BIOLOGICAL VARIATION IN BASAL METABOLIC RATE AND ENERGY METABOLISM

SUE L. REEVES

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Abstract

Biological variation is evident in all aspects of nutrition, particularly total daily energy expenditure (TDEE) and basal metabolic rate (BMR). The impact of ethnicity on biological variation on certain aspects of energy metabolism has been investigated.

Predictive equations to estimate BMR were published by the FAO/WHO/UNU (1985) in a report entitled *Energy and Protein Requirements*. Since its publication, serious concern has been expressed on the validity of these equations, largely because the analysis appears to be based on a biased and incomplete analysis of the world literature on BMR. Using an expanded database (n=10,004) and stringent selection criteria the global BMR data has been re-analysed and new predictive equations presented. The robustness of the new equations were tested by comparing their predictive accuracy with those of existing ones. The BMR of 77 women aged 18-30 years were found to be best described by the newly developed Oxford Brookes equations and the Henry & Rees (1991) equations for tropical peoples ($P<0.05$ and NS respectively). Furthermore, the new expanded data base was used to plot normal curves for BMR for individuals which compared ethnic differences. It was observed that when BMR is expressed per kilogram of body mass, ethnic differences are diminished.

The necessity to estimate TDEE in various ethnic groups prompted the evaluation of a non-invasive easy to use technique. Heart rate monitoring as a means of estimating TDEE is reviewed and compares favourably to the use of activity diaries. Whilst highly variable, heart rate monitoring is acknowledged as a valuable tool in the estimation of energy expenditure and activity in individuals and populations

Ethnic differences in energy intake in a migrating student population were assessed. Malaysian students recently arrived in the UK were requested to keep food diaries in order to detect changes in their diets. Particular emphasis was placed on changes in the energy densities of food consumed and their effect on body weight and energy balance. After 6 months, it was observed that energy balance was maintained despite the energy density of food consumed in the UK being significantly ($P<0.05$) more energy dense than food consumed in their native Malaysia. This illustrates the precise way in which the human body can maintain energy balance.

Anthropometric differences were compared in 553 individuals from 4 ethnic groups in a study investigating the arm-span and height relationship. Differences were found between the ethnic groups ($P<0.01$). The use of arm-span as a proxy for height should be used with caution.

It is imperative that more global data collected under strict control is required before human biological variation can be attributed to true ethnic differences and not merely individual variation.

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Table of Contents

List of Tables

List of Figures

List of Appendices

List of Abbreviations

ANOVA	Analysis of variance
BMI	Body mass index
BMR	Basal metabolic rate
BR	Benedict-Roth respiration apparatus
C	Celsius
CV	Coefficient of variation
d	Day
DIT	Dietary induced thermogenesis
EE	Energy expenditure
FM	Fat mass
FFM	Fat free mass
FFW	Fat free weight
h	Hour
Kcal	Kilo-calories
kg	Kilo-grams
KJ	Kilo-joules
LBM	Lean body mass
m	Metre
min	Minutes
MJ	Mega-joules
NTP	Normal temperature and pressure
PAL	Physical activity level
R	Respiratory exchange ratio
REE	Resting energy expenditure
RMR	Resting metabolic rate
RQ	Respiratory quotient
SMR	Sleeping metabolic rate
TDEE	Total daily energy expenditure
TEM	Thermic effect of a meal
W	Watts

Chapter

1

Introduction and Literature Review

1. INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Variations in energy metabolism and basal metabolic rate are of continuous interest to both clinicians and scientists. This interest coincided with the growing health and fitness industry, and public concern for "healthy" living. Obesity treatment and management still remain a major medical challenge. A better understanding of human biology, nutrition and energy regulation is fundamental to successful body weight maintenance. There are many factors which influence Total Daily Energy Expenditure (TDEE); these include body size and composition, sex, age, activity, genetics and climate (Bray & Atkinson, 1977).

TDEE is conventionally divided into four components; basal metabolic rate, dietary induced thermogenesis, growth and the energy cost of physical activity. Basal metabolic rate (BMR) can account for 70% of total energy expenditure. The variability of BMR and TDEE computed simultaneously have been found to be approximately 10.2% and 10.3% respectively, suggesting that the inter-individual coefficient of variance (CV) of BMR is reflected in the CV of TDEE, since BMR contributes significantly (70%) to the TDEE of an individual (Shetty *et al.* 1996). Whilst BMR may vary greatly between individuals, it can be measured accurately under standardised conditions. Hence BMR, as opposed to energy intake, is frequently used to predict total energy requirements. Normal food intake is not quantitatively the amount required to maintain body weight or optimal levels of physical activity. For this reason the FAO/WHO/UNU now use estimates of energy expenditure to predict energy requirements for individuals and populations.

Since BMR represents the largest component of energy expenditure, the first section of this thesis will concentrate on BMR and its variability.

The first world wide review of the BMR literature was performed by Quenoille (1951). More recently Schofield, Schofield and James (1985) reviewed the literature

on BMR in order to create equations to calculate BMR. These equations formed the basis of the FAO/WHO/UNU (1985) report entitled *Energy and Protein Requirements*. Since its publication, serious concern has been expressed on the validity of these equations and their universal application, largely because the analysis appears to be based on a biased and incomplete analysis of the world literature on BMR. In particular, James (1985) reported the fact that the equations overestimated the BMR of Asiatic Indians by 10-11%. Furthermore, James identified that there was insufficient information on other Asian groups such as the Chinese, Indonesian, Malaysian and Korean. Further examination of the Schofield database revealed that for males between the ages of 10 and 60 years, 50% of the data points came from Italian military subjects. Moreover, the Italian group appear to have a higher BMR per kilogram than any other Caucasian group (Hayter & Henry, 1994) which may have artificially elevated Schofield's (1985) equations. Since 1985, several laboratories have produced BMR data for different ages and ethnic groups. These clearly need to be incorporated into a new, up-to-date world-wide BMR analysis. Work is presented in this thesis on producing new equations which are suitable for predicting the BMR in subjects and populations world-wide.

As well as presenting predictive equations for BMR the work of the FAO/WHO/UNU Expert Consultation (1985) was important because the decision was made that all components of energy expenditure should be expressed as multiples of BMR. This included energy expenditure during activity and the use of physical activity levels (PALs). Since physical exercise is the most easily adjusted component of energy expenditure, a reliable method to estimate physical activity is required. In chapter 4, the use of heart rate monitoring in order to estimate TDEE was investigated.

Since the observation that the Schofield (1985) predictive equations for BMR overestimate the BMR of Indian subjects by 10-11% (James, 1985 and Soares & Shetty, 1988) there has been much discussion on metabolic differences between the

ethnic groups. Whilst metabolic adaptations and energy sparing mechanisms have been suggested in response to low planes of nutrition in some groups of individuals (Norgan, 1981; Shetty, 1984 and Minghelli, 1990) little is known about how energy balance is maintained in different population groups. A useful study model is to examine metabolic changes in subjects migrating from developing countries to Western countries. This will enable us tosee whether it is possible to remain weight stable and in energy balance when faced with a very different life style and culture. This is presented in chapter 5.

In conclusion the overall aim of this thesis was to investigate biological variation in man. In particular, how biological variation manifests itself in the domain of energy metabolism, and thereby suggest reasons for the highly variable nature of energy expenditure, BMR and energy balance.

1.2 General Literature Review

The effects of biological variability with respect to ethnicity, energy expenditure, energy intake and anthropometry are reviewed here. Due to the extensive area these subjects cover, the literature review has been divided into 4 subsections:

1.2.1) discusses variation in man

1.2.2) reviews the literature regarding energy expenditure

1.2.3) reviews the literature regarding variability in energy intake

1.2.4) discusses anthropometric variability

Variations in the species *Homo sapien*

Biological variation is no more evident than in the polymorphic species *Homo sapien*. The human race is a single species, yet there an extraordinary amount of variation is evident. Variations are apparent between populations, within populations and even on an individual level. We may differ in height, weight, hair texture, skin colour, facial features and expressions and even different blood enzymes. The human species shows remarkable diversity influenced by both genetic and environmental interactions. Environmental conditions are constantly changing and human populations are continually adapting themselves to existing conditions.

Homo sapiens as a species have commonly been divided into races. According to the rules of taxonomy, subdivisions of species should be referred to as subspecies. Therefore, in biology a race may be defined as a subdivision of a species which inherits physical characteristics distinguishing it from other populations of the species (Montagu, 1974). Some biologists have even managed to subdivide the species *Homo sapien* into as many as 30 subdivisions and this is not exhaustive, yet to others this is unnecessary. Stephen Jay Gould (1977) clearly states that he is reluctant to divide *Homo sapiens* into subspecies just as he is to divide land snails into subspecies. The use of sub-species as a form of classification may in actual fact quite simply be useless. For example, the boundaries of any particular subspecies can never be

properly fixed because members of subspecies can and do interbreed. It is not denied that the world-wide spread of human ancestors has placed man in a variety of different habitats and at times in the past these locations may have geographically isolated certain populations and resulted in certain differences between populations. Some of these differences may be direct responses to different environmental factors such as climate and nutrition. Whilst it is undeniable that the human species is strongly differentiated, this difference is not significant enough to require the designation of race. Montagu (1974) has from a classificatory point of view, recognised what he calls four distinct "major groups" of mankind which he names as follows: Black, Archaic white, Caucasoid and Mongolian. The term "major group" is purely arbitrary and speaks of the varieties of men which enter the formation of these major groups as "ethnic groups". Because prejudice is often associated with the word "race" it is seemly that the word should not be used and the term "ethnic group" substituted. Ethnicity has loosely been described as an identity which reflects the cultural experiences and feelings of a particular group (Spoonley, 1990). However, the fact remains that today all human beings are so mixed with regard to origin, indeed it is highly unlikely that any human population has remained in total geographic isolation for any significant length of time, that between different groups of individuals inter-gradation and overlapping of physical characters is now the norm. A constant gene flow between populations is brought about wherever migration, alliances, invasions and inter-marriages have occurred, constantly diminishing the differences between human populations. In the words of Darwin himself as written in The Descent of Man (1871) it should be remembered that "Although the existing races of man differ in many respects, as in colour, hair, proportion of the body etc., yet if their whole structure be taken into consideration they are found to resemble each other more closely in a multitude of points".

In this thesis, the term "ethnic group" is used in a geographical sense and may be taken to signify a broad range of people inhabiting a continent e.g. Asians, Africans, Caucasians and Orientals.

The human species does consist of a large number of diverse populations (although these populations are now very mixed and exhibit overlapping features). The world-wide spread of human ancestors has in the past placed man in a variety of habitats which has resulted in the evolution of certain differences between various populations. For example, skin colour may be correlated to the levels of solar radiation and body shape may be correlated with climate. Ethnic differences with respect to anthropometry and metabolism are discussed separately. Whilst in early history human populations were geographically isolated, today it is cultural barriers that may keep populations apart. It is possible that these cultural differences may be reflected in food eaten and hence energy intake and this is discussed in chapter 5.

Variations in energy metabolism

Energy expenditure is made up of four distinct components (Figure 1.1):

1. Basal metabolic rate (BMR)

2. Physical activity

3. Dietary induced thermogenesis (DIT)

4. Growth

All four of these aspects are subject to biological variability as a consequence of both genetics and environment and are discussed separately.

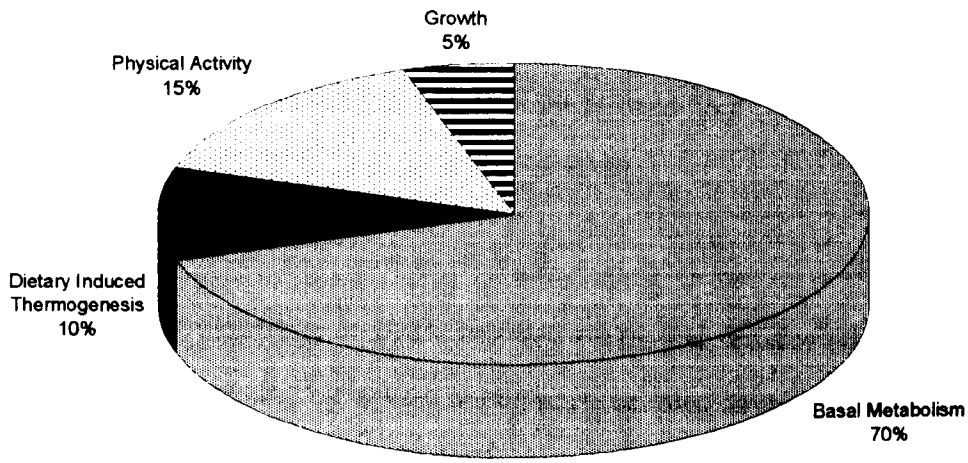


Figure 1.1

Breakdown of energy expenditure in man

.Energy expenditure is very closely related to BMR. It is possible that this is because BMR is the largest component of energy expenditure and makes the largest contribution to energy expenditure and therefore, variations in the energy cost of other activities contribute only small amounts to the total. Conversely it may be that the energy cost of common activities other than resting are themselves related to

BMR (Garrow, 1985), hence the importance of studying BMR in relation to total energy expenditure.

1.2.1 Variation in BMR

Basal metabolic rate (BMR) is the rate at which the body expends energy on homeostatic activities such as movements of the heart, respiratory muscles and cellular processes such as the maintaining of ionic gradients and organic synthesis. To quote Mitchell (1962) the BMR of an animal may be defined as "the minimal rate of energy expenditure compatible with life". BMR like any other biological component is subject to variability. BMR varies from one person to the next and may vary for an individual with changes in circumstance or physical condition. There are a variety of factors which may account for the variability of BMR:

i) Gender

There is a distinct difference in BMR between males and females (Boothby *et al.*, 1936). Whether compared by weight or surface area, men have a higher BMR than women. However, Dakshayani *et al.* (1962) showed that females in actual fact have a slightly higher BMR when expressed in terms of lean body mass or cell solids. Whilst other authors may not have found a higher BMR in women per kilogram of lean body mass they have observed the disappearance of sex differences in BMR if allowances are made for body fat. Yet, Arciero *et al.* (1993) demonstrated a 23% higher BMR in men independent of both differences in body composition and aerobic fitness. Garn & Clark (1953) suggested that the difference in metabolism may not be solely related to fat mass but due to metabolism stimulating steroid hormones which may underline the residual sex difference in BMR. Interestingly, it has also been demonstrated that BMR in women is more variable than in men. Whilst Benedict (1935) remarked on the "remarkable uniformity of BMR in man under standardised conditions" and Henry *et al.* (1989) commented on the "constancy of BMR in free living male subjects", the

same cannot be said of women. BMR in women is known to be affected by the menstrual cycle, and CV's for BMR as high as 12% may be found in some women over the course of one menstrual month (Curtis & Henry, 1997). The effect of the menstrual cycle on BMR is discussed further in section v) Hormonal factors that affect BMR.

ii) Age

Whilst a low BMR is noted at the time of birth, (for ease in experimentation the BMR of infants is usually measured during sleep), BMR and respiratory quotient have both been shown to increase during the first 14 days of life (Cross *et al.*, 1957) and continues to rapidly increase over the first year of life before showing a decline when expressed as BMR/kg. By 10 years of age energy per unit body size may decrease by as much as 20% (Dubois, 1936).

Adolescence is generally associated with a growth spurt when many metabolic changes are occurring (Topper & Mulier, 1932). Davenport *et al.* (1939) measured BMR in children before and after the adolescent growth spurt and identified that changes in BMR were found to slightly precede the spurt of growth in stature. However, both Webster *et al.* (1941) and Lewis *et al.* (1943) failed to find an increase in BMR at the time of puberty. Today it is generally thought that there is indeed a rise in BMR around puberty which is likely to be a result of the growth spurt associated with this age group (Bandini *et al.*, 1995 and Duval, 1942).

Due to the ageing process and often due to a loss of lean body mass and gain in fat mass, BMR continues to decline from approximately 40 years onwards. The difference between the BMR of a young adult and a 60 year old of identical body weight may be as much as 10%. The difference between the BMR of a 60 year old and a 70 year old is also 10%, (Durnin, 1981). After 60 years of age Tzankoff & Norris (1978) noted a 3.7% decline in whole body oxygen consumption for every decade of life, but there appears to be conflicting opinions as to whether this decline in BMR is a result of decreasing lean body mass or not. Whilst Visser *et al.* (1995)

found there was no significant difference in the BMR in elderly men and women compared to young adults after adjustments for body composition, Vaughan *et al.* (1991) claims even with adjustments for body composition the elderly exhibit a lower BMR. In general it can be surmised that BMR decreases with age but the reasons for this require clarification.

iii) Body size and body composition

Body size is one of the largest determinants of basal metabolic rate, and weight in particular has a definite linear influence on BMR, hence the reason weight was used to predict BMR in the FAO/WHO/UNU (1985) BMR predictive equations. But whilst BMR increases linearly with total weight, BMR per kilogram actually decreases as body weight increases. This was first discovered in Rubner's work with dogs (reported in Krogh, 1916). Using weight alone Kleiber (1932) plotted the log of BMR as a function of the log of body weight in a number of animal species, the relationship of which could be expressed as:

$$\text{BMR (kcal/day)} = 71 \pm 1.8\ W^{0.75}$$

This was later simplified to:

$$70\ W^{0.75}$$

This is known as Kleiber's allometric equation. Interestingly this equation was found to be true for all animals except elephants and whales on which little data was available (Holliday *et al.*, 1967).

In the past, height has also been used to predict BMR and Benedict (1924) claimed that the most important factor correlating to BMR was height. However, Schofield (1985) found that by using a combination of height and weight the accuracy of prediction did not compensate for the increased complexity of the equations. Alternatively, Cunningham (1980) found lean body mass to be the best predictor of BMR. Equations to predict BMR which take into account fat mass and fat free mass have also been developed (Nelson *et al.*, 1992) and it is said that these equations could be improved and account for more of the variability in resting energy

expenditure if the fat free mass was divided further into organ and skeletal muscle mass as previously suggested by Holliday *et al.*, (1967). The effect of body composition on BMR is well established, and several other workers have noticed that populations of healthy adults show good correlations between BMR and lean body mass (Garn & Clark, 1953; Cunningham, 1982 and Mifflin *et al.*, 1990). Different body components have very different metabolisms. Whilst organ tissue accounts for approximately 60% of basal oxygen consumption, muscle mass accounts for about 25%. Hence changes in body composition will also change BMR (Hunt & Groff, 1990). Notably body composition and BMR change with age. At birth the neonate averages 14% body fat, which rises to about 23% at 12 months and declines to 18% at 6 years of age. During this period girls have slightly more body fat than boys and this difference is more pronounced after 6 years (Haschke *et al.*, 1981). During adolescence, differences in the body fat content between the sexes become apparent and this difference is maintained throughout adult life. A major sex difference in the rate of gain in lean body mass is found. Boys appear to show a rapid and sustained gain in lean body mass, a moderate gain in body fat in the early phase of puberty, followed by a decline. This gain in lean weight appears to coincide with a rapid increase in height and continues up until approximately 25 years of age. During the teen years boys double their lean body mass resulting in a fat free weight of about 60 kg in a male of total body weight 70 kg. Girls, on the other hand, gain less lean mass, but acquire more body fat. By about the age of 18, the pubertal increase in both lean mass and height stops. There is a 1.5 fold increase in lean weight during the teen years and at maturation there is a fat free weight of about 42 kg in an average female of 63 kg total body weight (FAO/WHO/UNU, 1985). From adulthood onwards, there is a decline in lean body mass in both males and females. By 85 years the lean body mass has reached a value about 75% of that characteristic of a young adult. This decline in lean tissue partly accounts for the progressive fall in BMR in relation to body size (Tzankoff & Norris, 1978) as discussed previously.

The location of certain body components, fat in particular have also been shown to affect metabolism. Abdominal obese women have significantly higher BMRs, when adjusted for age, fat mass and fat free mass compared with gluteal-femoral obese women (Weststrate *et al.*, 1990).

Further biological variations in body composition and body size including height, weight and arm-span independent of BMR are discussed further in the relevant sections.

iv) Nutritional factors

The ingestion of food increases energy expenditure by inducing dietary thermogenesis immediately and in the longer term. Keys *et al.* (1955) and Welle *et al.* (1986) both studied the effect of overeating in man and found that BMR increases between 1 - 18% above normal levels when more calories than are required for energy balance are consumed. Reciprocally a lack of food will decrease energy expenditure.

Benedict (1922) demonstrated that there was a decline in BMR after a few days of total fasting, he suggested that as subjects lost weight they became "smaller animals" and hence gave off less heat. The effect of restricted food intake on BMR was demonstrated in Keys classic study done in the 1950's. Subjects underwent a 12 week control period, 24 weeks of semi-starvation, 12 weeks of restricted rehabilitation and 8 weeks unrestricted rehabilitation. Throughout the starvation period oxygen consumption declined, roughly corresponding to the weight loss of active tissue mass. BMR was found to decrease to 70% its original value (Keys *et al.*, 1950). Following starvation, decreased body weight, adjustments in physical activity and possibly increased efficiency in energy utilisation all contribute to the maintenance of energy balance (Shetty, 1984 and Soares *et al.*, 1992).

The same effect is evident in people on calorie restricted diets. Both twenty-four hour energy expenditure and BMR are found to decrease during hypo-caloric diets due to reduction of fat free mass (Ravussin *et al.*, 1985). When food restriction has ended BMR will increase but is unlikely to return to pre-dieting levels (Barrows, 1987).

Hence the predicament of the would be slimmer, who having lost weight finds their new weight hard to maintain.

v) Hormonal factors

Changes in BMR in females follow the secretion of progesterone and BMR can vary significantly during the menstrual cycle. BMR falls to a relatively low level about one week before ovulation and then increases again to a peak before the next menstrual period (Soloman *et al.*, 1982) Cyclicity of BMR during the menstrual cycle has been shown to vary as much as 12% (Curtis & Henry, 1997). Conversely women taking the contraceptive pill fail to show this cyclic effect (Curtis *et al.*, 1996) but have been shown to have a BMR almost 5% higher than women who have never taken the contraceptive pill (Diffey *et al.*, 1997). Females also experience other changes in hormonal status associated with pregnancy and lactation. BMR reaches a maximum during the third trimester of pregnancy and then falls during the lactation period (De & Nagchaudhuri, 1975). The higher BMR of the mother is a direct result of the higher foetal metabolism. Whilst BMR falls after birth, it is still higher during lactation when compared to non-lactating women (Spaaj *et al.*, 1994).

In both sexes hyperthyroidism is a result of an excess of the hormone thyroxin, this syndrome can be characterised by an increased BMR, (Boothby, 1921) and in fact in the past BMR has been used as an aid to diagnose hyper- and hypothyroidism.

