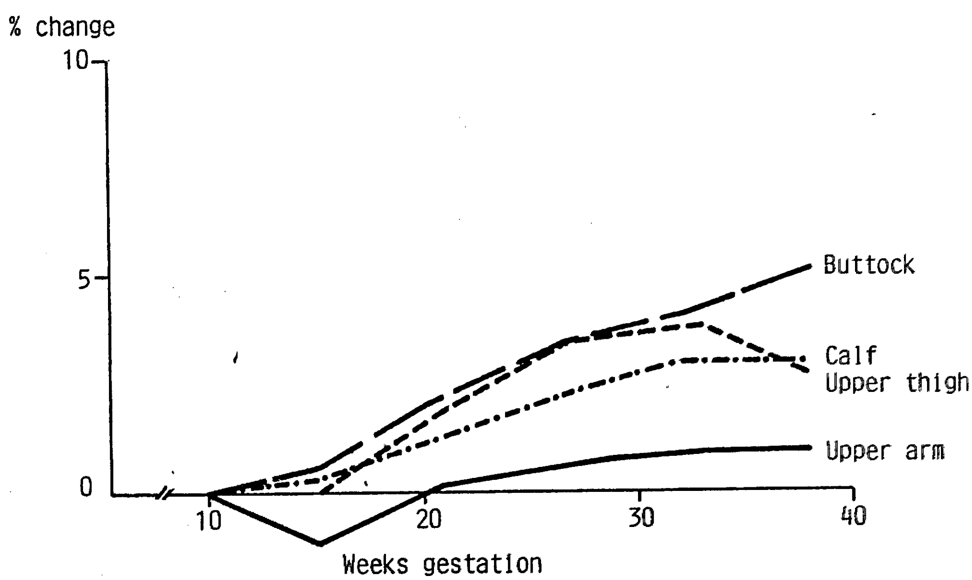
In this study, the weight gain measurement was done by using accurate and reliable weighing scales throughout pregnancy. There was no doubt about the result of weight change and weight gain of the women. Whereas there was no direct measurement of fat gain during pregnancy. Like in other previous study groups, fat was estimated using indirect method which was based on various assumptions depending on the method used.

However, skinfold thickness method is known to be a most simple method to use in the field situation and yet provide a good estimation of body fat in men and in

Fig.5a Changes of skinfolds thickness during pregnancy



Fib.5b Changes of circumferences during pregnancy



nonpregnant women (Durnin & Rahaman, 1967). So far there is no study that validate the method of fat estimation using skinfold thickness in pregnant women. Other method of fat estimation i.e. total body water and body density also prone to error due to the problem of water retention which is known as a common physiological change during pregnancy. If the amount of excess water could be estimated by using total body water method and use this total body water to adjust for the error of under water weighing method, this might be the solution of the best estimation of fat gain during pregnancy.

CHAPTER 4

4.1 THE ROLE OF BMR IN PREGNANCY

4.1.1 Definition

BMR is known as the key determinant for the estimation of energy requirements in different age groups. The FAO/WHO/UNU Expert Consultation on Energy and Protein Requirement (1985) stated that whenever possible, estimates of energy requirements should be based on the measurements of energy expenditure rather than energy intake. The committee also decided that there would be many advantages in expressing the various components of total energy expenditure as multiples of the BMR. As a consequence, great importance is attached to obtaining a reliable estimation of BMR.

However, this way of calculating energy requirement may not be appropriate for pregnancy and lactation due to the fact that there is a physiological change in maternal and fetal tissue synthesis during pregnancy and the energy required to produce milk during lactation. The way of estimating energy requirement is therefore different from nonpregnant women. BMR, however, is still an important factor as the theoretical increment of BMR during pregnancy is responsible for about half of the total energy requirement.

As stated by Hytten & Leitch (1971) and Hytten and Chamberlain (1980), the nutritional cost of pregnancy is composed of two main components. Firstly there is the energy equivalent of the protein and fat accumulated in the fetal and maternal tissues. Secondly, there is the energy cost of maintenance of these new tissues, the cost of increased material efforts (e.g. cardiovascular and respiratory systems, the cost of expansion of the blood volume and the enlargement of the reproductive organs). The energy cost of the second component could be determined by the measurement of oxygen consumption of different tissues as a whole.

BMR is defined by Passmore & Durnin (1967) and Schutz(1984) as the rate of energy expended in the postabsorptive state and under highly standardized conditions.

- at complete physical rest (immobile), lying down shortly after being awakened
- in a thermoneutral state
- 12-14 hours after the last meal (viz. post-absorptive)
- awake, at sexual repose and emotionally undisturbed
- without disease or fever

During the measurement, the subject has to be emotionally undisturbed and fully awake.

Due to these highly standardized conditions involved in the measurement of BMR, Resting Metabolic Rate (RMR) was introduced. RMR is defined as the rate of energy expenditure at rest measured under nonstandardized conditions, i.e. not in the postabsorptive state, lying down or comfortably sitting down, some hours after a meal (generally variable in composition), with possible previous physical activities. Therefore, RMR must be greater than BMR primarily because the dietary induced thermogenesis is included in the RMR measurement (Schutz, 1984).

Some other investigator, for example Dauncey (1979) preferred to use the term RMR to represent the classical term BMR, as he stated that condition of BMR measurement is difficult to obtain. In order to standardize the method, RMR should be used instead of BMR. With the reasons that the standard procedure of BMR measurement requires the subject to be mentally and physically at rest that even the subjects themselves can not be certain that this is achieved, hence standard conditions are virtually impossible. In addition, the measurement might have the effect of the last meal, though the subjects are asked to fast for 12-14 hours, this period might not be long enough. Dauncey therefore suggested to use the term RMR instead of BMR provided that, the conditions under which the measurement is made should be as close as possible to those for BMR, and it is essential that the method used is standardized and clearly stated.

Nevertheless, the classical term BMR is still preferable as the condition of RMR measurement, as stated by Schutz (1984), is not highly standardized and is quite flexible. The term used to represent the maintenance energy expenditure in the body might confuse the reader whether or not the measurement is done in a hightly standardized condition. This problem of adopting the term BMR or RMR can be solved by providing a full description of how the measurement is obtained.

4.1.2 Theoretical calculation of BMR increment

In order to cope with maternal changes during pregnancy, oxygen is needed for the products of conception, the enlargement of the breasts, etc. and also for the increased work load of the heart, lungs and kidneys. Therefore, serial measurement of oxygen consumption at different stages of pregnancy would represent the amount of oxygen needed in pregnant women. Hytten & Leitch (1971) reviewed previous studies of oxygen consumption in pregnancy and found that the previous published studies were unsatisfactory. This was because - the results showed a percentage of change in a wide range; only a few measurements were performed in the early stages of pregnancy; problems of nonstandardized methods of BMR measurement; and only a small number of pregnant women were studied serially. Hytten & Leitch, therefore, calculated basal metabolism in pregnancy by estimating the extra oxygen consumption of different tissue systems which were responsible and involved in pregnancy, i.e. cardiac output, respiration, uterine muscle, placenta, fetus, breasts, etc. Later the kidney reabsorption was also considered in this calculation (Hytten & Chamberlain, 1980). The cost of oxygen consumption for different tissues were estimated either in vivo or in vitro from different studies. The incremental calculation of oxygen consumption at different gestation age is shown in Table 13.

Increase in metabolism requires increase in oxygen supply; the requirement is met by increasing the ventilation, i.e. increasing the volume of air move in and out of the lungs per minute and increasing in the cardiac output, i.e. increasing the blood flow through the lung and to the body tissues.

Table 13 The extra components of oxygen consumption in pregnancy*.

Source of extra energy output	Increment of O_2 consumption (ml/min)			
	Weeks of gestation			
	10	20	30	40
Cardiac output	4.5	6.8	6.8	6.8
Respiration	0.8	1.5	2.3	3.0
Uterine muscle	0.5	1.2	2.2	3.6
Placenta	0	0.5	2.2	3.7
Fetus	0	1.1	5.5	12.4
Breasts	0.1	0.6	1.2	1.4
Kidneys Na^+ reabsorbed	7	7	7	7
Total ml/min.	12.7	18.7	27.2	37.9

* Ref. (from Hytten & Chamberlain, 1980).

During pregnancy, the demands for an increased flow of blood to different organs are met mainly by increasing the cardiac output. This results from an increase in heart rate and stroke volume. The increase in heart rate is present from early pregnancy and increased by about 15 beats/minute by the end of pregnancy. Stroke volume also increases but to a smaller extent than heart rate. Increased cardiac output itself results in an increase in oxygen consumption due to the extra work by the heart and lungs.

Distribution of cardiac output during pregnancy is demonstrated in different involved tissues. Cardiac output to the uterus, which is the central target of the increased circulation, slowly rises in the first half of pregnancy and later markedly increases until term. Fot the kidneys and skin, the blood flow is increased for the purpose of eliminating the materials from the kidneys and eliminating of heat from the skin. The increased skin flow is an adaptation to the presence of the growing products of conception which produce heat that must be dissipated if the women's temperature is not to rise.

The increase in blood volume is an adaptation to supply the needs of the new vascular bed. Although the total number and volume of red cells increase by about 20 percent the plasma volume increases by about 50 percent. This is because the process of increased blood flow to the kidneys and to the skin require plasma rather than whole blood which explains the disproportional increase of plasma in the expansion of the blood.

Hytten & Leitch reviewed the studies involving the measurement of cardiac output in pregnancy in which the measurements were carried out with the subjects lying on their sides, even though the standardized condition of cardiac output measurement is in the supine condition. This will have some effect on cardiac output measurement due to the fact that the uterus seriously impedes venous return through the vena cava with a consequent fall in cardiac output. It was therefore previously belived that the cardiac output fell after the 36th week. But if the pregnant women are on their sides, the cardiac output will be found to be undiminished in late pregnancy. Hence, for the normal pregnant women at rest but not lying on her back, cardiac output rises 1.0 litre/min for the first 10 weeks and later by about 1.5 litre/min which stays constant throughout pregnancy.

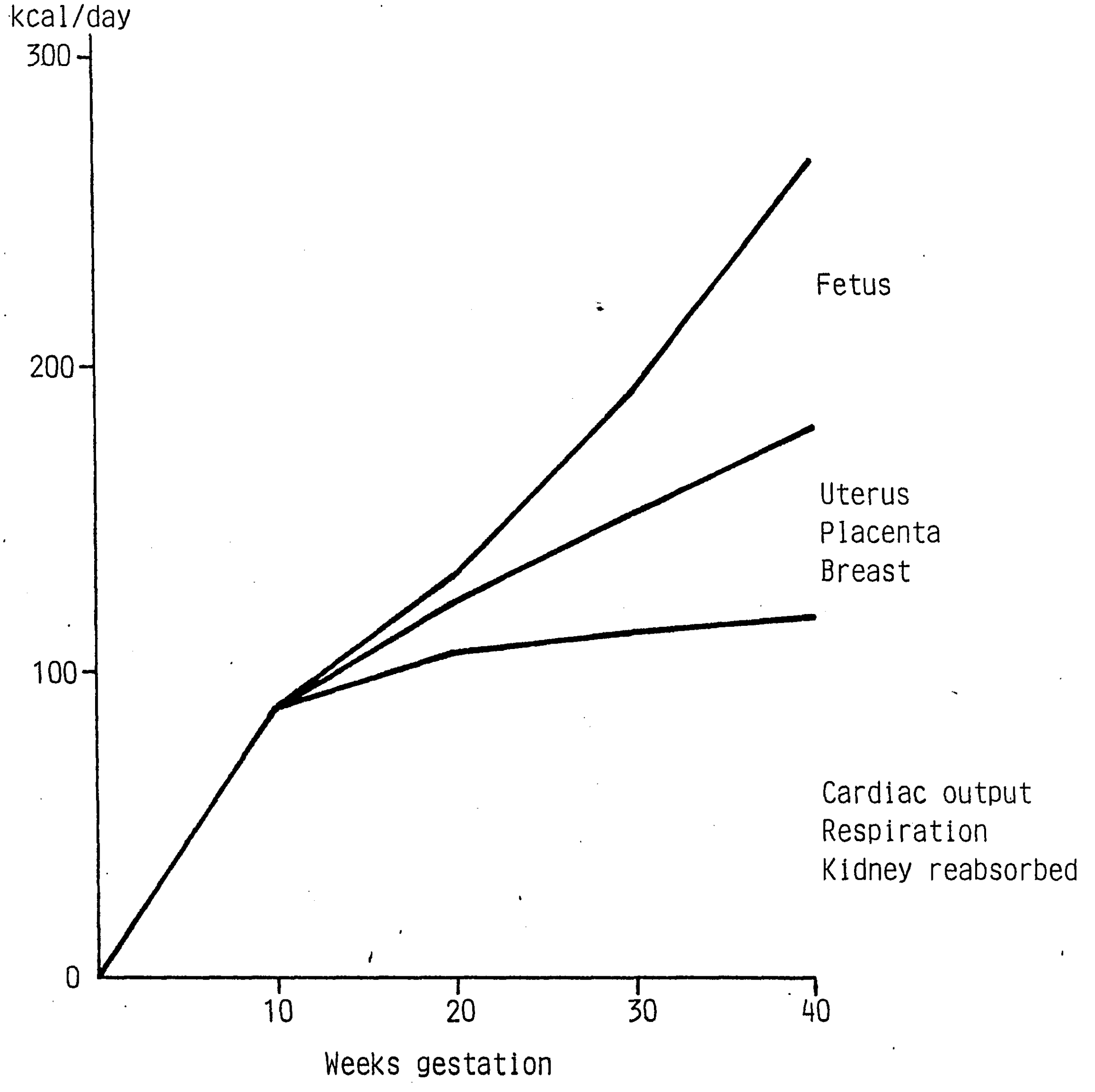
Another contribution to the BMR increment comes from sodium reabsorption in the kidneys. During pregnancy, there is a cumulative retention of about 150meqof sodium distributed between the products of conception and maternal extracellular volume. There is about a 30-50 percent increase in glomerular filtration rate during pregnancy resulting in an additional load of 3.5-7meq of sodium being filtered daily. Increased reabsorption occurs in the first 10 weeks of gestation and remains constant throughout pregnancy.

It is assumed by Hytten & Leitch that the fetus does not have any external surfaces and therefore does not need to maintain its own body temperature and has a metabolic rate comparable to that of the mother.

The placenta plays an important role in pregnancy. It enables the fetus to take oxygen and nutrients from the maternal blood then serves as the excretory organ of the fetus; carbondioxide and other waste products pass from the fetus to the maternal blood. The placenta forms a barrier against the transfer of infection to the fetus. In addition, the placenta secrets chorionic gonadotrophin, oestrogen and progesterone in large amounts and also other hormones, which play an essential part in the maintenance of the decidua and the growth of the uterus and breasts.

The cost of maintenance is calculated by Hytten & Leitch as shown in <u>Figure 6</u>. It is shown that during the first 10 weeks, about 95% of the BMR increment results from the increment of cardiac output, respiration and kidney reabsorption. The rest is from the increase in oxygen consumption in the uterus, placenta and the breast tissues. The increment in cardiac output, respiration and kidney reaborption is relatively small up to 40 weeks. Oxygen consumption due to fetus shows no increase during the first 10 weeks and slight increases up to 20 weeks. During the second half

Fig.6 Theoretical composition of BRM increment in different tissues.



of pregnancy, there is a marked increase in oxygen consumption due to the rapid growth of the fetus. The placenta, breasts and uterus, like the fetus, have a rapid increase in oxygen consumption in the second half of pregnancy. The total increment in BMR during the whole pregnancy results in 36,000kcal, of which only 15,900kcal contribute from 10 weeks until term. The bigger share which is about 20,100kcal is accounted for an early pregnancy i.e. from conception to 10 weeks.

In summary for the theoretical calculation of BMR increment during pregnancy, Hytten & Leitch calculated BMR increment purely on the assumption that the total increment of oxygen consumption in a whole body is simply from the combination of the increment of oxygen consumption in each and every tissue involved in pregnancy. This may or may not be true, since the effect of increase in oxygen consumption of one tissue might influence the increase in oxygen consumption in other tissues that will effect the total increment. So far this theoretical calculation has not been validated because of many difficulties involved. For example the changes of oxygen consumption for the whole body during pregnancy has to be done in a large number of subjects. The serially measurement is also needed as frequently as possible to pick up the changes at different stages of pregnancy. In addition, the method used for oxygen consumption has to be highly standardized and very well accepted by the subjects. Hence there is a need to quantify the total changes of oxygen consumption throughout pregnancy compared to the initial baseline at nonpregnant stages.

4.1.3 Evidence from actual measured BMR in pregnancy

Evidence from previous studies of BMR measurements showed an increase in the BMR during the second and third trimesters of pregnancy, i.e. the BMR was compared to the BMR measured at postpartum (Blackburn & Calloway, 1976a) or to the BMR measured in different groups of nonpregnant women (Khan & Belavady, 1973). The problem with BMR measurements during pregnancy is the difficulty in recruiting subjects at the prepregnant stage and following them up throughout pregnancy. Therefore, information on BMR changes in early pregnancy is very difficult to obtain.

Another major problem with BMR measurements during pregnancy is the frequency of measurement. Usually it is measured once in each trimester (Blackburn & Calloway, 1976a; Khan & Belavady, 1973; Forsum, Sadurskis, & Wager, 1985), or in one study a BMR measurement was performed in every 4 weeks only in the second half of pregnancy (Emerson, Poindexter & Kothari, 1974)

None of the previous studies were able to detect changes in BMR during the early stage of pregnancy or were able to make comparisons of the BMR during pregnancy to the prepregnant BMR of the same group of women. The increase in BMR in early pregnancy, particularly from conception to 10 weeks as calculated by Hytten & Leitch (1971) contributed almost 60% to the total increment of BMR for the whole pregnancy. It is therefore, crucial to know the change in BMR during this early period of pregnancy.

In spite of the difficulty in recruiting subjects in the prepregnant state and following up throughout pregnancy, some findings were reported from different study centers who successfully provided complete information on the change of BMR from preconception until term. Those findings are as follows:-

1. As a part of multicenter longitudinal study of energy requirements in pregnancy, Durnin et al., (1985) reported the finding of BMR changes in 67 pregnant women from Glasgow. Although the women were recruited as soon as they knew they were pregnant, the earliest data point of the change of BMR was about 3-4 weeks gestation. The women had their BMR'S measured at varying time intervals, i.e. - every 6 weeks, 4 weeks or 2 weeks. The combined results of these Glasgow pregnant women showed a fall in BMR during early pregnancy which then started to rise at about 13 weeks gestation until term. This finding was contradicted with the theoretical BMR change by Hytten & Leitch who assumed that there was a marked increase of BMR in early pregnancy.

2. An initial drop in BMR after conception was also demonstrated in both supplemented and unsupplemented group of 52 rural Gambian women (Lawrence et al., 1984). The drop of BMR was more pronounced in unsupplemented than in supplemented women. In the unsupplemented group, there was a significant drop in BMR at 10 and 25 weeks compared to the BMR at conception. From 25 weeks gestation BMR increased until term. The percentage increase in BMR at term compared to conception was only 8 percent (compared to a 20 percent increase in theoretical calculation by Hytten & Leitch).

In the supplemented group, though there was a slight drop in BMR in early pregnancy, it increased at about 10 weeks gestation and there was a significant difference in the BMR measured at term between the unsupplemented and supplemented groups. Hence the cumulative extra cost of tissue maintenance in rural Gambian women was only 1,000kcal and 13,000kcal in unsupplemented and supplemented group respectively.

3. In response to Lawrence's publication, Forsum, Sadurskis and Wager (1985) demonstrated a RMR increment during pregnancy in 19 Swedish pregnant women. The results showed a gradual slight increase in RMR during the first half of pregnancy less than that of Hytten & Leitch's and a marked rise in RMR in the second half. The total RMR increment in the Swedish study was 46,500kcal which was higher than theoretical value. Compared to the Glasgow study, the pattern of RMR increment was similar, except the Swedish group showed a steeper rise during the second half of pregnancy.

The number of subjects in the Swedish study however was rather small compared to the other two studies mentioned above. Because of the individual variation of RMR, the small group of subjects may not represent the actual increase of RMR. Furthermore a high value of the total increment of RMR might result from the method adopted for oxygen consumption measurement possibly as not highly standardize as BMR. The authors did not state clearly the exact method used for their study. The results, therefore, are still uncertain.

In general, it can be concluded from the data from these 3 different centers that the pattern of change in BMR differed from one population to another, but dit not increase markely from conception to 10 weeks as predicted by Hytten & Leitch (1971). The total increment of BMR during pregnancy varied from 1,000kcal in unsupplemented Gambian women to 46,000kcal in Swedish women.

In some studies, the auther expressed the change of BMR as percentage increase compared to the initial measurement, for instance, rate of BMR increment was found to be different during early and late pregnancy as shown by Nagy & King (1983). The authors found that the BMR increment during early pregnancy (10-20 weeks) was 13 percent higher than in the nonpregnant state and the increment during late pregnancy (30-40 weeks) was 28 percent higher than that of early pregnancy. This study supported the findings in other studies mentioned above that there was a higher increase of BMR during the second half of pregnancy compared to the first half of pregnancy.

Blackburn & Calloway (1976a) conducted the study of BMR increment in 21 pregnant women and found that BMR was increased in the second and third trimester in terms of kcal/min, but when it was expressed in terms of cal/kg/min, BMR was constant and then declined before term. After the delivery there was a marked drop in BMR both in terms of kcal/min and cal/kg/min. Blackburn & Calloway (1976a) also found that the BMR measured postpartum was not different from BMR measured in nonpregnant women, therefore the BMR of these two groups were combined and used for the comparison of the change in BMR during the second and third trimesters. The BMR increment was shown to be 21 percent higher at 20-28 weeks compared to the postpartum value. The BMR increased another 15 percent at 29-36 weeks compared to 20-28 weeks, yet showed a constant value of BMR per unit body weight.

Percent increase of BMR varies from one study to another. For example, in

India, Dakshayani (1964) showed an increase of BMR to be 12.2 percent in the third trimester while Khan & Belavady (1973) showed an increase to be 8.1 percent and 15.1 percent in the second and third trimester respectively in 1OO low socioeconomic pregnant women. The increment of BMR was apparently lower than the 20 percent stated by Hytten & Leitch (1964).

Banerjee Khew & Saha (1971) conducted a study in Chinese, Malaysian and Indian women. He showed that BMR increased 27 percent while body weight increased by only 13 percent. Therefore when BMR was expressed per unit body weight, the results showed an increase in BMR which was apparently different from Blackburn & Calloway's study (1976a). Banerjee concluded that BMR was independent of the change in maternal body weight.

4.1.4 BMR, body weight and lean body mass

In studies of BMR, there is a controversy whether lean body mass or fat mass has the greater influence on BMR. Garrow (1978) discussed the study of Halliday et al. (1978) in 22 obese women by looking at the multiple regression of lean and fat mass on BMR. They found that lean body mass made a greater contribution to metabolic rate than did fat mass. Garrow also mentioned that this finding corresponds with the explanation of why women have lower metabolic rates than men, or old people have lower metabolic rates then young people.

The FAO/WHO monograph on energy and protein requirements (1973) stated that "resting metabolic rate is correlated to the fat free mass". As a result, the resting metabolic rate of an obese person when expressed in relation to gross body weight is usually lower then that of a thin person.

Schofield, Schofield & James (1985) reviewed the past 50 years data on predicting BMR. The available data from developing countries showed that the subjects were not only smaller and had lower metabolic rate but also had lower rate per unit body weight than European and North Americal subjects. Widdowson (1985) agreed that in cases of severe energy deficit, when not only fat loss occurs but also a loss in lean body tissues, there is a decrease in BMR both in absolute terms and in per unit body weight. There is a loss of metabolizable material and an increase in the percentage of water, which is all extracellular fluid. This will have the effect of lowering the oxygen consumption per kg of the whole body, even if the oxygen consumption of the active cell mass is not reduced.

In moderate undernutrition, however, BMR per unit body mass is not significantly reduced. One explanation that has been suggested is that fat is lost first and this has a smaller influence on metabolic rate than the lean tissues.

During pregnancy, Blackburn & Calloway (1976a) compared and discussed BMR and standard activity in mature pregnancy and adolescent pregnancy (Blackburn & Calloway 1974). There was no difference of metabolic rate in absolute terms but adolescent pregnant women showed a higher BMR per unit body weight than in the mature group. However BMR per unit lean body mass was the same. The authors suggested that the difference was due to a higher percentage of fat in the older women. As the percentage of fat increases, a lower BMR per unit body weight was seen in the mature group.