Other hormones that are known to affect basal metabolism include the catecholamines epinephrine and norepinepherine as well as growth hormone.

vi) Disease

BMR is known to increase during fever and after surgery (Dubois, 1936). In the past BMR has frequently been used as a tool to help diagnose disease, for example to aid the prognosis of premature infants (Murlin & Marsh, 1922). Cases of goitre, leukaemia, serious heart disease, some diabetes and cancer are all known to elevate BMR (Stevenin & Janet, 1925), whilst other symptoms of disease such as pernicious

anaemia may decrease metabolism (Tompkins *et al.*, 1919). BMR has even been used in the alleviation of symptoms of disease. For example, although we now know that typhoid fever increases basal heat production up to 50% above normal, in the past doctors kept typhoid patients on very small diets, which resulted in profound tissue wasting and weight loss. In the early 1930's, Shaffer & Coleman on the basis of metabolism studies using the Benedict apparatus and the Sage calorimeter, found high calorie diets to be far more beneficial (Du Bois, 1936). Such studies have thus enabled hospital diets to be administered on a scientific basis.

Changes in metabolism are likely to be due to hormone-like compounds which the body produces, intracellular signalling agents such as cytokines, loss of moisture especially after burns and an increase in protein turnover (Hunt & Groff, 1990). Any form of trauma can cause changes in the whole body, even a minor leg break may result in a raised BMR.

vi) Genetic

It is now widely believed that genetics do play a major role in the variability of metabolic rate. Studies on both monozygotic and dizygotic twins have shown a definite genetic component in BMR (Fontaine *et al.*, 1985 and Henry *et al.*, 1990). Bouchard *et al.* (1989) has shown that heretability can account for approximately 40% of the variance in BMR after adjustments for age, gender and fat free mass. More recent research has focused on specific genes. For example Trp64Arg polymorphism's of the beta (3) - adrenergic receptor gene have been proved to affect BMR in obese twins (Sipilainen *et al.*, 1997) and this is obviously an area where much of the new research into BMR will be focused.

vii) Physical Activity

It is generally appreciated that exercise affects body composition which consequently influences BMR. Athletes, particularly endurance athletes do tend to have increased resting energy requirements (Poehlman *et al.*, 1991 and Sjodin *et al.*, 1996) and this is

a likely result of increased muscle mass. But whether exercise directly influences BMR independent of body composition is another matter. Frequently exercise is prescribed as part of weight control programmes yet both Pyes *et al.* and Bingham *et al.* (1983 and 1989 respectively) have shown that whilst decreasing body fat, an 8-9 week training programme does not significantly alter BMR. However that said, metabolism is known to be increased during exercise and Melby *et al.* (1993) has shown BMR to remain at elevated levels for up to 15 hours later and increased fat oxidation is also evident for some time after exercise (Calles-Escandon *et al.*, 1996). Certainly exercise should be encouraged in the obese and non-obese particularly for cardio-vascular health even if not a metabolic effect.

viii) Climate and Altitude

Climate affects BMR due to the body's need to retain a constant temperature. Malhotra *et al.* (1960) studied BMR at several intervals throughout a year and found no significant changes during the different months and therefore assumed that BMR is not affected by climate. Conversely Wilson (1956) studying subjects in Antarctica found a significant trend with season in the periodicity of BMR. However, it is possible that this was due to changes in activity, cold exposure or other factors. As well as looking at seasonal changes, the effect of migration (and possible more extreme temperature changes), has also been studied extensively. Mason (1940) showed that when Caucasians moved from a temperate climate to a tropical climate, either there were no metabolic effects or some people exhibited a distinct decrease in metabolism and concluded that there is no way of predicting which tropical response an individual will show. The reverse has also been studied in subjects migrating from tropical climates to the UK. BMR was found to be similar in both temperate and tropical residents and it is suggested that low BMRs in tropical countries may in fact be a result of a different relationship between BMR with body weight in individuals who are undernourished and of low socio-economic status (Hayter & Henry, 1993).

BMR is known to increase with altitude, but whilst Lewis *et al.* (1943) noted this increase he found no specific relationship between BMR and altitude. Not everybody acclimatises to altitudes, Gill & Pugh (1964) showed those that do not acclimatise do not tend to show an increased BMR. BMR is not the only biological variable to increase at altitude, indeed oral temperature, systolic blood pressure and heart rate are all shown to increase as the body adapts to cope with the decrease in partial pressure of the ambient oxygen (Hannon & Sudman, 1973).

ix) Pharmacological agents

Many pharmacological agents influence BMR. Work as early as 1915 tested the effects of various drugs on metabolism and Higgins found that atropine, and camphor increased metabolism, whilst morphine decreased metabolism and heroin and strychnine had no affect (Higgins & Means, 1915). Even everyday food substances may affect metabolism. Crile & Quiring (1939) studied the Maya Quiche Indians in Guatemala and concluded that the higher metabolic rate found was due to the quantity of chilli in their diet. Caffeine and theophylline have both been shown to significantly influence energy balance (Dulloo *et al.*, 1989). Smoking has been found to increase metabolism and a decreased metabolic rate is often a consequence after the cessation of smoking, hence the reason people often put on weight after quitting (Hofstetter *et al.*, 1986 and Moffat & Owens, 1991). Alcohol has also been shown to increase BMR (Rosenberg & Durnin, 1978). Research into substances which increase metabolism continues to be carried out in the ongoing search for the pharmacological treatment of obesity, particularly drugs such as fenfluramine, fluoxetine and ephedrine.

x) Psychological state

In 1925, Zeigler & Levine found that psychoneurotics were found to have an above normal BMR when thinking about an emotion producing aspect of their past history. Similar effects have since been observed in normal subjects when anxiety and

psychological stresses have been induced. Blaza & Garrow (1980) inflicted their subjects with a combination of mild electric shocks and arithmetic tests and found that both heat loss and heart rate increased. Weststrate *et al.* (1990) assessed RMR whilst subjects watched two types of film on video. One film was a horror film and the other a romantic family film. Whilst RMR was not significantly influenced by the type of film shown it was found that dietary induced thermogenesis assessed over 4 hours was significantly increased by the stress inducing treatment. It is experiments like these which emphasise the importance of subjects being in a non-emotional state whilst BMR recordings are being made in order to eliminate the possibility of a stress induced elevated BMR.

xi) Ethnicity

As long ago as 1896, it was proposed by Eijkman (quoted in Henry & Rees, 1988) that BMR may be different in spatially isolated populations. This was later confirmed by Almeida (1919) when it was reported that residents of Brazil, a country of tropical climate appeared to have lower BMRs than their North American counterparts. Benedict (1932) further confirmed this hypothesis when he noted different BMRs in Japanese, Chinese, Indian and Mayan subjects. However, at this stage it was acknowledged that these apparent differences in BMR were just as likely to be a result of differences in diets, climates, altitudes and activity as they were to truly ethnic differences. However, in another study of Oriental girls living along side American girls and hence under similar conditions, it was noted that the Oriental girls did exhibit a distinctly lower BMR than their American peers (Benedict & Meyer, 1933). In 1945, Wilson further emphasised the need to standardise conditions and advocated a need to study different ethnic groups with the same investigator and using the same equipment in order to minimise technical differences that could exaggerate any possible ethnic differences. From then onwards, studies tended to highlight the importance of climatic differences as a cause of different BMRs in different ethnic groups. Munro (1950) studied the effects on European subjects moving to the tropics

and discovered that within the space of 3 months a definite decline in BMR was apparent. However, similar studies by Mason and Mason & Jacob (1940 and 1972 respectively) found that the decline in BMR on migration to the topics was not a consistent phenomenon in everybody. Whilst 62% of those measured did show a decrease in BMR, 38% showed no measurable change. Interestingly 57% of Europeans exhibited this decrease in BMR whereas only 27% of Asians did. A similar study was undertaken in reverse by Hayter & Henry (1993) where inhabitants of tropical countries were measured on arrival in the UK. However, the BMR of both tropical and temperate residents was found to be similar. The debate as to whether there are differences in the BMRs of different ethnic groups still goes on. Geissler and Hamould Aldouri (1985) found lower RMRs in Asian and African men compared to Caucasian of similar weight. Yet, De Boer *et al.* (1988) discovered that whilst Asian subjects had significantly lower BMR, weight and fat free mass, when 24 hour energy expenditure and overnight energy expenditure were expressed in terms of weight and fat free mass the Asian subjects were actually found to have higher energy requirements and energy expenditures than Europeans. Henry & Rees (1990) using an extensive BMR data-base presented new equations for tropical populations which highlighted the fact that the FAO/WHO/UNU (1985) equations overestimated BMR in tropical populations by approximately 8%. Other authors continued to find conflicting evidence, such as energy sparing mechanisms in Gambian men when compared with Europeans of similar body mass (Minghelli *et al.*, 1990), evidence to claim African American girls have significantly lower BMRs than Caucasians (Wong *et al.*, 1996) and even evidence to suggest there are no ethnic differences at all (Spurr *et al.*'s work comparing White, Black and Mestizo children living in Columbia, 1992). However, it remains that there is no conclusive evidence of a distinct ethnic factor in the basal metabolism of humans. It would therefore appear that differences in BMRs between population groups are indeed, at this stage, likely to be a result of differences in the relationship between BMR and body size particularly in subjects under

nutritional stress as a result of low socio-economic status especially in tropical climates.

Further discussion regarding ethnicity is reviewed elsewhere in this thesis.

xii) Methodological factors

Apparatus for measuring BMR can be divided into two types; direct and indirect calorimetry. Direct calorimetry measures heat loss and indirect calorimetry focuses on gas exchange and measures oxygen consumption and carbon dioxide production which is then used to calculate the energy expended. Methods such as the Douglas bag and the Deltatrac used in the present study are both examples of indirect calorimetry. In theory there should be no differences between BMR measured either directly or indirectly. Indeed, Peabody *et al.* (1916) measured subjects using both methods and found that the results were in agreement within 1.9%. More recently Soares *et al.* (1989) compared BMR measured with 5 different instruments, namely the Oxylog, the Hartmann and Braun Metabolator, the ventilated hood and tent and the whole body calorimeter. No significant differences were found between any of the various methods. Whilst there may be little differences between the instruments, there are however, errors associated with all instrumentation. Typical errors include leakages in closed circuit systems or from mouth pieces and face masks. Mouthpieces and masks may be a source of discomfort and may cause hyperventilation. Hyperventilation in some cases may cause overestimates of BMR in the region of 7% (Garrow, 1974). Closed-circuit methods such as the Benedict Roth depend on the spirometer having a known volume of oxygen which diminishes as it is breathed by the subject. If dry oxygen is inspired, this will have an affect on the normal respiratory pattern and thus on metabolism (Durnin, 1981). Detailed accounts of the errors associated with different methods can be found in Consolazio's publication (1963), "Physiological Measurements of Metabolic Function in Man". Of all the

factors that influence BMR, those associated with the instrumentation tend to be the most controllable provided the apparatus is rigorously checked at periodic intervals .

On top of all the above factors which influence BMR, it is possible that two subjects, although identical in every other way, may still have very different BMRs. Some variation in BMR between similar subjects may be explained by measurement error (Garrow, 1985). For this reason every effort has been made to standardise the conditions of BMR measurement. It was Magnus Levi in 1899 who devised the term *Grundumsatz*, meaning basal metabolism that first emphasised the need to conduct metabolic experiments under strictly standardised conditions. These conditions are as follows:

1. The post-absorptive state: To avoid the metabolism enhancing effect of dietary induced thermogenesis, BMR should be measured 12 hours after the last food consumed.

2. Absence of gross muscular activity: A rest period is usually required of at least 20 minutes before measurements are made. Exercise before the measurement should be avoided altogether.

3. Minimal emotional disturbance: This may in some cases be difficult to achieve. Even quite minor disturbances in the testing environment may cause a change of 10% in the oxygen consumption of a trained subject at rest (Garrow, 1974). It is also preferable that the subjects are familiar with the apparatus in order to reduce any apprehension.

4. Awake: Sleep may cause metabolism to be lower than basal levels on average by 10% (Durnin, 1981).

5. Thermoneutrality: Rubner in 1883 (quoted in Elia, 1992) realised that dogs kept at 16°C for long periods of time would shiver and exhibit elevated metabolic rates. This could be avoided if kept in more thermoneutral temperatures. In humans thermoneutrality is very much dependant on the local climate and the state of dress of

the subject, but usually with the aid of heaters and air conditioning room temperatures may be controlled to within the thermoneutral range of 24-26°C.

BMR variability in individuals and populations

Whilst individual variability in BMR exists, it is of less importance when assessing the mean BMR of populations. However, individual variability in addition to other sources of error assumes significance when used to predict the BMR of populations (Durnin, 1981). Therefore, when compiling standards and equations to predict BMR it is of the utmost importance that the data used is of the highest quality and of course exhibits as little variability as possible. This was borne in mind during the development of the equations in the present study. A brief outline of the history and importance of equations to predict BMR is given here, but this area is discussed further in Chapter 3 with reference to the new equations that have been developed.

Equations to predict BMR

The history of equations to predict metabolism can be traced right back to 1883 when Rubner presented evidence that heat production is directly proportional to surface area from his work conducted on dogs. This was the origin of the famous "surface rule/law" which can be explained in terms of homeothermy. The surface law is based on the fact that all homeotherms maintain a body temperature close to 37°C. Heat output which takes place through the body surface must therefore entail the loss of the same number of calories per unit surface area in order to maintain a constant body temperature. Based on this work, Voit (1901) extended the concepts of this law and showed that basal metabolism is a simple function of surface area not only in dogs, but also across species. This finding was confirmed in humans by Atwater and Benedict (1903) during a series of experiments in men using the Atwater human respiration calorimeter. As more clinicians became interested in the surface law, and it was not long before reference values for metabolic rate expressed in terms of surface area were published. As a direct result of their formula created to predict

surface area from weight and height, Dubois and Dubois (1915) were fundamental in the acceptance of surface area as a biological variable to predict metabolism. Their formula is as follows:

$A = 71.84 * W^{0.425} * H^{0.725}$

where A = surface area cm^2, W = weight in kg and H = height in cm

Whilst this formula remains the most widely used (despite the fact it was based only on a group of 9 subjects and 1 cadaver), the fact remains that newer and more accurate formulas have been derived. Later Aub and Du Bois (1917) using the surface law published a table of $BMR/m^2/h$ for humans aged 14 to 80 years of age. It is likely that the more recent equations to predict surface area were never widely used because the use of surface area itself soon lost popularity. In the meantime however, BMR continued to be expressed in terms of surface area. In 1936, Boothby, Berkson and Dunn made a careful study of BMR in 639 males and 828 females and created new standards expressed per unit of surface area. The use of surface area is not without its problems. Estimates of surface area are only approximate and hence metabolic rate expressed in relation to surface area are also only approximate, beside which surface area can be predicted by any number of different formulas. Harris and Benedict (1919) challenged the surface area concept; they had practical and biological objections to the surface area law and they preferred to approach the concept of metabolism from the perspective of heat production and not heat loss. Moreover, they could see no particular advantage in using surface area. Later, Durnin (1959) showed that in a range of situations including sitting, standing and various types of exercise, there were no differences in correlation coefficients when metabolic rate was related to either gross body weight or to surface area.

Other authors were also developing their own BMR data, standards and equations. Boothby and Sandiford of the Mayo clinic started collecting BMR data in 1917. Unfortunately some of their subjects were hospital patients and therefore were hardly

ideal subjects on which to base metabolic standards. In addition, it was later reported that these hospital subjects were untrained in the measurement of BMR. Harris and Benedict (1919) were the first researchers to use and analyse BMR data biometrically. Using age, sex, stature and weight of 136 men, 103 women and 94 infants they proposed empirical formulae to predict energy expenditure. The Harris and Benedict (1919) BMR predictive equations are as follows:

For males $h = 66.4730 + 13.7516W + 5.0033S - 6.7750A$

For females $h = 665.0955 + 9.5634W + 1.8496S - 4.6756A$

where h = kcal/day, W = weight in kg, S = stature in cm and A = age in years

Benedict later recognised that these equations overestimated BMR, especially in young women. Much later in 1985, Daly produced evidence to show that the Harris & Benedict equations overestimated BMR by 10-15%. Nevertheless, due to the simplicity of the Harris-Benedict equations they remained a popular equation widely used, even today by many clinicians in North America.

Using the Harris and Benedict data base, Dreyer (1920) suggested a formula which was capable of expressing basal metabolism in a satisfactory manner over a wide range of body sizes and ages. Furthermore, Dreyer indicated that BMR is not a simple function of body surface. Dreyer's allometric equation is given below:

$C = K*(A^{0.133}) / W^{0.5}$

where C = kcal/day, A = age in years and W = weight kg

A comparison of the Dubois & Dubois (1915) surface area equation, the Harris & Benedict (1919) empirical equation and Dreyer's (1920) allometric equation was performed by Means & Woodwell (1921). They found that although all three equations showed normal variations, the Harris & Benedict equation fitted their data for obese subjects most accurately.

In 1947, Kleiber proposed a combination of the theoretical and empirical approaches to estimating BMR and again re-organised the Harris and Benedict data. His separate equations for males and females are given below:

male $\quad BMR = 71.2W^{0.75} [1+0.004(30-A) + 0.001(H / W^{0.33} - 43.4)]$

female $\quad BMR = 65.8W^{0.75}[1+0.004(30- A) + 0.018 (H / W^{0.33} - 42.1)]$

where BMR = kcal/24h, W = weight (kg), H = height (cm) and A = age (years)

Originally BMR for children was calculated using adult equations and lower weights or extrapolating data backwards. However, as far back as 1919, Benedict expressed concern about the indiscriminate use of adult equations to predict BMR in children. Standards specifically for children can be traced back to the work of Talbot (1925). Talbot's work resulted in tables enabling the estimation of BMR in children of various weights, heights and ages. Today equations for children form a substantial part of larger analyses. The Schofield (1985) analysis included 3 equations specifically for children aged 0-3, 3-10 and 10-18 years which incorporated 2359 individual BMR measurements.

In 1951, Quenouille *et al.* established differences between ethnic groups and published an effort that based standards on already existing data. These standards were based not only on sex, age and stature but also climate and most importantly race. This was probably the first paper to set standards for different racial groups and therefore emphasised a difference in BMR between different populations. In reality, these complex equations were found to be very impractical, and their use has therefore been limited.

Fleisch (1951) developed standards based on over 10,000 individual measurements. The collective data was obtained from 24 previously published papers and included the Aub and Dubois (1917), the Harris and Benedict (1919) data set and the Boothby,

Berkson and Dunn (1936) data. The majority of the subjects in this analysis were of American origin.

Robertson and Reid (1952), created predictive equations for the British population using 987 males and 1323 females. These were not widely used because the investigators used the lowest values of BMR recorded, not the mean value, and hence created very low standards.

The 1980's saw a couple of new large scale attempts to derive equations suitable for predicting basal metabolism in populations world-wide. In the past, the United Nations University and its specialised agencies, the World Health Organisation (WHO) and the Food and Agricultural Organisations (FAO) have played important roles in establishing energy and protein requirements for whole populations and in 1981, requested Durnin to survey the BMR literature in an attempt to use weight, age and sex alone to predict BMR. In 1981, Schofield was asked by the FAO/WHO/UNU committee to extend the existing work on energy expenditure requirements and derive equations using considerably more data. Schofield's research published in 1985, included work based on 114 published studies involving 7393 measurements on individuals of both sexes and all ages and included some data from developing countries. These formed the basis for the equations presented in the FAO/WHO/UNU report *Energy and Protein Requirements* (1985). Twelve years ago, Schofield's equations were considered the best available estimates of BMR in healthy people world-wide. However, Schofield's work did receive some criticism particularly from people who found the equation to over estimate BMR in tropical peoples (Minghelli *et al.*, 1990; Shetty, 1984; Henry & Rees, 1988, 1991; Valencia *et al.*, 1994; Liu *et al*, 1995 and Piers *et al.*, 1997 etc.). Close examination of the Schofield data base revealed around 6000 of the BMR values for males between 10-60 years old came from Italian military subjects. This was questioned because it was discovered that the Italian group appeared to have a higher BMR per kg than any

other Caucasian group (Hayter & Henry, 1994). This may have artificially raised the equations. There also appears to be a paucity of data in children between the ages of 10 and 16 years old and in the elderly over 60. Since 1985, several new predictive equations have been developed looking at specific populations. Mifflin *et al.* (1990) calculated equations for adults aged 19-78 years and his data set included normal and obese subjects. Obese subjects were included because 23% of white, black and Hispanic adult populations are known to be obese and his equations reflected this. Equations have also been developed for different ethnic groups. In 1991, Henry and Rees published equations to predict BMR in tropical people, Soares *et al.* (1993) computed equations for Indian males, Valencia *et al.* (1994) correlated BMR with other anthropometric variables in adult males in Northern Mexico and Lui *et al.* (1995) calculated equations suitable to predict BMR in the Chinese. However, these recent equations were not performed on a large enough scale to make them suitable to predict the BMR of any subject anywhere in the world.

Other recent equations to predict BMR have incorporated the use of body composition measurements. BMR and body composition was analysed extensively in women by Owen *et al.* (1986) and in men Owen *et al.* (1987) who reappraised human caloric requirements in relation to fat free mass (FFM). Unfortunately 27% of men and 36% of the women had a BMI greater than 30. Mifflin *et al.* (1990) also used lean body mass (LBM) to predict BMR. Whilst FFM or LBM are good predictors of BMR, the method of estimating them may introduce further errors into the resulting equations. In view of the new BMR data that has been published and the large basal metabolism data base that exists, new predictive equations have been developed which incorporate all possible international data, and these are presented in chapter 3.

1.2.2 Physical activity

This is the most variable component of energy expenditure. There are natural variations in individual efficiency in carrying out the same task. In most activities energy expenditure is closely related to body weight, although other factors are involved, for example walking is affected by body weight, speed and the surface being travelled on. There are several ways in which exercise might influence total energy expenditure and energy balance - effort expended in performing the exercise may considerably increase daily energy expenditure; as discussed previously BMR may remain increased for a considerable time after exercise; the thermic effect of food may be potentiated; and exercise may affect food intake by way of influencing the appetite (Garrow, 1974).

The gross energy expenditure of specific activities are frequently expressed in terms of BMR multiplied by a metabolic constant. For example the data compiled by Durnin for the FAO/WHO/UNU (1985). Multiples of BMR are frequently referred to as physical activity levels or PALs (Shetty *et al.* 1996). Because BMR is often predicted by body weight, it is therefore obvious that PALs are also influenced by body weight. The energy cost of exercise is affected in similar ways as BMR. For example if subjects are overfed or calorically restricted, the energy cost of both basal metabolic rate and exercise is affected in the same direction and to about the same extent. However, it does not necessarily follow that subjects with a raised BMR also have an increased energy cost for a given exercise (Garrow, 1974).

It is not entirely clear if lack of exercise is a major cause of increased body fat. Durnin & Rahaman (1967) found a clear inverse relationship between body fatness and the duration of physical activity, however, it is not certain if obese people are significantly less active than normal subjects or not (Johnson *et al.*, 1956).

Many methods exist for the measurement of the energy cost of activity and most are similar to those used for the measurement of BMR which depend on the measurement of consumed oxygen. However, there are other methods and these

included activity diaries and questionnaires, the use of pedometers and actometers, the bicarbonate-urea method, doubly labelled water and heart rate monitoring. The use of heart rate monitoring in calculating energy expenditure is discussed at length in chapter 4.