4.2. METHOD OF BMR MEASUREMENT

BMR or RMR measurement can be done by either direct or indirect calorimetry. In direct calorimetry, the individual is put inside a specially constructed calorimeter and the direct heat output of the individuals is measured. Much of the classical and fundamental work on energy metabolism was done in this way, in particular, the excellent and distinguished studies of Atwater and Benedict (1899). The use of this technique with a properly constructed calorimeter incurred no appreciable error in the actual measurement. Nevertheless, there are considerable disadvantages, such as the length of time necessary for the measurement and the high cost of running the experiment. Therefore indirect calorimetry was introduced to measure an individual's heat output and oxygen and carbondioxide exchange. This involved a shorter time period, varying from 10-30 minutes. There are several indirect methods which are used for BMR measurement such as a close circuit method (respiratory chamber or Benedict-Roth spirometer) or an open circuit method (Douglas bag method). These methods will be discussed later in the next chapter.

The Douglas bag method is one of the most common used for BMR measurement, because of its simplicity and accuracy. The subject breaths in atmospheric air and the expired air is collected in a Douglas bag. (The amount of oxygen and carbondioxide present in the atmospheric air is constant, i.e., oxygen 20.93 percent and carbondioxide 0.03 percent).

The expired gas is collected in a 100 litre or 150 litre Douglas bag during the timed experimental period by means of inspiratory and expiratory valves. The volume of the expired gas is measured, and the oxygen and carbondioxide content in the expired gas are analyzed either by chemical means (Scholander or a Lloyd-Haldane), or by using analyzers which depend upon certain physical characteristics of the gases. Wier (1949) suggested the simplified calculation which required only the determination of the volume of the expired air and its oxygen content.

$$E = \frac{\dot{V}}{20} \times (20.93 - O_2)$$

E = energy expenditure (kcal/min)

$\dot{V}$ = the volume of expired gas in litre/min at STP

O_{2e} = percent oxygen in expired gas

As this method does not require carbondioxide measurement and the error of not estimating carbondioxide is negligible, the calculation of energy expenditure base on Wier's formula is strongly recommended.

4.3 BMR MEASUREMENT IN THIS STUDY

4.3.1 Procedure of BMR measurement

BMR measurement must be carried out under standardized conditions because measurement is that the measurement should be measured shortly after being awake. With respect to this condition of BMR measurement, the women have had to come and stay overnight at the research center. In order to be able to do the BMR measurement early in the morning shortly after wakening up. This was impractical because the women had to take care of their children at home. Therefore, an experiment was carried out to compare the BMR measurement shortly after waking in their houses and the BMR measured in the lab by which the women could perform some light housework. The procedure, however, was the same, i.e. the women rested for 30 minutes prior to the measurement. The result is shown in Table 14a.

The results showed a slightly higher BMR measured at home than at the lab but not significantly different. This might be due to the fact that the measurement at home was performed in uncontrolled environmental conditions. For example, the BMR was measured in the bedroom which they shared with their children. It is possible that the women were not completely relaxed, whereas the measurement in the lab was carried out in a controlled quiet room with no interference from outside. BMR measuring in the lab was therefore acceptable.

4.3.2 Habituation effect

The habituation effect of the BMR measurement was also carried out in 21 pregnant women who came to the lab at their first visit for 2 consecutive days. Although the women were shown the apparatus and tried on the nose clip and the mouthpiece at the time of recruitment, they tried them on very briefly and not for 15-20 minutes as in the real measurement. The results of the BMR comparison of the first and second day (Table 14b) showed no difference of BMR in absolute terms and when expressed per unit body weight.

Therefore no habituation effect in the BMR measurement was found in this study, in spite of the subjects being unaccustomed to the apparatus used at their first measurement. In addition, the results of the measurements made immediately after

Table 14a Comparison of BMR in 13 women measured at home and at the laboratory ($\bar{X} \pm SD$)

	At home	At the laboratory
O_2 consumption (l/min)	0.187 ± 0.014	0.184 ± 0.180
BMR (kcal/min)	0.927 ± 0.072	0.900 ± 0.072
BMR (cal/kg/min)	18.35 ± 2.31	17.83 ± 2.52

Table 14b Comparison of energy cost of BMR in 21 pregnant women in two consecutive days ($\bar{X} \pm SD$)

	First day	Second day
O_2 consumption (l/min)	0.181 ± 0.021	0.181 ± 0.024
BMR (kcal/min)	0.880 ± 0.106	0.883 ± 0.111
BMR (cal/kg/min)	18.65 ± 1.98	18.64 ± 2.17

they woke up or about 1-2 hours later, were very similar. The result indicated that BMR measurement can be performed satisfactorily in 1-2 hours after awake, provided that physical activity was kept to minimum and the women rested for 30 minutes prior to the measurement.

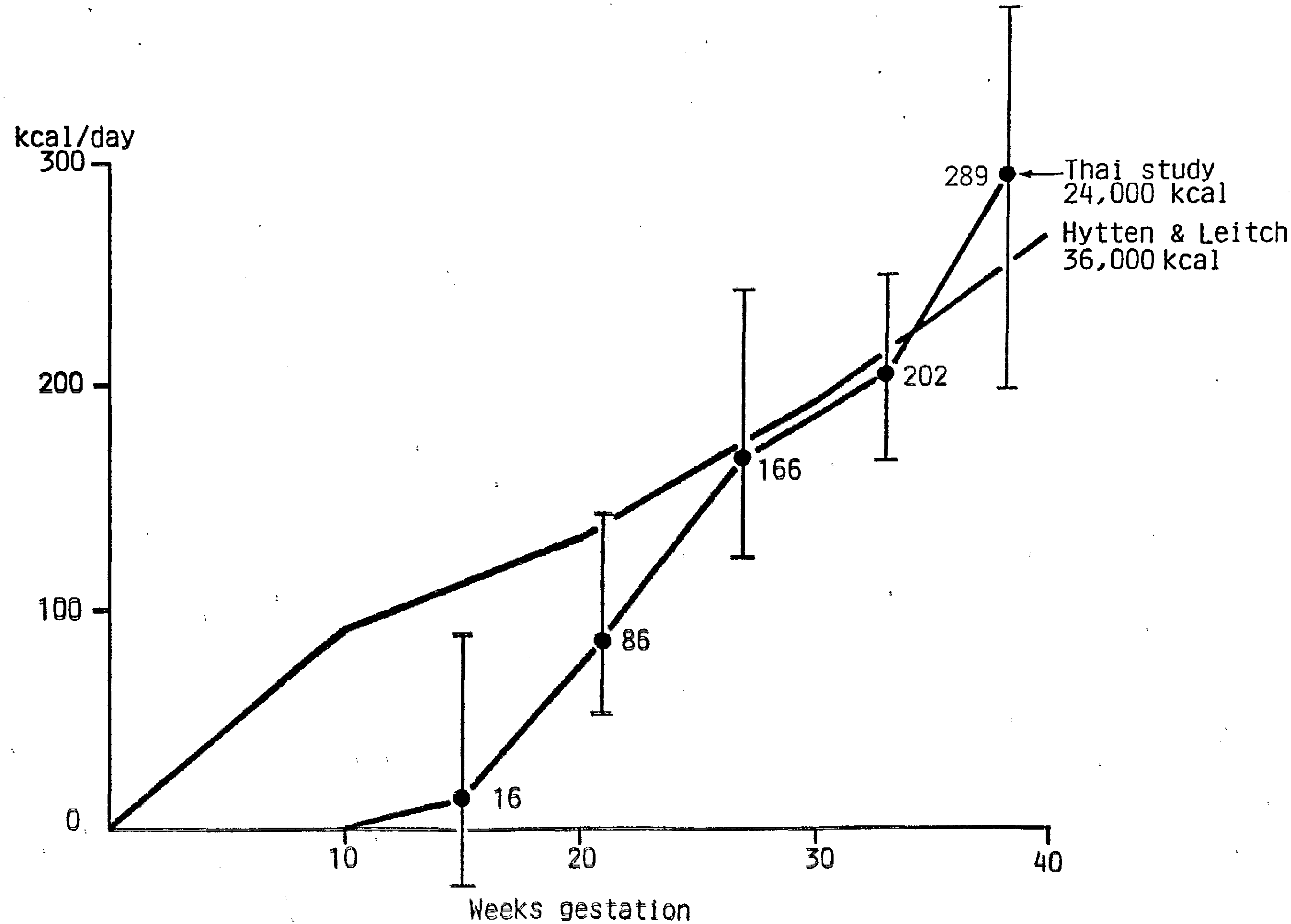
4.4 RESULTS AND DISCUSSION

4.4.1 Increment of BMR from 10 weeks until term

As mentioned earlier, the BMR was first measured at about 10 weeks gestation. Therefore the increment in BMR in the Thai study was considered from 10 weeks until term. Figure 7 demonstrates the comparison of BMR increment in this study with the theoretical estimated BMR increment from Hytten & Leitch. The theoretical BMR increment calculated by Hytten & Leitch showed a marked increase at the rate of 1.29kcal for the first 10 weeks and 0.83kcal for the rest of pregnancy. In the Thai study, there was a slightly increased rate from 10 to 15 weeks (0.46 kcal/day). Later from 15 weeks until term, there was a linear increment in BMR at the rate of 1.7kcal which was higher than that of Hytten & Leitch. The theoretical value for BMR increment from conception until term was 36,000kcal whereas BMR increment from 10 weeks until term in the rural pregnant Thai women was 24,000kcal.

During the second half of pregnancy (from 20 weeks until term), the increment of BMR was higher in the Thai study than the theoretical value. There is some evidence that the metabolic rate of new born babies is higher than estimated by Hytten & Leitch which would account for their lower increase in BMR at term. Ryser & Jequier (1972) used the direct calorimeter to measure the metabolic rate of new born babies and found that it was 6.0ml/kg/min. Therefore, for a mean birth weight of 3.4kg, the metabolic rate would be 20.4ml/min which was almost double the theoretical total oxygen consumption from Hytten & Leitch of 12.4ml/min.

Fig. 7 Comparison of BMR increment from 10 weeks until term in the Thai study (median and confidence limit) and from conception (Hytten & Leitch, 1964)



4.4.2 Individual variation of BMR

The individual variation in BMR in this study was found to be quite large. The initial measurements ranged from 0.7-1.1kcal/min. On a body weight basis, BMR ranged from 13-22cal/kg/min with an average 18.4 $\pm$ 2.4 (SD) and on an active cell mass basis, BMR ranged from 18-28cal/kg fat-free mass/min with an average at 10 weeks 24 $\pm$ 2.7 (SD).

BMR values differed not only in the change from the initial values, but BMR increments also showed different trends of change. For example, when the volunteers were grouped into those with initially low BMR's (<0.8kcal/min) and initially high BMR's (>1.0kcal/min), the results showed different patterns of BMR increments in the two groups as shown in Figure 8. For the initially low BMR group there was a marked increase from 10 to 15 weeks and then a drop at 21 weeks. A substantial increase was found after 21 weeks until term. For the initially high BMR group, there was no change in BMR up until the beginning of the third trimester. The common feature found in this total group of pregnant women and these subgroups was that BMR was markedly increased during the third trimester.

Though the number of volunteers in these two groups are rather small, the result could show the trends of BMR changes during pregnancy. The initially high BMR group might have some metabolic adaptation which meant that BMR did not increase until the last trimester. These results were confirmed by the Glasgow study - that is, most of the BMR increment occurred in the second half of pregnancy (Durnin et al., 1985). In the Gambian study, BMR increased in the last trimester in both supplemented and unsupplemented women (Lawrence et al., 1984). These Gambian women showed a reduction of BMR in the first trimester and then rise to the conception level during the last trimester.

The individual changes of BMR during pregnancy when compared to their own BMR at 15-24 months postpartum value is shown in Figure 9. The dotted line

Fig.8 Comparison of the increment of the initially low BMR group and the initially high BMR group (median and confidence limit)

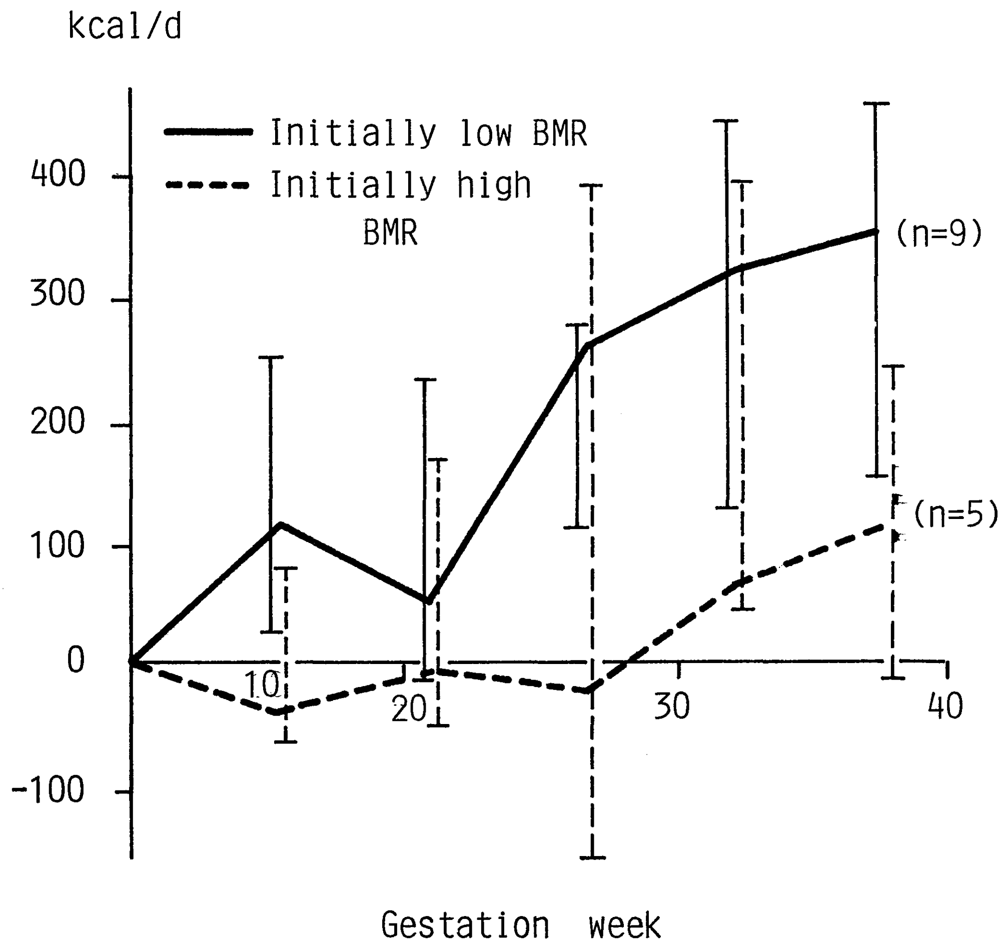
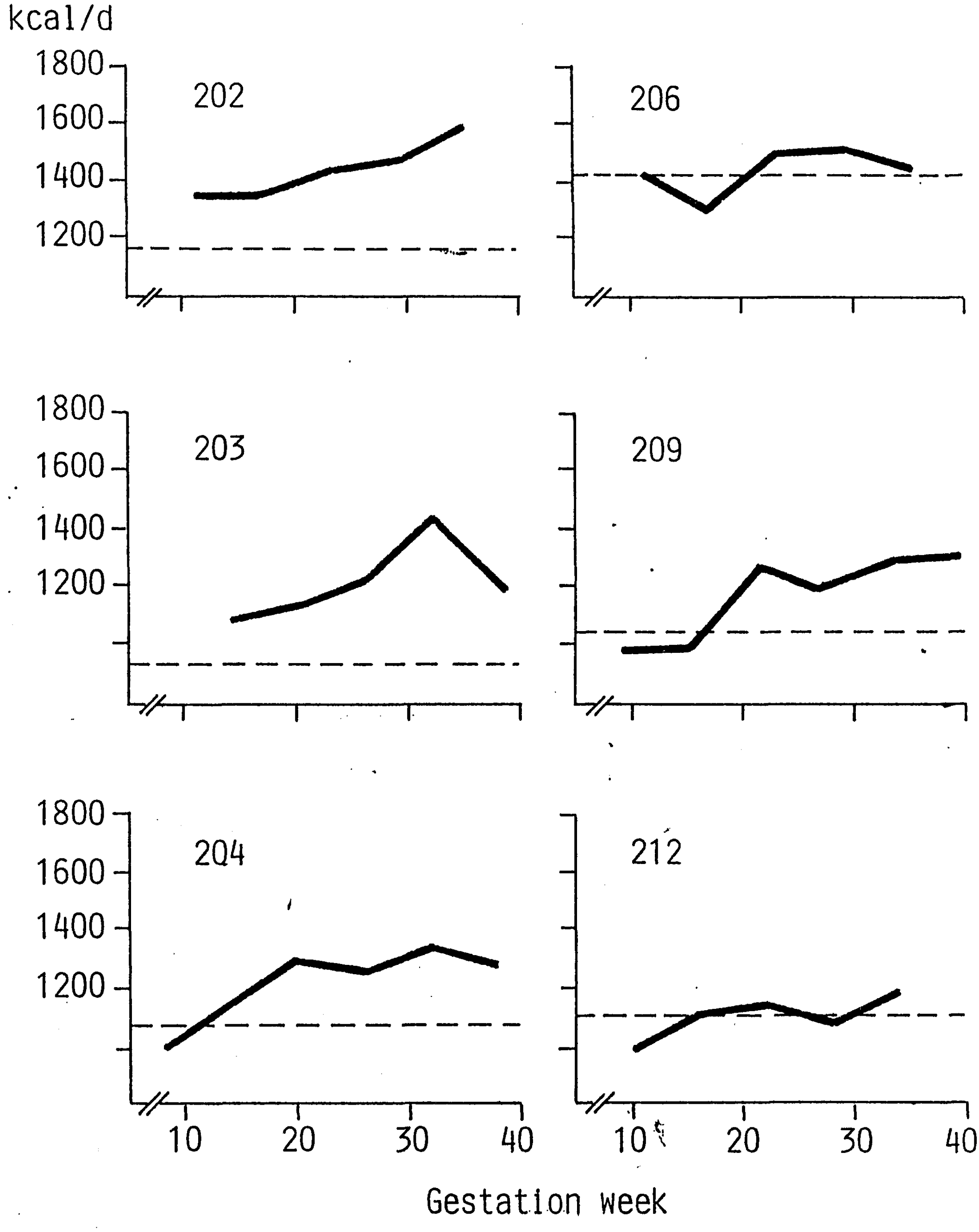


Fig. 9 Changes of individual BMR during pregnancy compared to the postportum BMR at 15-24 months.



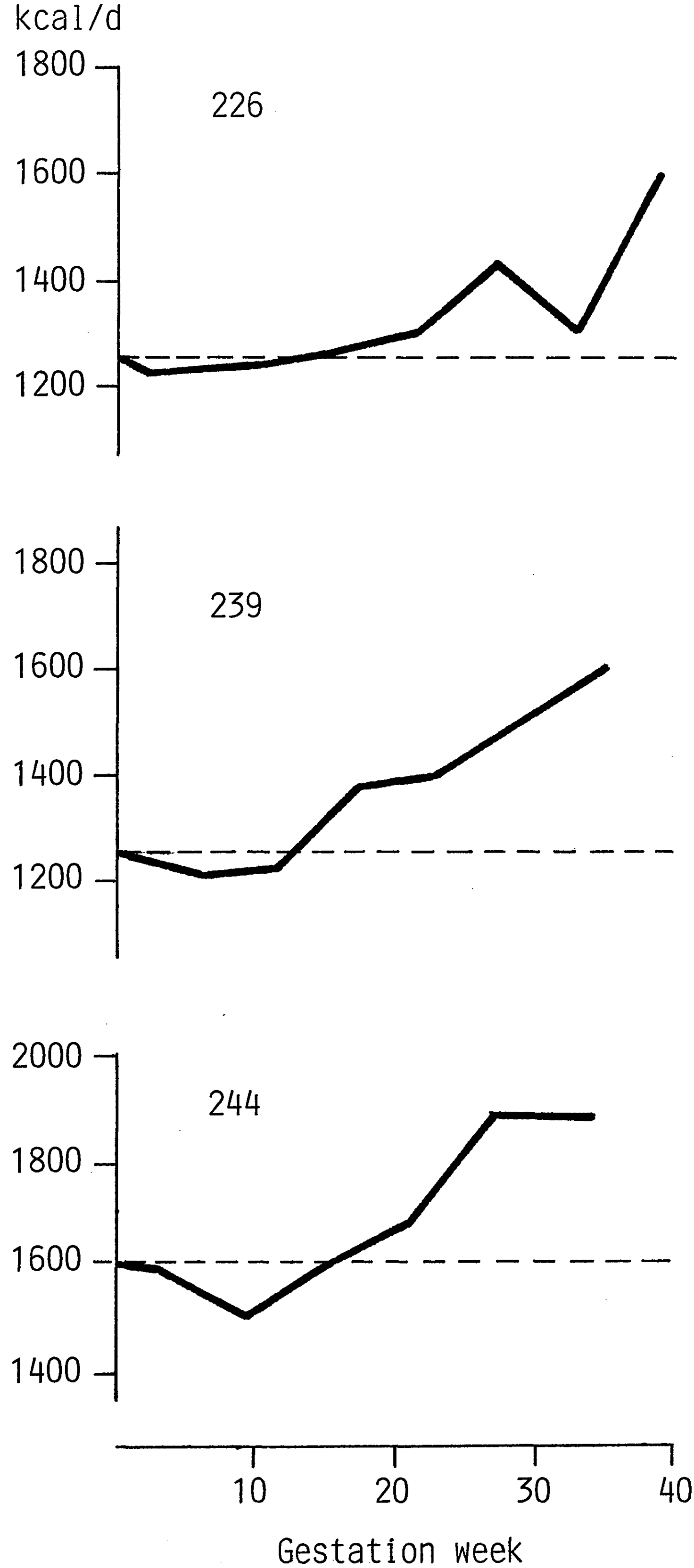
represents the average individual BMR measured twice at monthly intervals and was assumed to represent the prepregnant BMR value. This is because it is about the time that the women conceive for the next baby. At this period the rural women still breastfed the baby. It was common practice for the women to breast feed the baby until they knew they were pregnant again, when they weaned the baby. Therefore in this society the nonpregnant-nonlactating situation in women is difficult to obtain.

BMR of each individual showed a different pattern of change. For example, some of the women demonstrated a marked increase in the first measurement, of about 13-16% (#202,203) whereas some of the women demonstrated a decrease of about 4-9% (#209,204 & 212). Volunteer #206 showed no change in BMR at about 10 weeks compared to the BMR thereafter measured at 15-24 months, thereafter there was a drop in BMR of about 6%, which then increased gradually during the second half of pregnancy. All the women showed a gradual increase of BMR above the baseline value except #212 whose BMR dropped at about 10 weeks and then rose to the baseline level at about 16 weeks. During the second trimester there was no change in BMR and thereafter BMR started to rise until term.

Volunteer #203 demonstrated a gradual increase in BMR up until 26 weeks and then it rose steeply at 32 weeks and later dropped markedly at term. This was an unusual pattern of change. One explanation would be that the women might have had food before they came for the BMR measurement at 26 weeks which would increase their metabolic rate. However these results were not excluded, as no satisfactory explanation was apparent which would invalidate these measurements. It is probable that technical errors are not responsible for this unusual result.

The changes of BMR from preconception throughout pregnancy was demonstrated in 3 individual women as shown in Figure 10. The patterns of change are similar, i.e. no change of BMR after conception except for one woman (#244) who showed a slight drop in BMR in early pregnancy, and later increased in the

Fig.10 Changes of individual BMR of women measured before conception.



second and third trimester. This women'also showed a higher absolute value of BMR compared to the other two women, which illustrates the wide inter-individual variability. Although the number of observations was rather small (n=3), the results suggested the trend of little change of BMR during early pregnancy.

Other evidence that might support this was obtained from the comparison of a group of 8 women who were measured at about 10 weeks gestation and later at about 15-24 months postpartum (the approximate time of the next expected conception), no changes in BMR were observed as shown in Table 15. The body weight of the women at 15-24 months was significantly higher than at 10 weeks gestation ($p<0.01$). This higher body weight in nonpregnant group (some of them still lactated the babies) might be the result of their higher energy intake which partly contributes to the energy required for milk production for the baby. Total daily energy expenditure was compared and there was no difference in these two periods.

4.4.3 BMR in relation to body weight

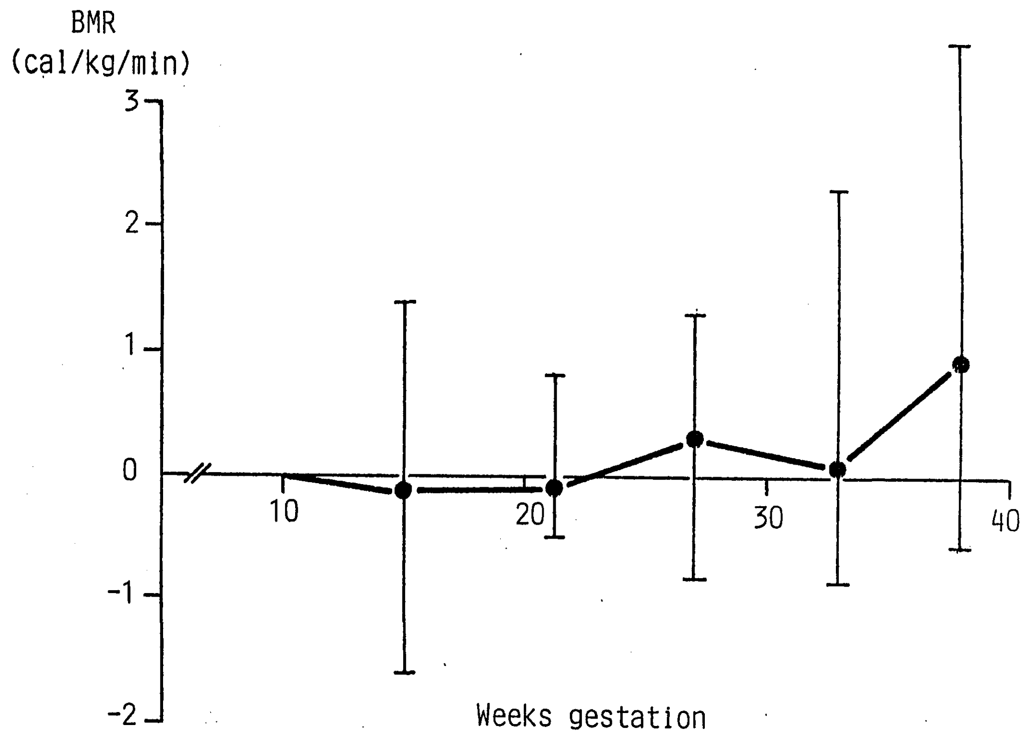
Although there was an increase in BMR in absolute terms, no change of BMR expressed per kilogram body weight was found in this study except at term as shown in Figure 11 This finding indicated that the tissue laid down during pregnancy had a metabolic rate similar to maternal tissues. During the third trimester, however, the increase in BMR was probably higher due to increased fetal growth or activity near term. This is confirmed by direct calorimetry measurements of the new born baby (Ryser & Jequier, 1972).

Mean BMR per unit body weight of this group of women was 18cal/kg/min. This value was higher than those measured in developed countries where BMR/kg was found to be 15cal/kg/min. (Durnin et al., 1985; Forsum, Sadurskis & Wager, 1985; Blackburn & Calloway 1976a). In the developing countries, where the women showed a comparable stature to this group of women BMR per unit body weight showed a similar result., 17-19cal/kg/min (Lawrence et al., 1984; Khan & Belavady 1973; Barba & Tauson 1986).

Table 15 Pairwise comparison of BMR at 10 weeks gestation and 15-24 months postpartum of 8 women (mean ± SEM)

	10 weeks gestation	15-24 months postpartum
BMR (kcal/d)	1266 ± 44	1282 ± 29
Body weight (kg)	46.1 ± 1.0	48.3 ± 1.6
BMR (cal/kg/min)	19.2 ± 0,8	18.6 ± 0.7
Energy intake (kcal/d)	1875 ± 107	2307 ± 157
Energy expenditure (kcal/d)	1833 ± 77	1799 ± 44

Fig. 11 BMR increment per unit body weight, (median, confidence limit).



Even though it is quite common to express BMR per kilogram body weight, the expression per unit lean body mass may give a better estimation of total metabolically active tissues. In this study, fat mass was estimated using skinfold thickness measurements at different stages of pregnancy. Since there were problems with the estimation of fat mass during pregnancy, particularly during the third trimester the comparison of BMR per unit of fat free mass has not been attempted.

It can therefore be concluded from this study that BMR markedly increased and demonstrated a different pattern of increment, from the data obtained by Hytten & Leitch, i.e. BMR slightly increased at 10 to 15 weeks and thereafter a marked consistent increase until term whereas Hytten & Leitch showed a marked increase during early pregnancy and a more gradual increase until term. Total increment in BMR in this study was 24,000kcal from 10 weeks until term.

BMR in the pregnant rural Thai women did not seem to decrease at any stage of pregnancy as would have been expected if maternal adaptation had taken place. A vital aspect of this kind of study is the baseline BMR. The baseline BMR at 10 weeks might already be lower than the BMR at conception. If this was the case, i.e. adaptation by lowering the BMR right after conception, implies that the BMR at 10 weeks would be lower than the BMR at conception hence result in a higher increment of BMR than what actually occurred overall.

On the other hand if the BMR baseline at 10 weeks was real and the increment of BMR from conception until 10 weeks followed the pattern of theoretical increment of BMR, the 10 weeks baseline would already be higher than that at conception and result in an under-estimation of total BMR increment in this study.Hence no firm conclusions can be drawn from the total increment of BMR during pregnancy in this study, but only the increment from 10 weeks until term.

CHAPTER 5

5.1 RATIONALE FOR MEASURING TOTAL ENERGY EXPENDITURE

Energy requirement can be determined by either energy intake or energy expenditure. In developed countries, where the food is abundantly available, measurement of energy intake is the preferred method of determining energy requirement, because the measurement of energy expenditure in free living population is difficult, labourous and expensive and can be done only on relatively small numbers of individuals. However, in developing countries, if only food intake is measured, true energy requirement may not be obtained. When energy expenditure is measured, better information will be obtained (Durnin 1983). For example, the work situation for a large majority of people both men and women is the critical factor for maintaining their living standard. Energy may be expended for occupational activities such as in subsistence farming, paid labouring, caring for the household, etc. to such a degree that there may not be sufficient energy leftover for any desired leisure activity. In such cases, measurement of the energy expenditure should cover an acceptable allowance for non-occupational activities as well (Durnin 1983; FAO/WHO/UNU 1985, Keller 1983).

The measurement of energy expenditure is not only a useful piece of information in an energy requirement study but also helps to assess the effect of food supplementation. This is because the information indicates that total energy expenditure may have increased during work and also whether or not total changes have taken place in the type and duration of leisure activities. Energy expenditure measurement therefore gives a better picture of energy requirement than the measurement of energy intake alone.

The FAO/WHO/UNU Experts consultation on Energy and Protein Requirement (1985) has modified the energy requirement in different age and sex groups based on energy expenditure measurement. Energy needs vary with the type of occupation, the time spent in doing the task, and the size of the individuals concerned. The calculations of energy expenditure are multiples of the BMR. Predicted BMR is calculated based on the age, sex and size of the individuals. The metabolic cost of various activities is divided into occupational and discretionary activities. The first category needs an adequate description of the occupation. For example, the metabolic cost of agricultural activity in developed countries differs from that of developing countries due to the degree of mechanization involved in the task, etc. The second category (discretionary activities) is also important and desirable for the well being of the community and the health of the individual and the population.

During pregnancy, however, physical activity also plays an important role in determining the energy expenditure and therefore the energy requirement. This is because the extra energy requirement in pregnancy depends on the extent to which mothers can and do reduce their physical activity (FAO/WHO/UNU 1985).

In the developed and developing countries, changes of energy expenditure pattern and magnitude during pregnancy may be somewhat different due to the way of living. In developing countries, the physical activities of the rural pregnant women would be expected to be much higher than that of pregnant women in developed countries because they have to be involved in agricultural work despite their physiological change during pregnancy.

In order to be able to detect the changes in energy expenditure of individuals or of populations, the appropriate method has to be used. A number of techniques have been developed and are currently used for assessing energy expenditure in human. Durnin (1981) and Horton (1984) reviewed the methods which are widely used by many investigators. It has to be borne in mind that energy expenditure measurement has to be as accurate as possible in order to be able to quantify the magnitude of changes in energy expenditure during pregnancy.

5.2. METHOD FOR ENERGY EXPENDITURE MEASUREMENT

5.2.1 Direct calorimetry

Energy expenditure of the body can be estimated by measuring the heat output of the body. This heat output is the result of the energy used by the body in carrying out either external work (physical activity) or internal work (such as the movement of the heart, respiratory muscle, etc.) or in chemical synthesis (such as enzyme productions) or in maintaining the ionic gradients between the fluid inside and outside the tissue cells (Durnin, 1981).

Ever since the pioneering experiments of Atwater and Benedict (1899) direct calorimetry has provided the standard method for measuring energy expenditure in man over a long period of time. The calorimetry chamber was a small room with approximate dimensions (2.11 x 1.22 x 1.93) m^3 with a complete insulating shield surrounding the room to prevent heat loss. Heat production was measured directly and provided the most accurate energy expenditure measurement. The limitation of this method is that - firstly, only a limited number of measurements can be performed in the calorimeter chamber, not only because of the restricted area but also the difference in types of work. Secondly, construction and operation of the chamber is complex, it is expensive to build, and requires highly trained staff for its successful operation. Thirdly, the measurement must be made during a period of several hours because of the response time is usually too slow and stored heat is not measured until it is dissipated in the chamber environment.

Obviously, this method is not a practical method for measuring a large number of individuals but it does provide, however, an extremely valuable resource for obtaining highly accurate results on energy expenditure in human.

Recently, a technique has been developed by using an insulated, water-cooled suit, as a form of direct calorimetry (Webb, Annis and Troutman, 1980). This method gives results which compare to the energy expenditure measured by indirect calorimetry.

5.2.2 Indirect calorimetry

One of the disadvantages of direct calorimetry is that it is in general incapable of measuring heat output over short periods. Indirect calorimetry was therefore developed to measure heat output in a shorter response time than the direct calorimetry method. This is based on the fact that the energy available in food is used in the body only as a result of oxidations, which ultimately depends on a supply of oxygen from the air. A measurement of the oxygen uptake by the body therefore is a measure of energy expenditure.

In order to calculate energy expenditure, the volume of expired air and the O_2 content must be known and sometimes the CO_2 content must be analyzed. Both of these gases need to be analyzed if the respiratory quotient (RQ) technique of calculating energy expenditure is utilized. However the commonly - used method of Wier (1949), as discussed in chapter 4, required only the measurement of oxygen percentage of the expired air, and yet provided a satisfactory result. The technique that required the measurement of RQ did not provide any advantages of the energy expenditure measurement, because there was an uncertainty attached to any RQ measured over a short period of time that might still not represent the actual RQ in the tissues. In addition, the error involved in not estimating the CO_2 content is only about 0.5% and is, usually of no significance.

Energy expenditure can be determined from the amounts of O_2 consumed and CO_2 produced, either by 1) Open circuit method - the subject breaths from the atmospheric air, expired air was collected for the O_2 consumed and the CO_2 production. The methods include "the portable respirometer" and "the Douglas bag method" which will be described later. 2) Closed circuit methods include "the respiration chamber and "the Benedict-Roth spirometer". For the respiration chamber method a subject is put in a large airtight room. Fresh air is drawn into the chamber and allowed to mix with the expired air. Simultaneously, air is drawn from the chamber, the flow rate is measured and it is analyzed continuously for O_2 and CO_2 contents. For the Benedict Roth spirometer, the CO_2 is not measured but the O_2 consumption can be read off directly from the reduction in volume of O_2 in the spirometer.

Open circuit method is the most common used particularly in the field situation. This will be discussed as follows:-

5.2.2.1 Portable respirometers

For field situation, portable respirometer is one of the satisfactory methods for measuring O_2 consumption and CO_2 production. A portable respirometer contains a flow meter and a sampling device to collect the expired gas which can be analyzed for O_2 and CO_2 content at a later time (Kofranyi & Michaelis, 1940). The machine is a simple and compact unit, measures 20 x 27 x 11 cm^3 and weighs 3kg. This method employs a face mask with a valve that directs expired air through a collecting tube to the respirometer, which is carried on the subject's back by means of canvas straps. Alternatively, noseclips and a mouth piece can be used instead of the mask. A small amount of expired air is passed into the sampling rubber bag and is analyzed for oxygen and carbondioxide content. The volume of gas can be measured by a built-in gas meter. The energy expenditure can be calculated using Wier's formular (1949). Passmore and Durnin (1967) adopted this technique for measuring a wide range of energy expenditures which is currently used as the reference metabolic cost of different activities.

The accuracy of this method, however, depends on whether the instruments are regularly serviced and frequently calibrated by skilled personnel. This will minimize any technical errors in the procedure. The respirometers from the factory are normally calibrated, yet they need to be checked again for a correcting factor, which may vary for each respirometer depending upon the rate of air flow and the resistance of the apparatus to the air flow. The method used in calibration and in maintenance are fully described in Durnin & Brockway (1959).

5.2.2.2 <u>The Douglas bag method</u>

The Douglas bag was introduced for the collection of expired gas during physical activity measurements in 1911. It has been a very practical method particularly for BMR, stationary activities and some other activities which do not require much movement of the body.

In principle, the subjects breath in the atmospheric air by mouth via the mouthpiece which is attached to the respiratory valve. The expired gas is collected in the Douglas bag and later is analyzed for the volume and O_2 & CO_2 composition. The metabolic cost of the activities is calculated using Wier's formular (1949).

Even though the Douglas bag is a direct and simple way for expired gas collection, there are some precautions to be taken in its use. The possible errors of the Douglas Bag method are the leakage of the expired gas from the bag, and a loss of CO_2 content in expired gas (Shephard 1955). These problems can be lessened by regularly checking for any leakage and for the expired gas to be analyzed as quickly as possible.

This method is widely used because of its simplicity and accuracy. The versatility and cost of this method are excellent for relatively short-term measurements of energy expenditure in a fixed location.

Both respirometer and Douglas bag method involve the use of nose clips, mouth pieces, masks, respiratory valves and the tubing for the expired gas collection. Precautions of using these equipments are needed. For example, the nose clips have to be put in a proper position that will be tight enough not to let the air pass through the nose and not too tight to make the subject feel uncomfortable.

In an early study, metal valves which housed rubber inspiratory and expiratory valves were used for the expired gas collection (Passmore & Durnin, 1967). Even though it was reliable, the disadvantage was its weight, which made them unsuitable for its use. Later, the proper rubber mouthpieces and the plastic valves were developed and have been used satisfactorily for this purpose. As with the Doublas bags the mouthpieces and the valves need to be checked regularly to make sure that there are no leakage during the measurements. Nose clips are sometimes found to be irritating when they are worn at a period of 10-15 minutes. In hot climate, the nose clips tend to be quite difficult to properly wear, because when the subject sweats, the nose clips tend to slide off and change its position.

Masks are not commonly used, as they are not simple things to fit, and meticulous care must be taken to see that there is no leakage around the cheek and chin. Hence the mouthpieces and the respiratory valves are more prefereable to use for the expired gas collection. The tubing also needs to be checked for leaks and for a tight connection between the tubing and the valves and to the Douglas bags or the respirometers.

-Calculation of energy expenditure by time-motion study.

The combination of the recording of time and motion with the determination of the energy cost of the activities is an available method of assessment of human energy expenditure under field conditions. The total energy expenditure is calculated by multiplying the number of minutes spent in each activity by the caloric value of that activity. The total is summed to cover all the activities in each individual's day (Durnin 1981)

Energy expenditure = E time spent in each activity (min) x metabolic cost of activity (kcal or kj/min)

The determination of metabolic cost of different activities can be measured using a portable respiration calorimeter or the Douglas bag method as mentioned. However, possible errors may arise in the assessment of energy expenditure. This is due to (a) errors in recording of the duration of the separate activities; (b) failure to define the activity accurately; (c) error in the technique of measuring the metabolic cost of an activity; (d) failure of the subject to behave in typical fashion while the expenditure of energy is being measured. Over and above these sources of error, there is also possibility that the subject may digress from his normal general routine because of the experiment (Durnin & Brockway 1959). The authors not only discussed at length the way in which to eliminate these problems, in both the techniques of measurement and also in the psychological approach for convincing the subjects for their cooperations.

The time-motion record has been widely used for the calculation of energy expenditure in free living condition, the precautions in using the record were dealth with specifically at the "International Workshop Energy Expenditure under Field Condition" in 1981. The precautions can be summarized into three main categories as follows:-

1. A time-motion record is very tiresome for the observer or for the subjects who are recording themselves. The presence of the observer might introduce a change in behaviour of the subjects, making the recording inaccurate, unless the subject is accustomed to being closely watched throughout the day.

2. Details of the physical activities need to be recorded in order to be able to measure the energy cost of the activity as naturally as possible. If the values from the published table have to be used, certain considerations have to be taken into account due to differences among subjects or populations.

3. At present, there is, as yet, no adequate way to check the accuracy of this method. Therefore, every attention to detail must be given when using this method and ideally it should be used only by highly trained and experienced personnel.

5.2.3 Non-calorimetric assessment of energy expenditure

5.2.3.1 Heart rate monitoring method

This method is used for indirect assessment of energy expenditure or simply of general physical activity, and has been proposed as an alternative method of estimating energy expenditure in free living condition. The method is based on the regression equation that relates the level of energy expenditure to the heart rate. With miniature telemetric systems, the heart rate can be monitored continuously without interference of the activity performed. Booyens and Harvey (1960) investigated the possibility of using heart rate as an index of metabolic rate and noted that there were large variations between individuals in this relationship, so a calibration factor based on the average results from a group could not usefully be transferred to any one individual.

The regression line is therefore calculated for each individual. In order to esablish an individual regression line, the measurement of oxygen consumption and heart rate is performed with the subject at rest and at several levels of activities and later the regression equation is constructed for each individual. Energy expenditure for a period of time is obtained by using the mean heart rate for the corresponding period and referring to the individual's regression line, (Bradfield 1971).

There are many factors influencing the relationship between the heart rate and rate of energy expenditure, such as:- age, sex, state of training, state of fatigue, bodily position (e.g. standing versus supine), site of muscular activity (e.g. arms versus legs), kind of muscular activity (viz., static versus dynamic) emotional state, smoking, eating and environment. Consequently, the proliferation of regression equations becomes a serious limitation to the heart rate method since separate regression equations are required for each subject and/or each type of muscular activity, (Durnin 1978; Andrews 1971).

Warnold and Arvidsson-Lenner (1977) demonstrated that because of the variation in correlation between the level of work and heart rate, they proposed to use the correlation of heart rate and oxygen consumption in two levels, i.e., the resting and the exercise conditions. This has also been shown by Viteri et al (1971) that the relationship between heart rate and energy expenditure at the lower intensities of energy expenditure was curvilinear not rectilinear. Later Dauncey and James (1979) also confirmed that two calibration curves of light and moderate activities could reduce the errors as contrast with one linear plot.

Acheson et al., (1980b) showed that the best predictor of energy expenditure was from a regression line derived from heart rate and log of energy expenditure. This approach solved the problem of the HR/EE regresssion line being curved in its lower part and linear in the high ranges of energy expenditure.

In practice, the limitation of this method is not only due to the interindividual variability. The heart rate monitor also needs a lot of mechanical and electrical back up because the monitors should be frequently checked in order to obtain a reliable record of the heart rate.

5.2.3.2 Doubly-labelled water method

The doubly-labelled water method was introduced as an ideal technique for the measurement of total energy expenditure in free living individuals over relatively long periods of time, without any interference of their normal activities. This method was first developed for the study in small animals (Lifton, Gordon & McClintock 1955) and later applied in humans (Schoeller & van Santen 1982).

This method involves the administration of a mixture of $^2H_20$and $H_2{}^{18}0$ to the subject. (These isotopes are not radioactive and do not themselves decay. They are therefore safe to use in human studies). The labelled oxygen ($^{18}0$) is eliminated from the body as CO_2 and H_2O; while labelled hydrogen (^2H) is eliminated as H_2O. The difference between the elimination of the two isotope is proportional to the total CO_2 output. Energy expenditure is calculated from the rate of CO_2 production using standard indirect calorimetric calculations which require an estimated value for the mean RQ. The measurement of the differential rate of isotope disappearance from the body is performed using mass spectrometric analysis of urine or saliva samples.

This technique provides a substantial advance in the measurement of energy expenditure in terms of accuracy and also that there is no interference of being observed. Validation of the method in man was done in 4 adult men (Prentice et al., 1985) by measuring CO_2 production rates by continuous whole-body indirect calorimetry and by the doubly-labelled water over the period of 12 days. The results of these two methods seemed to agree well.

Doubly-labelled water method is therefore a very promising method for energy expenditure measurement in free living individuals. Since this method is just recently adopted, the number of studies using this method is still small.

5.3. CHOICES OF METHOD FOR THE THAI STUDY

Many methods are available for energy expenditure measurement as mentioned. Since the measurement should be done in the free-living situation, the direct calorimetry was ruled out. Doubly-labelled water method, though it is a very accurate method, was not available at the time the study started. The only possible methods which were available were the heart rate method and the time motion study either by using Douglas bag or portable respiration calorimeter.

Between these two available methods, heart rate measurement is better in terms of involving the least interference with the normal daily physical activity of the subjects which is a necessity for the habitual energy expenditure measurement. This method, however, can not provide the detailed information such as changes in activity pattern, e.g., reducing or increasing the time spent in certain activities which is useful information in the longitudinal study of pregnant women.

The time-motion record, though it requires labourious work for the volunteers if they have to record their own activities or for the observers, provides good information in not only the changes of total energy expenditure at different gestational periods but also the changes in physical activity pattern as the pregnancy progresses.

In addition, this approach of energy expenditure measurement using the time-motion record was the standardized technique used in the many different study centres where this research study was conducted.

In the Thai study, time motion study using the Douglas bag technique was adopted.

A portable respirometer, though very handy for moving-about activity, may not be appropriate for the study in the villages where the maintenance of the equipment could not be satisfactory, as its accuracy is dependent upon regular servicing and frequent calibration. Whereas the Douglas bag technique needs only simple care for the check-up and it can be used for both BMR measurements and field activities in a satisfactory way.

An activity record can be kept either by the volunteer or by an observer. In this study, the observers were responsible for recording the women's activities. Since all of the pregnant women were farmers who finished only the compulsory education, it was difficult for them to write, particularly in detail, what they were doing. Furthermore the diary record needed to be quite accurate, that means they needed to spend time recording each and every detail of their activities. This might somehow interfere with their normal life style. The activity record was done during the day time by the observers but during a few hours before the women went to sleep, they recorded their own activities in a very simple way which will be discussed later.

5.4. ENERGY EXPENDITURE MEASUREMENT IN THIS STUDY

5.4.1 The observers

Altogether eight observers took part in this study. The number of observers was gradually increased according to the number of volunteers. One observer was responsible for one woman throughout the study and was able to observe 3-4 women a month.

The observers were female dietitians, with a good standard of education. They were all from the local area and were very friendly and could speak the local dialect of the women. They therefore were able to establish a good relationship with the women and their families. These observers were first trained how to record the physical activities of the women in the village under the supervision of the principal investigator. After the ways of recording and the attention of the observers toward the women were satisfactory, they were then allowed to record the pregnant women's activities.

5.4.2 Activity record

5 consecutive days of activity record along with food intake record was carried out in this group of pregnant women. The observer arrived at the women's houses, at about 6 o'clock in the morning. By this time the women had usually got up and were doing some housework such as cooking, tidying the house, taking care of the child, etc. On arrival the observer would start recording the women's activity throughout the day. The observer left after the women finished their evening meal which was about 6-7pm.

The diary used for recording the activity was a minute to minute record. The observer used the digital watch which made it very easy to record the time the activity was started. Each and every time the women changed their activity, the starting time was recorded. The details were given in terms of the exact time the activities were started, the posture of the women; the type and intensity of work performed for example walking with or without load, watering the garden, sitting chatting, standing carrying a baby, etc. The example of diary record is shown in Table 16.

The physical activity observation was well accepted by the women. In order to make them feel at ease, the observer normally observed from a distance. This was possible because the observation was done in an open air house or in the field where the observer could easily spot the women. This way of approach minimized any feeling of being watched. Hence the interference of the observer in the volunteer's normal pattern of daily activity was kept to a minimum.

The volunteers were also trained to record their own activities early in the morning after wakening up and before the observers arrived and in the evening after the observers left the houses. According to their normal life style, the women spent time steaming the rice or doing some light housework in the morning and after the observers left, they spent time chatting or resting for a few hours before they went to bed.

Table 16 An example of activity record of a rural pregnant woman

threshing	38
stand	8
walk	44
sit	40
collect thing	2
take bath	8
get dress	6
pour water	1
arrange food	5
prepare food	21
drawing water from the well	2
carry water	5
Total	180 min.

pm	0	1	2	3	4	5	6	7	8	9
4:00	threshing									
4:10										stand & talk
4:20						walk		sit		
4:30										
4:40		walk		threshing						
4:50										
5:00			walk			stand & talk		walk		
5:10		collect thing		sit					walk w/o load	
5:20										
5:30										
5:40			sit							
5:50				prepare food						
6:00										
6:10					sit			walk		
6:20					take bath					
6:30			draw water from the well		carry 2 buckets of water					pour water
6:40	walk		get dress						sit	
6:50						arrange food				

In order to record their own activities, the women were given a digital watch and a diary to continue their activity records. Most of the women found difficulty in writing down their activities in the small space for the particular activity in the activity diary. They were then trained to write down the time and the activity performed as such.