1.2.3 Dietary-induced thermogenesis (DIT)

The stimulatory effect of food on energy expenditure was first observed by Rubner in 1902 (quoted in Bursztein *et al.* 1989). He named his observation the 'specific dynamic action of food'. This was later referred to as the 'thermic effect of food' and today it is known as 'diet-induced energy expenditure' or more commonly 'diet-induced thermogenesis' (DIT). DIT can be divided into two components; the *obligatory* portion is related to the digestion, absorption and storage of nutrients and *luxuskonsumption* which is regarded as a way of disposing of excess energy intake by increased heat generation (Westerterp, 1994), this may also be referred to adaptive thermogenesis. The postprandial rise in energy expenditure after food lasts several hours and is often assumed to be completely terminated 10 hours after the last meal (hence BMR may be measured 10 hours after the last food eaten). The postprandial rise in energy expenditure is influenced by the quantity and type of food and may include other factors such palatability and familiarity of the food. Variability in individual DIT varies enormously with individual characteristics. For example the meal size required to promote the maximum thermic effect is much smaller in energetically-efficient individuals compared to energetically inefficient individuals (Morgan *et al.*, 1982). Fitness also plays a part in DIT and high fit subjects have been shown to have higher DIT (Poehlman *et al.*, 1989 and Burke *et al.*, 1993). The effect of the menstrual cycle on DIT is relatively undetermined. Whilst Weststrate *et al.* (1990) found no cyclic effect, Piers *et al.* (1995) found a significant increase of 18.5% during the luteal phase of the menstrual cycle. Diet of course plays a major role in DIT since fat is digested slower than protein and carbohydrate. Vegetarians have

been found to have lower DIT than meat eaters (Poehlman *et al.*, 1988). Much interest in DIT has focused on the possible link with obesity. It has been suggested that DIT may be blunted in the obese (Segal *et al.*, 1985 and Jequier & Schutz, 1985) yet others (including Nair *et al.*, 1983) have shown that this is not the case. However, evidence suggests that in some groups of overweight people, in particular those that are insulin resistant, they may indeed have lower DIT than normal weight individuals (Westerterp, 1994). Clearly this is another area worthy of future research.

1.2.4 Growth

Growth is a continual state of biological variation and of particular importance in children and pregnant women. Growth is highly dependant on nutrition, and protein in particular. For example even if energy intakes are high but the quality or amount of protein is low, growth will be affected. Different amounts of protein are laid down by the body daily. In order to maintain average growth rates, children should be provided with enough protein for the days when growth is rapid. Children from developing countries who are frequently ill, particularly with gastro-intestinal diseases which disrupt absorption will show arrested growth. In cases like these additional protein (and energy) are needed for catch-up growth (Garrow & James, 1993). Generally the higher the growth rate the greater the need for total protein. Growth charts are available to help determine if a child's growth is normal, the most widely used are those of Tanner and Whitehouse (Tanner *et al.* 1966). After infancy, the pubertal growth spurt is the period of most rapid growth. Chronic under-nutrition may delay the onset of puberty. In general though, short interruptions of growth and development arising as a result of nutritional failure can be made good by catch-up growth provided an adequate diet is available. Natural variations in growth rate may vary as much as 35% (Passmore & Eastwood, 1986).

1.2.5 Variations in dietary intake

Food intake, food preferences and food aversions are determined by multi-factor mechanisms, dependant on senses such as taste, smell, vision, afferent and humoral signals from the gut, body size and changes in the internal environment (Stellar, 1980). Effects such as these cause large inter-individual differences in food intake. Most variance could be associated with day-to-day variability, therefore one day data is inadequate to estimate the daily intakes of individuals (Beaton *et al.*, 1983).

Additionally there are large food intake differences both in quantity and quality of what is consumed between populations. Whilst normal intakes may be considered as 11.3 MJ/d for men and 8.4 MJ/d for women not all populations can achieve this. Populations with low energy intakes such as < 8.4 MJ/d in men and < 6.3 MJ/d in women have been found in populations in New Guinea, Ethiopia, Indonesia, Jamaica (Norgan, 1981). Such intakes may have been dismissed as inaccurate in the past, but may provide evidence of adaptive increases in efficiency due to reduced body weights. Indeed as far back as 1907, Benedict indicated man's ability to adapt to low food intakes. Keys *et al.* (1950) in their classic study showed that the human body was capable of adapting to calorie restriction by utilising the bodies tissues as a source of energy. It has been noted by other authors that a reduced tissue respiration rate and a reduction in the activity of enzymes are also evident during starvation in order to enhance survival (Shetty, 1984, Ulijazsek, 1996). Of course there are also instances when over-nutrition is achieved, this is particularly true of Western societies. The response to long term overfeeding is obesity, yet in some individuals it does appear that they are capable of adapting to high food intakes without gaining weight (Ashworth *et al.*, 1962). Miller & Mumford (1967) overfed subjects yet found that the actual weight gain was very small compared to the extra calories consumed. Dietary induced thermogenesis has been implicated as a mechanism by which the body can adapt to increased calorie intakes (James & Trayhurn, 1976). However, Sims and Horton (1968) found that subjects differed greatly in the amount of weight gained for

a given energy excess. It is likely that not all subjects can adapt to high calorie intakes and those that cannot become obese.

It is apparent, that not only is food intake between individuals highly variable, but that the response to different food intakes is also subject to biological variation.

Factors that affect Food intake

There are many factors that influence food intake and these are briefly reviewed below:

i) Social setting

Food has been said to be the vehicle for expressing friendship, for smoothing social intercourse and for showing concern. Celebrations and rituals are frequently centred around food, as are social meeting places e.g. the coffee shop the pub etc. (Fieldhouse, 1995). Social setting has a great affect on what is eaten and how much is eaten. The amount of variance in meal size can be accounted for by the presence of other people. Interestingly the amount of influence of companions on the amount eaten are surprisingly significantly affected by the genes (de Castro, 1997). Changes in social setting and home life also cause dietary changes, these may become evident after marriage and/or cohabitation (Anderson *et al.*, 1997). To turn this discussion around it may be said, that food habits are both a guide to social relationships and social structure (Fieldhouse, 1995).

ii) Food availability

During some months of the year fruits and vegetables are not available. Yet it is not only these foods which are subject to seasonality. Both hot cereal, roast turkey and other seasonal foods may be unavailable at certain times of the year. Even Cocoa Cola has a pattern of seasonal consumption, whilst chocolate has 3 peaks; Christmas, Easter and Valentines day. Staples such as eggs, bread and milk tend to be fairly constant (Joachim, 1997). Natural disasters such as tornadoes, hurricanes, flood or

early frost are all examples of factors that may affect food supplies and in some areas of the world these are factors which greatly influence food availability. Food availability is also subject to trends that change over time i.e. in the 1950's pork was the most popular meat in America today it is chicken. In England similar changes have occurred in relation to the popularity of beef. Removal of British beef from the market in order to protect the public from "mad cow disease" resulted in decreased availability in some supermarket chains. Activities by both food manufacturer and food outlets influence the popularity and availability of different foods e.g. packaging, special offers, coupons all effect the demand and the intake of particular food items.

iii) Culture

Whilst food habits and patterns vary greatly from person to person even within the same culture, culture has a great influence on what food is eaten. For example African tribesmen consume insects and the French eat snails, to which average the English man would turn his nose up, however he continues to eat beef, yet to Indians the cow is a sacred animal (Grivetti, 1981). It has even been suggested that some long-term genetic changes in human populations may have come about as a result of consumption of particular foods e.g. animal milk after weaning and lactose malabsorption (Simoons, 1980). The prevalence of eating disorders amongst Western societies may also be attributed to culture as anorexia is rarely, if ever found in developing countries.

iv) Physiology and endocrinology of food intake regulation

The hypothalamus is believed to be a key internal physiological regulator of hunger and satiety. The hypothalamic centres in the brain are sensitive to blood glucose and hormones associated with blood glucose such as insulin. Food may be taken when the utilisation of glucose by the organs of the body is insufficient, as a result of non-adequate levels of glucose itself in the blood or of the hormone insulin; this is known as the 'glucostatic theory' (Strubbe, 1994). Other neurotransmitters that reach the

hypothalamus of particular importance are gamma amino butyric acid (GABA), norephinephrine, serotonin, and dopamine (Hunt & Groff, 1990). It is well established that the hypothalamus plays a great role in regulating food intake because people who suffer damage to the hypothalamus either from trauma or tumours may display abnormalities in weight regulation (Garrow & James, 1993). The cortex is also involved in feeding and receives and integrates the cognitive and externoreceptive influences that modify the internally regulated eating behaviour.

Gastric motility has also been related to intake, an empty stomach will perform contractions associated with feelings of hunger. However, gastric motility appears to only exercise a weak and irregular influence on hunger (Stunkard & Fox, 1971).

v) Palatability and sensory preferences

There is a distinct difference between appetite and hunger. Hunger may make a normal unpalatable food acceptable (Garrow, 1974). Palatability is the psychological measurement of sensory preference. All intakes are a result from choices of what and how much to eat and drink. Choices depend on the appropriateness, relative preference and sensory qualities such as colour, odour and taste of particular foods. Food preferences are a strong influence on food choices and hence on nutrition.

vi) Psychology

Emotional sensations such as yearning, craving and compulsion may cause patterns of eating behaviour that relieve anxiety and tension, provide comfort and security (Fieldhouse, 1995). Thus eating disorders are now thought to be a result of psychological problems.

vii) Gender

In many societies there is distinct division of labour with regards to food production, preparation and consumption. In Thika, females are responsible for feeding animals, watering plants and all cooking whilst the men are responsible for sowing and

ploughing crops and for purchasing (personal observations in Kenya). There are even gender differences in actual consumption. In American females the day of the week was found to have a significant effect on several nutrients. At weekends more of all nutrients were consumed than on weekdays. In general women consume less of all nutrients than men (Beaton *et al.*, 1979).

Measuring food intake

It is very difficult to find reliable information on food intake and it is often thought that variability in dietary intake is a direct result of inadequate methods of assessment. Different methods are available to measure food intake, but with all methods the greatest problem is ensuring accurate results. One of the main problems with dietary assessment is under-reporting. Under-reporting is usually classified as a ratio of energy intake (EI) to basal metabolic rate (BMR). An EI:BMR ratio of 1.2 is considered too low to maintain body weight and therefore a cut off point of 1.35 was established for all normal circumstances (Goldberg *et al.* 1991). At an individual level dietary under-reporting is influenced by the dietary assessment tool, some methods may not always be representative of true dietary variations (Kortzinger *et al.*, 1997). It has been found that under-reporters are significantly heavier than other subjects, and under-reporting has been especially noted in obese subjects (Bingham & Nelson, 1991). It is also important to consider the population sample when analysing group data. Restrained eating low energy reporters may not necessarily be randomly distributed within a population, they may be over-represented among smokers, self-reported alcohol non-drinkers, among men, the manual social class, among women and those receiving state benefits (Garrow & James, 1993). There are many reasons why people under-report. Diets may be altered deliberately, knowingly or reluctantly due to difficult circumstances. Often subjects are more conscious of what was being eaten or feeling embarrassed or guilty about recording specific foods or amounts and thus under-report. Often weighing and recording the food requires too much effort, is difficult and inconvenient or subjects may specifically choose to eat foods that were

easy to weigh (Macdiarmid & Blundell, 1997). It is important to establish if subjects are under-reporters in order to obtain true estimates of dietary intake.

The different methods that are available to estimate food intake are described below:

i) Food frequency questionnaire (FFQ)

The subject is presented with a list of foods and asked to indicate how often each item is eaten. The FFQ is a simple and economical tool to establish relationships between diet and health and is widely used for assessing diet in epidemiological studies (Abrahamson *et al.*, 1963). It should be ensured that the questionnaire does not contain ambiguous questions and should be rigorously tested to ensure accuracy (Bingham & Nelson, 1991).

ii) Diet history questionnaire/interview

During an interview subjects are asked open ended questions in order to construct typical eating patterns. Short interview techniques such as this have high response rates, low respondent burden and can be easily administered (Balogh *et al.*, 1971).

iii) Estimated dietary intake methods

A record of actual food and drink consumption is kept by the subject for a specified period of time. Portion sizes are recorded and described in terms of household measures with or without the use of diagrams in order for the investigator to be able to estimate the actual quantity of food consumed. It has been suggested that photographs may be better alternatives than household measures in the estimation of portion sizes (Robson *et al.*, 1994) but it has also been suggested that a computer based food atlas is better than a picture based atlas (Horan *et al.*, 1994).

iv) Weighed dietary intake records

Similar to the above method except the subject is asked to individually weight each item eaten. This method is thought to be more accurate than merely estimating

portion sizes. The length of time subjects are required to keep such records do vary. Whilst 7 day records are easily adequate to estimate the average nutrient intakes of groups, for individual intake data for more than 7 days may be required (Young *et al.*, 1953)

v) Recall methods

The subject is asked to recall the actual food and drink consumed on specific days usually the immediate 24 hours, but sometimes for longer periods. Recall methods are invaluable in classifying dietary intakes but one day recalls may be considered atypical and may not be representative of an individuals usual diet (Todd *et al.*, 1983). Interestingly women appear to be better at recalling their calories and nutrients than men and younger respondents are better than older respondents (Campbell & Dodds, 1967).

vi) Duplicate portion techniques

Subjects are requested to keep a duplicate portion of any food eaten for later analysis by the investigator. Of all the dietary survey methods available this is regarded as the most accurate although the accuracy depends on being able to obtain a sample that is identical to the food consumed by the subjects under study. It is this technique to which all other methods are compared (Bingham & Nelson, 1991).

1.2.6 Anthropometric variation

Biological variability in weight

Body weight is an important variable in all mammals, not only for its direct effects on metabolism and bio-mechanics but its indirect effects on life history such as fighting for resources or for mates (Western, 1979). There are distinct correlations between body size and immunocompetance, both protein-energy malnutrition and obesity are associated with changes in parameters of immunity (Chandra & Sarchielli, 1996). It may be of interest to note that it is possible to graphically plot practically any variable against weight, e.g. height, age, reproductive parameters etc.. In fact it has even been suggested that there are correlations with weight and any biological variable (May & Rubenstein, 1982). Hence the importance of weight as a biological measurement. Because weight is such an important variable it is important that it is measured accurately. Ideally weight is measured first thing in the morning after the subject has been to the toilet and whilst wearing few clothes. Day to day variability of weight is due to the intake and elimination of food and water and this may be particularly evident in females during the week before a menstrual period when there may be an increase in the fluid content of the fat free mass (Roche *et al.*, 1996). Variation in body size and body proportion may be marked both within and between populations (Brues, 1977).

Environmental causes of weight variation

There does appear to a general relationship between climate and body weight. Within a species such as *Homo sapien*, body size increases proportionately as distance from the equator increases (Nelson & Jurmain, 1991). When body size increases, the increase in surface area does not keep pace with the increase in body weight. Therefore a tall heavy subject has a lower surface area than a short light weight subject. Accordingly under conditions where the ambient temperature is lower than the skin temperature, a short, lightweight or a tall lean subject with a high surface area

: weight ratio would produce less heat and smaller ranges of heat loss and have a greater area for sweat evaporation and for heat loss by radiation and convection than a short stocky individual. In contrast, under conditions in which the ambient temperature is higher than skin temperature, the subjects with a high surface area : weight ratio would have little advantage, since the relatively large surface area provides extensive evaporation of sweat also results in significant heat gains by radiation and convection, negating the positive effects of the evaporative process (Frisancho, 1979). In humans this relationship holds up fairly well e.g. the generally tall and slender Masai of East Africa compared to the shorter stouter Eskimos. However, there are exceptions e.g. Polynesians of the warm south Pacific tend to be tall and heavy. This relationship between body size and environment may account for some superficial anthropometric differences between ethnic groups.

Other causes of weight variation

Weight is not a stable measurement and may fluctuate on a daily basis. Whilst in the long run control of body weight is achieved by a conscious limitation of energy intake or possibly an increase in energy expenditure (Garrow & James, 1993). People who do not maintain a constant mass have been studied extensively as they may help us understand the mechanisms of energy balance. In general it has been found that factors that are associated with significant weight gains include a low level of education, chronic disease, little physical activity, heavy alcohol consumption, getting married or stopping smoking (Garrow & James, 1993). Perhaps of a greater interest is how do subjects that don't put on weight manage to stay in energy balance. This is one of the areas that is considered in Chapter 5 in relation to changes in the dietary habits of International students.

Another cause of weight variability in an individual is weight cycling associated with dieting. It has been found that adolescent male wrestlers who lose weight in order to compete in lower weight classes and then regain their weight have distinctly lower RMRs than non-cyclers (Steen *et al.*, 1988). More importantly, there is some

evidence that people whose weight is stable have less liability to die young, particularly of heart disease than those who show large weight changes during adult life (Garrow & James, 1993).

Biological variations in height

Height is ideally measured in the morning as up to 1 cm of height may be lost during the day due to the gravitational pull compressing the spinal discs. Adult stature involves at least 2 sets of causal factors: those affecting growth rate, and those affecting the onset of puberty, the latter limiting the length of time during which growth continues. Nutrition can affect both the rate and the duration of growth, with contradictory effects on stature. A low height for age is known as stunting. Stunting is the nutritional indicator most consistently correlated with the mental development of children. Stunting is associated with poor development in young children and delayed neurosensory integration, low IQ and predicts poor later development (Grantham-McGregor *et al.*, 1996). However, height for age can only estimate past and chronic malnutrition and not necessarily the present nutritional status (Keller *et al.*, 1976). Height is often required to normalise or standardise measurements of, for example pulmonary rate or metabolic rate. In fact Benedict (1924) claimed height to be the most important factor which correlates with BMR (however, most authors would say weight is of greater importance).

Body weight and height

Body weight and height are used universally as predictors of health status and are probably the oldest, simplest methods available. In 1846, a surgeon named John Hutchinson developed the first height/weight table based on 30 year old English men (taken from Hunt & Groff, 1990) in order to establish acceptable weight for heights in the general population because he believed such information would be valuable in the study of health and disease. This method is generally used by physicians to judge whether development is proceeding normally in children and to see whether their

height and weight maintain a constant relationship compared with the average for children of their age. Height/weight tables are frequently used by life insurance companies and were instrumental in the development of the concept of "ideal" weights and the acceptance that lower weights could be associated with longevity. These tables are available today although the word "ideal" is frequently substituted by "acceptable" in order to prevent negative emotional responses to those subject who would not be considered ideal. Population differences in body weight and stature are well documented (Eveleth & Tanner, 1990) Whilst body size may be strongly influenced by genetics, body weight and height are both phenotypically plastic, i.e. both are significantly influenced by external factors such as the environment and diet. Genetic differences in size and build that may characterise populations must be taken into account when attempting to develop standards for height and weight. Clinical Standards for growth and development have been based primarily on Caucasian populations in North America and Europe, simply because that is where the research workers are. This should be regarded as a makeshift; ideally standards of this kind should be developed specifically for each population in which they are to be used (Garn, 1965).

A combination of weight and height frequently used to assess obesity is Quetelet's Index also known as body mass index (BMI). A BMI of 20-25 is considered to be desirable, 25-29 is overweight and over 30 is obese (Garrow & James, 1993). BMI is widely used as an indicator of adiposity and lean body mass (Garn *et al.*, 1986) yet the relationship between BMI and adiposity may vary from population to population (Wang & Bachrach, 1996). In one study Asians were found to have lower BMIs than whites but were found to have more subcutaneous fat and a different fat distribution (Wang & Bachrach, 1996). Gallagher *et al.* (1996) studied BMI across different age, sex and ethnic groups and found that the relationship between body fat and BMI was age and sex dependant but was ethnically independent when based on a cohort of black and white Americans.

Other anthropmetric measurements

BMI and other indices of body composition which include height have been used as measures of stature. Measuring the height of the critically ill, elderly and subjects with musculoskeletal injury is difficult. Measurements on supine subjects differ significantly from standing height (Watt *et al.*, 1994). Limb lengths may offer useful height predictions. Lower leg lengths and arm spans are useful when height is unavailable, since they are easy to measure and highly reproducible (Han & Lean, 1994). Much of the early anthropometric research using alternative anthropometric measurements for height has been confined to Caucasian subjects. However, Steele & Mattox (1987) reported a significant relationship between arm-span and height in black and white females. Further discussion regarding ethnicity and arm-span is presented in chapter 5.

Other simple anthropometric measurements that are easy to perform are body circumferences. Both waist and hip circumferences are frequently measured and can be presented as a ratio. Waist/hip ratios (WHR) are often used as an index of the distribution of adipose tissue. Males naturally have higher WHR than females due to their characteristic android fat patterning. In females WHRs increase significantly after the menopause due to changes in their hormonal status which affect fat distribution. It is suggested that males with WHR over 0.95 and females with WHR over 0.85 should be prioritised in treatment to prevent the onset of heart disease and diabetes (Ashwell, 1994). Ethnic differences have been found with respect to WHR. Studies have shown that WHR on average are larger in Mexican-Americans than White -Americans who in turn have larger WHRs than French subjects for all age groups (Malina, 1996). It is possible that social class has a greater effect on WHR rather than pure ethnic differences.

Obtaining information on the human body's actual composition can be far more complicated than measuring height, weight and limb lengths when the body is studied as a whole. Whilst analyses of the human body had been performed as early as 1863 by Bischoff (cited in Forbes, 1987), it was Behnke in 1942, that rekindled the interest

in the study of body composition during the second world war when he demonstrated that several football players who had been found unfit for military service because of their weight actually had less body fat than normal weight recruits (quoted in Hunt & Groff, 1990).

Most methods of measuring body composition are based on a two compartment model of the human body e.g. hydrostatic weighing. Here the body is divided into fat or fat-free mass, (Keys & Brozek, 1953). Fat (or stored triglyceride) has a density of 0.9 g/cm^3 at 37°C, whilst fat-free mass has a density of 1.1 g/cm^3 at 37°C and a potassium content in men of 60-70 mmol/kg and 50-60 mmol/kg in women, (Lukaski, 1987). Keys and Brozek, (1953) then divided the body into four chemical groups; water, protein, ash or bone mineral and fat. Recently Heymsfield *et al.*, (1993) divided the body into six compartments; water, fat, bone mineral, extra cellular minerals and muscle. Only the most recent computerised methods e.g. Magnetic Resonance Imaging or Computerised Tomography are able to determine the above variables *in-vivo*. Skinfold thicknesses were used to estimate body composition within the present study and these are discussed in chapter 2. Like BMR, body composition is subject to many factors including age, gender, genetics, environment and ethnicity.

i) Age

As previously discussed in relation to changes in BMR with age, body composition alters as the body develops, matures and ages. Body composition changes during childhood, adolescence and during adulthood, although changes during adulthood are much slower. With increasing age the fat mass (FM) steadily replaces the fat free mass (FFM). The principle cause of loss of FFM is diminishing skeletal muscle. In the young adult male, the skeletal muscle mass may account for about 45% of his body weight while a man aged 65 years has only 27% (Westerterp, 1994). The increase in FM associated with the decrease in FFM with age in normal adults is shown in Figure 1.2.

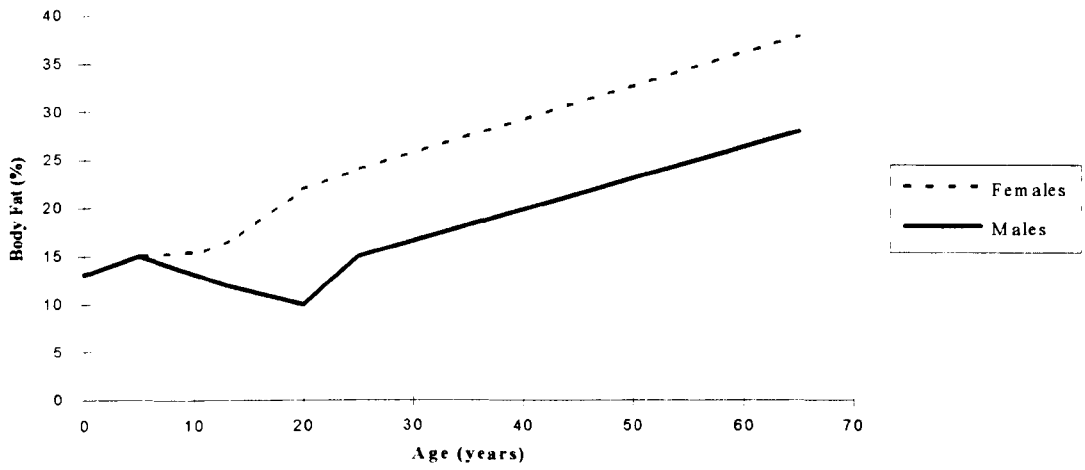


Figure 1.2

Changes in Fat mass with Age (source Westerterp, 1994a).

Most knowledge of changes in total body composition has been inferred from cross-sectional data, which can show mean changes but not individual variation (Westerterp, 1994). Clearly there is a need to identify individual changes in body composition over the life span.

ii) Sex

At birth and during childhood there are virtually no differences in body composition between the sexes. However, during adolescence and early adulthood when girls gain relatively more fat mass than boys and reach a higher percentage body fat as adults. It has been suggested that body fat has a regulatory effect on reproductive status in women and a minimum of 17% body fat is needed for normal menstrual cycles (Westerterp, 1994). At adulthood females have on average between 20-25% fat and males have between 10-15% body fat. The gender differences in body composition are so large that males and females should always be considered separately in any analysis regarding lean body mass.

iii) Ethnicity

Many of the equations designed for estimating body composition were based on adult Caucasian populations and therefore may not be valid for use with other populations. It does appear that there may be differences in body composition between ethnic groups. For example, there are differences in bone mass in black and white Americans which appear to be related to ethnicity because, blacks have not only greater skeletal calcium content, but also a greater total body potassium and muscle mass (Pollitzer & Anderson, 1989). Orientals have been shown to have a lighter lean body mass than other ethnic groups, and Afro-Caribbeans have been shown to have a greater LBM than Caucasian subjects (Forbes, 1987). Another study has found that Asians have more subcutaneous fat and a different fat distribution from whites, although they do have a lower body mass index (Wang *et al.* 1994). Interestingly in contrast to popular belief, Eskimos have been proved to be no fatter than Caucasians, although shorter LBM has been calculated to be similar to Caucasians (Forbes, 1987). Clearly there are ethnic differences in body composition, (although it is possible that these are due to lifestyle factors). Therefore current equations to estimate body composition need to be validated in other ethnic groups and in some cases a need may arise to create equations specifically for different population groups.

iv) Hormones

Hormones greatly affect body composition, whilst testosterone, insulin and growth hormone all have anabolic effects on muscle and adipose tissue, cortisol exerts the opposite effect. It is the hormones that are primarily responsible for body composition differences between males and females. The female sex steroid hormones, namely estradiol and progesterone appear to regulate the accumulation of fat in the gluteal-femoral region in females by activating lipoprotein lipase activity (LPL). Men have no LPL activity in the femoral region and this suggests a possible inhibitory role of testosterone on femoral LPL activity and also a stimulatory effect on lipolysis producing the relative leanness of young adult males. Females with

polycystic ovarian syndrome are known to have increased levels of testosterone and low levels of sex hormone binding globulin and are seen to have an android type of fat distribution, therefore their adipose tissue metabolism can be said to be similar to that of men (Rebuffe-Scrive, 1988). After the menopause many women choose to have hormone replacement therapy (HRT) which is effectively oestrogen replacement. Oestrogen's during female puberty are primarily responsible for the increase in body fat, but if given to menopausal women will alter body shape causing lower amounts of abdominal fat, in effect giving them younger, healthier figures and additionally protection against coronary heart disease (Day, 1996). Other studies examining the effects of hormones have looked at cigarette smokers. Smoking has an anti-oestrogenic effect in women and evidence has linked smoking to abdominal localised adipose tissue. There are significant interactions between smoking and serum testosterone levels which have an observed effect on increasing the waist:hip ratio. Smoking appears to promote android adiposity by increasing abdominal fat deposition and decreasing femoral fat deposition via interactive effects with the sex steroids (Daniel *et al.*, 1992).

v) Genetics

Whilst families may show similarities, obese parents are likely to have obese children, it is possible that this is a result of similar lifestyle factors such as identical eating habits. However, twin studies have shown that there is a genetic component. Bouchard *et al.* (1985) have shown that there is a clear indication that body density and fat free weight are significantly determined by the genotype. Whatever the genetic influence on physique phenotypes, these are attenuated or exacerbated by non-genetic factors as shown in Figure 1.3.

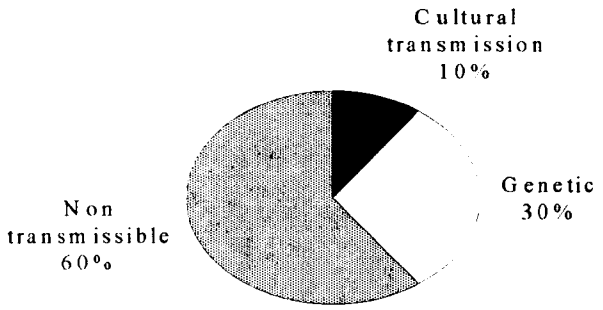


Figure 1.3

The transmissible variance and the genetic component of FFM and FM (source Bouchard *et al.*, 1988).

Further studies will define body composition and physique phenotypes by a series of contributing and interacting genes (Bouchard, 1996).

Thus body composition, like other biological variables is subject to intra- and inter-person variation.

1.3 Summary

Biological variation is evident all around us, from our dietary preferences to our height and BMR. Some of these variations are investigated further within this thesis, but let us not forget Darwin's (1871) immortal words "man differs in many respects, as in colour, hair, proportion of the body etc., yet if their whole structure be taken into consideration they are found to resemble each other more closely in a multitude of points".

Chapter

2

Materials and Methods

2. Materials and Methods

This chapter is divided into two sections.

Section I. Subjects and Methods:

These describe the subjects, the settings, the instruments used and the procedures that were followed during the different sections of experimental and practical work. Some statistical analyses are also described here but further details are given in the relevant results chapters.

Section II. Validation of Methods:

Tests the accuracy, precision and reproducibility of methods used and compares data obtained using different instruments

2.1 Subjects and Methods

Subjects

There were several phases of experimental work. Table 2.1 shows a breakdown of the numbers of subjects in each experiment. All subjects were staff or students at Oxford Brookes University, except those included in the re-analysis of the equations for BMR where the subjects were collated from the copious BMR literature. All subjects were free from any known physical disorders that could influence any of the measurements recorded.

Table 2.1

Breakdown of subject numbers used in each study

Study	Male	Female	Total
BMR Equations	5786	4945	10731
Heart Rate	15	8	23
BMR and Body Composition	0	37	37
Arm-span and Height	272	281	553
International Students	56	53	109
Totals	**6129**	**5324**	**11453**

Setting of studies

All measurements were made within Oxford Brookes University, in a room with privacy. The room was quiet and the temperatures maintained within the thermoneutral zone (between 24 and 26°C, McLean & Tobin, 1987). On occasions, when temperature in the room was lower, a portable heater was used to heat the room to the thermoneutral zone.

Ethical approval

Ethical approval for all the experiments carried out was obtained from the School of Biological and Molecular Sciences, Oxford Brookes University.

2.1.1 Equations for BMR

Creating a BMR data base

A data base was created using Microsoft Excel 4.0. Papers written over the last 80 years on BMR that were considered scientifically sound were collated along with raw data obtained from various research laboratories. Initially over 200 separate studies were included in the data base. 8100 male subjects and 5053 female subjects formed the basis of this compilation. After statistical screening the number of studies included was eventually reduced (to 194) making the total number of individuals 10,731, of which 5786 were male and 4945 were female. All studies included in the data base had to provide the following information:

1. Sex of subject
2. Individual body weight and height
3. Individual BMR data either as absolute values of kilo-calories or kilo-joules or oxygen consumption per minute
4. A brief description of the instrumentation used for measurement of BMR
5. Approximate temperature at which the measurements were made
6. Geographical location of measurements
7. Conditions under which BMR was measured e.g. hours after food intake, emotional state.

Studies were rejected if the measurements were taken at high altitudes, if the subject had eaten, if the temperature was beyond thermoneutrality, if the subject was ill, if

subjects came from a goitre belt region. Moreover, the student type apparatus and wet gas meter instruments were excluded since they are considered unreliable.

Screening the data

Analysis of the data was carried out in collaboration with statistician Vanessa Simonite of Oxford Brookes Univeristy.

To ensure the inclusion of only reliable quality data for the equations to estimate BMR, considerable screening took place. All individual data was screened to identify errors of data input and transcription. Bi-variate screening allowed outliers or extreme cases to be identified and removed from the database where appropriate. As well as screening data on an individual basis screening also took place at a study level. This enabled the detection of aberrant studies. A two-level random slopes model was applied to the data divided into age groups according to Schofield (1985) and for males and females separately. Analyses were carried out using the ML3 statistical package (Prosser et al 1990). As a result of applying this model, regression lines for BMR and weight were plotted for all studies contributing data for each age group. This then allowed us to identify studies in which the relationship between BMR and weight appeared to deviate. Studies with aberrant regression lines were then examined to see whether the study as a whole was an 'outlier' or whether a small number of points were causing an unusual relationship. This resulted in a few individual data points and some studies being completely excluded from the database.

Calculation of predictive equations

Equations to predict BMR were calculated using the statistical package SPSS and a simple linear model. Equations were derived that used a) weight alone and b) weight and height together to calculate BMR.

Equations were calculated using the traditional age bands that have been used in previous studies which the FAO/WHO/UNU (1985) state "reflect the physiological characteristics in relation to growth, body composition, physical activity and food intake". In addition BMR equations have also been calculated using a new set of age bands which are intended to be more representative of the biological and physiological changes that occur with age. These new age bands are as follws; 0-2, 2-5, 5-10, 10-15, 15-20, 20-40, 40-60, 60-70, 70-85 and 85+ years.

Linear regression models were also used to compare mean BMR's between Caucasian and other ethnic groups, after adjusting for any differences in weight.

2.1.2 Measurement of Energy Expenditure

Basal Metabolic Rate

Basal metabolism was measured under strict standardised conditions similar to those emphasised by Magnus Levi in 1899. Subjects were requested to refrain from any physical activity for 24 h prior to the BMR measurement so muscular activity could be kept to a minimum. Measurements took place at least 12 hours after the subject's last meal and subjects were instructed not to consume any food or drink other than water during that time. All BMR measurements took place in the morning. Subjects were asked to lie down at rest on a camp bed for 20 minutes before any measurements were made. All the subjects had been shown the apparatus previously to help reduce any anxiety regarding the experiment or cause any emotional disturbance. Where possible, female subjects were measured during the mid-follicular phase of the menstrual cycle (Solomon, 1982), when this was impossible the day of the measurement was recorded and this was taken into consideration later. BMR measurements were either made with the Deltatrac^{TM} or the Douglas bag technique.

Datex Deltatrac^{TM}

The Datex Deltatrac^{TM} metabolic monitor (Datex Instrumentarium Corp. Helsinki, Finland) is an indirect calorimeter which measures oxygen consumption (VO_2), carbon dioxide production (VCO_2) and then calculates from these values the respiratory exchange ratio ($R = VCO_2/VO_2$) and energy expenditure (EE). Measurements were made by the Deltatrac^{TM} every minute and were displayed graphically on the video screen and printed out numerically. It can monitor both mechanically and spontaneously breathing subjects although in this establishment only spontaneously respiring subjects were measured. A picture of the Deltatrac^{TM} can be seen in Figure 2.1.

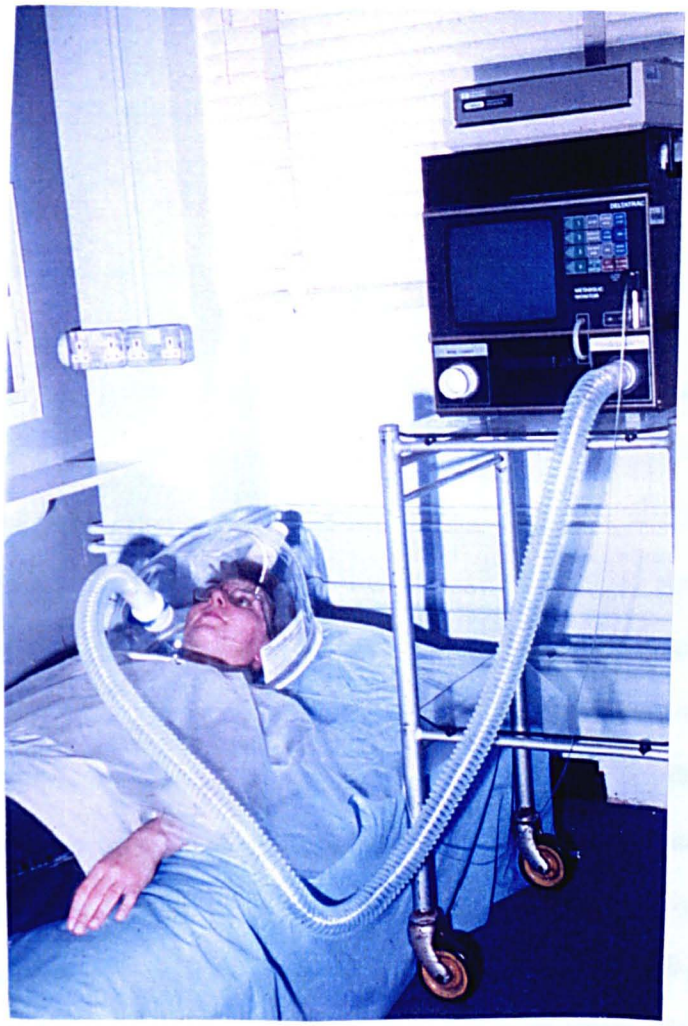


Figure 2.1

The Datex Deltatrac^{TM} Indirect Calorimeter

A transparent plastic canopy was used as opposed to a face mask primarily for the subjects comfort. The Deltatrac^{TM} generated a constant flow of about 40 l/min, (this was checked periodically) through the canopy to the instrument. All air expired by the subject was collected in the constant flow and analysed. The Deltatrac^{TM} measured carbon-dioxide with a Datex infra-red sensor of type CX-104. Oxygen was analysed paramagnetically with a differential oxygen sensor OM-101. Both gases were measured within the Deltatrac^{TM} unit itself.

The Deltatrac^{TM} was always switched on at least 30 min before being calibrated. Calibration took place every morning. Atmospheric pressure was read by the Deltatrac^{TM} and only adjusted if the reading did not match that of a wall mounted barometer. The gas sensors were calibrated with accurate calibration gases, a standard mixture of 95% oxygen and 5% carbon dioxide (Quick Cal^{TM} calibration gas, Datex).

Periodically the RQ and air flow measurements of the Deltatrac^{TM} were tested and calibrated according to the manufacturers recommended procedures. The RQ test was performed by lighting an alcohol burner filled with 100% ethanol. The burner was then placed on a base and sheltered with a glass bell cover. The canopy hose was connected to the burner unit and to the Deltatrac^{TM}. measurements were then started and recorded. The test usually ran for 30 min, the average RQ value for the last 15 min was always between 0.64 - 0.69, in line with the manufacturers recommendations. Flow calibration was set up as above except the alcohol burner was replaced with a burner vessel. The burner vessel being a thimble like container holding exactly 5 ml of ethanol. The alcohol was lit and the glass bell cover replaced. After approximately 20 min the flame extinguished. The total amount of carbon dioxide produced during the test was calculated by summing all the minute by minute VCO_2 values on the printout. The new flow constant for an adult was then determined using the following formula:

New Flow = 1.03 * (3820 / Total CO_2) * old flow

If necessary the flow constant could be adjusted on the Deltatrac^{TM}.

Additionally every two years the Deltatrac^{TM} was serviced by a trained engineer. The repeatability of BMR measurements recorded using the Deltatrac^{TM} can be seen in Section II.

Douglas Bag

When the Deltatrac^{TM} was not available, energy expenditure was estimated using the Douglas bag (Douglas, 1911). After the mandatory rest period subjects were given a nose-clip and a mouth piece. The subjects were given approximately 5 minutes to familiarise themselves with the correct breathing technique, breathing out into room air, before being connected to the Douglas bag. A two-flap one way valve mouthpiece allowed the subject to breathe in room air, whilst the expired air was collected in a Douglas bag over a 10 minute period. Three or four separate collections were made, the first bag was discarded in case of a training effect (Durnin, 1981) and the average of the remaining bags was recorded. Expired air was then analysed using a paramagnetic oxygen analyser (Servomex 570A, Servomex plc, East Sussex, UK.) and the total volume of air expired was determined using a Harvard dry gas meter (supplied by Cranleigh, Birmingham, UK). Energy expenditure was then calculated using the Weir Equation (Weir, 1949).

$$V * \frac{21 - r}{100} * \frac{CF}{t} * 20$$

Where:

V= volume of expired air (l)

r = O_2 content of expired air (%)

21 = O_2 in inspired air (%)

t = time (min)

CF = correction factor for temperature and pressure

20 = energy equivalence of O_2 (kJ/l)

The Douglas bag and associated tubing were periodically examined for leaks and punctures. The Oxygen analyser was calibrated daily using both oxygen-free nitrogen as the zero gas and pure (100%) oxygen as the span gas. A drying tube filled with silica gel was fitted ahead of the oxygen analyser inlet to prevent the entrance of particles and moisture condensate into the analyser as well as removing water vapour from the sample gas. Silica is known to absorb some of the background/carrier gases and it is possible that very small inaccuracies in the oxygen readings may have occurred because of this (Consolazio *et al.*, 1963). Another source of error is the motorised internal sampling pump. The oxygen analyser is known to sample air at 350 ml per min, on average an oxygen measurement took just under 10 seconds to stabilise and therefore approximately 58 ml of expired air were lost before the volume was measured with the dry gas meter. The dry gas meter was regularly checked with a calibration syringe (Hans Rudolph Inc., Kansas, USA) by feeding 3 litres of air through the inlet. The dry gas meter always registered 3 l exactly.

The repeatability of BMR measurements made using the Douglas bag and can be seen in section II.

2.1.3 Total daily energy expenditure

Heart Rate Monitoring

Heart Rate (HR) naturally increases with physical activity and this increase is closely related to oxygen consumption. It is therefore possible that by monitoring heart rate, total energy expenditure can be estimated (Bradfield, 1971). The relationship between O_2 consumption and heart rate is unique to each individual, but once this relationship is established energy expenditure can be computed from continuous recordings of HR (Dauncy & James, 1979; Ceesay *et al.*, 1989 and Livingstone *et al.*, 1990).

The device used for recording heart rate was the Polar Sport Tester^{TM} heart rate monitor (Polar Electro Oy, Kempele, Finland). The monitor was worn as a belt around the chest where it would not interfere with any of the subjects normal activities. A test designed to show the accuracy of the Polar heart rate monitor can be seen in section II.

Before the subjects wore the heart rate monitor for any period of time calibration curves were established to find the relationship between heart rate and energy expenditure for each individual subject. This was done by simultaneously measuring heart rate and energy expenditure during different activities. The activities included lying down at rest, sitting still, standing and cycling at different speeds and work loads. Energy expenditure was measured with the Douglas bag using the methods described previously.

After the individual calibration, (the individual data obtained for calibration can be seen in the results section) had been completed subjects were requested to wear the heart rate monitor. Heart beats were recorded every minute for a total period of 24 hours. During the same 24 hours subjects were also requested to complete an activity diary (see below)

At the end of the 24 hour period the heart rate data was downloaded from the monitor onto an IBM computer using a Polar interface. Using the subjects individual calibration graphs and the equations produced, the HR data was extrapolated to calculate total energy expenditure. The individual equations are presented in the results section.

Effect of DIT on Heart Rate

It is well established that dietary induced thermogenesis (DIT) increases energy expenditure (Piers *et al.*, 1995 and Kinabo & Durnin, 1990). Thus it was therefore possible that any rise in energy expenditure due to food may alter the relationship between heart rate and energy expenditure. To establish if there were any changes in this relationship subjects had their heart rate and their energy expenditure measured simultaneously whilst lying down, standing and at two different work loads on a cycle ergometer. Subjects were then presented with a breakfast consisting of a cereal of their choice, semi-skimmed milk, 2 slices of toast, margarine and jam. Caffeine is known to increase the heart rate (Booyens & Hervey, 1960) and for this reason half the subjects were allowed 1 mug of coffee whilst the remaining subjects were allowed no caffeine. After breakfast the subjects were allowed to rest for 30 min before the energy expenditure and heart rate calibration experiment was repeated.

Activity Diary

Subjects were given diaries which were divided into 5 minute periods and asked to complete them for a 24 hour period. Participants were instructed to try and account for every minute of their day and to give details of every activity that they engaged in. Ideally activity diaries are completed for a period 3 days including at least one week day and one weekend or longer to ensure an accurate representation of the subjects

activities, but for this study the diary was used to evaluate the heart rate method of estimating energy expenditure. The activity diaries were then analysed and total energy expenditure estimated using the subjects actual measured BMR multiplied by standard metabolic constants for gross energy expenditure in specified activities (FAO/WHO/UNU, 1985) or values obtained from Durnin and Passmore's classic publication "Energy, Work and Leisure" (1967) as well as actual energy expenditure results obtained whilst establishing individual calibration curves relating energy expenditure to heart rate.

2.1.4 Food Intake

The following two methods were used to estimate food intake:

3 day food diaries

International students who had recently arrived in Oxford were given food diaries which covered a period of 3 days at a time. The first diary that participants were given requested them to recall what they had eaten in their country of origin before departing for the UK. (in most cases a week had passed since they had left their home country). Subsequent diaries were filled in during the subjects stay in Oxford. Subjects were asked to carry the diaries around with them at all times and to record everything that passed their lips during the 3 days in question. A full description of the food that had been eaten was requested including the type and brand, how the food was cooked and the amount eaten. The time of day that any food was consumed was also recorded to help establish what foods were eaten as part of a meal and what foods were consumed as snacks. Subjects were asked to complete diaries at regular intervals during their study time in Oxford so any changes in their diets could be monitored. The diaries were analysed using the computer package Diet 5 for Windows, McCance and Widdowson's The Composition of Foods (Holland *et al*, 1991) and the second supplement Immigrant Foods (Tan *et al*, 1985).