For example: am5:28 wake up and tidy the bed.

5:32 wash face and get dressed.

5:40 stand and talk.

5:56 make fire in the stove.

6:02 cook rice.

6:05 sit and talk.

6:09 sweep the floor.

During the night the women also recorded the time and activity every time they got up such as ...2:08am sit and hold the baby, 2:15am - sit and rock the cradle, 2:32am walk to the toilet ... etc.

The women who had difficulty in writing, were given a form which had the picture of common activities such as sitting, walking, cooking, standing cooking, get up time, bed time, ...etc. as shown in Table 17. By this method the women only wrote down the time they started the particular activity.

5.4.3 Reliability of the activity record

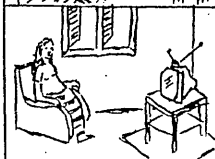
In order to check the observers at work, the principal investigator paid unexpected visits to the women's house and the field. The checking was about how close the recorded time was to the actual time, the detail of the record and the reaction of the women to observation. The diary recording was also supervised at that time. Though the recording of activities was quite a tedious job, the observers performed the task in a statisfactory manner.

The observer also checked the women's record which was taken after they left the previous night and early that morning after they got up. The record was checked

ชื่อ..............................ระหัส [| |]

วัน.............วันที่.......เดือน.............พ.ศ.......

Table 17 The example of picture-form for the activity record

	ตื่นนอน Wake up				เข้านอน Go to bed		
	นั่งเล่น นั่งคุย นั่งดูทีวี	Sitting Sitting talking Sitting watching TV					
	นอนเล่น นอนดูทีวี	Lying down Lying watching TV					
	เดิน	Walking					
	งานบ้าน กวาดบ้าน	Housework Sweeping the floor					
	ทำครัว	Cooking					
	เลี้ยงลูก	Child care					
	งานส่วนตัว อาบน้ำ เข้าห้องน้ำ	Personal need					

by asking indirect questions and by general conversation with the women during the day.

Changes of activity pattern due to the observers presence was one of the difficult things to check. However, efforts had been made to urge and convince the volunteers to behave as normally as possible, by asking them what they had been doing before the study period and what they planned to do after the study period. In the light of this information along with the normal life style of rural pregnant women, whether or not the women changed their life style due to the observer's presence could be checked.

5.4.4 Activity pattern

It was difficult to identify activities in a very detailed form. The physical activities were therefore grouped into different categories as follows:-

Sleeping : sleeping, resting in bed, lying down

Sitting : sitting activity with a small movement
e.g. sitting, sitting talking, sitting listeningto the radio, eating.

Standing : standing, standing talking

Walking : walking without carrying any load

Personal needs: taking bath, washing face, dressing.

Childcare: any activity involved with taking care of the baby; bathing, dressing, feeding, holding the baby.

Housework - cooking: preparing food

- light housework: sweeping floor, cleaning dishes, tidying the house

- moderate housework: washing clothes, carrying the water.

Agricultural work, as specified e.g.

- harvesting -pounding

- threshing -watering ... etc.

5.4.5 Expired gas collection and analysis

-expired gas collection

Indirect calorimetry using the Douglas bag method was used in this study. The procedure involved using nose clips and mouthpieces. Attached to the mouthpiece was the respiratory valve (as shown in diagram 1) which allowed air to be breathed in only through the inlet valve and breathed out only through the outlet valve to the tubing.

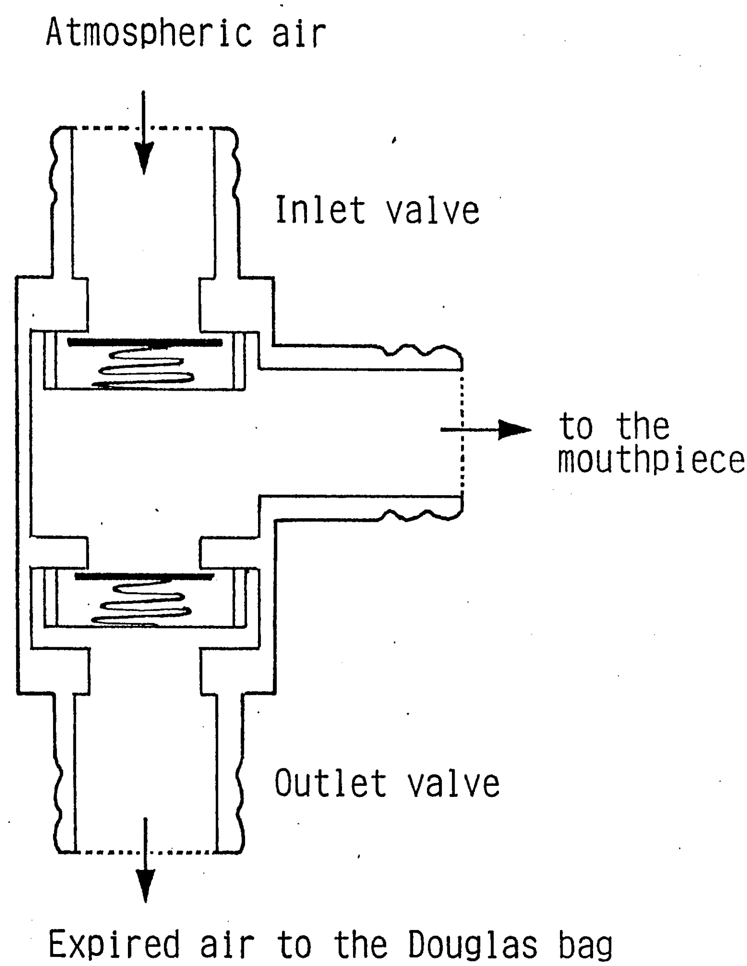
The time for gas collection was 10 minutes with 3 minutes "run in" prior to the collection for every activity except for BMR which was 15 minutes gas collection with 5 minutes "run in". This "run in" period allowed the women to get used to the way of breathing only through the mouth with the nose clips on. The exact time for the gas collection was recorded by the observers. The timer was started at the same time as the valve on the Douglas bag was opened, and later was stopped at the same time as the valve was closed.

The equipment used for the expired gas collection were regularly checked to ensure the accuracy of this method. In this study, Douglas bags (Plysu Industrial Ltd., Milton Keynes, UK) were checked every week for leakage, as this would affect the volume of the collected expired gas. A known volume of atmospheric air was filled in the Douglas bag and was left overnight. This volume was checked the next day. The acceptable value was a difference of less than 1%. If a leakage was suspected, the Douglas bag was checked by putting the inflated Douglas bag in water. Pressure was put on the bag which was then observed for bubbles. If a leakage was found, the Douglas bag had to be changed.

Respiratory valves, mouthpieces, nose clips and the collecting tube were also very important and needed to be checked every time before being used. The valve had to be checked to ensure that there was no leakage at either the inlet or the outlet because small movement of the disc could cause leakage and introduce an error.

During the expired gas collection, the observers had to observe the function of

Diagram 1 Respiratory Valve



the respiratory valve and the proper position of the mouthpiece and noseclips. Inother physical activity measurement besides BMR, the observer needed to hold the Douglas bag behind the women and checked for any malfunction of the equipment. The collecting tube was about 5 ft. long which was enough to allow the woman to move freely while she was doing the task.

There was however, some difficulty for the mother to use the expired gas collection equipment. At the time of recruiting the women, they were shown the gas collection equipment, particularly the mouthpiece, the valve and the noseclips. They were asked to try to breath by mouth only. Most of the women could manage to do so but some of them found it difficult not to breathe the way they were used to. Hence, whenever the nose clips was not put in the proper position, they tried to breathe by nose and by mouth at the same time. Because of this breathing problem, one women dropped out from the study.

-O_2 & CO_2 analysis

After the expired gas collection was completed, the Douglas bag was brought back to the air conditioned lab for the analysis. For BMR and the standard activity measurement which was performed at the research center, the expired gas analysis could be done immediately. For some other activities that were measured in the field, the transportation of the Douglas bag to the lab took a longer time but this was not more than two hours after the collection otherwise the composition of the expired gas would have changed. It was, however, encouraged that the bags were brought back to the lab as soon as possible.

The expired gas was thoroughly mixed and then a sample was transferred into a 2-litre sampling bag. The sampling bag was washed by pushing the expired air from the Douglas bag into it, mixed thoroughly and then pushing the expired air back to the Douglas bag. This washing procedure was done 2-3 times before the sampling gas was taken for the analysis.

The expired gas which was left in the Douglas bag was pushed through the dry gas meter (Singer DTM-325). By taking the initial and final reading on the gas meter, the volume of the expired gas was obtained. The two litres volume in the sampling bag was added to get the total volume of the expired gas. In addition the temperature of the expired gas was recorded by the gas meter.

The gas meter was regularly calibrated for the volume reading using Tissot respirometer at Siriraj Hospital in Bangkok. The calibration was done every 2-3 months. A correcting factor was used to get the actual reading of the expired gas volume when using the gas meter.

The expired gas volume was read at a certain barometric pressure so it needed to be corrected to reduce saturated gas volume to dry volume at standard temperature and pressure (STP) (at 0^o celcius and 760mmHg). The barometric pressure at the time the expired gas was collected was obtained from the Weather Forecasting Bureau. Hence the expired gas volume which was read from the gas meter was increased by 2 litres to get the total volume and then corrected to the volume at STP.

The 2 litre expired gas in the sampling bag was then analyzed for 0_2 and $C0_2$ percentage by using Servomex OA 272 Oxygen Analyzer and $C0_2$ Analyzer type SS1 (Taylor Instrument Analytics Ltd., Crowborough, Sussex, U.K.). These two analyzers were calibrated by using a standard gas mixture. This gas mixture was made of 0_2, $C0_2$ and equilibrated by N_2. The percentage of 0_2 and $C0_2$ of the gas mixtures were made up in order to cover a range of 0_2 and $C0_2$ in expired gas. Three gas mixtures were used for the calibration of 0_2 and $C0_2$ analysers. Out of the three, two were used as the standard gas mixtures for both 0_2 and $C0_2$ and one was used as the test gas. The composition of gas mixture ranged from 15-20% for 0_2 and from 1.5-4.0% for $C0_2$.

There was normally an uncertainty in the reading of the gas mixture composition provided from the factory. The Sholander, which is a sophisticated apparatus for the chemical analysis of the 0_2 and $C0_2$ and provides a high accuracy of reading, was used to check the composition of the gas mixture. These accurate readings at the standard gas mixtures were then used to calibrate the 0_2 and $C0_2$ analyzers. During the day, not only was the calibration of 0_2 and $C0_2$ performed frequently and regularly, but spot checks of these analyzers were also done once a week by comparing the test gas measured by the 0_2 and $C0_2$ analysers and the Scholander. For the unusual results obtained from the analysers, they were then double checked by using the Scholander.

5.4.6 Standard activity measurement

In order to be able to detect the changes of the metabolic cost of activity as the result of pregnancy, the women in this study were asked to perform a standard activity, i.e. walking on the treadmill at the fixed speed, 3.0km/h at six weekly intervals throughout pregnancy.

The measurement was carried out for 10 minutes with 3 min "run in" prior to the expired gas collection. The difference between duplicate measurements had not to be more than 5%, otherwise a third measurement had to be done. The average value was taken to represent the metabolic cost of the standard activity at that particular gestation week.

The habituation effect of the standard activity measurement was also carried out in a group of 15 women. They were asked to come for the measurement on 2 consecutive days. The result of the oxygen consumption and the metabolic cost of walking on the treadmill is shown in Table 18. Like the test performed for BMR measurement, no habituation effect was found in the standard activity measurement. The metabolic cost showed a slight decrease in the second day but there was no significant statistical difference in the mean value.

Table 18 Habituation effect of the standard activity measurement (Treadmill 3.0km/h) (mean weight 48.0kg)

	Mean $\pm$ SD
n	15
Oxygen consumption (1/min)	
first day	0.46 $\pm$ 0.06
second day	0.45 $\pm$ 0.05
kcal/min	
first day	2.22 $\pm$ 0.27
second day	2.18 $\pm$ 0.21
cal/kg/min	
first day	46.31 $\pm$ 5.12
second day	45.35 $\pm$ 4.62

5.4.7 Measurement of the metabolic cost of different activities

During the first phase, the metabolic cost of different activities in 13 pregnant women were measured. These activities were selected from the main activities during 5 consecutive days of each period. Eight measurements were taken after each study period, hence a reasonable number of measurements were taken and the energy cost of different activities per unit body mass were then grouped and used as the representative values for the calculation of total daily energy expenditure.

The energy cost of common daily activities was estimated by indirect calorimetry using the Douglas bag method. The women were asked to perform the task in their normal way. The observer who observed the women's activities for 5 consecutive days was responsible for the activity measurement so that she could recognise whether the way in which they did the task would represent the activities recorded during the 5 day study period. Since the common measured activities could not be standardized, there was bound to be considerable variation between different measurements of the same activity in any individual women. Therefore, as many measurements as possible were needed on all the major time-spent activities, so that a reasonable representative mean value was obtained.

Those major time spent activities for each period did not include the sleeping activities, because the BMR value at each period was used for the calculation of metabolic cost of sleeping (Passmore &, Durnin, 1967).

For rare activities or those lasting only a few minutes, energy expenditure was obviously not mesured, but the assumed metabolic cost was obtained from the metabolic cost measured in the non-pregnant women who lived in the same environment (Thongprasert and Chaivatsagool, 1985). Adjustment was made in these calculations for body weight by using the average metabolic cost values expressed per kilogramme body weight.

The total daily energy expenditure of each women was then calculated by multiplying the time spent in each activity by the metabolic cost of that particular activity.

5.5. RESULTS AND DISCUSSION

5.5.1 Reference metabolic cost values

Altogether 493 measurements of metabolic cost of activities were performed. The results are shown in Table 19 for the common daily activities and in Table 20 for the agricultural activities. Even though standard metabolic cost of reference values are available for the total daily energy expenditure calculation (Durnin & Passmore, 1967) which was later used as the metabolic cost of different activities world wide reference (FAO/WHO 1973), and the metabolic cost as a multiple of BMR (FAO/WHO/UNU 1985) these values may not be the most appropriate because these measurements are done on women in different community who possibly have a different way of doing the tasks and at a different intensity. This consideration is of importance because the total daily energy expenditure is not only dependent on the exact time spent in each activity but also the representativeness of the metabolic cost. The metabolic cost measurements should be done in a population who live in the same environment and condition.

The metabolic cost measurement was done on 13 pregnant women in the same environment and the values were used for all the pregnant women in this study. The measurements were done at different stages of gestation and used to represent the metabolic cost of different activities during pregnancy.

A large number of measurements were performed on the common activities that contributed to the main proportion of time spent by the women. For example 144 sitting activity measurements were performed whereas other activities were assessed using a smaller number of measurements as shown in Table 19.

According to the classification of the metabolic cost of different activities (FAO/WHO 1973), light activities cost less than 3.5kcal/min, whereas moderate activities cost less than 5.5kcal/min and heavy activities more than 5.5kcal/min. In this study, all the common housework activities were considered to be light activities, although some of the activities were classified as moderate housework, as the

Table 19 Metabolic costs of some common activities of pregnant rural women (mean ± SD).

Activity	No. volunteer	No. measurement	kcal/min	cal/kg/min
Sitting	13	177	1.161 ± 0.12	22.71 ± 1.73
Standing	11	12	1.223 ± 0.16	24.02 ± 2.14
Walking	13	51	2.224 ± 0.34	43.71 ± 4.85
Child care during				
bathing	8	10	1.961 ± 0.41	38.58 ± 9.98
holding	7	9	1.622 ± 0.37	32.51 ± 6.87
feeding	1	1	1.144	23.83
rocking cradle	2	5	1.770 ± 0.51	33.01 ± 9.23
Child care during lactation				
holding	12	16	1.145 ± 0.16	23.52 ± 2.95
breast fed	11	11	1.162 ± 0.18	23.53 ± 2.72
rocking cradle	7	9	1.206 ± 0.41	25.11 ± 2.91
Cooking	13	61	1.547 ± 0.22	31.05 ± 4.20
Light housework				
house keeping	11	21	2.039 ± 0.42	40.02 ± 7.33
floor cleaning	6	10	2.320 ± 0.45	44.40 ± 8.39
dish washing	3	3	1.493 ± 0.24	31.56 ± 2.41
paper cutting	1	2	1.224 ± 0.06	20.06 ± 1.03
wood cutting	1	1	1.364	26.74
doll making	1	2	1.138 ± 0.15	24.22 ± 3.30
Moderate housework				
fetching water	8	11	3.272 ± 0.64	64.42 ± 11.57
washing	4	5	2.009 ± 0.21	42.06 ± 6.92

Table 20 Metabolic costs of some common field activities of pregnant rural women (mean ± SD)

Activity	No. volunteer	No. measurement	kcal/min	cal/kg/min
Fields activities				
harvesting	4	9	2.278 ± 0.22	47.38 ± 4.63
tilling & digging	3	7	2.984 ± 0.38	61.27 ± 8.77
milling	1	4	1.928 ± 0.29	36.33 ± 4.64
threshing	1	1	3.380	66.27
pulling small plant	4	8	2.970 ± 0.41	56.88 ± 5.30
planting	5	11	2.712 ± 0.27	52.92 ± 4.42
plowing	1	2	3.276 ± 0.21	67.50 ± 1.44
Jute skinning	1	2	1.390 ± 0.21	26.46 ± 4.02
grass cutting	3	7	2.056 ± 0.10	39.49 ± 4.98
brick laying	1	4	2.797 ± 0.18	53.17 ± 5.38
watering	2	3	3.734 ± 0.39	76.07 ± 1.67
animal feeding	1	1	2.316	48.76
nets making	1	2	1.286 ± 0.09	21.98 ± 1.47
peeling kapok fruit	1	1	1.664	32.95
cassava root cutting	2	3	1.648 ± 0.16	32.74 ± 6.10
catching Tadpole	2	3	3.616 ± 0.57	64.88 ±12.33
pulling cow	1	1	2.598	57.73
gathering cucumber	1	1	2.764	61.42
weaving	1	2	1.612 ± 0.22	29.30 ± 4.07
wood cutting	1	1	2.364	55.74

investigator had the impression that the women work hard on these tasks. Among the household activities, water fetching gave the highest metabolic cost which was 3.27kcal/min. For this activity, the women had to draw the water from the well by drawing the rope attached to the bucket or by mechanical pump, then carried the two 10 litre-buckets on a shoulder yoke from the well to the house. There are two types of well in the village, one is in the village which is used for washing or other purposes except for drinking. The other well, which is normally far from the village, is used for drinking. Men sometimes helped the women carry the water from the well.

For agricultural activities measured in this study, it was found that most of the women did not have as high energy cost as one would expect. There were only two activities that cost more than 3.5kcal/min., i.e. garden watering and tadpole catching. The women spent more energy in the garden watering than the water fetching atcitivy as mentioned. This was because the work was more intensive, since the women carried the water in two - 20 litre buckets on a shoulder yoke from the well nearby. They poured the water from the bucket while walking along the garden. For the tadpole catching activity, which was a common activity in an early rainy season, the women carried a special net and waded through the rice field. Most of the time, the women bent down while they walked through the rice field. They normally found it inconvenient to do this task particularly near term.

As mentioned earlier, the number of activity measurement performed were based on the majority of time spent in these activities during the day by the pregnant women at different stages. The number of agricultural measurements therefore was rather small because the women normally spent their time in the common activities like sitting, housework, .. etc. Therefore the number of each measurement was not more than 10. The presented metabolic cost values might not represent those activities, in general, but these metabolic values were considered to be satisfactory for the calculation of the energy expenditure in these pregnant women.

The energy cost of some agricultural activities in rural nonpregnant women and men were also measured in this study as shown in Table 21.The agricultural activities which were measured in a large number of volunteers can be used as a reference value. Duplicate samples were performed for each individual and the average value was used. For some activities, the metabolic cost values were applied for the pregnant women in this study, which was again on the basis of unit body weight.

There was some evidence which indicated that metabolic cost of standard activity increased as body weight increased. In pregnant women, Nagy & King (1973) found an increase in the metabolic cost of walking at a fixed pace as pregnancy progessed, in terms of absolute value whereas there was no change when expressed in terms of kg body weight. Blackburn & Calloway (1976b) studied 21 mature pregnant women at different gestation periods and found that the increase in energy cost of work, for maintenance of the posture, i.e. sitting, standing, and the energy cost of physical activities, such as bicycling at 300kpm, walking 3mph with or without the level of elevation, showed an increase in energy cost that paralleled the gain in body weight. The energetic efficiency of the work performance in pregnancy was also demonstrated in the other multicenter study in this project. Durnin & McKillop (1982) studied in 35 Glasgow women who walked on a treadmill at a speed of 3.8km/h. The results showed an increase in energy, expenditure as body weight increased and the value per unit body weight did not alter at all, apart from a small, non significant initial fall. The study in Wageningen (van Raaj, Peek & Hautvast, 1986) demonstrated the same finding that there was no change of metabolic cost in absolute term of walking on a treadmill in the first two trimesters and later there was a significant increase in the last trimester. When expressed per kg of body weight, there was a significant decrease from before pregnancy to 34-36 weeks of gestation. Banerjee, Khew and Saha (1971) showed that the energy expenditure of self-paced work was not increased as much as one would expect during pregnancy, as it showed that the women performed all tasks in a more relaxed and economical manner than nonpregnant women.

Table 21 Metabolic costs of some agricultural activities of rural men and nonpregnant women (mean ± SD)*

Activity	Sex	n	Age (yr)	Weight (kg)	Height (cm)	Energy cost (kcal/min)
Harvesting	M	10	29	53.5 ± 5.7	161.3 ± 4.1	3.11 ± 0.63
	F	7	32	52.5 ± 2.9	148.9 ± 4.2	2.84 ± 0.66
Threshing	M	10	29	59.2 ± 3.8	167.1 ± 4.4	5.83 ± 0.89
	F	6	23	49.7 ± 10.2	148.8 ± 3.9	3.72 ± 1.05
Pounding rice	F	9	24	51.9 ± 6.0	157.8 ± 5.1	3.42 ± 0.45
Watering vegetable	M	11	27	58.1 ± 6.0	164.0 ± 6.0	5.36 ± 0.73
Harrowing	M	4	40	54.2 ± 13.8	-	5.31 ± 2.58
Jute skinning	F	3	32	54.0 ± 4.5	-	1.64 ± 0.08
Planting	M	3	26	54.8 ± 2.8	-	3.12 ± 0.42
Tilling and digging	M	1	53	54.0	154.2	4.64
Sowing	M	1	61	51.0	158.0	3.47
	F	1	35	55.0	155.0	2.103
Cloth weaving	F	4	27	47.8 ± 14.2	148.1 ± 12.0	1.56 ± 0.18
Weed weaving	F	1	31	46.5	157	1.25

* from (Thongprasert and Chaiwatsagool, 1985).

In the study of rural Gambian women, Lawrence et al., (1985) measured various activities of rural pregnant Gambian women at different stages throughout pregnancy. A comparison was made between the metabolic cost of different activities in the early and late pregnancy. Their results showed no difference in the metabolic cost of different activities in absolute terms and they decreased on the body weight basis. The authors discussed that either the work intensity was reduced or the activities were not load bearing.

As the pregnancy progressed, some activities such as bending digging would be inconvenient for the pregnant women to perform, therefore the work intensity would be less. For other activities which involved only arm muscle there was little effect of increasing body weight.

5.5.2 Total daily energy expenditure

The reference metabolic cost values of the 13 women in phase I along with the actual measured time spent in each activity were used for the calculation of daily energy expenditure. In this study, the comparison of the total daily energy expenditure calculated by using the actual measured metabolic cost data, and using the reference values at different stages of pregnancy is shown in Table 22. The results showed that the difference between the mean values at each gestational age using these two methods was less than 3% which was rather small.

A similar result was obtained from the study of Blackburn & Calloway (1974) who conducted an energy expenditure measurements on a pregnant adolescent girl at different levels of activites. These metabolic cost values were used to estimate the daily energy needs in a second group. There was no difference between the energy expenditure computed using mean energy cost of the first group in kcal/min and using the data from the first group that the subjects of similar age and weight. Therefore the energy expenditure in our study was calculated using the reference metabolic cost values of different activities.

Table23 shows the total daily energy expenditure at different periods of

Table 22 Comparison of total daily energy expenditure using the measured and reference values of metabolic cost of activities.

Gestation week	n	Energy expenditure ($\bar{X} \pm SD$) Measured value	Reference value	% difference
7-12	9	1896 ± 296	1846 ± 219	-2.6
13-16	12	1938 ± 179	1885 ± 172	-2.0
17-24	13	1985 ± 181	1957 ± 217	-1.4
25-30	13	2061 ± 220	2043 ± 211	-0.6
31-36	13	2149 ± 390	2152 ± 355	+0.1
32-40	5	2189 ± 268	2132 ± 197	-2.6

Table 23 Total daily energy expenditure of pregnant rural women.

Gestation week	n	Energy expenditure kcal/min	Energy expenditure kcal/kg/min
7-12	31	1870 ± 287	39.0 ± 4.9
13-18	44	1924 ± 276	39.8 ± 4.9
19-24	43	2011 ± 253	39.7 ± 3.8
25-30	44	2115 ± 274[a]	40.0 ± 4.8
31-36	41	2108 ± 300	38.0 ± 5.3
37-40	20	2092 ± 259	37.1 ± 3.0[b]

Significant difference at [a].($p<0.001$); [b].($p<0.1$)

gestation in 44 rural pregnant women. At 10 weeks the average daily energy expenditure was 1870 ± 287kcal and was gradually increased until 27 weeks gestation to a level of 2115 ± 274 kcal/d. A significant increase was observed at this period ($p<0.001$). Though the average mean increase of energy expenditure at this period was as high as 245kcal/d, the energy expenditure on the body weight basis showed a slight but insignificant increase. Thereafter there was no change in energy expenditure, whereas the total daily energy expenditure on the body weight basis showed a slight decrease ($p<0.1$) near term, despite the increase in actual measured BMR and the body weight. These results indicated that the increase of metabolic cost near term was mainly due to the increase in BMR and that the women tended to spend more time resting and less time in heavier activities. This is confirmed by the changes in the activity pattern of the women.

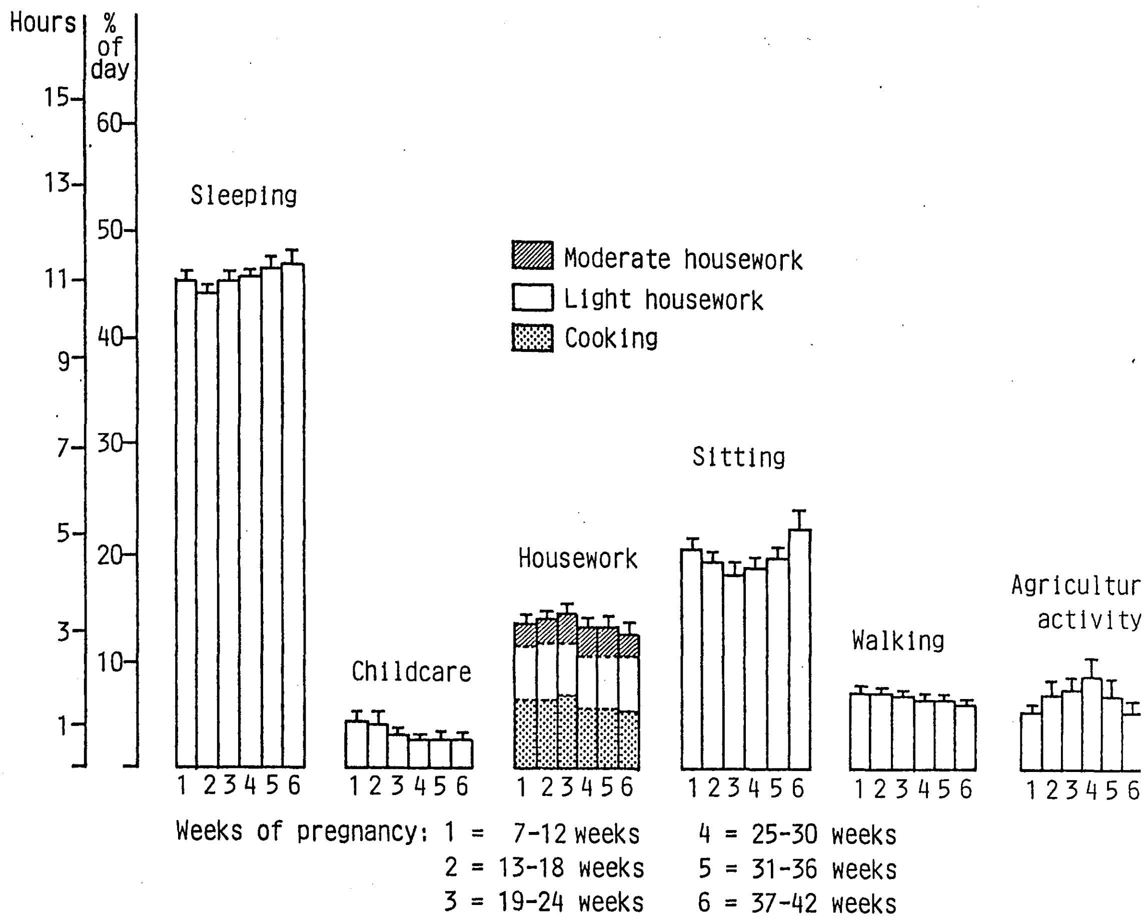
5.5.3 Activity pattern

The activities of rural pregnant women were grouped in to 8 different categories, i.e. sleeping and lying down, childcare, housework (the combination of cooking, light housework and moderate housework), sitting, walking, agricultural work and personal needs. The comparison of the mean values of each category at different gestation was shown in Figure 12. The majority of time spent during the day was sleeping, which contributed about 11 hours. A slight increase was observed in the second and third trimester. At the end of pregnancy, the women spent about half an hour more for sleeping or lying down when compared to the initial value at 10 weeks.

Time for sitting was found to be the second major activity which contributed about 4-5 hours daily. A significant increase in time spent sitting was observed ($p<0.05$) during the last few weeks before pasturition, when compared to the time spent sitting at about 20 weeks.

For other activities such as housework, it was shown that the women spent

Figure 12 Average time per day of mothers activities during pregnancy



little more than one hour for daily cooking. The same amount of time was spent for light housework, which consisted of sweeping the floor, cleaning dishes, tidying the house, ... etc. In addition about half an hour a day spent in moderate housework which consisted of washing clothes and carrying water.

The women spent about 1-2 hours a day walking. Even though they showed a trend of decreasing the time for walking, no significant difference was observed. The same pattern was also shown in childcare activity.

Being farmers, one would assume that the women spent quite a number of hours in agricultural work, but this was not the case in this study. The reasons were that, - 1) as in the way of recording other activities, the agricultural activities were recorded only when the women really performed the work without any interruption. Whenever they took a break, even for a short period of time, the changing of activity was also recorded. Hence the actual time spent on that particular activity was recorded. 2) the women were recruited at different times of the year, therefore the mean value was taken for each gestation period from the women who spent quite a long time in the field during the rice cultivation period and also from the women who spent no time working in the field during other seasons. Hence the number of hours spent in agricultural activities as shown did not imply that as farmers, the women spent only a few hours on this task.

The method of recording energy movements was not only useful to classify the length of activity pattern as accurately as possible, but also useful in providing a specific time for applying the reference metabolic cost value to that particular activity, since when the energy cost of activity was measured in the women, it normally involved no interruption.

5.5.4 The increment of energy expenditure

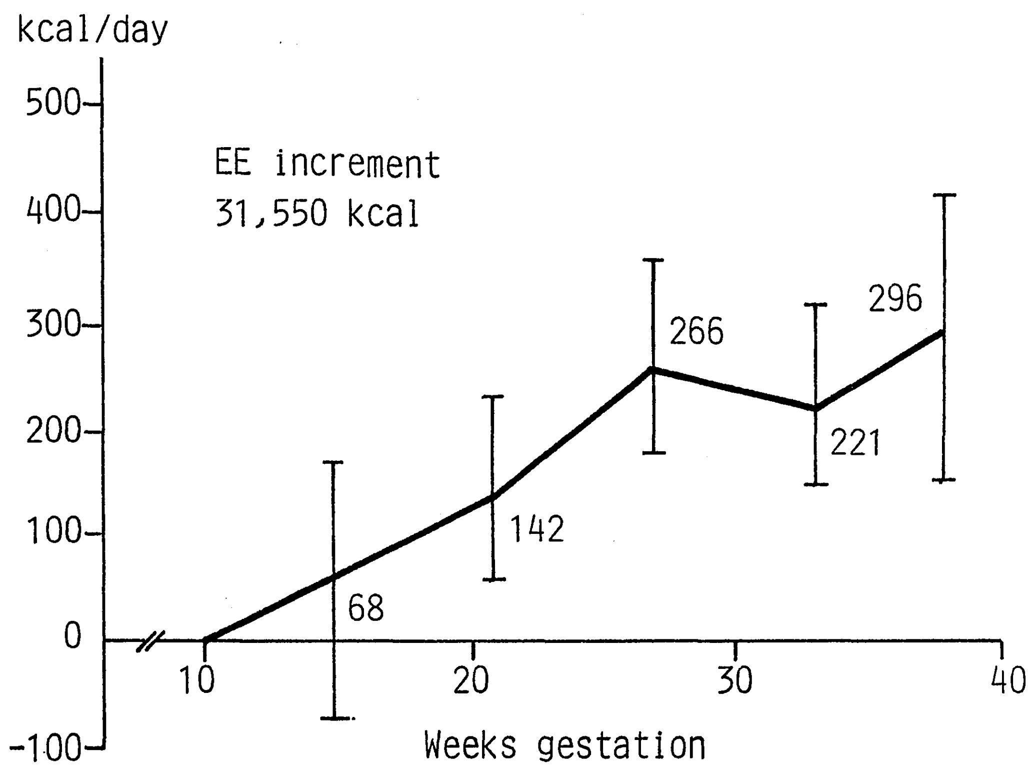
As the energy intake increment, the energy expenditure was calculated using the within subject incremental analysis from 10 weeks until term. At 10 weeks the energy expenditure was an average 1864 $\pm$ 295kcal/day. Energy expenditure markedly increased until about 30 weeks gestation and then decreased. By calculating the area under the curve of the graph, the total increment of energy expenditure from 10 weeks until term was 31,600kcal as shown in Figure 13.

Out of this 31,600kcal, the increase in BMR contributed 24,000kcal, which was about three quarters of the increment. BMR measurement was performed in a highly standardised way in quite a large number of subjects (n=44). It was therefore most unlikely that the results would not represent a real increment of BMR. The calculation of total daily energy expenditure however was based on the assumption that the metabolic cost of expenditure increased as body weight increased. It seemed as if the difference in energy expenditure and BMR was the result of the energy involved in doing other activities and moving heavier body weight. Whether or not the women could save some energy by reducing the work intensity and/or by changing the activity pattern needed to be considered carefully.

In this study, the activity pattern of these women demonstrated that they spent more time sitting and less time in agricultural work. Therefore they tended to rest more as pregnancy progressed. No attempt has been made to measure the changes in work intensity. However, the result from Holland (van Raaj, Peek & Hautvast 1986) showed that pregnant women who were asked to walk on a treadmill at a self-selected pace showed a steady decline in the pace throughout pregnancy, but mainly in late pregnancy. At 36 weeks the self-selected pace was 25% lower than at 6 weeks (p<0.01).

There were also some evidence from Gambian's study (Lawrence et al., 1984) that the rural pregnant women did not show an increase in the metabolic cost measured in the first and second trimesters and in a third trimester, despite the fact that the women gained weight during pregnancy. In order to do so the women needed to work in a more economical efficient way and/or reduce the intensity of the task. Therefore, it can be concluded from these two studies that if the women had a choice to work at their own paces, they worked slower and did not increase the metabolic cost

Fig. 13 Increment of energy expenditure during pregnancy (median and confidence limit)



of different activities.

If this is a case in this study, the calculation of total daily energy expenditure using the metabolic cost values on body weight basis might be overestimated. If they could save some energy by spending more time in the same work, the actual metabolic cost of that work would be less than the estimated value.

Figure 14 shows the ratio of energy expenditure to BMR at various stages of pregnancy. At 10 weeks, the ratio was 1.5 and remained constant at this level until 30 weeks gestation. Thereafter the ratios dropped to about 1.4 times BMR. This was not surprising since part of the energy expenditure was from BMR. In this group of women, BMR per unit body weight was constant throughout pregnancy but showed an increase near term. BMR of each individual was used to represent the sleeping metabolic cost value which contributed about 45% of time spent during the day. The remaining activities were calculated by applying the reference value per kg body weight for each individual, since BMR is constant per kg body weight and the rest of activities were also calculated per kg body weight. No change in the ratio was therefore demonstrated. During the last 10 weeks of pregnancy BMR still increased whereas other activities did not increase or even decreased resulted in a drop of EE/BMR ratio. The results confirmed that the women spent more time resting near term.

5.5.5 Standard activity

Table 24 shows the energy cost of walking on the treadmill at the speed of 3.0km/h in absolute terms and per unit body weight. The women in this study showed no change in the metabolic cost of walking until near term. A significant difference was found at 37-40 weeks compared to the initial value at 10 weeks ($p<0.05$). It seemed as if the women managed not to spend more energy even though they had to move a heavier body as pregnancy progressed. In terms of unit body weight the women started to decrease their metabolic cost of energy expenditure during the second half of pregnancy ($p<0.05$).

Fig.14 Ratio of energy expenditure and BMR at different gestation age.

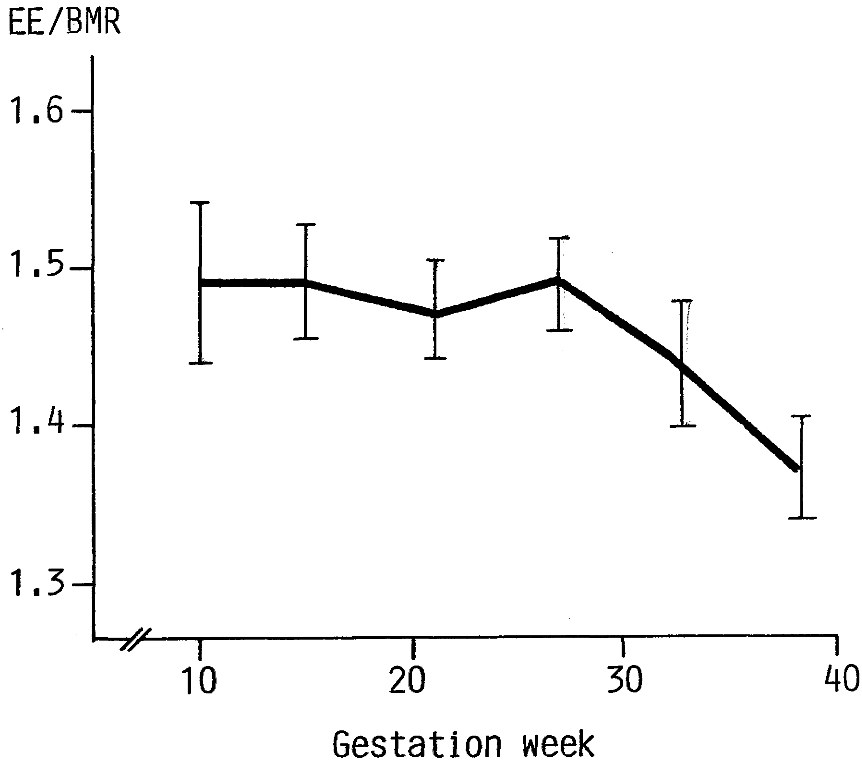


Table 24 Energy cost of walking on the treadmill at the speed of 3.0km/h (mean $\pm$ SD).

Gestation week	n	kcal/min	cal/kg/min
7-12	31	2.27 ± 0.25	47.3 ± 0.5
13-18	44	2.23 ± 0.27	46.1 ± 4.7
19-24	43	2.29 ± 0.25	45.3 ± 3.8[a]
25-30	44	2.34 ± 0.24	44.1 ± 3.2
31-36	41	2.41 ± 0.28	44.1 ± 3.2
37-40	20	2.52 ± 0.26[a]	44.7 ± 3.0

[a] Significant difference at $p<0.05$.

No habituation effect was found in this group of pregnant women. Hence a slight drop of the metabolic cost in both kcal/min and cal/kg/min was not because of the habituation effect. The women continued to significantly decrease the metabolic cost per unit body weight during the second half of pregnancy . Therefore an increase in walking efficiency at the fixed pace was demonstrated in this study.

Assuming that the women normally walked at the same speed as they walked on the treadmill (3.0km/h), the energy cost of walking calculated using the actual measured energy cost (from the metabolic cost of walking on treadmill) and the mean energy cost at different gestation periods were compared. The results are shown in Table 25. The time spent for walking at each gestation period was measured in the time motion record and the body weight at each period was the mean weight of the women. A small difference in the total metabolic cost of walking was observed (ranged from -10kcal to +6kcal). The results indicated that to calculate the total energy expenditure using the absolute value or on the body weight basis gave similar results. In addition the results demonstrated that the energy cost calculated using kcal per kg body weight resulted in a slight underestimation when the body weight was low at early pregnancy and a slight overestimation when the body weight was high in the late pregnancy. And the reason for the metabolic cost at term being lower than 33 weeks might be due to the small number of women presented at term.

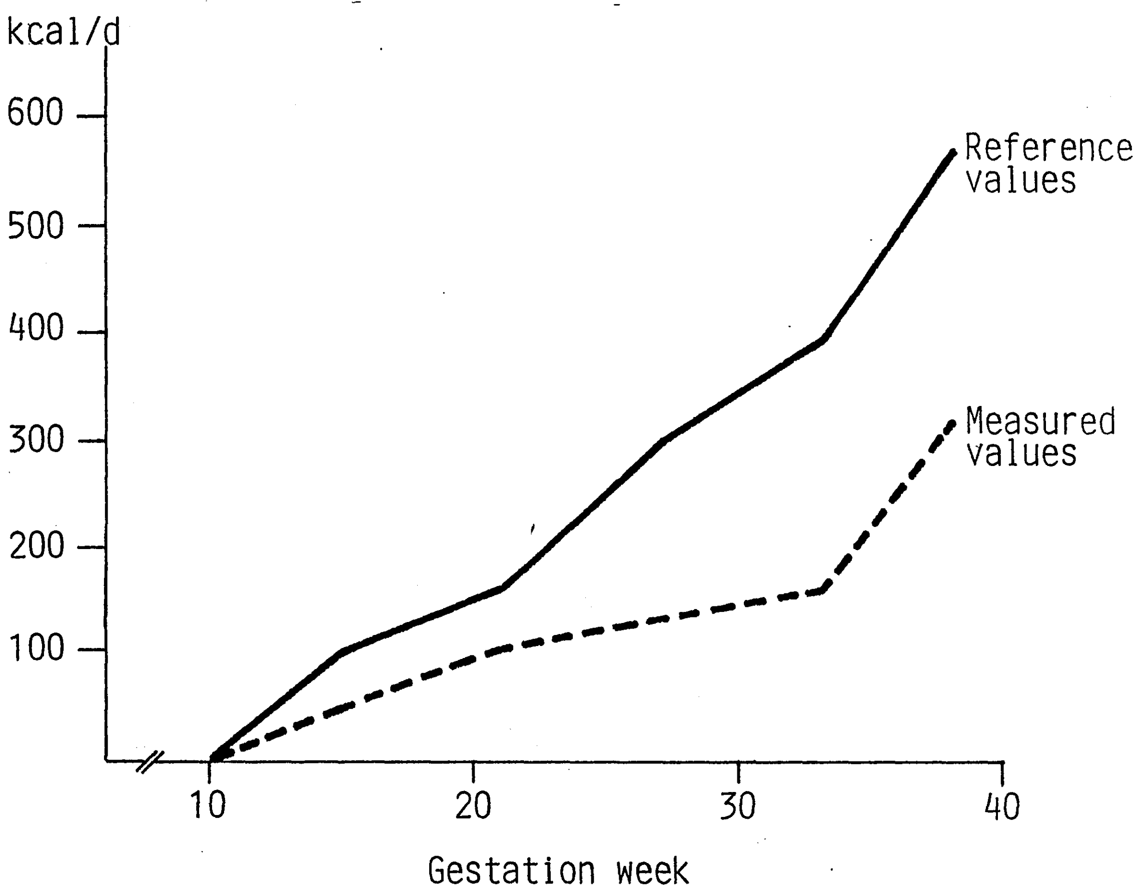
Although there was no difference in the average energy expenditure at different gestational ages calculated using the reference metabolic cost values and the actual measured metabolic cost values, the increment of energy expenditure by these two methods gave a different pattern as pregnancy progressed, as shown in Figure 15. In this figure, the energy expenditure in 13 women calculated by using the reference values showed an increase of 48,300kcal. This was double the amount calculated by using their own metabolic cost values.

The reasons why there was a different in energy expenditure increment

Table 25 Comparison of the total energy cost of walking by using the actual energy cost (kcal/min) and the mean energy cost (cal/kg/min) at different gestation weeks.

Gestation week	n	Actual time spent on walking (min)	Weight (kg)	Energy cost 1 (kcal/min)	Energy cost 2 (cal/kg/min)	Total energy cost (kcal) 1	Total energy cost (kcal) 2	Total energy cost (kcal) difference
7-12	29	103	48.0	2.27	47.3	234	223	-10
13-18	44	105	48.3	2.23	46.1	234	229	-5
19-24	43	102	50.4	2.29	45.3	234	232	-2
25-30	44	95	53.0	2.34	44.1	222	228	+6
30-36	41	95	54.8	2.41	44.1	229	235	+6
37-40	20	89	56.4	2.52	44.7	224	227	+3
					Mean 45.2			

Fig.15 The comparison of the increase in energy expenditure of 13 women calculated using the reference metabolic cost values and the measure values.



calculated by these two methods were -

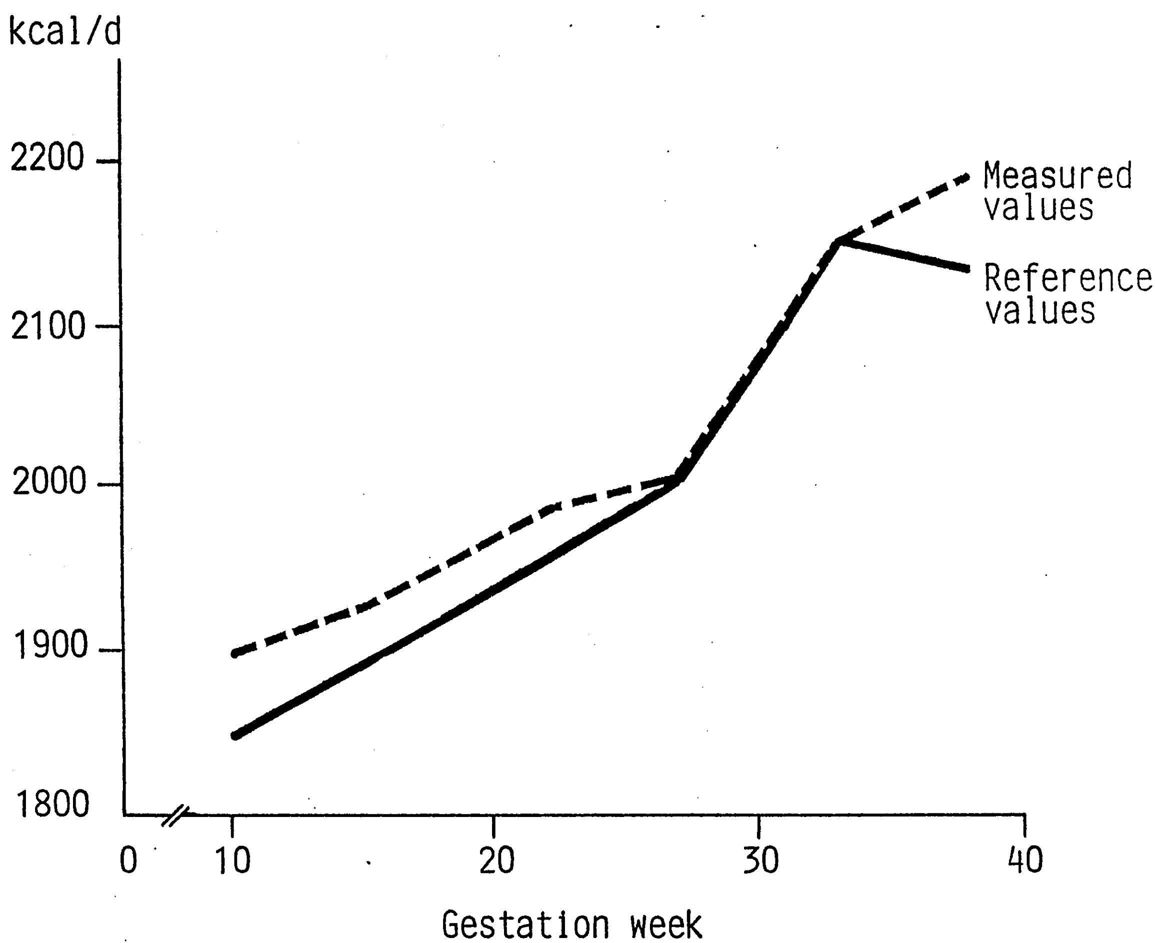
1) Total daily energy expenditure was calculated using the reference value based on unit body weight for every activity except BMR which was from the actual measurement at each period in both methods. The calculation of daily energy expenditure therefore affected by the weight of the women.Therefore at early pregnancy when the body weight was less, the effect would be in a way to underestimate the results, and when the pregnancy progressed, the body weight increased, the effect would be in a way to overestimate the results.