Food frequency questionnaire

Food frequency questionnaires were distributed to International students at the beginning and the end of the study so that any gross changes in food consumption that occurred during their stay in the UK. could be noted. The questionnaire was also completed by a group of UK based Caucasian students who represented a control group. The food frequency questionnaire included 31 commonly consumed items of food and drink. Respondents were asked to tick the box that most applied to each particular food i.e. was the food consumed on average more than once a day, once a day, more than once a week, once a week, once a month or never. An example of the food frequency questionnaire can be seen in the appendix. At the end of the study changes in the frequencies of foods eaten were analysed using an ANOVA statistical test.

2.1.5 Body Composition

Body composition was estimated using standardised anthropometric measurements and bio-electrical impedance.

Anthropometric Measurements

Height

Height was measured using a Seca stadiometer (Seca, Germany). The stadiometer had a fixed measuring scale and a rigid raised platform and an adjustable horizontal bar. Subjects were barefoot and stood erect with their head positioned in the Frankfort plane, arms were relaxed at the subjects side, with palms facing inwards. Readings were taken to the nearest 0.1 cm.

Weight

Weight was measured using a spring balance (Seca, Germany). Subjects removed shoes, cardigans and any heavy contents from their pockets such as coins. Weights were measured to the nearest 0.5 kg. The scales were periodically checked by the investigator against an electronic balance accurate to 100g (Soehnle model 7300, CMS Weighing Equipment, London) as well as a set of beam scales. Differences between the scales was never more than 0.5 kg.

Arm-span

Arm-span was measured using a 2 metre tape adopting the following procedure. The tape was affixed to a flat surfaced wall. Subjects stood erect (minus shoes) with their backs to the wall, arms outstretched laterally and maximally at shoulder level, palms facing outwards. The subjects longest finger (excluding the fingernail) of the left hand was in contact with a strip of wood attached parallel to the wall and at zero on the tape measure. The distance between the tip of the longest finger on the left hand to the longest finger on the right hand represented the arm-span measurement. Readings were taken to the nearest 0.1 cm (Lohman *et al.*, 1988).

Circumferences

Circumferences were measured with a tape measure. The tape was kept at right angles to the long axis, and the skin was in contact continuously along the tape, although the skin was not in any way compressed (Norgan & Jones, 1990). All circumferences were made to the nearest 0.1 cm.

Mid-upper arm circumference

The subject stood erect, with the subjects elbow flexed at 90° in order to locate the midway point between the olecranon and the tip of the acromion. A tape measure was used to find the exact midway point, which was marked. The subject then allowed their arms to hang freely by their sides whilst a tape measure was placed around the arm, touching the skin at the marked height, and the measurement was made. Measurements were only taken on the non-dominant arm (Lohman *et al.*, 1988).

Chest circumference

Subjects stood erect facing the investigator and raised their arms to allow a tape to be passed around their trunk. The subject lowered their arms once the tape was in place. The measurement was taken horizontally at about the fourth sternebrae (corresponding to the sixth rib). The measurement was taken during normal light respiration, mid-inspiration as recommended by Norgan & Jones (1990).

Waist circumference

Subjects stood erect, the waist was taken to be the point between the ribs and the iliac crests where the smallest horizontal circumference could be measured (Lohman *et al.*, 1988).

Hip circumference

Subjects stood erect whilst the investigator crouched down to be level with the subjects hips. The tape was placed over the great trochanters at the site which gave the largest hip circumference (Lohman *et al.*, 1988).

Upper thigh circumference

A tape was passed around the thigh over the gluteal furrow. The thigh circumference was only measured on the non-dominant side of the body (Lohman *et al.*, 1988).

Calf circumference

The subject sat so the lower limbs were relaxed. The point on the calf where the measurement was taken was where the largest circumference could be measured, over the belly of the gastrocnemius (Norgan & Jones, 1990).

Breadths

Only two breadths were measured, the wrist and the elbow, to enable frame size to be approximated. Small sliding calipers were used to measure the breadths to the nearest 0.1 cm.

Elbow breadth

The subject raised their non-dominant arm with the elbow flexed at 90°, the back of the subjects hand faced the investigator. The blades of the sliding calipers were pointed upwards and placed either side of the epicondyles of the humerus for the measurement to be taken (Norgan & Jones, 1990).

Wrist breadth

The subject held out their fore-arm whilst the investigator placed the calipers on the most medial aspect of the ulnar styloid and the most lateral aspect of the radial styloid (Norgan & Jones, 1990). The investigator used her fingers to help identify these landmarks.

Skin Folds

Skinfolds are the actual thicknesses of double folds of skin and subcutaneous adipose tissue at specific sites on the body (Lohman *et al.*, 1988). Skinfolds were measured with Holtain skinfold calipers at four sites; biceps, triceps, sub-scapular and supra-iliac. A skinfold was obtained by drawing the investigators thumb and index finger on the left hand over the site being measured towards each other to grasp the skinfold between them. The skinfold was slightly pulled away from the underlying tissue, whilst the calipers held in the investigators left hand were applied to the skinfold. The skinfold was grasped 1 cm under the specified site of the actual skinfold so the investigators fingers could support the skinfold as the calipers were placed on the actual skinfold site. All skinfolds were made on the non-dominant side of the subjects body, this being determined by asking the subject if they were right or left handed. All skinfolds were measured to the nearest 0.2 mm. Measurements at each of the four sites were taken three times in quick succession, the average value being recorded. Total body fat was then estimated by taking the sum of the average skinfolds values taken at the four sites and ciphering the Durnin and Womersley equations (Durnin & Womersley, 1974).

Biceps

The subject stood facing the investigator with their non-dominant arm flexed at an angle of 90° to enable the investigator to locate the mid way point between the lateral tip of the acromion and the most distal point on the acromial process, the olecranon. A tape measure was used to pinpoint the exact midway point. The subject was asked to relax their arms by their side whilst the skin fold was taken at this midway point, on the anterior aspect of the arm, over the centre of the biceps muscle (Lohman *et al.*, 1988).

Triceps

The subject stood with their back towards the investigator whilst being measured. The triceps were measured at the same midway point as described above but on the posterior aspect of the arm over the triceps muscle (Lohman *et al.*, 1988).

Sub-scapular

The subject stood erect, with their shoulders relaxed and arms by their sides. The sub-scapular skinfold was picked up on a diagonal just below the inferior angle of the scapular (Lohman *et al.*, 1988).

Supra-iliac

Subjects stood erect with their arms by their side. An oblique skinfold was grasped following the natural cleavage of the skin, just above the iliac crest in the mid-axillary line (Durnin and Rahaman, 1967).

2.2 Validation of Methods

2.2.1 The Datex Deltatrac^{TM}

The repeatability of BMR measurements using the Deltatrac^{TM} was determined by measuring one female subject 8 consecutive times during the course of one morning. Each measurement lasted at least 10 minutes and the Deltatrac^{TM} was re-calibrated between measurements. This not only estimated errors due to the Deltatrac^{TM} but also intra-investigator error.

Table 2.2

Repeatability of the Deltatrac™

Measurement	**BMR (kJ/24h)**
1	4920
2	4620
3	4750
4	5240
5	4890
6	5230
7	5110
8	4820
n	**8**
Mean	**4947.5**
Standard Deviation	**226.26**
Coefficient of Variation	**4.57%**

A low coefficient of variation (CV) indicates that BMR measurements made with the Deltatrac™ are relatively consistent and are not subject to variation caused by the investigator or the machine itself.

2.2.2 The Douglas Bag

The repeatability of BMR measurements using the Douglas bag was determined similarly to that of the Deltatrac^{TM}. One female subject was measured 8 consecutive times during the course of one morning. Each Douglas bag measurement lasted at least 10 minutes and the oxygen analyser was re-calibrated between measurements.

Table 2.3

Repeatability of the Douglas bag technique

Measurement	**BMR (kJ/24h)**
1	4125
2	3970
3	4065
4	4419
5	4228
6	4352
7	4238
8	4355
n	**8**
Mean	**4219**
Standard Deviation	**156.38**
Coefficient of Variation	**3.71%**

A low CV indicates that BMR when measured using the Douglas bag technique is not highly variable.

Comparison between the Deltatrac™ and Douglas Bag

There are many advantages and disadvantages of the two methods of BMR measurement. One of the main advantages of the Deltatrac™ is that all analysis is done within the unit itself. Not only are gas analysers inbuilt but a computer enables the automatic calculation of both the respiratory quotient and energy expenditure. All the data is displayed on a video screen and printouts are available making the Deltatrac™ very user friendly. Unfortunately the Deltatrac™ is an expensive piece of apparatus which constitutes its major drawback. Other disadvantages are that periodic checks with an alcohol burner are required, and because in most cases it is used in conjunction with a canopy, subjects are limited to supine positions during measurements. The Douglas bag in comparison, has been in use for nearly a century, is very simple and easy to use as well as being reasonably robust. It is also relatively inexpensive and does allow the subject some freedom to move around, although it would interfere somewhat with normal activity. Depending on the size of the collecting bags and the level of physical activity, only short periods of measurements are possible, and the contents of the bag do require prompt analysis in case of carbon dioxide diffusion (Murgatroyd, 1993). The advantages of both methods are summarised in Table 2.4.

Table 2.4

Summary of the advantages of the Deltatrac™ and the Douglas bag

Deltatrac™	**Douglas Bag**
Accurate and reliable data	Reliable results
Gas analysers and computers incorporated	Simple and robust
Automatic and good display	Inexpensive
User friendly	Some movement possible

In order to directly the compare the measurements obtained using both the Deltatrac™ and the Douglas bag, 12 subjects, 6 males and 6 females were measured using both techniques. Half the subjects were measured first with the Deltatrac™ followed immediately by the Douglas bag and the other subjects were measured first using the Douglas bag and then immediately afterwards using the Deltatrac™. The results obtained are shown in Table 2.5.

Table 2.5

BMR measured using two techniques

Subject	Sex	Method of BMR Measurement (kJ/24h)	
		Deltatrac*	**Douglas Bag***
1	m	6772	6794
2	m	5530	5853
3	m	7210	7970
4	m	7043	6798
5	m	6990	7029
6	m	7550	7780
7	f	4450	4146
8	f	5010	5839
9	f	6120	5820
10	f	6360	6077
11	f	6220	5843
12	f	5490	5242
	Mean	6228	6266
	SD	951	1072

*NS

Using the computer package Microsoft Excel 4.0 a paired t-test was performed. No significant differences was found between the two techniques.

Since there were no significant differences between the two techniques and despite the pro's and con's of each method, the most important factor which determines which method is chosen is availability.

2.2.3 The Polar Sports Tester Heart Rate Monitor

The Polar Sports Tester heart rate monitor (Polar Electro Oy, Kempele, Finland) was tested for accuracy by measuring 6 subjects with the Polar heart rate monitor itself and immediately afterwards with a Siemens Cardiostat (Siemens - Elma AB, Medicinsk Teknik, Solna, Sweden). The results obtained using both techniques can be see in Table 2.6.

Table 2.6

Heart Rate measured using two techniques

Subject	Data Points Recorded	Cardiostat			Polar		
		Mean (beats/min)	SD	CV	Mean (beats/min)	SD	CV
1	39	54	8.36	15.45	59	2.03	3.40
2	34	68	5.11	7.55	69	2.58	3.77
3	46	45	2.15	4.77	46	1.07	2.33
4	51	69	30.2	4.41	69	1.80	2.58
5	30	53	3.47	6.52	54	1.52	2.80
6	44	67	4.57	6.84	61	0.76	1.26

No significant differences were found between the two methods of recording heart rate. However the coefficient of variations varied considerably between the two

methods. The Polar heart rate monitor showed very consistent CV's, the range being 1.26 - 3.77 % whilst the Cardiostat CV's ranged from 4.41 - 15.45 %. It is very likely that this is due to the method of heart rate monitoring. The Cardiostat measures heart rate continually whilst the Polar heart rate monitor measures heart rate at set intervals, which may eliminate some noise. For this reason and the fact that the Polar heart rate monitor is less obtrusive it was the Polar heart rate monitor that was used for the present studies.

The Polar heart rate monitor having been established as providing reliable heart rate measurements i.e. showing small intra-individual variation over short periods of time was then assessed for a longer time frame. One subject agreed to wear the monitor for 3 days continuously. No significant differences were found between the heart rates recorded on any of the 3 days. It was therefore deemed that the Polar heart rate monitor was capable of supplying consistently accurate and reliable heart rate data.

Chapter

3

New predictive equations to estimate BMR in humans

3. New Predictive Equations to Estimate BMR in Humans

This chapter deals with the creation of new equations to predict BMR in humans. This work is an extension of the work of Schofield, Schofield and James (1985) which set the foundations for the FAO/UNU/WHO (1985) publication "Protein and Energy Requirements". An extended BMR database was created that incorporated data collected from the literature and directly from laboratories, enabling the calculation of equations that are suitable for the prediction of BMR in individuals and populations world-wide.

3.1 Equations to predict basal metabolic rate

Basal Metabolic Rate (BMR) represents the largest component of energy expenditure and is therefore widely used to calculate an individual's energy and food requirements. BMR has not always been used as the basis for the estimation of energy requirements. Indeed, in the beginning BMR was used as a clinical tool to aid the physician in the diagnosis of diseases such as diabetes, leukaemia, obesity and disorders of the pituitary (McLean & Tobin, 1987). The first comprehensive study that used BMR as the basis to estimate energy requirements and hence food requirements was described by Bedale (1923). She studied and measured BMR in a group of 100 children aged 7-18 years. It is of interest to note that the FAO/WHO/UNU (1985) approach to estimate energy requirements is a refinement of the method described by Bedale (1923).

Since it is not always convenient, nor practical to measure BMR using direct/indirect calorimetry, BMR is frequently predicted using equations. A comprehensive review of equations to predict BMR can be seen in the introductory chapter. Today many equations are in existence (Harris & Benedict, 1919; Boothby *et al.*, 1936; Quenouille *et al.*, 1951; Robertson & Reid, 1952; Schofield, 1985 etc.) in fact some of these equations are still in use. Notably, the Harris & Benedict equations created in 1919

are still used widely by clinicians in America who wish to estimate the BMR of patients. The most recent frequently used equations for estimating BMR are those developed by Schofield, Schofield & James (1985). At the request of the FAO/WHO/UNU, Schofield renewed and analysed the world-wide data for BMR and produced a series of predictive equations. These equations formed the basis of the equations used in the FAO/WHO/UNU document "Energy and Protein Requirements" (1985). The Schofield data base comprised of 114 published studies, including 7173 individual data points. Whilst Schofield's equations were considered the best estimates of BMR at the time, the work did receive criticism, particularly by people who found the equations overestimated BMR in tropical inhabitants (Minghelli *et al.*, 1990; Shetty *et al.*, 1984; Henry & Rees, 1991 and Valencia *et al.*, 1994). Close examination of the Schofield data base revealed around 6000 of the BMR values for males aged between 10-60 years of age had originated from Italian military personnel. Later, Hayter & Henry, (1994) showed that this Italian group appeared to have a higher BMR per kg than any other Caucasian group, therefore it is possible that this large data set artificially raised the predicted BMR. Additionally, there also appeared to be a lack of data in children between the ages of 10 and 16 years of age and in the elderly over 60 years of age. Its is now a decade since the Schofield analysis. During the interlude, several laboratories and investigators have generated BMR data for different ages and ethnic groups and hence the global BMR data base has clearly expanded. Therefore, it was considered the appropriate time for a new and up-to-date set of equations, suitable for predicting BMR in populations throughout the world.

The Oxford Brookes Data base

In October 1993 the Oxford Brookes BMR data base was created. This data base consisted of 194 papers, including 10004 BMR measurements. The data base included information on the subjects age, sex, height, weight, BMR and ethnicity. Further information such as the instruments used, geographical location, and the

preparation of the subjects was also requested in order to ensure that the results entered into the data base were of the highest possible quality. Table 3.1 shows a summary of this data base.

Table 3.1

Summary of the Oxford Brookes data base

Number of papers	194
Number of individuals	10004
Number of mean scores	74 (representing 4495 individuals)
Number of males	7986
Number of females	5090
Number of ethnic groups	22

Table 3.2 shows a breakdown of the Oxford Brookes data base alongside the Schofield data base to allow direct comparisons. The Oxford Brookes data base clearly contains more data than the Schofield data base for all the age groups. This is due to a combination of new data published and data directly collated from researchers in the field since 1985. Additionally, further papers published before 1985 that were not incorporated into the Schofield data base were identified by scouring the literature; hand searches of references listed in papers and searches in Index Medicus and Nutrition Abstract Reviews. A bibliography of all the BMR papers in existence, as well as those included in the Oxford Brookes data base has recently been published (Reeves *et al.*, 1997) which presents summaries on the contents and finding of these papers.

Table 3.2

Comparison of the Oxford Brookes and Schofield databases

	Oxford Brookes data base			Schofield data base		
Age (years)	Male	Female	Total	Male	Female	Total
0-3	326	258	584	162	137	299
3-10	468	433	901	338	413	751
10-18	975	1111	2086	734	575	1309
18-30	3019	1405	4424	2879	829	3708
30-60	766	779	1545	646	372	1018
60+	272	192	464	50	38	88
Total	5826	4178	**10004**	4809	2364	**7173**

The physical characteristics of the subjects included in the Oxford Brookes analysis are presented in Table 3.3 The mean and standard deviations are given for weight, height, BMI and BMR for each sex and age group separately.

Table 3.3

Mean physical characteristics of the Oxford Brookes data base

Age range (years)	Sex	Weight (kg)		Height (m)		BMI		BMR (kJ/24h)	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
0-3	m	7.65	4.35	0.70	0.17	15.20	1.90	1779	1079
	f	7.97	4.31	0.71	0.18	15.09	2.17	1820	1014
4-10	m	23.75	5.45	1.23	0.12	15.42	1.45	4319	606
	f	24.56	7.33	1.24	0.14	15.58	2.0	4150	687
11-18	m	43.76	12.38	1.53	0.14	18.23	2.82	5783	1056
	f	45.31	11.03	1.52	0.09	19.30	3.36	5321	759
19-30	m	61.12	10.24	1.70	0.08	21.10	2.70	6451	953
	f	52.88	10.19	1.60	0.07	20.66	3.30	5224	776
31-60	m	61.77	10.81	1.66	0.09	22.27	2.91	6158	967
	f	58.61	13.91	1.58	0.08	23.36	4.51	5348	815
60+	m	66.08	14.15	1.67	0.09	23.40	3.77	5779	965
	f	55.89	13.9	1.54	0.10	23.35	4.43	4749	786

For comparative purposes the mean physical characteristics of the subjects included in the Schofield database are presented in Table 3.4.

Table 3.4

Mean physical characteristics of the Schofield (1985) data base

Age range (years)	Sex	Weight (kg)		Height (m)		Wt/Ht		BMR (kJ/24h)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
0-3	m	6.57	3.489	0.64	0.139	9.59	2.967	1510	918
	f	6.86	3.615	0.66	0.151	9.81	3.074	1540	915
4-10	m	21.47	4.352	1.18	0.112	18.02	2.257	4140	498
	f	21.35	4.656	1.17	0.115	18.00	2.551	3850	493
11-18	m	41.76	14.61	1.49	0.169	27.32	6.77	5860	1171
	f	38.53	11.24	1.46	0.131	25.96	5.537	5040	780
19-30	m	63.04	8.689	1.70	0.073	36.92	5.882	6870	843
	f	52.98	8.420	1.60	0.067	33.14	7.308	55330	721
31-60	m	64.11	10.79	1.68	0.067	38.08	5.882	6750	872
	f	60.97	12.45	1.60	0.067	38.14	7.308	5620	630
60+	m	62.33	12.84	1.65	0.080	37.66	6.540	5590	928
	f	55.54	10.89	1.53	0.085	36.25	6.859	4850	605

By comparing the physical characteristics of subjects included in both the Oxford Brookes and the Schofield databases the following observations may be made: In general, subjects included in the Schofield database below 18 years of age tend to be lighter, shorter and have lower BMRs than subjects in the Oxford Brookes database. Subjects aged 19-60 years in the Schofield database tend to be heavier, taller and have greater BMRs than subjects of the same age in the Oxford Brookes database. Subjects over 60 years of age in the Schofield database also tend to be lighter, shorter and have lower BMRs than subjects in the Oxford Brookes database.

These characteristic differences will affect the outcome of the equations created to predict BMR.

Using the newly created Oxford Brookes data base, linear equations to predict BMR were created using the statistical package SPSS with the assistance of V.Simonite (this study only). Initially equations were developed in accordance with the age groups as outlined by previous worker (Schofield, 1985), i.e. 0-3, 3-10, 10-18, 18-30, 30-60 and 60 +. Equations were created for six age groups with males and females analysed separately.

Presented below is an example of how the data was organised to create the equations, the example below is that used for the female group aged 18-30 years.

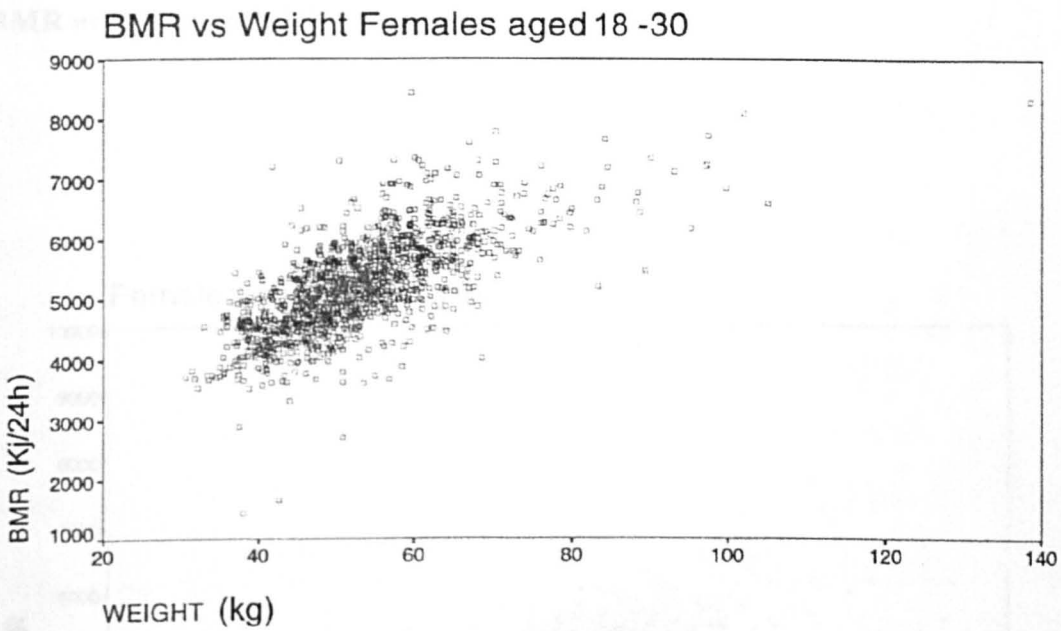


Figure 3.1

BMR according to weight

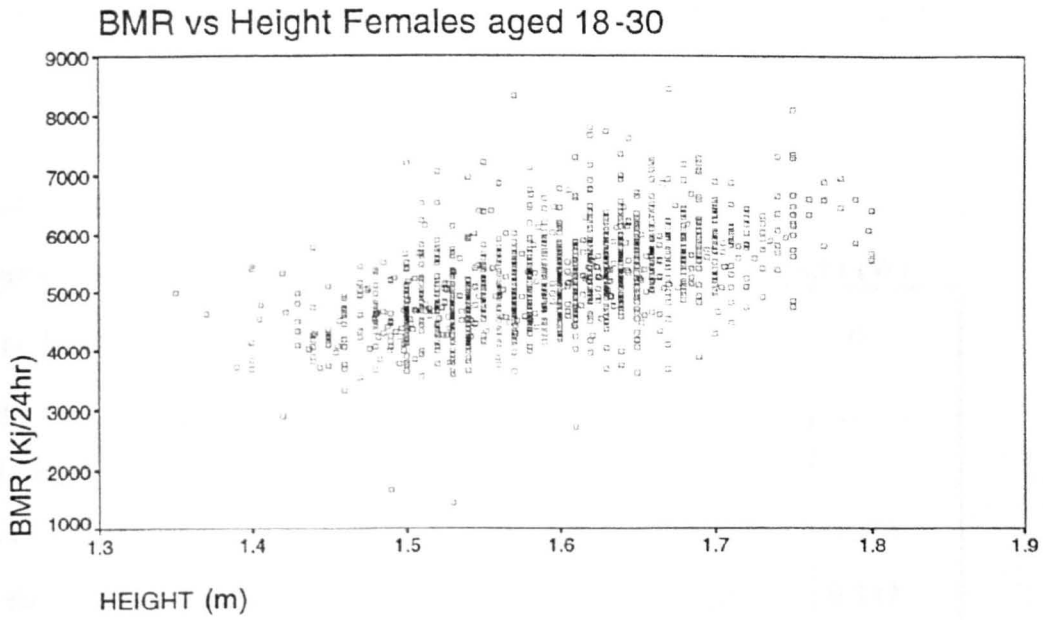


Figure 3.2

BMR according to height

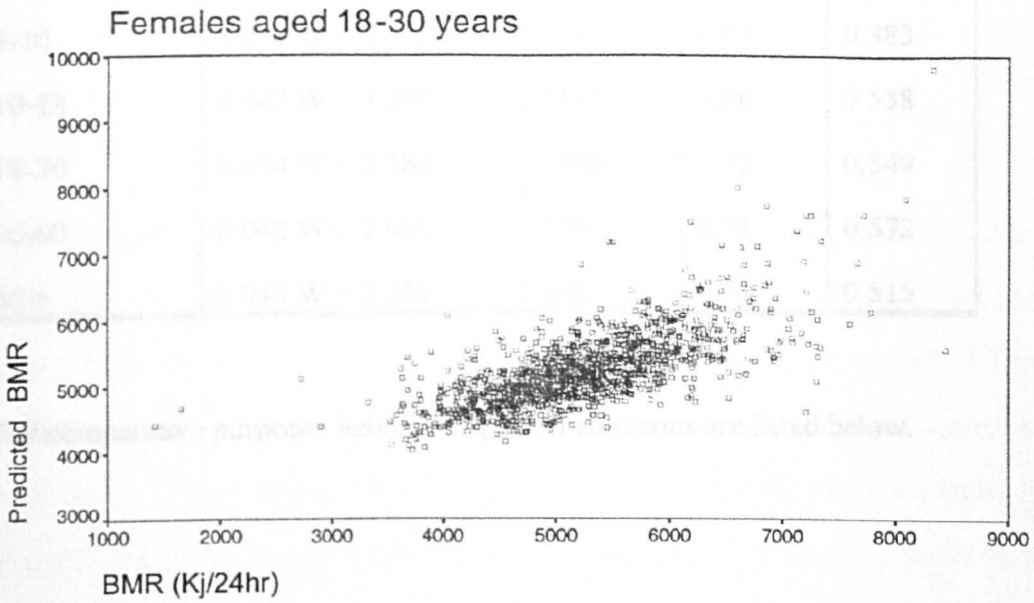


Figure 3.3

Actual BMR compared to predicted BMR

The Oxford Brookes linear equations created to predict BMR from weight are presented in Table 3.5.

Table 3.5

Equations for predicting basal metabolic rate from body weight (W)

Age Range (years)	MJ/24 h	n	r	SD
Males				
0-3	0.240 W - 0.056	326	0.97	0.272
3-10	0.091 W + 2.156	468	0.82	0.347
10-18	0.069 W + 2.746	975	0.81	0.615
18-30	0.067 W + 2.341	3019	0.72	0.659
30-60	0.054 W + 2.831	766	0.60	0.772
60 +	0.055 W + 2.138	272	0.81	0.571
Females				
0-3	0.227 W + 0.01298	258	0.96	0.271
3-10	0.078 W + 2.236	433	0.83	0.383
10-18	0.047 W + 3.205	1111	0.68	0.558
18-30	0.054 W + 2.380	1405	0.71	0.549
30-60	0.042 W + 2.900	779	0.71	0.572
60 +	0.043 W + 2.355	192	0.76	0.515

For comparative purposes Schofield's (1985) equations are listed below.

Table 3.6

Schofield's equations for predicting basal metabolic rate from body weight (W)

Age Range (years)	MJ/24 h	n	r	SD
Males				
0-3	0.249 W - 0.127	162	0.95	0.2925
3-10	0.095 W + 2.110	338	0.83	0.2803
10-18	0.074 W + 2.754	734	0.93	0.4404
18-30	0.063 W + 2.896	2879	0.65	0.6407
30-60	0.048 W + 3.653	646	0.60	0.6997
60 +	0.049 W + 2.459	50	0.71	0.6865
Females				
0-3	0.244 W - 0.130	137	0.96	0.2456
3-10	0.085 W + 2.033	413	0.81	0.2924
10-18	0.056 W + 2.898	575	0.80	0.4661
18-30	0.062 W + 2.036	829	0.73	0.4967
30-60	0.034 W + 3.538	372	0.68	0.4653
60 +	0.038 W + 2.755	38	0.68	0.4511

The '*r*' values or correlation coefficients as they are known are presented for each equation. These describe how accurately the linear equation calculated fits the raw data. If we look at the male equations first, we can see that the Oxford Brookes equation for males aged 0-3 has a slightly better fit than the Schofield equation (r = 0.97 vs. r = 0.95). For males 3-10 years and 10-18 years the relevant r values show that the Schofield equations have higher r values and hence depict a better fit to the data. Males aged 18-30 years in the Oxford Brookes equation have an r value of 0.72, compared to 0.65 with the Schofield equation. For males aged 30-60 the Oxford Brookes and Schofield equations have an identical r value of 0.6. However,

males aged 60 years and over the Oxford Brookes equations depict a better line of best fit with an *r* value of 0.81 compared to 0.71. Correlation coefficients for the female equations are identical between the two data bases for females aged 0-3 years. However, for 3-10 year olds the Oxford Brookes equation has a higher *r* value than the Schofield equation (0.83 compared to 0.81). For the 10-18 year old females the Schofield equation appears to show a more accurate fit of the data having an *r* value of 0.8 compared to 0.68 with the Oxford Brookes equation. However, the Oxford Brookes equation was developed from nearly twice as many individual data points, which inevitably introduces more scatter. For the 18-30 age group the Oxford Brookes data has an *r* value of 0.71 compared to 0.73, again substantially more data was incorporated. The Schofield equations for both the 30-60 and the 60 and over age groups was 0.68. However, the Oxford Brookes equations had *r* values of 0.71 and 0.76 for 30-60 and 60+ years respectively despite containing more data.

Comparison between Oxford Brookes and Schofield's equations

The equations produced using the Oxford Brookes and the Schofield databases were compared.

The tables and graphs below shows the different BMR results using both equations The weights used in order to predict BMR are taken from Frisancho (1990) and are appropriate for the relevant age and sex group.

Tables and Graphs to compare the Oxford Brookes and Schofield equations

Males aged 0-3 years

BMR = 0.240 W - 0.056

Table 3.7a
Comparison of the Oxford Brookes and Schofield equations to predict BMR

Weight (kg)	Schofield (MJ/24 h)	Oxford Brookes (MJ/24 h)	Difference (MJ/24 h)
9.5	2.24	2.22	0.02
10.7	2.54	2.51	0.03
11.6	2.76	2.73	0.03
13.6	3.26	3.21	0.05
15.5	3.73	3.66	0.07
16.8	4.06	3.98	0.08
18.9	4.58	4.48	0.1

Key to all graphs
The Oxford Brookes equation is depicted by a bold plain line _____
The Schofield equations are depicted by a dashed line ----------

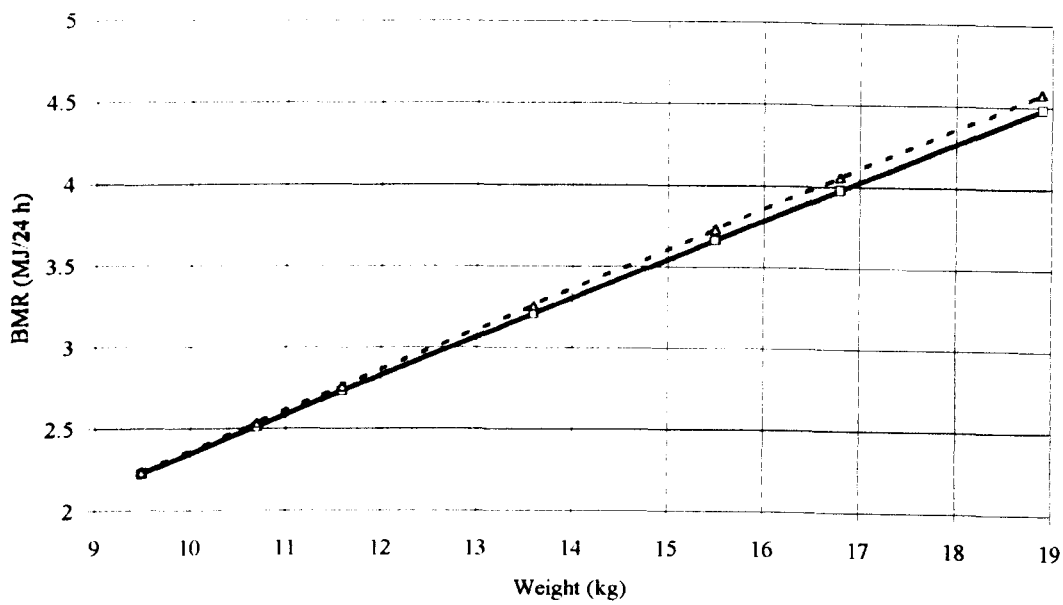


Figure 3.4a
The Oxford Brookes and Schofield equation for males 0-3

Using average weights appropriate for males aged 0-3 years (taken from Frisancho, 1990) the Oxford Brookes equation was found to predict a lower BMR that calculated using the Schofield equation. This difference became greater with increasing weight, particularly at weights over 18 kg.

Females aged 0-3 years

BMR = 0.227 W + 0.01298

Table 3.7 b
Comparison of the Oxford Brookes and Schofield equations to predict BMR

Weight (kg)	Schofield (MJ/24 h)	Oxford Brookes (MJ/24 h)	Difference (MJ/24 h)
8.8	2.02	1.87	0.15
9.9	2.29	2.12	0.17
10.8	2.51	2.32	0.19
12.8	2.99	2.78	0.21
14.9	3.51	3.25	0.26
16.2	3.82	3.55	0.27
18.5	4.38	4.07	0.31

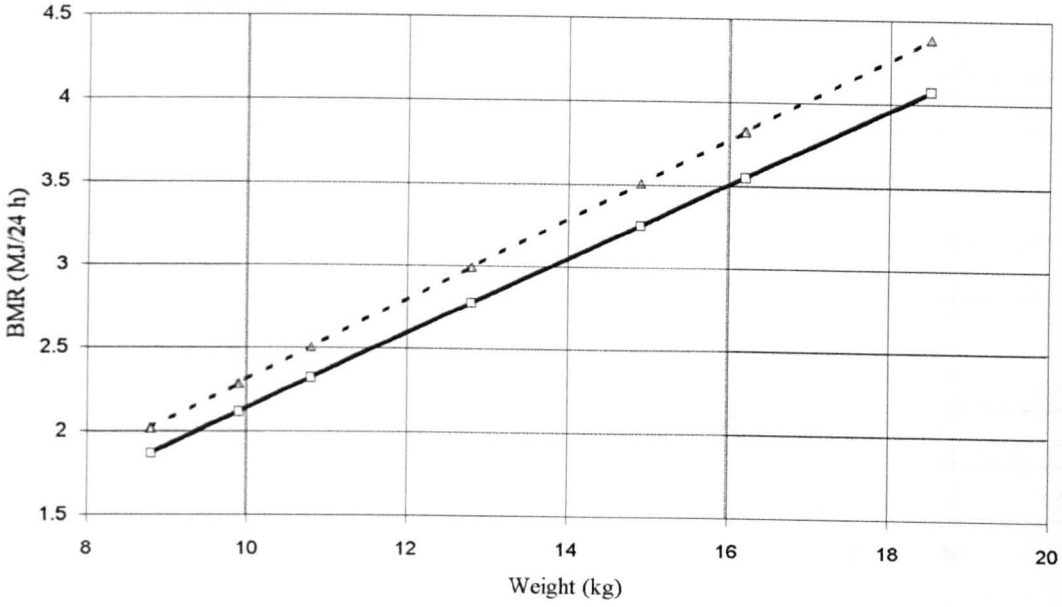


Figure 3.4 b
The Oxford Brookes and Schofield equation for females 0-3

A difference was seen between the two equations at all body weights for females aged 0-3 years, this difference appeared toincrease with increasing weight. Already a gender difference is evident, females having lower BMRs than males of the same age.

Males aged 3-10 years

BMR = 0.091 W + 2.156

Table 3.7 c
Comparison of the Oxford Brookes and Schofield equations to predict BMR

Weight (kg)	Schofield (MJ/24 H)	Oxford Brookes (MJ/24 h)	Percentage Difference (Oxford/Schofield)
12.9	3.34	3.33	0.01
14.4	3.48	3.47	0.01
15.5	3.58	3.57	0.01
19.5	3.96	3.93	0.03
33.9	5.33	5.24	0.09
38.4	5.76	5.65	0.11
52.3	7.08	6.92	0.16

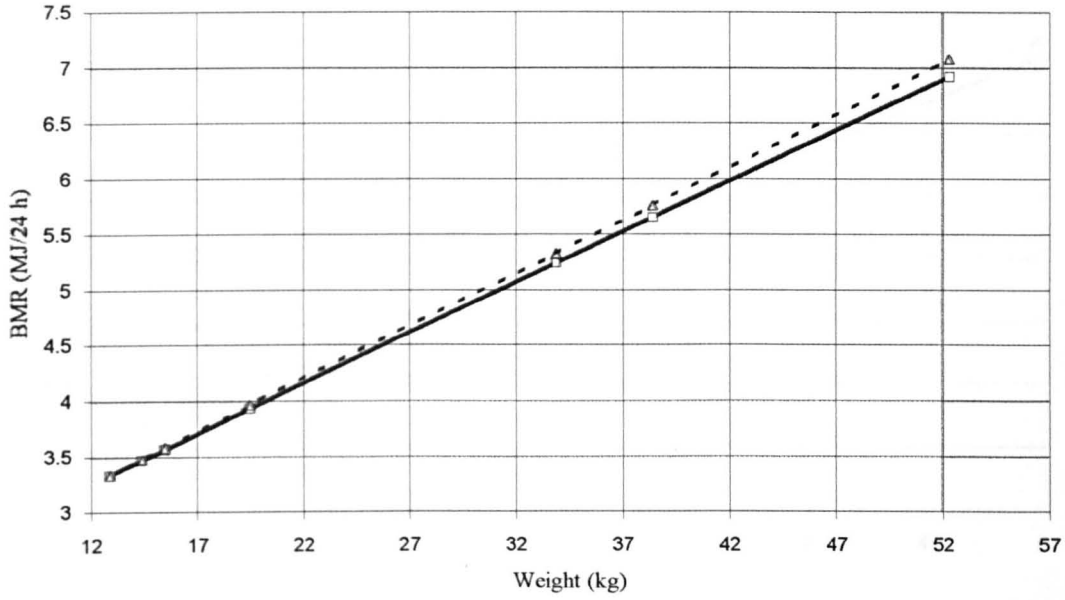


Figure 3.4 c
The Oxford Brookes and Schofield equation for males 3-10

A slight difference was seen between the two equations, as with previous equations this difference became more pronounced with increasing weight.

Females aged 3-10 years

BMR = 0.078 W + 2.236

Table 3.7 d
Comparison of the Oxford Brookes and Schofield equations to predict BMR

Weight (kg)	Schofield (MJ/24 h)	Oxford Brookes (MJ/24 h)	Difference (MJ/24 h)
11.8	3.04	3.16	-0.12
13.7	3.20	3.30	-0.1
14.9	3.30	3.40	-0.1
18.9	3.64	3.71	-0.07
33.6	4.89	4.86	0.03
38.9	5.34	5.27	0.07
49.7	6.26	6.11	0.15

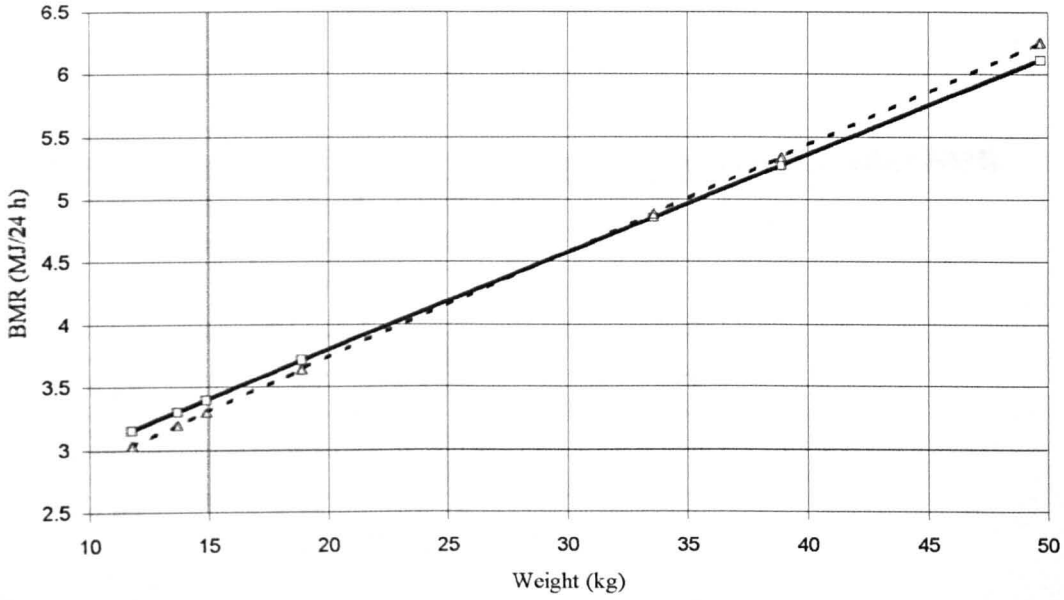


Figure 3.4 d
The Oxford Brookes and Schofield equation for females 3-10

No real difference was seen between the two equations, however, whilst for subjects below 30 kg weight the Oxford Brookes equations estimated BMR to be greater than that calculated using the Schofield equations, at weights greater than 30 kg the opposite was found to be true. In this age group gender differences do not appear evident at any given weight.

Males aged 10-18 years

BMR = 0.069 W + 2.746

Table 3.7 e
Comparison of the Oxford Brookes and Schofield equations to predict BMR

Weight (kg)	Schofield (MJ/24 h)	Oxford Brookes (MJ/24 h)	Difference (MJ/24 h)
26.8	4.74	4.60	0.14
30.4	5.00	4.84	0.16
33.9	5.26	5.09	0.17
56.1	6.91	6.62	0.29
71.9	8.07	7.71	0.36
81	8.75	8.34	0.41
99.9	10.15	9.64	-0.51

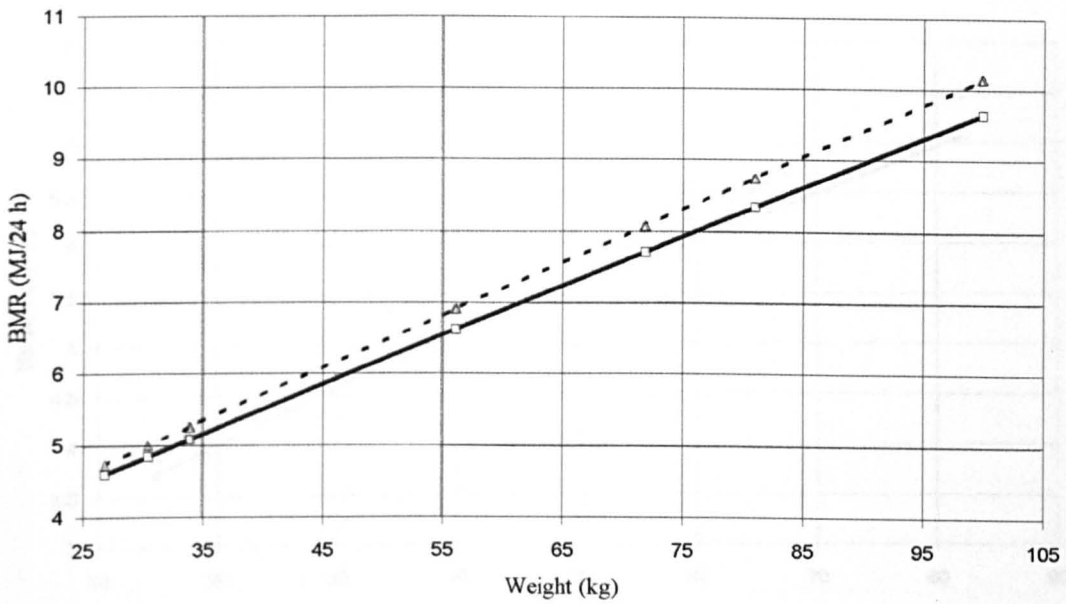


Figure 3.4 e
The Oxford Brookes and Schofield equation for males 10-18

A difference was seen between the two equations, again this difference became more pronounced with increasing weight, the Oxford Brookes equations predicting lower BMRs.