The assumption that there is a constant metabolic cost per kg body weight was found to be a satisfactory approach when the study was started, because of the evidence from other studies as mentioned (Nagy & King, 1973; Blackburn & Calloway 1976a). However the result from this study showed a constant metabolic cost in absolute terms during the standard activity of walking on the treadmill at a fixed speed. Though the women carried heavier body as pregnancy progressed, they tended to walk on the treadmill in a more efficient way to that there was no increase in energy expenditure (kcal/min) and a decrease in energy expenditure per unit body weight were observed.

2) This underestimate in the energy expenditure particularly at early pregnancy and the difference in energy expenditure at 10 weeks calculated by using reference values is shown in Figure 16. Hence there was a difference of energy expenditure at the baseline (at 10 weeks). The energy expenditure baseline level calculated by using the reference value was then lowered by 50kcal/d than the actual baseline which resulted in an overestimate in the total increment of 50kcal/d x (38-10wk) x 7d/wk = 9800kcal.

This amount of an overestimation when using reference values still doesn't fill the gap between these two methods. However, since the baseline of the energy expenditure was lower than it should be, the increment inenergy expenditure near term would be more pronounced and therefore exaggerate the total increment calculated by this method.

Fig.16 Average total daily energy expenditure calculated using the reference values and the measured values.



These results suggest that in order to get an accurate measure of energy expenditure it would be advantageous if the metabolic cost of different activities was measured [illegible] This suggestion might sound impractical because it demands a lot of work particularly for a large number of subjects. A more appropriate method which not only requires less numbers of measurements but also requires no interference of the subjects is needed. Among all indirect calorimetry methods at present, the doubly-labelled water technique is the most promising method for a further research study.

CHAPTER 6

6.1 WHY SHOULD FOOD INTAKE BE MEASURED?

At attempt to estimate food intake in free-living populations is constantly sought by physicians, epidemiologists, nutritionists, the food industry and others. Accurate information is frequently desired for a few individuals, or representative groups, or on thousands of individuals for prospective study. Food intake measurement is usually performed for two main purposes, food requirements and the association of food and disease.

Epidemiological study of disease is important to determine the association of food intake and the prevalence of diseases. Food intake measurement indicates an excess or deficit of various nutrients. For example, when food intake exceeds energy expenditure for a long period of time, an increase in the storage of body fat will result and lead to obesity. This topic of food intake and disease is very broad and will not be discussed in this thesis.

For the purpose of estimating food requirements, Widdowson (1947) noted that the majority of food surveys have been inspired by an interest in food requirements. In order to study the energy requirements, an accurate estimate of energy intake is needed. Extensive reviews of dietary intake methodology have been presented by Becker, Indik & Beeuwkes (1960) and Marr (1971). These workers reviewed the most common methods of assessing dietary intake of individuals and discussed the advantages, disadvantages and reliability of each method.

Suitability and validity of each method has to be assessed with regard to the clearly defined objectives of any dietary study. The objective would determine the appropriate method to be employed, in collecting, processing and interpreting dietary data. On one hand, one method can measure very accurately the current intake of a few individuals and on the other hand by a different method, it can assess food habits of a population over a considerable period, both have their part to play in dietary surveys. Therefore a dietary survey can be carried out for a nation, a group or an individual and each type of survey can provide valuable information.

Surveys are conducted on a national level in order to assess the total food supply in various countries. This is of special importance in developing countries where large sections of the nutrient deficiency population may be suffering from undernutrition. Therefore, a suitable and accurate method of food intake measurement is needed to identify the habitual food intake.

6.2 METHOD USED FOR FOOD INTAKE MEASUREMENT

There are different methods available for energy intake measurement. They are divided into two main categories; the record of present intake and recall of the past intake. Marr (1971) described the recording of present intake in three different ways, i.e. the amount of food eaten being (a) weighed; (b) recorded in household measures; or (c) a menu can be recorded with no quantities. The recall of past intake is performed in terms of (a) food actually eaten during a stated period of time; (b) usual consumptions (History method). However when dealing with larger populations, a method may have to be employed which is less accurate but more convenient for the type of study.

From the Euronut workshop (1982) on the assessment of nutritional status with emphasis on food consumption, it was mentioned that there is not one common method for the study of food consumption that will be appropriate for all purposes. This is due to each study having a different objective, whether to measure the current intake or to measure the food habits over a considerable period of time, and the size of population possibly considering, the availability of personnel, time and equipments, ..etc.

However, only two methods, which are widely used for energy, balance or energy requirement studies will be discussed.

6.2.1 24 hours dietary recall

This method is widely accepted by the subjects and the investigators because of its simplicity. It therefore, can be applied for a large number of subjects. The recall is usually performed by well trained interviewers who would ask the subjects about the type and amount of food consumed. Food which is described by this recall method has to be converted to weight before the nutrient estimations are calculated.

Qualified interviewers, preferably skillfull and experienced dietitians or nutritionists are needed for this type of survey. The way to approach the subjects has to be very friendly so that the subjects will feel at ease and try their best to answer the questions. Sometimes the interviewers used food models for demonstration purposes in order to get an accurate estimation of food intake (Morrison, Russel & Stevenson, 1949). Sometimes a food menu could help to remind subject of any item omitted in the recall (Campbell & Dodds, 1967).

Marr (1971) reviewed the articles of dietary intake measurement and discussed the validity of the method used. Marr stated that "the validity of each method can only be tested comparatively, for there is no absolute method of dietary assessment against which to measure other methods". For the 24 hours dietary recall method, the validity depends on (a) the measurement of the household measures and the conversion into real weights; (b) the estimation of the amount of food (c) the memory of the subjects in recalling intakes.

No matter how intelligent the subjects are, it is quite difficult to estimate their food intake by this method. This was shown by Morrison, Russel & Stevenson (1949), who conducted a 24 hours dietary recall study in 8 scientists. The amount of food provided for them was, unknown to them, carefully measured during 24 hours, at the end of which they were individually asked to recall in detail what had been eaten. They were all interviewed by an experienced dietitian. The results showed an underestimate of their food intake. These scientists were intelligent and accustomed in their daily work to quantifying procedures. Nevertheless, since these scientists did not choose or prepare the food, they possible scarcely noticed what they had eaten the previous day.

Thomson (1958) therefore conducted a 24 hours dietary recall in 11 pregnant women who were known to give good cooperation in weighed inventory method, the result was still not satisfactory. Thomson concluded that for reasonable accuracy, the dietary survey must rely on the direct measurement and not by the recall method. The recall record with quantities estimated from the household measurements gave a mean result lower than a weighed method. The accuracy was greater after the quantities had been corrected by weighing the household measures.

The accuracy of this method therefore depends on various factors: whether the interviewers are experienced enough, whether the food menu and models are used to remind the subjects about the type and quantity of food, whether the subjects are able to convey estimates of the quantity to the interviewers, and whether the subjects are motivated and cooperative. This method is therefore not suitable for an accurate food intake study which requires a high level of accuracy.

6.2.2 Food weighing method

6.2.2.1 <u>The weighed inventory method</u>

This method is one of the most widely used food weighing method. According to Marr (1971), the cooked food is weighed immediately before consumption and any plate waste is weighed at the end of the meal. The weighing of food can be successfully carried out by the subjects themselves with supervision from investigators. The subjects need to weigh all food that they consume during the day, except for the noncaloric food such as water, tea or coffee. (But the amount of sugar and milk in these drinks have to be weighed)

Analysis of the nutrient intake can be determined chemically from aliquote samples or by using the food composition table appropriated to the population under investigations which include certain cooked foods and made up dishes. (Widdowson, 1947; Garry et al., 1955; Edholm et al., 1955; Thomson, 1958; Durnin, Blake &

Brockway, 1957; Norgan, Ferro-Luzzi & Durnin, 1974).

Not only supervision from trained investigators but also cooperations from the subjects are required in this method. Marr stated that "not every individual is willing or able to carry out a weighed inventory dietary survey. It is important to ascertain to what extent the data collected represents the population from which the sample was drawn. The investigators always face the problem of those who fail to cooperate".

Thomson (1958) concluded from the food intake record by using this method in different social class pregnant women that there was progessively higher rates of failure to obtain reliable data as social status diminishes. He made a note that "the subjects yielding reliable dietary data were, on an average, slightly older, taller and healthier than the average of the original sample. Intelligence-test results available for some of the subjects indicated that they were also more intelligent".

In order to apply this technique, the selected subjects are needed. These subjects need to have good cooperation and be able to record food intake in a satisfactory manner.

6.2.2.2 The precise weighing method

This classical study of the daily food intake was carried out by Widdowson (1936) and later by Flores & Garcia, (1960). In this method, raw ingredient food, cooked food and a portion taken by subjects are carefully weighed, and then the plate waste is weighed at the end of the meal. The amount of food consumed and the nutrient intake are calculated using either values determined chemically from duplicate samples or by using food composition tables.

In practice, it is uncommon to request the subjects some foods to be provided for chemical analysis. Marr (1971) stated that "this duplicate chemical analysis method might introduce an unknown factor into the household, which may then alter the purchasing and cooking habits".

The precise weighing method is known to be the most accurate in dietary assessment because the exact amount of food consumed can be weighed directly.

This can be done either by the subjects themselves (Widdowson 1936, 1947) or by the observers (Flores and Garcia, 1960). However this method is claimed to be labourour and can be used only for good cooperative subjects, and this selection of subjects might introduce significant bias. When the observer records the food intake of the subjects, this might introduce some interference in normal habits of the subjects. It is, therefore, very important to have well experienced observers and the interference of the observers should be kept to a minimum.

6.3. PROBLEM INVOLVED IN ENERGY INTAKE MEASUREMENT

Energy intake measurement of individuals or groups is normally used to determine the energy requirement due to its being less complicated than the energy expenditure measurement. Several studies and reviews of the reliability and validity of dietary survey methods have been published over many years (Widdowson, 1947; Marr 1971; Thomson 1958; Bingham, 1982; 1985).

Bingham (1982) discussed the problem with present day methods of dietary assessment and stated that "For the present method used of dietary assessment, there are no such markers for energy and other nutrient intakes sufficiently accurate to validate dietary survey data and for the time being, the validaty of more simple methods will have to be assessed by comparison with weighing record data, provided this is continued for a sufficiently long period of time to characterize the items of diet in question to a stated level of accuracy, taking into account seasonal variations".

Problems involved in the measurement of energy intake are: the accuracy of the method; the individual variation in dietary intake; the length of the study period, whether it is long enough to predict the actual food intake; how the food information is transformed to energy and other nutrients intake; and the effect of being measured.

-The acceptable procedure

In order to study the energy balance, the precise and accurate method of food intake measurement is usually carried out. This can be done by the precise weighing method or the weighed inventory method. The 24 hours dietary recall and the estimated food intake by household consumption are less accurate. In practice, the weighed inventory method is more suitable and less expensive than the precise method. This method can be used in a field study to measure the free living condition.

The standard procedure and precautions of food measurement is discussed in detail (Durnin & Ferro-Luzzi, 1982) that - the method used should be explained clearly about how food intake is measured, and by whom, how experienced the observers are if the subjects are not measuring the food themselves, duration of the study period, the exact way in which food intake is measured and recorded, the type of balance used, to what degree of exactitude they read, are they calibrated and how? what sort of log books are used and how the subjects record their food, which Food composition table is used for calculation, ...etc. These details of the exact procedure are needed to let the reader judge how reliable the data is.

In practice, the subjects should be, as far as possible, representative of a clearly defined population, and that food intake should be determined by methods of proved accuracy. Therefore any sample which includes careless, unintelligent, unconcientious or non cooperative subjects will yield a corresponding number of inaccurate and incomplete records.

-Duration of the study period

The time which is needed for food intake mesurement should be long enough to make a good prediciton of energy and nutrient intake but not too long to interfere with the normal life. Edholm et al., (1955) conducted a study of food intake and expenditure on 12 cadets for 14 days and found perfect agreement between food intake and expenditure in the group but not in the individual.

Later Marr (1971) demonstrated that a 7 day weighed record would be adequate for energy carbohydrate and protein intake estimation, whereas fat intake has a greater daily variation, so that 9 days are necessary. In addition, a large number of observed days is required for the micronutrients. Durnin, McLees & MacLeod (1965) carried out a comparison between a 3 and a 7-day study of the food intake of 200 infants and found no significant difference in any case for energy or nutrient intake.

At present, the 7-day weighing record method is thought to be the most appropriate food intake measurement in weighed and recorded surveys. Even though this is not often used in large populations due to the work load and the high cost. In addition, the rather long period of time involved might be a contributing factor to a poor response. In practice, therefore, it is convenient to use only a 5 day weighing record provided that the weekend is included in the observation.

-Individual variation in dietary intake

It is generally accepted that the food intake of an individual varies from day to day (Widdowson 1947, Marr 1971) and from season to seaon (Lawrence et al., 1984; Prentice, 1980). When the data was presented, it was always accompanied with a high standard deviation. The standard deviation is at least 25% of the mean, for protein and energy and much greater for vitamins, minerals (Bingham 1982). The daily variation is in fact a real situation, as long as the investigators follow the proper procedure, use the accurate scale, the proper food tables and above all have no interference in the normal intake of the subjects due to the effect of being measured.

The individual variation is also applied in the diet of pregnant women. Studies in the past revealed that the diet of pregnant women could vary widely in quantity as well as in quality in all social classes which might be associated with differences of well being during pregnancy (Thomson 1959a).

Many studies showed that there was an intra and inter-individual variation both in developed and developing countries. The shorter the time, the greater the coefficient variation (CV). For the study of one day and seven days in developed countries, the coefficient variation decrease from 33% to 13% while in developing countries, it was 56% and 21%. In order to achieve the coefficient variation of less than 10% with 95% range of observed individual value from the true mean, it was calculated that 11 days and 32 days for data collection was required in developed anddeveloping countries (Ferro-Luzzi 1984).

This number of days for food intake measurement is ideal but impractical because it is time consuming and is an inappropriate way of dealing with the subject. Nevertheless Acheson et al (1980a) showed from his study in limited number of subjects (n=12) that there was no significant improvement in CV%, when the variation of intakes of 1,2,3 and 4 weeks were compared. The conclusion therefore is that one week would probably be enough for food intake measurement, or 5 days if the weekend is included.

-Food composition tables

All methods of food intake mesurement rely on food composition tables for the calculation of various nutrients intake except when using bomb calorimetry. Many food tables, particularly those derived from FAO, use Atwater factors for the energy derived from protein, fat and carbohydrate, by taking into account the different digestibility of different types of food (Merrill and Watt, 1955).

The limitation of using food composition tables is that it presents the average figure of the analyses of the food samples from various sources, and many tables cover a wide geographical area. As a result, it has only a limited accuracy when applied in any particular case. This problem might be more pronounced in composite dishes where there may be different ingredients in the recipe. For example, a difference in the amount of fat used in different recipes will result in a large error in the estimation of the energy intake.

However, in some areas where food recipes contain little fat, a simpler method of energy intake assessment can be adopted. Paul (1983) demonstrated that the energy value of Gambian food can be accurately predicted from a simple analysis of the water content. This principle would be applicable in any area where foods contain a small amount of fat, a situation which holds for many third world countries.

Food composition tables, however, are still widely used because of its simplicity. In order to closely estimate the different nutrients by using food tables, a local food table is the most appropriate. Furthermore it is important that the food tables used should be appropriately matched to the foods which are eaten, and that this should be considered an important part of the processing of dietary data (Marr, 1971).

A study in the validity of using food tables for the assessment of food intake was performed by Bransby, Daubney & King (1948). The study was done in 33 adults who weighed their food for three days. Different nutrient intakes were compared using the food composition tables, and the chemical analysis. The correlation coefficients between analyzed and calculated values varied from one nutrient to another. In terms of energy intake and macronutrients the correlation coefficients were rather high ($r \sim 0.9$) but micronutrients gave a lower correlation. However it is possible to compare 'individual' intakes relative to each other and also to compare groups of individual by using food composition table.

Therefore food composition tables can be used satisfactorily provided that the local food table is used and the food description is stated clearly.

-Effect of being measured food intake

When the person is required to weigh their food eaten in order to assess their dietary intake, it is possible that - this situation of being measured might make the subjects to be more concious of the food eaten, and their food habits may therefore be interferred with. According to the evidence given by Warnold, Carlgren & Krotkiewski (1978), obese women who took part in a weight reduction regime reported lower than their normal food intakes during the experimental period.

Norgan, Ferro-Luzzi & Durnin (1974) conducted a study of energy intake measurement in about 200 New Guinean Adults using weighed inventory method measured by the observers. Each dietary survey covered a period of about 5-7 days. The statistical analysis was tested to demonstrate the effect of being observed, if any, by making the comparison of the energy intake of the first day and the last day of each period. No significant difference was observed. The authors concluded from this finding that the method of investigation caused little apparent influence on the feeding habits of the subjects. The contact of the observers with the subjects was found to be very friendly and informal.

It is therefore necessary to be as friendly and informal as possible to make the subjects feel at ease and to encourage them to cooperate well.

6.4 THE METHOD OF FOOD INTAKE MEASUREMENT USED IN THAI STUDY

The method of measurement of food intake selected for this study was the precise weighing method, that is, every item of raw food and drink consumed by the subjects was accurately weighed and recorded by well trained observers. The measurement was carried out over a 5-day study period at 6-weekly intervals.

This method was selected for several reasons -

1) The precise weighing method is known as the most accurate technique available which can be used on a reasonable number of people, without causing too much inconvenience to the subjects involved. Other techniques of measurement of food intake as previously described would not have been suitable for this study. For example, a 24-hour dietary recall would not have yielded results with the degree of accuracy required. This method is really only of use for qualitative information on types of food and a rough estimate of the amount of food consumed. Therefore it is not the most suitable method for the particular study.

2) The precise weighing method selected because of the nature of available food composition table, i.e. the food table (Wu Leung, Buirum & Chang 1972; Div. of Nutr. 1978, 1981) provides the information of raw food and not cooked food. The reason is that the East Asia Food Table is used for different countries in that region and therefore the cooked food is not available because it differs from place to place. Even the Thai Food Table provides only a limited number of cooked food because of the

variation of recipes involved. Hence the precise weighing method is the most appropriate method for this study.

The duration of food intake measurement was 5 days, always including the weekend and always starting on the same day of the week to reduce any possible bias on any particular day. 5-days was selected as this is thought to be the most suitable length of time for the subjects involved.

6.5 HOW FOOD INTAKE IS RECORDED

6.5.1 The observers

Before the study was started in August 1982, qualified dietitions were recruited and trained as observers to record both food intake and the time-motion study. Altogether 8 observers were responsible for 44 subjects. One observer would observe one volunteer through the study. These observers were local natives who can speak the local dialect and knew their cultures, food habits and how the food was prepared in this region. Other necessary qualifications were good personalities and an ability to communicate with the subjects. They were always friendly and got along well with the subjects and all members of the family.

Early in the morning about 6:00am, the observers were brought to the women's houses to record food intake and activity during the day. Food eaten for each meal of the day and snacks were recorded by the observer who stayed with the women until they had finished their evening meal which was about 6-7pm. The observers were then brought back to the reasearch center.

6.5.2 Food scales

There were two types of scales used in food intake measurement. The first one was "Soehnle" digital spring balance which read to the nearest 29 and had the capacity to 1kg. This spring balance was very simple to operate, i.e. the plate on which the food would be weighed was placed on the balance. The zero knob was pressed and the scales read "zero". After the food was put on the scale, its weight was digitally displayed. The scales gave an accurate, clear reading, and were very easy to operate even for the subjects themselves. On very rare occasions volunteers were needed to weigh the snack at night after the obverser had left. When the food weighed more than 1kg, the second spring balance scale was used. This balance had the pointer moving around the dial with the nearest reading 10g up to 3kg. Both sets of scales were carefully calibrated using standard weights before the food intake measurement.

Because of the limited amount of plates and dishes in the family, extra rice containers, plates and dishes were provided for the mother's food. Therefore the family could still have a meal together but the mother had food which was separately weighed in her own dishes.

6.5.3 Procedure for food intake measurement

When the observers arrived at about 6:00am, the volunteers were steaming the rice which had previously been weighed in the raw state or else, the rice was cooked and ready to be weighed. The observers weighed the rice in a rice container and the weight of the container was deducted. In order to get the actual cooked rice weight.

Rice is known to be a staple food which contributes about 70-80% of energy intake in this region. For this reason, special care was taken to get actual rice consumption. Rice is normally cooked twice a day, i.e. in the morning and in the evening. The process of cooking glutineous rice is quite different from ordinary rice. It has to be soaked overnight and then steamed the next morning. On the day before the 5-day study period, the observer took the food scales and the food and activity records to the women's house. The observer weighed the raw glutineous rice which would be kept separate and later be soaked by the subject before she went to bed. The next morning, the rice would be steamed and the observer would weigh the cooked rice when she arrived at the woman's house. Raw and cooked rice were weighed every day, and although the food composition tables provide the nutrient composition of cooked glutinous rice, this value was not used because of the uncertainty of the length of time of soaking and cooking the rice which would result in changing the conversion factor from the raw to the cooking state due to changing in water content.

When food was being prepared for the family, all raw ingredients were carefully weighed by the observers using "Soehnle" digital scales, unless the raw ingredients weighed more than 1kg when the larger scale would be used. These raw ingredients would be prepared in a form ready for cooking. For example, the vegetables, only the edible portion that would be used for cooking was weighed. For meat which contained bone, such as chicken, duck or fish, the subjects normally cooked meat with bones, the weight of the raw food was weighed and the bone would be collected and weighed again after the meal. The weight of the bones would be subtracted from the original raw weight in order to get only the edible weight of the raw meat, since the food composition table provides only the nutrient composition of the raw edible weight. Cooked food was treated differently according to its appearance. When the cooked food was well mixed, a portion of the mixed food would represent that total cooked food. For example the chili sauce, papaya salad, fried mince beef with vegetable and spices....etc. On the other hand, when the cooked food was not well mixed such as "soup" which contained various ingredients that the subjects could select any portion of each component in the "soup". In this case the portion taken by the mother would not represent the cooked food in the pot. Therefore, individual components would be weighed in raw, cooked and portion taken as such.

Mixed cooked food was weighed and the woman's individual portion was then weighed using the accurate digital scale. The left over rice and other food consumed by the mothers were then weighed and the actual amount of food consumed was calculated by subtracting from the initial weight.

For the non-mixed cooked food, the weighing procedure would be a little different from the normal procedure mentioned above. Not only was the total weight of the cooked food weighed, but also the weight of the individual items of food in the woman's individual portion such as meat with bone, vegetables, etc. The same individual weighing would be done again for the leftover food.

Any food which was consumed between meals was also recorded in detail by the observers. Normally they eat fruits which were locally grown in the village such as banana, mango, papaya, tammarin, etc. The description of fruits was given whether it was raw or ripe because of the difference in the energy and nutrient content. In addition, the women normally drink rain water which need not be measured.

The observers were responsible for weighing all food and snacks for the whole day. They always carry the Soehnle digital scales in order to be able to weigh food at any time. All the food eaten by the mother was recorded in one book a day. The book was brought into the lab the next day to be carefully checked for the individual weights of raw food eaten by the subjects to be calculated.

Two food record forms were used for this particular purpose, i.e. the daily food record form used in the field and the computer form. The food record form has a table on the right of the page and a blank space on the left. The observer wrote down the weight of the container, the container with food in the blank space and the amount of food consumed was put in the table on the right page. In every occasion, the container weights were recorded and subtracted from the food with the container weight. The amount of food and the items of ingredient were then put into the computer form which consisted of the name of the food, the computer code and the amount eaten by thewomen.

Example of how to record food intake is shown in Table 26. In the morning, this women had rice, grilled fish with chilli sauce and steamed vegetable. Raw rice was weighed in the night before and cooked rice was weighed in the morning. A portion of rice for the mother would then be put in a separate rice container and weighed. Raw fish was weighed before and after it was cooked.

The woman's portion of cooked fish was weighed again before eaten. The bone which was left from the woman's portion and from the family's portion was

Table 26 An example of daily food intake of a pregnant woman.