Females aged 10-18 years

BMR = 0.047 W +3.205

Table 3.7 f
Comparison of the Oxford Brookes and Schofield equations to predict BMR

Weight (kg)	Schofield (MJ/24 h)	Oxford Brookes (MJ/24 h)	Difference (MJ/24 h)
14.9	3.73	3.91	-0.18
18.9	3.96	4.09	-0.13
25.6	4.33	4.41	-0.08
27	4.41	4.47	-0.06
33.6	4.78	4.78	0
65	6.54	6.26	0.28
82.4	7.51	7.08	0.43

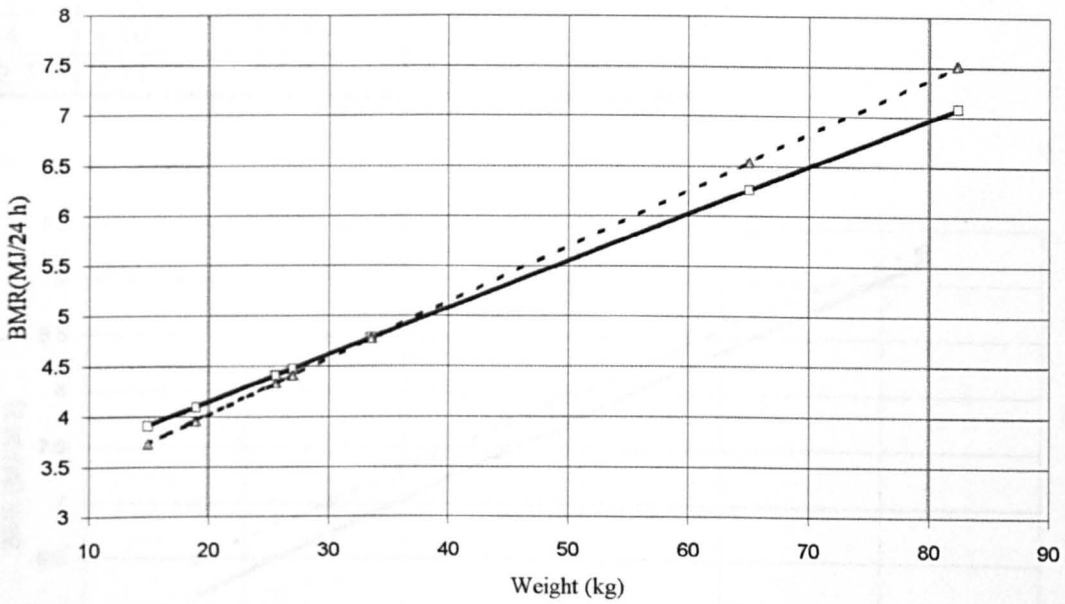


Figure 3.4 f
The Oxford Brookes and Schofield equation for females 10-18

It was seen that at very low body weight (below 32 kg) the Oxford Brookes equations predicted higher BMR than the Schofield equation. However, at weights greater than 32 kg the Oxford Brookes predicted a lower BMR and this became comparatively lower than the Schofield equation as body weight increased. Gender differences from

this age onwards are very pronounced. Males having higher BMRs than females at all body weights.

Males aged 18-30 years

BMR = 0.067 W + 2.341

Table 3.7 g
Comparison of the Oxford Brookes and Schofield equations to predict BMR

Weight (kg)	Schofield (MJ/24 h)	Oxford Brookes (MJ/24 h)	Difference (MJ/24 h)
56.8	6.47	6.15	0.32
65.3	7.01	6.72	0.29
71.9	7.43	7.16	0.27
76.7	7.73	7.48	0.25
79.1	7.88	7.64	0.24
87.4	8.40	8.20	0.2
102.7	9.37	9.22	0.15

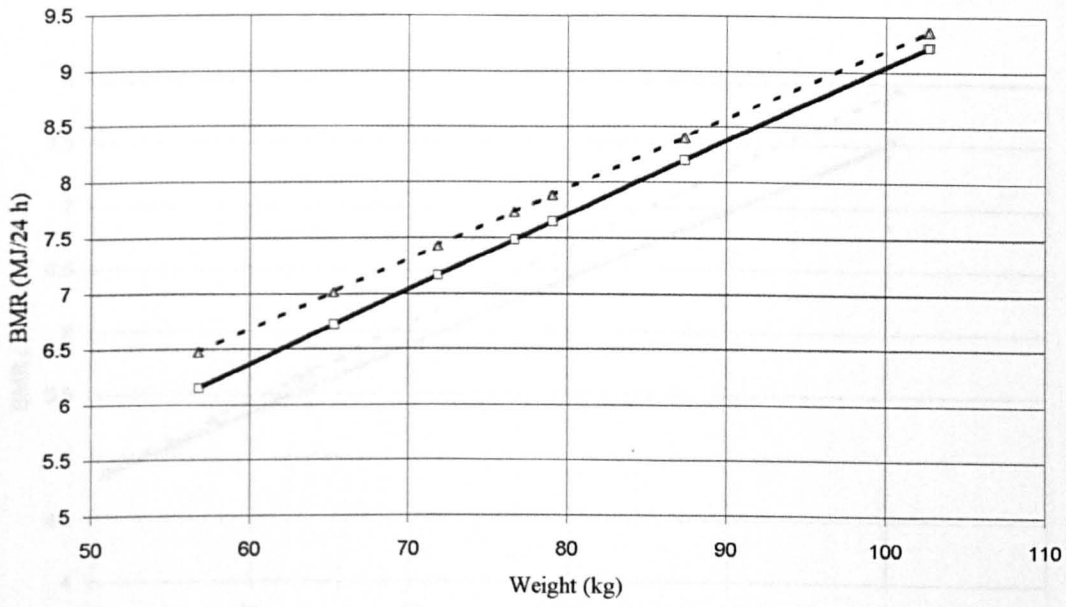


Figure 3.4 h
The Oxford Brookes and Schofield equation for males 18-30

A difference was seen between the two equations. At lower weights the Oxford Brookes equations predicted BMR lower than by use of the Schofield equations. However as weight increased the difference between the two equations became less.

Females aged 18-30 years

BMR = 0.054 W + 2.380

Table 3.7 h
Comparison of the Oxford Brookes and Schofield equations to predict BMR

Weight (kg)	Schofield (MJ/24 h)	Oxford Brookes (MJ/24 h)	Difference (MJ/24 h)
45.9	4.88	4.86	0.02
52.6	5.30	5.22	0.08
57.9	5.63	5.51	0.12
58.7	5.68	5.55	0.13
60.7	5.80	5.66	0.14
70.1	6.38	6.17	0.21
95.6	7.96	7.54	0.42

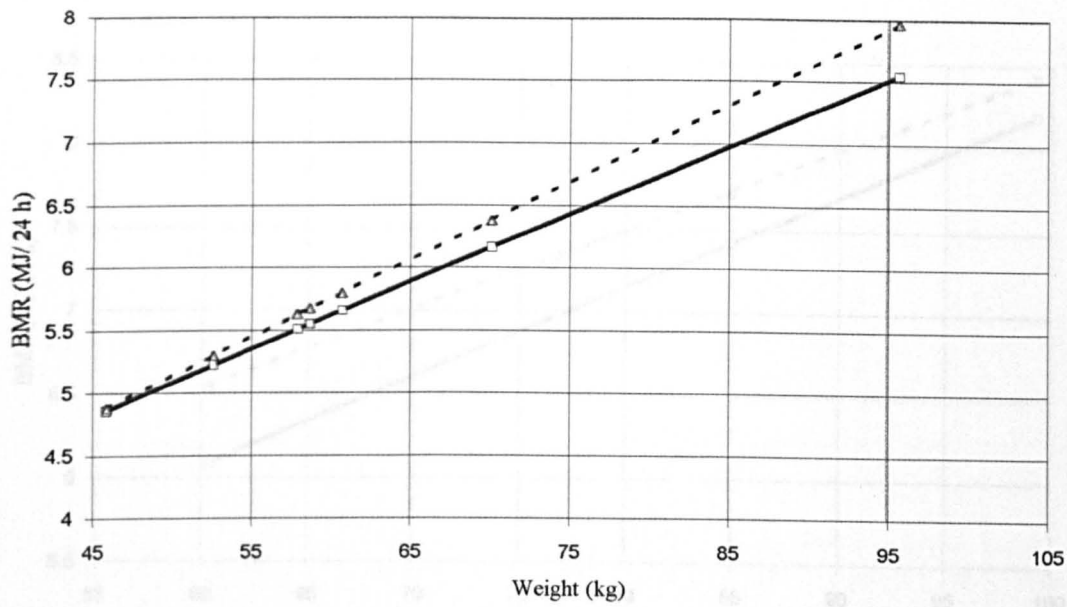


Figure 3.4 h
The Oxford Brookes and Schofield equation for females 18-30

The Oxford Brookes equation was clearly seen to predict BMR lower than the Schofield equation. The difference between the two equations was found to increase with increasing weight. Gender differences at this age are very pronounced.

Males 30-60 years

BMR = 0.054 W +2.831

Table 3.7 I
Comparison of the Oxford Brookes and Schofield equations to predict BMR

Weight (kg)	Schofield (MJ/24 h)	Oxford Brookes (MJ/24 h)	Difference (MJ/24 h)
60.4	6.55	6.09	0.46
70.4	7.03	6.63	0.4
79.1	7.45	7.10	0.35
79.8	7.48	7.14	0.34
76.8	7.34	6.98	0.36
84.9	7.73	7.42	0.31
99.3	8.42	8.19	0.23

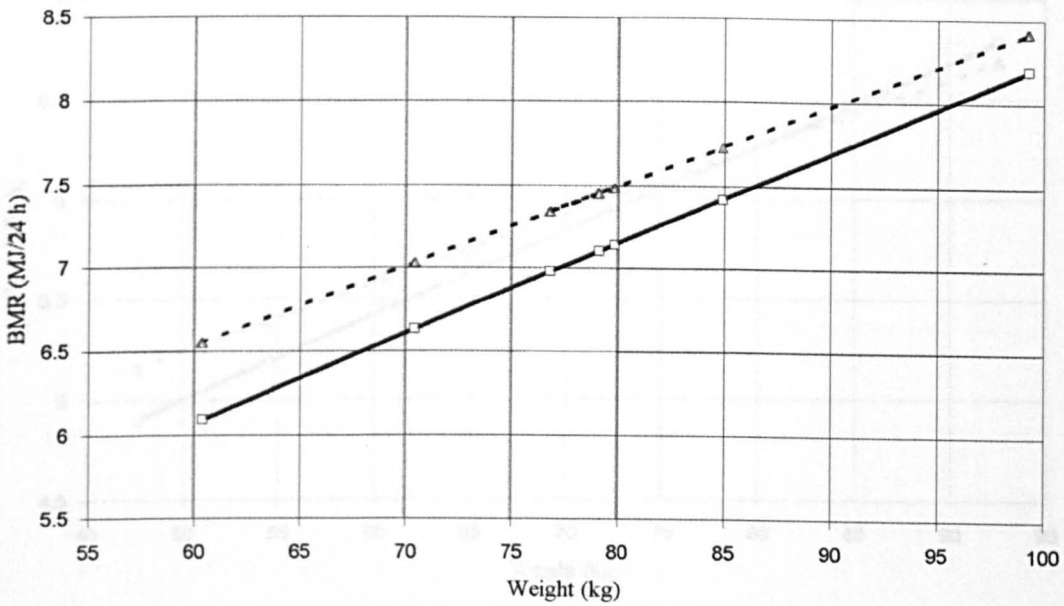


Figure 3.4 i
The Oxford Brookes and Schofield equation for males 30-60

Again, a difference was seen between the two equations, however this time the difference between the two equations became less with increasing body weight.

Female 30-60 years

BMR = 0.042 W + 2.900

Table 3.7 j
Comparison of the Oxford Brookes and Schofield equations to predict BMR

Weight (kg)	Schofield (MJ/24 h)	Oxford Brookes (MJ/24 h)	Difference (MJ/24 h)
47.6	5.16	4.90	0.26
54.5	5.39	5.19	0.2
60.7	5.60	5.45	0.15
64.3	5.72	5.60	0.12
65.2	5.75	5.64	0.11
75	6.09	6.05	0.04
92.6	6.69	6.79	-0.1

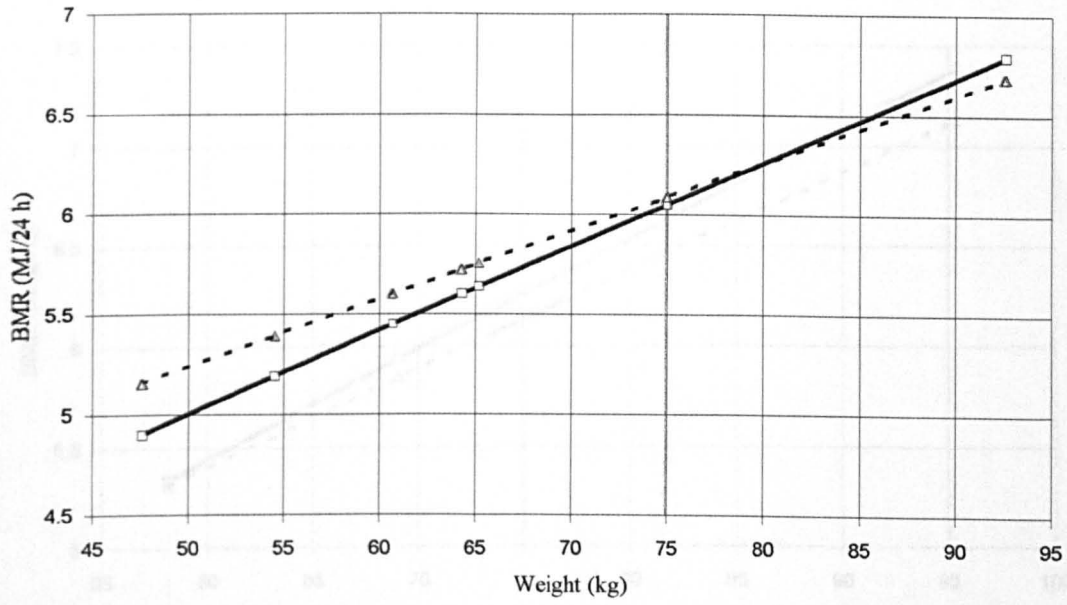


Figure 3.4 j
The Oxford Brookes and Schofield equation for females 30-60

The graphs show the two equations to differ. Below 80 kg of weight the Oxford Brookes equation predicted a lower BMR, but at weights greater than 80 kg the Oxford Brookes equation predicted BMR to be higher than that calculated using the Schofield equation.

Male 60 years and over

BMR 0.055 W + 2.138

Table 3.7 k
Comparison of the Oxford Brookes and Schofield equations to predict BMR

Weight (kg)	Schofield (MJ/24 h)	Oxford Brookes (MJ/24 h)	Difference (MJ/24 h)
58.2	5.31	5.34	-0.03
69.1	5.85	5.94	-0.09
76.8	6.22	6.36	-0.14
75.3	6.15	6.28	-0.13
73.5	6.06	6.18	-0.12
81.4	6.45	6.62	-0.17
95.4	7.13	7.39	-0.26

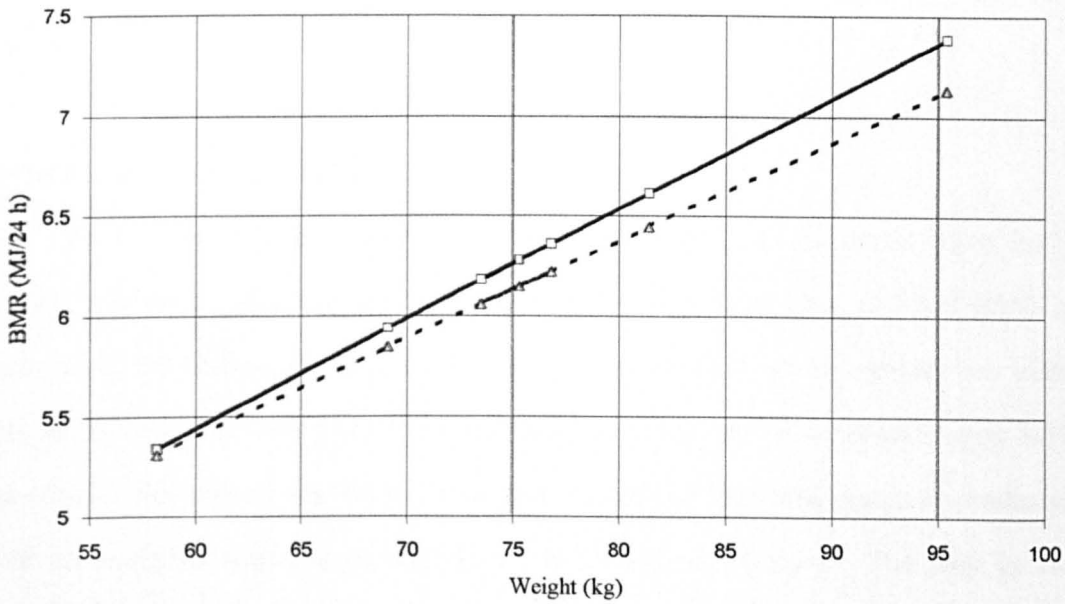


Figure 3.4 k
The Oxford Brookes and Schofield equation for males 60 +

A clear difference was found between the two equations, the Oxford Brookes equations predicting significantly greater BMRs. Whilst this difference is minimal at lower body weights, as weight increases the Oxford Brookes equations deviates further away from the Schofield equation.

Female 60 years and over

BMR = 0.043 W + 2.355

Table 3.7 l
Comparison of the Oxford Brookes and Schofield equations to predict BMR

Weight (kg)	Schofield (MJ/24 h)	Oxford Brookes (MJ/24 h)	Difference (MJ/24 h)
48.3	4.59	4.43	0.16
57.9	4.96	4.84	0.12
65.2	5.23	5.16	0.07
65	5.23	5.15	0.08
64.1	5.19	5.11	0.08
73.9	5.56	5.53	0.03
87.4	6.08	6.11	-0.03

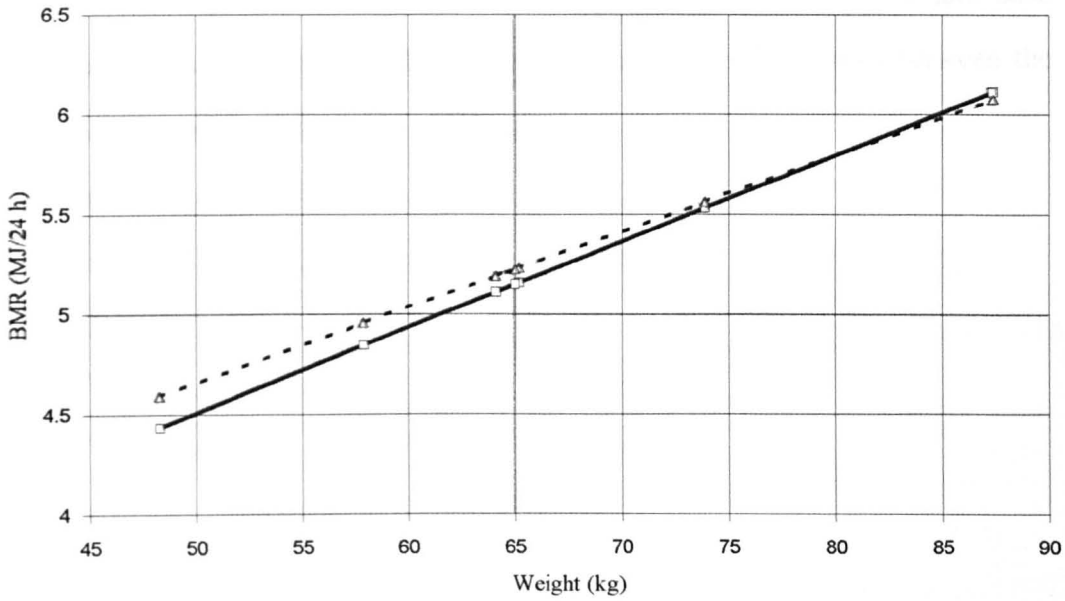


Figure 3.4 l
The Oxford Brookes and Schofield equation for females 60 +

A difference was seen between the two equations for females age over 60 years. Whilst the Oxford Brookes equations predicted BMR to be lower than BMR predicted using the Schofield equation at lower weights. However, at 80 kg of body weight the equations converge and at weights over 80 kg the Oxford Brookes equation predicts BMR to be higher than the that calculated using the Schofield equation.

Summary of equations using weight

When the Oxford Brookes and the Schofield equations are compared using body weights for the appropriate age and sex group in most cases the predicted BMR is lower using the Oxford Brookes equations. However, there are exceptions, no clear differences were found between the equations that predict BMR in females aged 3-10 and 10-18. For males over 60 years of age the Oxford Brookes equation predicted BMR to be higher than that predicted with the Schofield equation. The male group aged over 60 years of age is one group where there was a considerable increase in the data available from which the new equations were created. Whilst Schofield only had

data from 50 male subjects over 60 years of age, the Oxford Brookes data base included data from 272 subjects. Table 3.8 summarises the differences between the Oxford Brookes and the Schofield (1985) equations.

Table 3.8

Summary of differences between the Oxford and Schofield (1985) equations

Sex and Age Band (male/female, years)	Oxford Equation (MJ/24 h)	Schofield (1985) Equation (MJ/24 h)	Difference*
Males, 0 - 3	0.240W-0.056	0.249W-0.127	Diverge with increasing weight
Females, 0 - 3	0.227W+0.01298	0.244W-0.130	Yes
Males, 3 - 10	0.0910W+2.156	0.095W+2.110	Similar
Females, 3 - 10	0.078 W+2.236	0.085W+2.033	Very similar
Males, 10 - 18	0.067W+2.341	0.063W+2.896	Yes, with increasing weight
Females, 10 - 18	0.047W+3.205	0.056W+2.898	No, cross at 35 kg
Males, 18 - 30	0.067W+2.341	0.063W+2.896	Yes, for all weights
Females, 18 - 30	0.054W+2.380	0.062W+2.036	Yes, especially with increasing weight
Males, 30 - 60	0.054W+2.831	0.048W+3.653	Yes
Females, 30 - 60	0.042W+2.900	0.034W+3.538	At lower weights, but cross at 75 kg
Males, 60 +	0.055W+2.138	0.049W+2.459	Yes with increasing weight
Females, 60+	0.043W+2.355	0.038W+2.755	Cross at 80 kg

* as compared visually

3.1.2 Equations using height and weight

Equations using the Oxford Brookes database were also computed with the assistance of Simonite (1997) using both weight and height as independent variables with which to predict BMR. The equations created using height and weight are presented in Table 3.9. In theory equations that use both weight and height should predict BMR more accurately since the equations are tailored to fit a particular individual's physical characteristics more accurately. Observed BMRs are compared with BMR calculated using the Brookes equations that use weight alone and the Brookes equations that use weight and height in Table 3.11.

Table 3.9

Equations for predicting basal metabolic rate from body weight (W) in kilograms and height (H) in metres.

Age Range (years)	MJ/24h	n	r	SE
Males				
0-3	0.103 W + 3.530 H - 1.424	326	0.97	0.263
3-10	0.870 W + 0.200 H + 2.003	468	0.82	0.347
10-18	0.069 W + 0.783 H + 1.871	975	0.81	0.613
18-30	0.062 W + 0.957 H + 1.009	3019	0.73	0.654
30-60	0.044 W + 1.942 H - 0.233	766	0.61	0.763
60 +	0.046 W + 2.005 H - 0.616	272	0.77	0.514
Females				
0-3	0.101 W + 3.097 H - 1.141	258	0.97	0.256
3-10	0.660 W + 0.731 H + 1.620	433	0.83	0.379
10-18	0.042 W + 0.813 H + 2.192	1111	0.68	0.556
18-30	0.045 W + 2.290 H - 0.705	1405	0.73	0.533
30-60	0.036 W + 1.778 H + 0.429	779	0.73	0.560
60 +	0.360 W + 1.382 H + 0.599	192	0.77	0.514

For comparative purposes Schofield equations for height (m) and weight (kg) are also presented.