Type of food Ingredient	Raw weight	Cooked weight	Portion for the mother	Left over	Amount consumed
Breakfast					
- Glutineous rice	1220	2710	450	22	428
- Grilled fish					
fish	530-82 (bone)	438-82 (bone)	122-16 (bone)	16	
salt	8				
- Steamed vegetable					
water crest	170	186	52	10	42
- Chilli sauce		90	18	4	14
fresh green chilli	28				
garlic	22-2				
onion	16				
lime juice	48-36				
fish sauce	12				
sugar	4				
fermented fish	6				
Lunch					
- Glutineous rice			260	20	240
- Papaya salad		378	144	32	112
raw papaya	282				
fish sauce	20				
fermented fish	18				
garlic	4				
tomato	30				
dry chilli	14				
lime juice	28-22				
sugar	8				
- Mango (raw)	244		244	62	182
- Salt mixed with sugar					
salt	8	32	84	76	12
sugar	24				
Dinner					
- Glutineous rice	870	2070	290	-	290
- Chicken & mushroom "soup"		1840	312		
chicken with bone	1120-380 (bone)	1210-380 (bone)	78	24 (bone)	52
mushroom	248	256	60	-	60
fish sauce	42				
chilli (fresh)	24		124	50	124
tomato	146				
salt	10				
H_2O					
- Chilli sauce			10	2	8

collected and weighed. This weight was then subtracted from the raw weight as well as the cooked weight in order to get the actual raw and cooked fish. The amount of cooked fish consumed by the mother was calculated only for the fish meat.

Chilli sauce was made in a homogenous form. The observer weighed the raw ingredients, the cooked chilli sauce, the portion taken for the women and then the leftover. Fresh vegetables were weighed before they were steamed and after they were cooked. The woman's portion of vegetables was then weighed seperately and the left over were weighed again.

For lunch, it is very common that the family would have the rice which is leftover from the morning. In this meal, the mother had papaya salad with fresh vegetables. All raw ingredients and thereafter mixed papaya salad was weighed. This food is well mixed, therefore a portion of food consumed by the mother could be calculated back to get the raw ingredients consumed. Fresh vegetables before the woman consumed and the left overs were weighed as usual.

Raw mango and salt mixed with sugar were taken as a snack for this volunteer, the observer weighed and recorded the type and amount of mango and the mixture of salt and sugar consumed.

For the evening meal, glutineous rice was once again cooked for the family consumption. Raw rice was weighed and soaked after lunch and then steamed in the evening. For chicken and mushroom "soup", the raw ingredients were weighed as such. Since the food was not well mixed, the weight of cooked chicken and cooked mushroom in the "soup" were weighed seperately. The weight of total cooked food was also recorded. A portion of "soup", mushroom and chicken with bone in that portion were weighed. Therefore the amount of mushroom which was taken by the mother was calculated back to the raw state. However, the chicken bone from the mother's portion and from the family portion were collected and weighed.

This bone weight would be subtracted from the raw and cooked weight of the whole chicken in order to get the conversion factor of cooked to raw chicken weight.

The amount of cooked chicken consumed by the mother, which was calculated from the chicken weight present in the portion minus the bone weight of that portion, was calculated.

Late evening food consumption of the mother also rarely occured, as a few hours after dinner, they went to bed. Nevertheless, the food scales were left at the woman's house during the night, just in case the woman took some snack or food, when they would weigh the food by themselves. Any such recording would be carefully checked by the observers in the following morning.

Normally the mothers cooked their own food for the whole family. Only on very rare occasions was food bought from outside or sometimes given by the neighbours. On those occasions, the name of the dishes and the details of cooked food were carefully recorded, afterwards the raw ingredients of these particular dishes were worked out from the information on cooked dishes accumulated since the study started. In some cases when the woman consumed food which there was no information of the recipe, the observer went to ask for the recipe from the food seller. Later the dietitian would make the food according to that recipe and weighed all the raw ingredients and the cooked food to be used for the food intake calculation.

6.5.4 Food data analysis

On completion of each day's food record, the following day the form was brought back to the research center where the supervisor carefully checked the record. After 5 days food record was complete, the supervisor calculated the raw food consumption of the mother for each day of the 5-day period. Details of the raw food and the amount eaten for each day were then double checked and carefully coded in the computer sheet for food consumption. Each weighed item of food was coded according to the available food tables.

Two sources of food tables were used in this study, i.e. Thai Food Composition Table (Div. Nutr. 1978, 1981), Food Composition Table for use in East Asia (Wu Leung, Buirum & Chang 1972). If the information could not be found in these two references, nutrient composition of that particular food was obtained by chemical analysis from the food laboratory in Ramathibodi Hospital, Bangkok, Thailand. However, those two references would cover more than 95% of food used in the village.

Food composition table from both Thailand and South East Asia references provide food consumption information in 100g edible portion in the raw state which contained energy,protein,and fat. The type and details of each food were coded and put in the computer. The common dishes which were accumulated from various volunteers were also coded as the reference food composition in the computer and was used for the cooked food bought from outside.

Daily energy nutrient composition of food consumed by the mother was calculated and the average value of those 5-consecutive days was used as being representative of that particular period.

6.6 RESULTS AND DISCUSSION

6.6.1 Daily energy intake during pregnancy

For each 5-consecutive day food intake record, the mean energy intake was calculated to represent energy intake at the particular gestation. Table 27 gives the mean energy intake at different gestation weeks from 10 weeks until term. Mean intake at 10 weeks was 1932 $\pm$ 358 (1 SD) kcal. The percentage increase of food intake at term was about 19% higher than the baseline intake at 10 weeks. The women continued to increase their food intake until about 30 weeks of gestation and thereafter they reduced their food intake until term.

During 37-40 weeks gestation, only 19 pregnant women were observed for food intake measurement. This was because the serial measurement of food intake was done at six weekly intervals. Therefore, the measurement was not carried out until the next 6 week period.

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It is generally accepted that there is not only a day-to-day variation of energy

Table 27 Average daily energy intake during pregnancy ($\bar{X} \pm SD$)

Gestation week	n	Energy intake	CV%
7-12	31	1932 ± 358	18
13-18	44	2092 ± 358	17
19-24	43	2279 ± 380	17
25-30	44	2295 ± 326	14
31-36	43	2201 ± 350	16
37-40	19	2136 ± 386	18

intake in each individual, (intraindividual) but also a variation of energy intake between individuals (interindividual). There is much available data to suggest that individuals of the same age and sex may differ substantially one from another in their intake of food and therefore nutrients. In pregnant women, Darke, Disselduff & Try (1980) conducted a nutritional survey in 485 pregnant women in Britain at 6th-7th months gestation. By using 7-day weighing record, the energy intake of these women varied from 1325 to 3,000kcal, with the average mean intake 2,152 ± 503 (lSD)kcal. Beal (1971) also found a wide variation in energy intake in American pregnant women, for example the energy intake of pregnant women at 6 months ranged from 1,100 to 2,900kcal, or with the average mean intake 1878 ± 414 (1 SD) kcal.

In this study inter-individual variation was calculated by coefficient variation (CV%) and showed the large variation ranged from 14-18%. The standard deviation of each gestational age was about the same, whereas the mean intake was gradually increased up to 30 weeks and then declined.

The individual record of food intake during each study period, showed a fluctuation of total daily energy intake on a day to day basis with the high coefficient variation ranging from 12-26% as shown in Figure 17. Whereas the intraindividual variation in the total daily energy expenditure did not show much of a fluctuation as found in the enrgy intakes. The coefficient variation of total daily energy expenditure of each period ranged from 2-7%. The reason was that the woman performed more or less the same task in every day life and there was not much influence to change in the pattern of work. Simultaneous measurements of food intake could vary from day to day due to many influences, for example, the emotion, the type of food on that particular day, e.g. if she liked the food she could eat more, or if she did not feel like eating, she could eat less. The interindividual variation of these two parameters however gave a wide variation as shown in Figure 18.

Fig. 17 Variation of energy intake and expenditure in each study period of an individual.

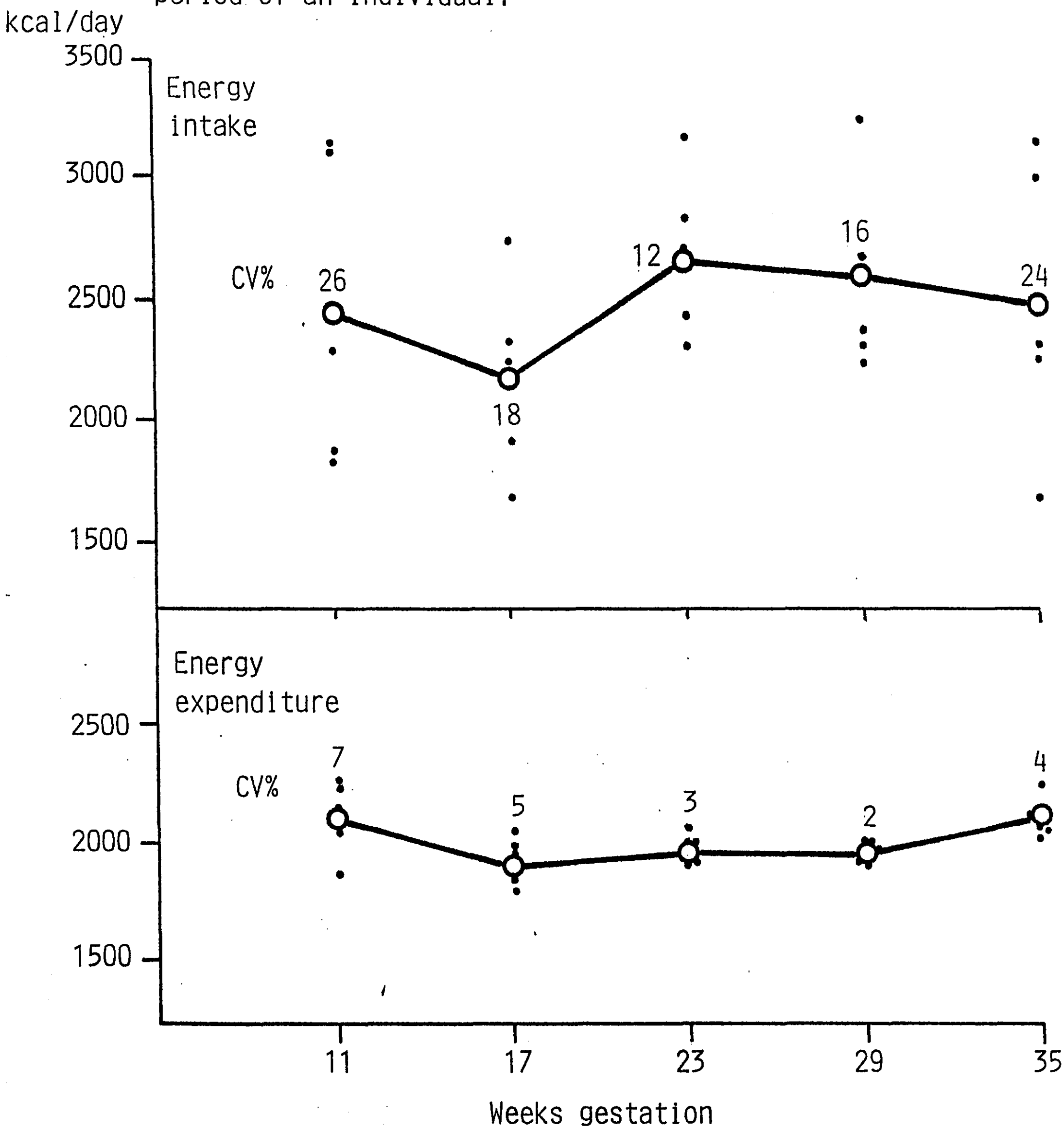
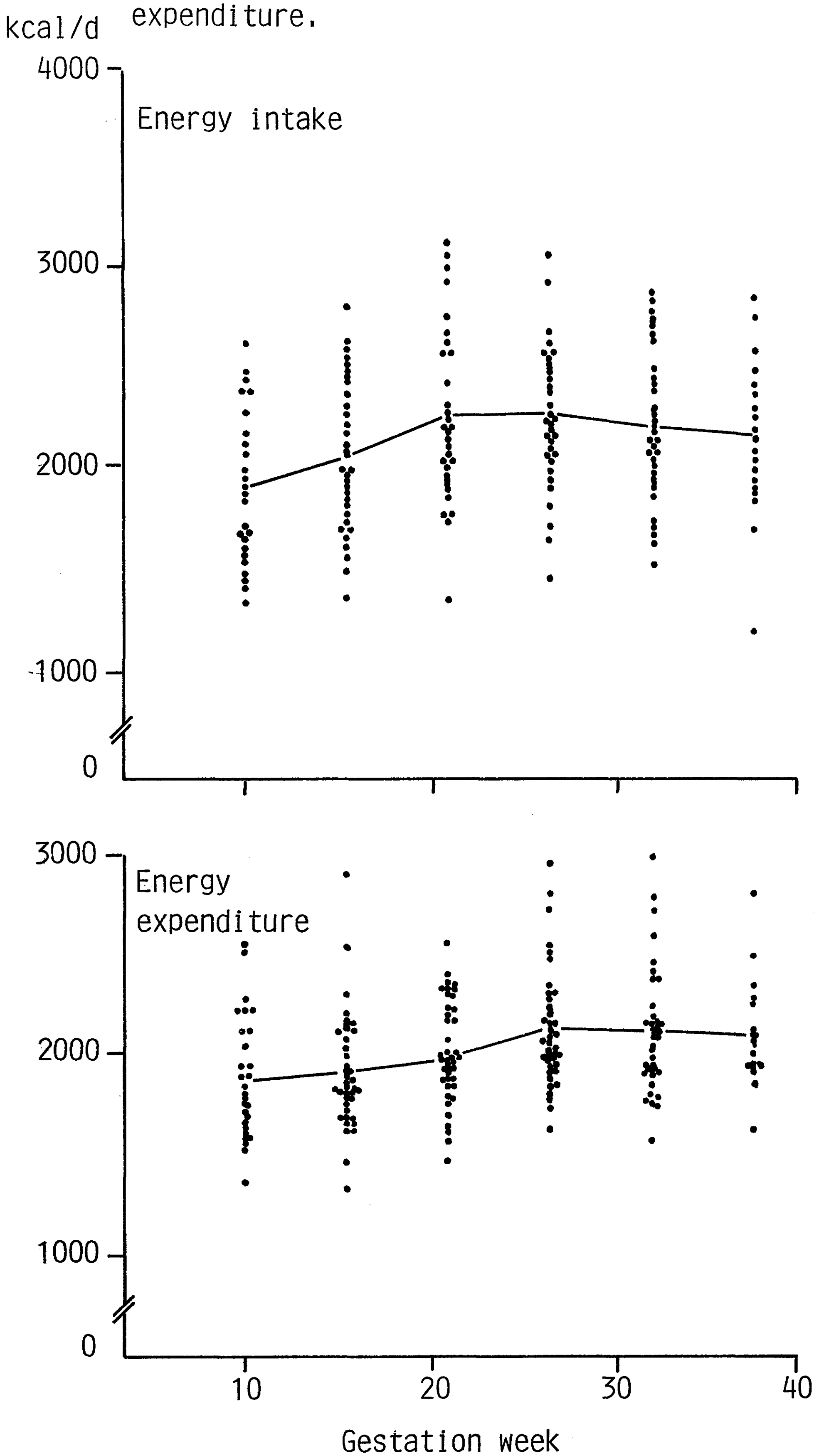


Fig. 18 Individual variation of energy intake and expenditure.



6.6.2 The total increment of energy intake

Because of the different number of volunteers presented in each measurement, it is most likely that the mean value might give a bias result due to the individual variation. In order to solve this problem, the within subject incremental analysis of food intake during pregnancy is adopted.

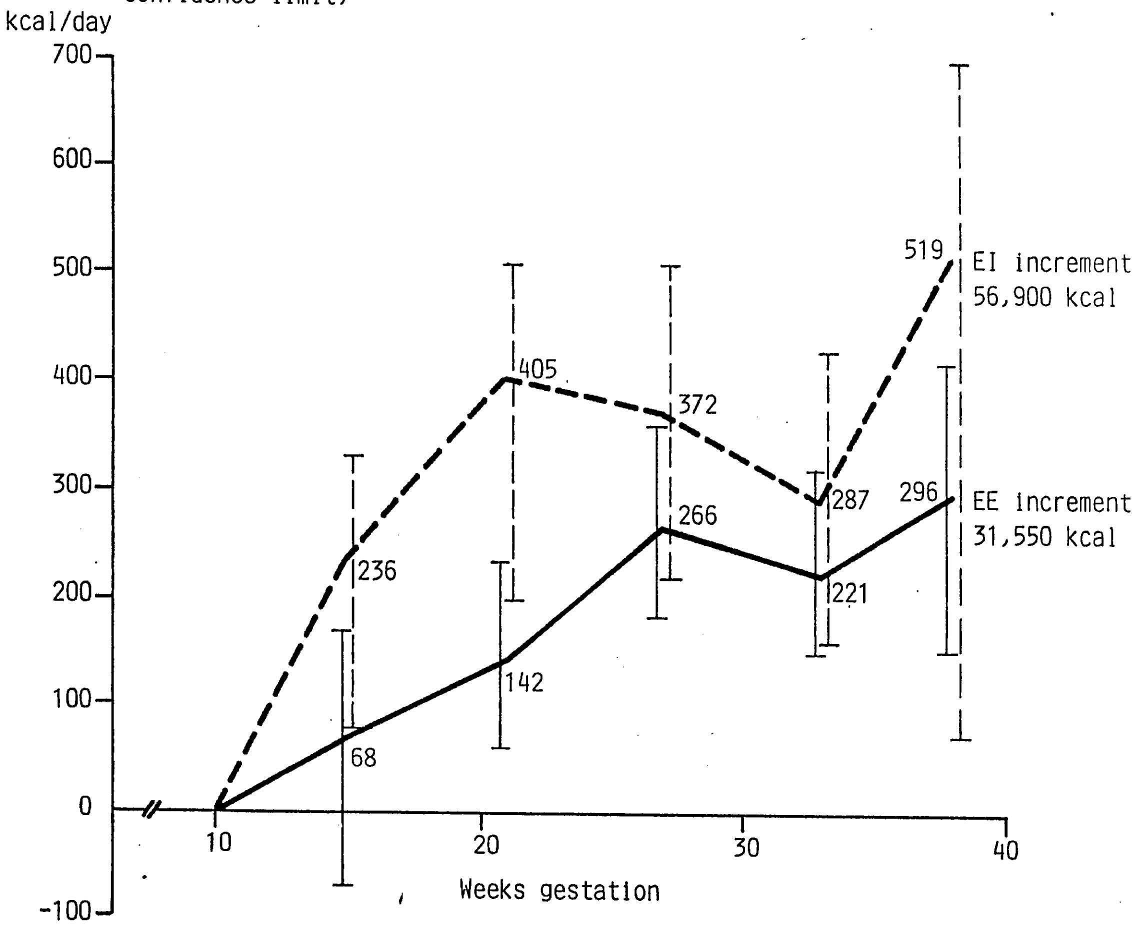
Only 31 women, out of the total 44 women, were presented at the initial starting point, i.e. at 10 weeks. Therefore the other 13 missing values were estimated by assuming the same magnitude of change from the mean change of those 31 women of the first increment. By this method, the initial missing values of energy intake were estimated. The increment of the 44 women was then calculated from 10 weeks until term. The median value (instead of mean value) and confidence limit of energy intake at different gestational weeks was also applied. The reason for this is that it could not be assumed that the data was normally distributed. The mean value might well give a bias result, particularly when high or low values are presented.

Figure 19 gives the increment energy intake in and energy expenditure in 44 pregnant women from 10 weeks until term. The value was given in the median and confidence limit. A positive energy balance was observed throughout pregnancy. The energy intake showed a marked rise from 10-20 weeks of about 400kcal/day and then dropped to about 300kcal/day at 33 weeks gestation. At term, there was an increase of median energy intake about 500kcal/day or 400kcal/d for the mean value, compared to the intake at 10 weeks. This large increase could possibly be explained by the fact that the number of women measured near term was only 19 and a wide range of confidence limit was observed.

The total increment of energy intake from 10 weeks until term calculated using median increment was 56,900kcal which was similar to the calculation using the mean increment which was 57,600kcal.

Even though when the missing values of baseline were not estimated as mentioned above, a similar amount of total increment of energy intake from 10 weeks

Fig.19 Increment of energy intake and expenditure during pregnancy (median and confidence limit)



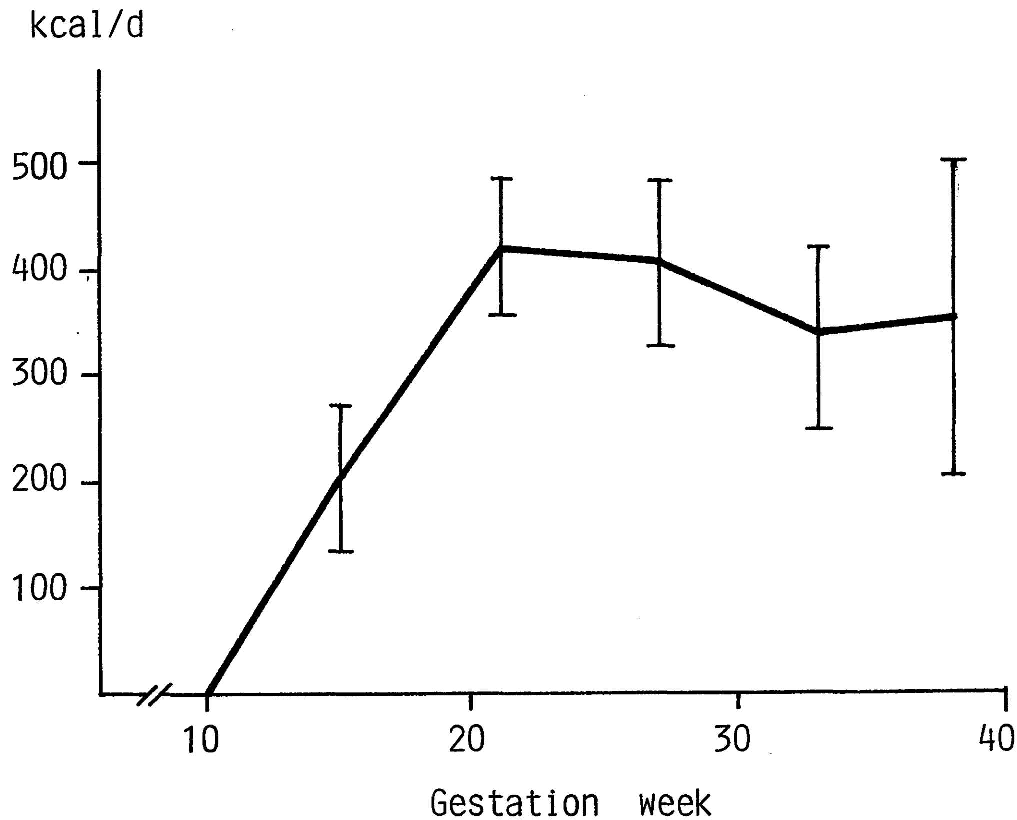
until term was found in 29 women at the mean increase 57,750kcal as shown in Figure 20. Therefore, it can be concluded that the women who did not have the baseline information of energy intake at 10 weeks behaved in the same way of increasing the food intake as the women who started the measurement at 10 weeks.

The baseline information at 10 weeks plays an important role in the incremental analysis. Energy intake at 10 weeks gestation could be altered from the energy intake at conception. For example, it is generally accepted that morning sickness and/or loss of appetite is common in this early period of pregnancy. If this was the case it could possibly mean that the energy intake was already dropped at 10 weeks gestation and thereafter the marked increase was observed due to the lowering of the baseline at 10 weeks. Unfortunately the information of energy intake at conception in this study was not enough to provide the information on the early stage of pregnancy.

During the second trimester, morning sickness usually disappear or diminsih and appetite tends to increase. In the third trimester, in developed countries it is not uncommon that the pregnant women restrict food in an effort to control weight gain whereas in developing countries, particularly in the hard labour working pregnant women, the workload may not allow the women to decrease their food intake, unless the seasonal variation and socioeconomic factors presents a constraint factor and prevents them to eat according to appetite. In this study, the women increased their food intake during the second and third trimester.

There are very few studies to demonstrate the changes of energy intake during the early pregnancy. The only complete study of energy intake throughout pregnancy was demonstrated by Durnin et al. (1985) who conducted one of the multicenter study of energy requirement. The study was carried out in 71 Glasgow women and demonstrated a drop of energy intake at about 6 weeks gestation. In addition, there was no change of daily energy intake at 10 weeks compared to the energy intake at conception. Food intake measurement was done for 5 consecutive days by the weighed inventory method. The total increment of energy intake in this study was

Fig. 20　Increment of energy intake of 29 pregnant women (mean ±SEM)



20,000kcal throughout pregnancy.

Beal (1971) made a nutrition survey in 95 pregnant women using 24 hour dietary record at different gestation ages. Even though the method of dietary survey was not as precise as the weighed method, the results showed no change in energy intake in the first trimester compared to the preconception value of 1890kcal.

In this study, energy intake increment of 56,900kcal may not represent the true increment depending on the changes of energy intake from preconception until 10 weeks.

6.6.3 Caloric distribution of energy intake

Table 28 shows the caloric distribution in food intake which was classified into the macronutrients; -carbohydrate protein (animal and vegetable) and fat. The results showed no change in caloric distribution throughout pregnancy. Carbohydrate contributed the major part of the caloric distribution which was about 77%. Two thirds of the protein source was from vegetables whereas the rest was from animal sources. And fat contributed less than 10% of total caloric intake.

Accordng to the villager's habitual food intake, rice is used as a staple food. Normally food is prepared very spicy in order to make rice palatable. A large quantity of rice is consumed for each meal which not only provides carbohydrate but also vegetable protein, because rice contains about 80 percent carbohydrate, 7 percent protein and negligible amount of fat. In this study the women consumed an average of about 400-500g raw rice, which contributed about 1,800kcal daily.

Fat intake in this group of pregnant women was less than 10% which was very common in the rural area. Cooking oil is used occasionally. Most of the fish or meat was normally grilled or roasted and then mixed with chilli and some vegetables to make it spicy and tasty so that they could eat more rice. Even though cooking oil was occasionally used, the weighing procedure of cooking oil in this study was done in a very careful way.

The main animal protein source in the rural area was from fish which did not

Table 28 Percentage caloric distribution in the diet of volunteers during pregnancy.

Gestation week	No.	Carbohydrate	Protein		Fat
			Animal	Vegetable	
7-12	29	75.8	4.2	8.5	9.9
13-18	42	76.7	3.8	8.6	9.3
19-24	41	77.0	3.3	8.8	9.0
25-30	42	76.8	3.6	8.6	8.8
31-36	41	77.8	3.2	8.7	8.5
37-40	19	76.3	3.5	8.5	9.6

contribute much to the fat intake because of its low fat content. In addition poultry, eggs and some meat were also taken as the protein source.

6.6.4 Comparison of volunteers with initially low or high energy intake

Two distinct groups of initially high energy intake (about 2500kcal/d) and initially low energy intake (about 1,500kcal/day) at 10 weeks gestation were compared in this study. The result is shown in Figure 21 and Figure 22. The comparison was made not only for the changes of energy intake as pregnancy progressed but also the changes in energy expenditure and BMR in each individual. In the initial low energy intake group, a marked increase in energy intake was observed during the second and third trimesters. For example volunteers # 256, who showed an initial energy intake at 10 weeks of about 1400kcal/d, increased her intake to about 2500kcal/d in the early second trimester and to about 3000kcal/d in the third trimester. The level of intake was not changed at this level until term. Whereas volunteer # 204 showed the same marked increase in the early stage of the second trimester but later decreased the increment in the second and third trimester.

Energy expenditure of the initial low energy intake group showed a comparable result to energy intake. Whereas in the initial high energy intake group, the energy intake exceeded the energy expenditure throughout most of the period and the energy intake was consistently high, or showed some dropped during the last trimester (in volunteers #202 and #241). BMR of these two groups showed an increasing trend as pregnancy advanced. The average of each parameter throughout pregnancy for these two groups was compared as shown in Table 29. The results indicated that although the average energy intake was significantly different ($p<0.001$) in these two groups, other parameters such as energy expenditure, BMR, maternal weight at 10 weeks weight gain and birth weight showed a higher value but it was not significant in the initial high energy intake group compared to the initial low energy intake group. The only difference between these groups was the energy intake which was 2,500kcal/d and 1,970kcal/d respectfully. Though the initial low energy intake was shown to be

Fig. 21 Comparison of energy intake with energy expenditure and BMR in the initially low intake volunteers.

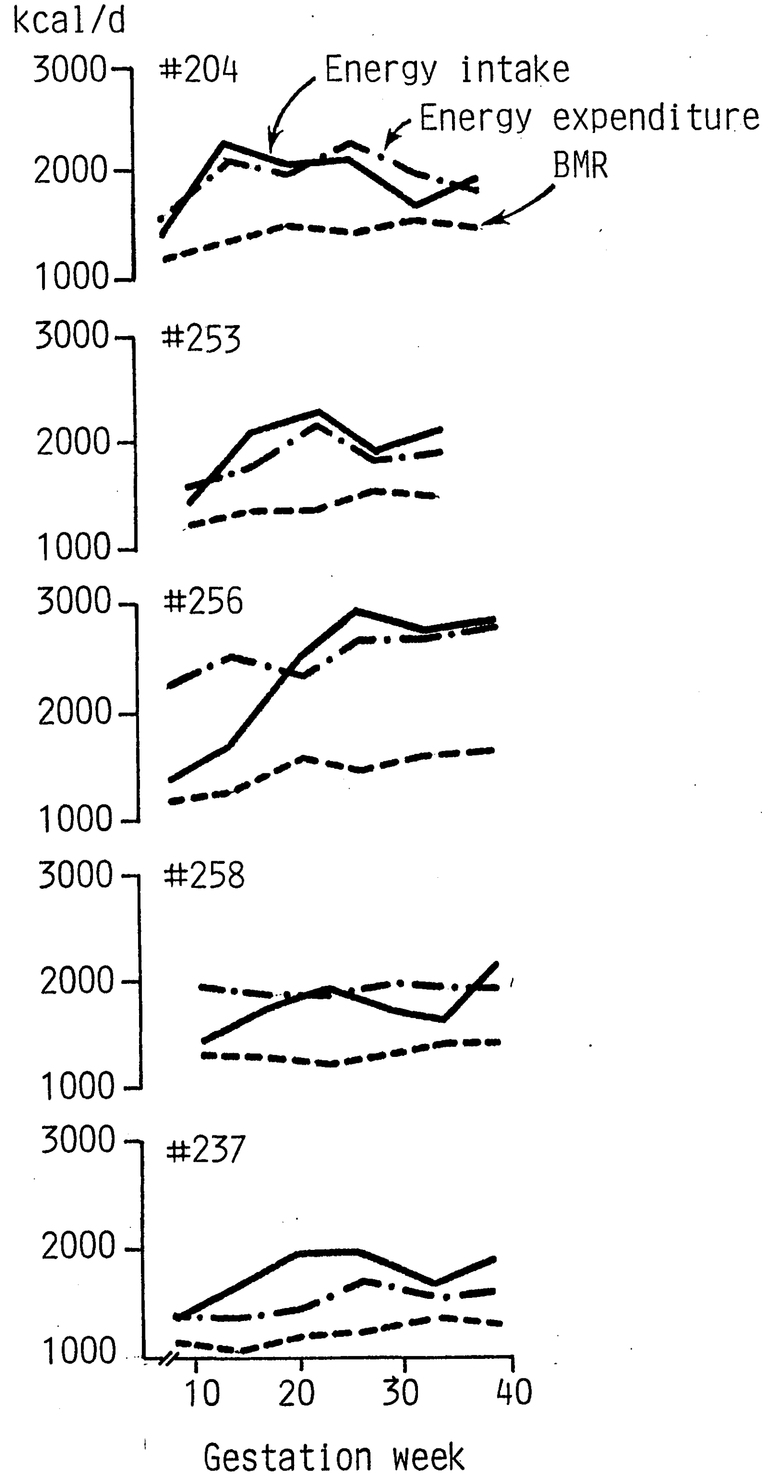


Fig.22 Comparison of energy intake with energy expenditure and BMR in the initially high intake volunteers.

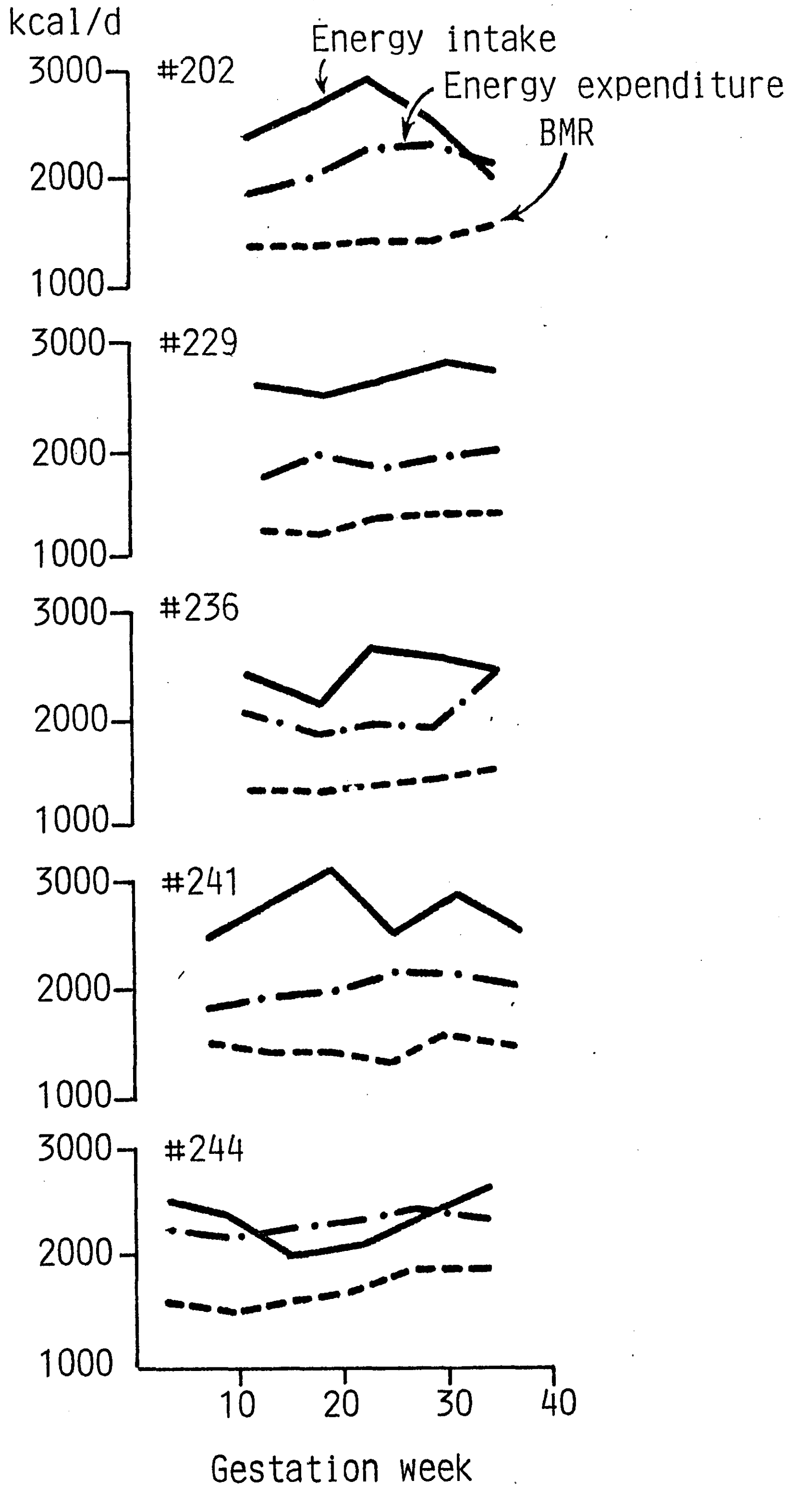


Table 29 The comparison of different parameters (mean ± SD) of the initially high and low energy intake groups.

	Initial high EI	Initial low EI
n	5	5
Energy intake (kcal/d)	2546 ± 120	1971 ± 243[a]
Energy expenditure (kcal/d)	2082 ± 159	1980 ± 372
BMR (kcal/d)	1476 ± 128	1382 ± 92
Maternal wt at 10 weeks (kg)	50.96 ± 8.5	48.86 ± 92
Maternal wt gain (kg)	10.2 ± 1.4	8.1 ± 3.8
Baby birth wt (kg)	3.04 ± 0.25	2.96 ± 0.31

[a] significant difference at $p<0.001$.

rather low at the beginning (~ 1500kcal) due to the marked increase in the subsequent measurements, the average value was 1970kcal/d.

In the initial high energy intake group, it was clear that the women continued their high intake throughout pregnancy. If this is the case then it would result if a large positive energy balance. For the initial low energy intake group, the energy intake and expenditure seemed to agree very well. Even though this study group showed a large interindividual variation. The energy intake and expenditure in initial high energy intake group showed a small standard deviation in comparison.

This results indicated that the high energy intake group might have been an over estimate. The number of subjects in each group, however was rather small, therefore no firm conclusion can be drawn from this comparison.

6.6.5 Explanation of high energy intake during pregnancy

Unlike most of the previously published papers (Blackburn & Calloway, 1976b; Whitehead et al. 1981; Beal 1971; English & Hitchcock, 1968; Darby et al. 1953,...etc.) the results of this study showed a substantial increase in energy intake during pregnancy. One of the Swedish studies by Lunell, Persson & Sterky (1969) demonstrated an extra energy intake (~ 400kcal/d) in the second trimester compared to the value in the first trimester, and only 100kcal/d more in the third trimester compared to the initial value. The result, however, was based on a small number of subjects (n = 15) and the method used was 24 hour dietary recall of the previous day, which might not be the best method of dietary intake measurement.

The question that needed to be asked is "Did the women consume that much energy and if they did, were there any factors which influenced their food intake during the study period?

In the light of the methodology used in this study, which was the precise weighing record, it can be strongly said that there was no doubt about the method used, because the food was accurately weighed for each and every ingredient, the amount taken and also the amount left over. Caution has been taken in every step of measurement, particularly the rice intake because the amount of water present in cooked rice is important in the accuracy of the measurement. The observers were asked to measure raw rice before and after cooking; instead of using the published value of cooked rice from the food tables. The same precaution also applied to the cooked food which was not mixed, the observer weighed the different portion of cooked food presented in the dish and each ingredient was therefore calculated back into the raw food. Food intake assessment was therefore carefully carried out in this study.

Another explanation that might answer the question is whether the initial baseline data at 10 weeks is possibly rather low due to the morning sickness and/or the loss of appetite. Even though there was no obvious recording of morning sickness, the women might have lost their appetites and tended to eat less. Or perhaps, the women were too shy to allow the investigators to measure the food, particularly during the first measurement, when they might have been eating less than normal. Providing that these phenomenon happened at 10 weeks gestation, this could explain why the baseline value was rather low and therefore resulted in the relatively higher intake for the rest of pregnancy.

The presence of observers to measure the food intake might as well play an important role in the measurement. This factor is difficult to quantify, i.e. whether the effect of being measured would lead to the higher or lower estimate of food intake.

It could be shown from this study that the women did not change their food habit as the result of the presence of observers, as the caloric distribution did not change throughout pregnancy. If there was any affect of observer, one would suspect the increase in the amount of animal protein consumption. One possible source of error may be that the women were eager to please and therefore finished their food portion in order that the observers did not have to weigh them again. Nevertheless, this was not the case in most of the women, because the leftover of food was regularly measured.

No food advice was given to the women during pregnancy. They were all informed that the food intake and the activity should be continued as normal as possible.

In addition to that this group of rural women grow enough rice for their own consumption throughout the year. The limitation of food intake, particularly rice, is out of the question. In this study, rice contributed about 77% of the total caloric intake. If they have enough rice to consume, along with the accurate measurement of rice consumption as mentioned above, it is most unlikely that the increase in food intake is not real.

This study, however, still lacks important information on what happened during early pregnancy, because the baseline data started at 10 weeks gestation. Further study is badly needed to confirm this high level of food intake in a complete picture, i.e. from preconception throughout pregnancy. In addition, a greater number of subjects would be advantageous in order to give evidence to answer the question whether or not food intake should be substantially increased in farmers who do not reduce their physical activities during pregnancy. This information would be very important for the national policy makers in the future, in terms of food planning and the proper advice for the pregnant women.

CHAPTER 7

7.1 ENERGY COST OF PREGNANCY

The theoretical extra energy needed in response to the physiological stress during pregnancy is calculated primarily from the increase in metabolism associated with the production of new tissue in the placenta, foetus and mamary gland, and secondly the deposition of a certain amount of maternal fat in preparation for an adequate lactation performance. Hytten & Leitch (1971) estiamated the energy cost of pregnancy by adding the energy equivalents of the increment of 0_2 consumption and of the protein and fat laid down in both fetus and mother. The extra energy needed is 80,000kcal throughout the whole period of pregnancy.

In this study different parameters were measured in 44 pregnant women from 10 weeks until term. However the early pregnancy period (from conception until 10 weeks) plays a crucial factor in providing baseline information on the prepregnant stage, and this was not satisfactorily available in this study. This is due to the difficulty in recruiting the volunteers at the nonpregnant stage and following them up until they conceived. Only a limited number of women recruited in the prepregnant state were followed up throughout pregnancy. Hence the energy cost of pregnancy in this study covered only the period from 10 weeks gestation until term.

BMR, is known to make a major contribution in the extra energy needed. This was measured under highly standardised condition. The increment of BMR from 10 weeks gestation until term was 24,000kcal. During early pregnancy, there was evidence from this study which demonstrated that the increase in BMR duringpregnancy might not be as high as in theory. Evidence in some women measured longitudinally at the prepregnant stage and actual but nonsignificant decrease of 2-3% in BMR at 10 weeks compared to the prepregnant value. In addition the comparison of the BMR in a group of pregnant women at 10 weeks with a nonpregnant group showed no change. The BMR in early pregnancy in this study therefore did not differ much from the baseline value at conception.

Another major contribution to the energy cost of pregnancy was from the deposition of about 3.8kg of fat at estimated by Hytten & Leitch. In this study the fat was estimated by several different methods:- by skinfold measurement a few days after delivery, skinfolds at 1 month after delivery, fat calculated using factorial method, and by the weight change method, all showed agreeable results. The women in this study laid down about 1.2kg of fat which is much less than the assumed theoretical value at 3.5-4.0kg throughout pregnancy.

Other components, such as the energy required for the synthesis of fetal tissue, placenta and amniotic fluid, for the enlargement of the breasts and the uterus, and for the increase in extracellular and extravascular fluid were not measured here. However, the energy cost of these components is rather small compared to the previous components, i.e. BMR and fat deposition. The estimated value of these components from Hytten & Leitch, adjusted for the body weight of the mother, were used in the calculation of the energy cost of pregnancy in this study, as shown in Table 30.

It is shown that the extra energy needed to fulfill the energy cost of pregnancy from 10 weeks until term was about 47,200kcal. Half of the energy cost was accounted for by increase in BMR alone and the other half from the tissue deposition in both fetus and mother. This energy cost of tissue deposition during pregnancy must have come from the extra food consumption and/or the saving from the metabolic adaptations during pregnancy, if any. In this study the energy balance, i.e. energy intake and expenditure increment from 10 weeks until term was measured. As noted earlier, there was a positive energy balance throughout pregnancy which resulted in the excess energy intake of 25,300kcal. This amount of energy would - presumably be available for use in tissue deposition. The independent calculations of energy balance and the energy equivalents, calculated from the actual measurement of maternal fat deposited and the estimatednatural and feal protein and fetal fat, is shown in Table 31.

Table 30 Energy cost of pregnancy in rural pregnant Thai women

	Energy equivalent (kcal)
BMR	24,034
Protein	5,385[a]
Fat (fetus)[b]	4,544[a]
Fat (maternal), 1.2kg[b]	13,200
Total	47,163

[a]Assumed from Hytten & Leitch (1964)

[b]Energy cost of fat deposition is 11,000kcal/kg.

Table 31 Available energy for tissue deposition during pregnancy

- Energy balance	kcal
Total net increase in energy intake	56,900
Total net increase in energy expenditure	31,600
Reserved energy	25,300
- Analysis of energy deposition in maternal adipose tissue stores and the products of conception.	kcal
Protein	5,385
Fat (fetus)	4,544
Fat (maternal), 1.2kg	13,200
	23,129

The results of the energy balance study and the energy deposited in the form of maternal adipose tissue and the products of conception seemed to agree well. The difference in these two calculations was only about 10%. However there is a problem in assessing daily energy expenditure that the energy cost of activity is increased in proportion with the body weight of the mother, i.e. we assumed that the energy cost of activity/kg was constant. But the results from the metabolic cost of walking on the treadmill did not show a constant energy cost per unit body weight but showed a significant reduction in the metabolic cost of walking during the second half of pregnancy. Therefore the assumption might mislead the result of total daily energy expenditure in the way that energy expenditure might be overestimated.

One would argue, however, that in the real situation, the women may not work at the same intensity throughout pregnancy. It was shown that as pregnancy progressed, the pregnant women tended to reduce the pace of walking, if they were allowed to walk at their own speed (van Raaj, Peek, Hautvast, 1986). When the Gambian pregnant women were asked to perform the same task at different stages of pregnancy, there was no increase in the metabolic cost in absolute terms but a decrease in the metabolic cost per unit body weight (Lawrence et al., 1984).

In this study if this decrease in the metabolic cost per kg had occurred in other activities (except in BMR which was found to be constant until 33 weeks gestation) then energy expenditure would not be increased by as much as 31,600kcal. Unfortunately, we did not obtain a sufficient number of measurements of other daily activities to enable us to investigate the longitudinal changes during pregnancy so no firm conclusions can be drawn from the total daily energy expenditure calculation.

Nevertheless, the incremental analysis of different parameters in this study was based on the initial value at 10 weeks. If somehow this baseline value as underestimated, i.e. the baseline had shifted to a lower level than that of conception, this will result in an overestimation of the total increment throughout pregnancy.

This was the only apparent source of error in an otherwise straight forward method of measuring energy intake. If at about 10 weeks gestation the women lost appetite and/or had morning sickness, the energy intake measurement, even though was performed very accurately, might result in a low measurement of intake. Evidence from this study showed that when the women started their energy intake measurements, a marked increase was observed after the initially low intake of 1,500kcal/d whereas the women who had initial energy intakes of about 1,000kcal more than the previous group, showed only a slight change in energy intake throughout pregnancy.

The classical question raised about dietary intake mesurements is the reliability of the results, intake measurements is the reliability of the results, due to the large inter-intraindividual variation of the subjects, which is common in any food assessment study. In our study, the food intake was measured for a reasonable length of time (5 consecutive days) and as frequent as two measurements in each trimester. No previous study of energy intake measurement in pregnancy has been carried out as frequently as in this study. Furthermore, the precise weighting method which is known to be the gold standard of food intake measurement (Marr 1971) was used. The only problem in using this method is whether or not there was any effect of the presence of observers. Ferro-Luzzi (1984) however suggested from the results obtained from Norgan & Ferro-Luzzi (1978) that "even if the subjects were not totally oblivious to the presence of an intruder weighing all their food, such presence did not disturb their spontaneous weekly cycle of eating behaviour."

In conclusion, this extra energy needed during pregnancy of 47,200kcal based on the assumption that there was an increase in the energy cost of moving a heavier body. If there was no change in this energy cost of moving heavier body, the energy cost would be less than 47,200kcal.

7.2 ENERGY REQUIREMENT IN RURAL PREGNANT THAI WOMEN

Even though the result of the energy cost of pregnancy was met by the increment of energy intake in this study, the energy cost of pregnancy was calculated only from 10 weeks until term. Any changes that happened during that missing 10 weeks of early pregnancy would, at least, change the baseline and thus the total energy cost. Further study is needed, particularly to detect any physiological changes and the changes in energy intake of the prenant women during the early pregnancy and also in the prepregnant stage, in order to fill this gap in the knowledge of energy requirements in pregnancy. The conclusion from this longitudinal study is that the pregnant rural Thai women need an extra 47,200kcal throughout pregnancy or about 225kcal daily.

This extra energy needed during pregnancy did not differ from the recommended allowance for pregnant women. FAO/WHO/UNU (1985) advised an average addition of 285kcal daily throughout pregnancy for the women who maintain their physical activity and only 200kcal/d for the women who reduced their activity. In this study, the women maintained physical activity therefore the full energy allowance should be provided during their pregnancy period. When the adjustment is made for the small stature of Thai pregnant rural women, the extra energy needed during pregnancy is similar to the recommended energy allowance.

This study supported the idea that the women needs extra energy to cover their maternal needs during pregnancy and to produce healthy offspring with satisfactory birth weights. These results are consistent with the classical concept that a satisfactory nutritional status is achieved whenever an adequate food supply is in balance with energy expenditure. Provided that information on the physiological changes during early pregnancy is obtained, there is no reason why the results of this study can not form the basis of a recommendation for rural pregnant women in Thailand, i.e. women who have to continue their work despite the physiological stress during pregnancy. The pregnant women in this study were not recruited randomly to represent the whole population which was impossible, considering the nature of the study. The volunteers in this study were however all healthy, had no previous medical or reproductive problems and, as the result, they produce a satisfactory outcome. This agrees with the Aberdeen standard (Thomson, Billewicz and Hytten, 1968), where the mother who had small stature (48kg weight and 1.52m height produced the baby with the average birth weight of 3.14kg.

In practice, the advice that should be given to the pregnant women is that they should consume more energy during pregnancy. The type and the amount of extra food needed, the energy equivalents should be transformed into simple terms to make it easily understandable to these pregnant women. For example, in rural Thailand, the advise should be that during pregnancy the women need to consume an extra of 60gm or a handful of raw rice or 1.5 tablespoons of cooking oil daily. Each type of food would provide approximately 225kcal.

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