Table 3.10

Schofield's equations for predicting basal metabolic rate from body weight (W) and height (H)

Age Range (years)	MJ/24h	n	r	SE
Males				
0-3	0.0007 W + 6.349 H - 2.584	162	0.97	0.2425
3-10	0.082 W + 0.545 H + 1.736	338	0.83	0.2795
10-18	0.068 W + 0.574 H + 2.157	734	0.93	0.4394
18-30	0.063 W - 0.042 H + 2.953	2879	0.65	0.6408
30-60	0.048 W - 0.011 H + 3.670	646	0.60	0.7002
60 +	0.038 W + 4.068 H - 3.491	50	0.74	0.6600
Females				
0-3	0.068 W + 4.281 H - 1.730	137	0.97	0.2160
3-10	0.071 W + 0.677 H + 1.553	413	0.81	0.2904
10-18	0.035 W + 1.948 H + 0.837	575	0.82	0.4525
18-30	0.057 W + 1.184 H + 0.411	829	0.73	0.4925
30-60	0.034 W + 0.006 H + 3.530	372	0.68	0.4660
60 +	0.033 W + 1.917 H + 0.074	38	0.73	0.4289

The comparison between the Oxford Brookes equations using weight alone and weight and height presented below were compared with data measured in females aged between 18-30 years (own observations) and data measured from the same laboratory in children aged 10-14 years (Dyer, 1997).

Table 3.11

Comparison of the Oxford Brookes equations using weight alone and weight and height

Sex	Female	Female	Male
Age (years)	18-30	10-18	10-18
n	85	198	298
Observed BMR (kJ/24h)	5451	5447	5683
SD	826	747	797
BMR predicted using weight (kJ/24h)	5690	5255	5509
SD	493	493	634
BMR predicted using weight and height (kJ/24h)	5844	5232	5784
SD	507	481	677
% difference (BMR predicted from weight / observed BMR)	104.38	96.48	96.948
% difference (BMR predicted from weight and height / observed BMR)	107.29	96.049	101.78

The table show that for females aged 18-30 years and females aged 10-18 years, BMR predicted using weight alone approximates observed BMR better than BMR predicted using weight and height. However, for males aged 10-18 years, BMR predicted using weight and height approximates observed BMR better than BMR predicted using weight alone. It does appear that which equation is the most accurate depends on the age and the sex of the subjects being studied. This may reflect changes in body composition and stature during the pubertal phase.

The Schofield equations using both height and weight never really gained popular acceptance. Indeed, Schofield (1985) suggested that the increased accuracy of the BMR prediction is not really compensated for by the increased complexity of the equation. It is suggested here, that similarly to the Schofield equations, the BMR equations that use height and weight are no better at predicting actual BMR than equations that use weight alone. For this reason the equations that use weight alone are preferred because of their simplicity and ease of use.

A proposal to redefine the age bands

The equations presented thus far have followed the format of previous studies in that equations were presented for 6 age bands (0-3, 3-10, 10-18, 18-30, 30-60, 60+). The FAO/WHO/UNU (1985) state the age-bands reflect the physiological characteristics in relation to growth, body composition, physical activity and food intake. Several of the currents age bands are very broad, particularly those that cover infancy (0-3 years), adolescence (10-18 years) and old age (60+ years). These are ages when large changes in body composition are particularly significant. For instance, the age band 0-3 includes the 12 months of rapid growth where an infant increases from 14% body fat to 23% (FAO/WHO/UNU, 1985). The ages 10-18 years covers a time when many metabolic changes are occurring as a direct result of puberty (Topper & Müllier, 1932). The 30-60 years age band for females also encompasses a time of profound changes in metabolism and body composition, notably changes in skeletal composition, associated with the menopause (Klinge, 1997). In the elderly there is a progressive fall in energy expenditure and fat free mass (Pannemans & Westerterp, 1995) which can make substantial differences in between the BMR of a 60 years compared to an 80 year old. In the past subjects over 60 years of age have all been grouped together, largely due to the lack of data preventing further subdivision. Today more information regarding the elderly is available and hence it has been possible to create separate equations for older age groups.

Ten new age groups that are more representative of the biological and physical changes that occur with age have been developed. These new age bands are as follows:

0-2 years

2-5 years

5-10 years

10-15 years

15-20 years

20-40 years

40-60 years

60-70 years

70-85 years

85 years and over

The 0-2 year age band was chosen because this is the period of rapid growth which is reflected in the BMR. During the ages 2-5 years, growth continues but is not as rapid as was between 0-2 years. Between the ages of 5-10 years the first signs of gender differences become apparent. At 5 years of age girls are about 1% fatter than boys and have less bone mineral than boys. By 10 years of age girls are slightly heavier and 6% fatter than boys (Roche *et al.*, 1996). The ages between 10-15 years include the years associated with the pubertal growth spurt when BMR is known to increase (Dyer, 1997). The ages 15-20 years include the later stages of growth before full adulthood is achieved. The years 20-40 may be classified as the adult years prior to menopause. From 40 years onwards changes associated with the menopause are evident in women. This can lead to alterations in the circulating hormones resulting in an altered body fat distribution and even the primary stages of osteoporosis (Roche *et al.*, 1996). The elderly years have been divided into 60-70 years, 70-85 years and 85 years and over. This is because there are substantial differences in the body composition and physical activities performed by subjects between these age groups which influence BMR (Vaughan *et al.*, 1991).

Equations that use these new equations to predict BMR from weight are presented in Table 3.12. This means that there are now 20 equations needed to predict BMR throughout the life span as opposed to the 12 that were previously in existence.

Table 3.12

Equations for predicting basal metabolic rate from body weight (W)

Age Range (years)	MJ/24h	n	r	SE
Males				
0-2	0.273 W - 0.274	251	0.94	0.239
2-5	0.111 W + 1.769	169	0.77	0.271
5-10	0.053 W + 3.312	601	0.44	0.502
10-15	0.082 W + 2.334	691	0.85	0.509
15-20	0.075 W + 2.104	918	0.73	0.675
20-40	0.063 W + 2.521	2815	0.69	0.689
40-60	0.055 W + 2.624	336	0.65	0.702
60-70	0.052 W + 2.313	135	0.79	0.621
70-85	0.058 W + 2.041	115	0.83	0.497
85 +	0.049 W + 2.102	22	0.70	0.453
Females				
0-2	0.266 W - 0.202	183	0.94	0.238
2-5	0.111 W + 1.587	164	0.77	0.268
5-10	0.074 W + 2.351	344	0.79	0.398
10-15	0.055 W + 2.981	757	0.76	0.498
15-20	0.059 W + 2.224	715	0.72	0.519
20-40	0.047 W + 2.685	1464	0.70	0.570
40-60	0.044 W + 2.671	359	0.77	0.541
60-70	0.039 W + 2.619	95	0.66	0.583
70-85	0.042 W + 2.371	89	0.83	0.416
85 +	0.067 W + 0.777	8	0.91	0.429

To see if BMR was more accurately predicted using the proposed new age bands, that are both smaller and more specific, a test was performed. BMR data collected by the present investigator, from females aged between 18-30 years old were used. These subjects who would have formerly been considered as one age band, were compared with BMR predicted using the equation for the old age band and BMR predicted using the equations with the appropriate newly proposed age bands. In the case of the 18-20 year old subjects, the equation devised to predict BMR in subjects aged between 15 and 20 years was used. In the case of the 18-30 year old subjects the equation devised to predict BMR in subjects aged between 20 and 40 years was used. Table 3.13. shows how the new age bands were found to predict BMR more accurately in the female subjects measured.

Table 3.13

A comparison of the equations using the old and new age bands for females aged 18-30 years.

Age (years)	18-20	20-30
Measured BMR (kJ/24h)	5909	5368
SD	1056	757
Predicted BMR using old age bands (kJ/24h)	5725	5684
SD	543	486
Predicted BMR using the relevant new age band (kJ/24 h)	5879*	5560**
SD	594	426

*Using the equation for15 -20 year olds

** Using the equation for 20-40 year olds

From the above table it can be seen that in both the 18-20 year old subjects and the 20-30 year old subjects the new age bands predict BMR closer to actual measured BMR than the equations that were created using the former age bands. This is thought to be largely a result of growth that may still be occurring in the 18-20 year olds. It is therefore considered appropriate to use the equations that incorporate the new age bands as these appear to predict actual BMR more accurately within the subjects studied.

Ethnic Differences

Since it has previously been previously been pointed out by several authors (Minghelli *et al.*, 1990; Shetty *et al.*, 1984; Henry & Rees, 1988 and Valencia *et al.*, 1994) that the Schofield equations overestimated BMR in tropical populations, it was deemed necessary to look for ethnic differences within the Oxford Brookes data set. The table below sets out the general ethnic classification of the subjects.

Table 3.14

Allocation of ethnic group

Ethnic Group	Native Peoples
Caucasian	North Americans, White Australians, Europeans
African	Africans, Caribbeans
South American	Central Americans, South Americans
Asian	Ceylonese, Indian, Indonesian, Malaysian, Filipino, Samoan, Nepalese, Burmese
Oriental	Chinese, Japanese, Korean, Hawaiian

Due to small sample sizes, both Aboriginal and Eskimo subjects were excluded from further analyses.

To compare the ethnic groups separate analyses were carried out for males and females. A linear regression model was used to compare the mean BMR's of subjects of Caucasian origin with subjects of the same weight but of different ethnic groups. The findings are presented in Table 3.15.

Table 3.15

Differences in BMR amongst the ethnic groups

Ethnic Group	Sex	Age	n	Mean difference in BMR vs. Caucasians (kJ/24 h)	SE	P for difference
Oriental	m	18 - 30	418	-11	30	NS
	m	30 - 60	108	-133	94	NS
	f	18 - 30	291	+11	45	NS
	f	30 - 60	62	-168	72	P< 0.05
Africa	m	18 - 30	98	+29	52	NS
	f	18 - 30	44	+231	69	P< 0.001
	f	30 - 60	26	+200	97	P< 0.05
South	m	18 - 30	196	-156	10	p < 0.001
American	m	30 - 60	63	-105	102	NS
Asian	m	18 - 30	909	-183	25	P<0.001
	m	30 - 60	255	-270	83	P< 0.001
	f	18 - 30	320	-342	46	P<0.001
	f	30 - 60	206	-86	56	NS

Data from South American females and African men aged 30-60 have been discarded due to the small sample size making comparisons difficult in these groups.

The mean difference given as a positive number indicates that BMR in the non-Caucasian group is higher than for Caucasian and a negative mean difference indicates that BMR is higher in the Caucasian group when compared to the non-Caucasian groups.

To summarise, Table 3.11 shows that Oriental females aged 30-60 and Asian females aged 18-30 years have statistically lower BMR's than Caucasian females of the same weight. African females have a higher BMR than Caucasian females. Both South

American and Asian males aged 18-30 years have BMR's lower than Caucasian males. There were no significant differences in BMR between in the Caucasians and the Oriental males aged 18-60, Oriental females aged 18-30, African males aged 18-30. South American males aged 30-60 and Asian females aged 30-60.

Separate equations for each ethnic group were not created because not only were there insignificant differences between several of the groups, but there was insufficient data to warrant such a procedure. Besides which an increasing number of equations is not practical.

Summary

The Oxford Brookes data base has been used to create equations that predict BMR from weight alone. The new Oxford Brookes equations were compared with those of Schofield (1985) and in most cases were found to predict BMR to be lower than that calculated using Schofield's equations.

Equations to predict BMR from weight and height were also created. Additionally equations were developed for a new set of age bands, these new age bands reflect the biological and physical changes that occur throughout the life span.

The effect of ethnicity was also investigated. BMR was not consistently found to be different between the groups studied.

It is hoped all the equations produced will be used to accurately predict BMR in populations world-wide.

2.2 BMR in females aged 18-30 years; measured and predicted

This section compares BMR measured in females aged 18-30 year olds with existing equations and the new Oxford Brookes equations for predicting BMR, in order to test the applicability and appropriateness of using equations to predict BMR in this group.

BMR and body composition was measured in 77 females between the ages of 18 and 30 years old. The average age of this groups was 23.08 years (*SD* = 2.95). 46 of the females in this group took no pharmacological contraceptive, 27 took the contraceptive pill, 2 were on the progesterone only pill and 2 received a 3 monthly contraceptive injection. Age, weight, height, BMI, percentage body fat and waist:hip ratio are presented in Table 3.16.

Table 3.16

Subjects characteristics

	Mean	SD
Age (years)	23.08	2.95
Weight (kg)	61.37	9.30
Height (m)	1.65	7.52
BMI (kg/m^2)	22.41	3.18
Fat (%)	28.62	4.75
Waist:Hip ratio	0.75	0.06

BMR was measured using a Datex Deltatrac^{TM} and the results and those computed using various BMR prediction equations are presented in Table 3.17 and Figure 3.5.

Table 3.17

Mean BMR; measured and predicted using equations

Source of BMR	Mean (MJ/24 h)	SD
Observed BMR	5.49	0.846
Oxford Brookes	5.69	0.502
Oxford Brookes with height	5.85	0.447
Schofield (1985)	5.84	0.577
Schofield with height (1985)	5.87	0.534
Kleiber (1947)	6.41	0.717
Henry & Rees (1991)	5.51	0.446
Harris & Benedict (1919)	6.07	0.394

ANOVA $P < 0.00001$

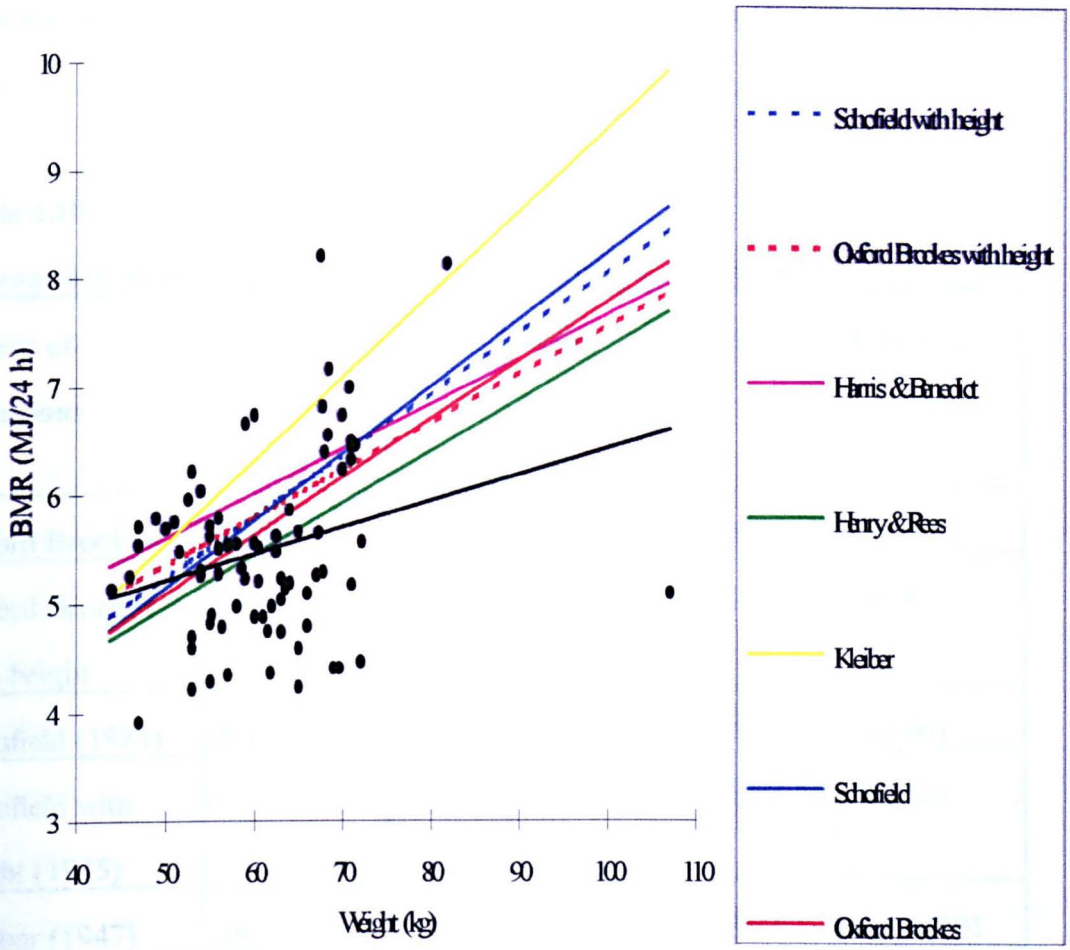


Figure 3.5 Comparison of different equations to predict BMR with actual measured BMR

The ratio's of the predicted to the measured BMR expressed in percentages, and the mean difference between the predicted and measured BMR are presented in Table 3.18.

Table 3.18

Comparison of BMR predicted by equations with measured BMR

Source of Equations	% Mean difference	SD	Mean difference (MJ/24 h)	SD	P values
Oxford Brookes	3.6	0.04	0.204	0.859	< 0.05
Oxford Brookes with height	6.6	0.02	0.356	0.800	<0.001
Schofield (1985)	6.4	0.03	0.344	0.891	< 0.001
Schofield with height (1985)	6.9	0.02	0.378	0.846	< 0.001
Kleiber (1947)	16.8	0.09	0.919	0.947	< 0.00001
Henry & Rees (1991)	0.4	0.38	0.018	0.843	NS
Harris & Benedict (1919)	10.6	0.01	0.577	0.805	< 0.00001

With the exception of the Henry & Rees (1991) equation the prediction equations on average overestimated the measured BMR of the subjects by 8 $\pm$ 3%. When expressed in absolute differences, t-tests between predicted and measured BMRs indicated that the average over-estimation was significantly different in all but the Henry & Rees (1991) equation. Whilst BMR measured with the Deltatrac^{TM} was lower than any of the predictive equations it is acknowledged that the standard deviations were also larger than for any of the predictive equations.

It would appear that the Henry & Rees (1991) equation yielded the most accurate mean BMR, compared with mean BMR by the Deltatrac^{TM}, closely followed by the newly developed Oxford Brookes equation.

Discussion

The results were not totally unexpected. The Harris & Benedict (1919) equations overestimated BMR in female 18-30 year olds by 112.644%. Yet Benedict himself admitted concern that his equations tended to over predict BMR in young women. The Kleiber (1947) allometric equations whilst being suitable to predict BMR in a wide range of species, were not specifically created for use in human females. Whilst it is well know that the Schofield equations over-estimate BMR in tropical populations (Shetty, 1984 and Henry & Rees, 1991) it has also recently been identified that these equations overestimate BMR in Australian Caucasian populations (Piers et al, 1997) and in this case a British Caucasian sample. The Oxford Brookes and Henry & Rees (1991) equations were the most similar to measured BMR, any differences may be accounted for by the large standard deviations of the measured BMRs. Interestingly, the Henry & Rees (1991) equations were designed specifically for use in tropical peoples yet appear to be highly suitable for use in Caucasian populations (Piers *et al.*, 1997).

Specific problems related to BMR equations

One of the problems in creating equations to predict BMR is that there is wide variation between subjects. The coefficient of variation between the individual subjects in this study was found to be 15.41%. Henry *et al.* (1989) found BMR in male subjects to vary 4% within the same subject and 8% between subjects. However, with respect to females Curtis *et al.* (1996) found BMR in females to vary as much as 12% within one individual and consequently even greater between female subjects. BMR is influenced by many factors such as gender, age, body composition, nutritional, hormonal and psychological states and hence it is a highly variable

component of energy expenditure. Because of the variability in BMR, predictive equations to calculate BMR may be seen as an imprecise tool with which to predict energy expenditure. However, whilst it is simple to directly or indirectly measure BMR in individuals, it is impossible to do the same for whole populations. Therefore, equations that accurately predict BMR are invaluable. However, it is essential that the equations used to predict BMR are the best available and have been proved to be suitable and appropriate for the population, gender and age group, within which they are to be used.

Summary

Actual BMR measurements of 77 females aged between 18 and 30 years of age were compared to 7 different equations. Out of all the equations, the Henry & Rees (1991) equations and the newly developed Oxford Brookes equations were found to approximate actual BMR the most accurately.

Chapter summary

- New equations were presented that predict BMR using weight alone and weight with height. Equations were created using age bands in accordance with Schofield (1985) and new age groups which attempt to reflect the biological and physiological changes that occur with age.

- BMR measurements of females aged 18-30 years were reviewed and compared to the new and existing equations. Observed BMR compared favourably with the new Oxford Brookes equations.

Chapter

4

The Development of Normal Curves for BMR

4. The Development of Normal Curves for BMR

4.1 BMR standards

The assessment of anthropometric dimensions has become an indispensable approach for the assessment of nutritional status of clinical and non-clinical populations (Frisancho, 1990). Anthropometric and growth standards allow the assessment of individuals and populations for normality. Individual growth curves differ from populations curves. If an individual falls below the appropriate standard they may be treated, clinically and individually for growth failure. If a population or sub-population falls below a suitable reference then it may be an indication that the population should be treated with better health care, increased public services, better sanitation, better food distribution, more jobs, less discrimination or whatever action is appropriate (Eveleth & Tanner, 1990). Standards are an important tool in the assessment of public health. There are several methods of creating standards. A cross-sectional study is one in which children are measured once only. Typically a large number of subjects are measured at each age and means and variability's are calculated (Eveleth & Tanner, 1990). In growing subjects, such as children, a measurement of this kind (whilst giving a good indication of the life time experiences of the subject and growth up until the time the measurement was made), gives no indication of the subjects current growth status. For this reason velocity standards can be measured or calculated mathematically. Individual growth velocities may be calculated by measuring a subject at two points in time, finding the difference between the two measurements and dividing by the time interval (Falkner & Tanner, 1985). Both types of standards are presented within this chapter. Whilst growth curves using various anthropometric measures have been established (Falkner & Tanner,1985 and Tanner *et al*, 1966), remarkably no investigator has developed normal curves for BMR. This has been part due to the lack of BMR values at various ages and a limited access to BMR values during the entire life cycle. As far as the present investigator is

aware this chapter, for the first time attempts to describe and quantitate normal curves for BMR from birth to 85 years of age.

4.1.1 Normal curves

In order to create normal plots a large amount of data over a wide range of ages is required. The Oxford Brookes data base contains substantial data (n=10,004) to allow standards to be created. Normal plots are useful in that they provide a method of detecting outlying values and allow assessment of a single measurement taken at a single point in time. Whilst numerous growth curves using height and weight data have been created (described in Falkner & Tanner, 1985 and Bogin 1988), no such standards have been set that describe BMR through the life span. Assessment of normal BMR may be useful in assessing a subjects energy requirements and may even highlight reasons for changes in body weight. Normal BMR curves were created from the Oxford Brookes data base. The normal curves were created using the computer package Excel 5 by collating the entire Oxford Brookes data base and ordering the BMR data, first according to weight and then subsequently according to age. Figures 4.1 and 4.2 show the changes in BMR with weight for males and females separately.

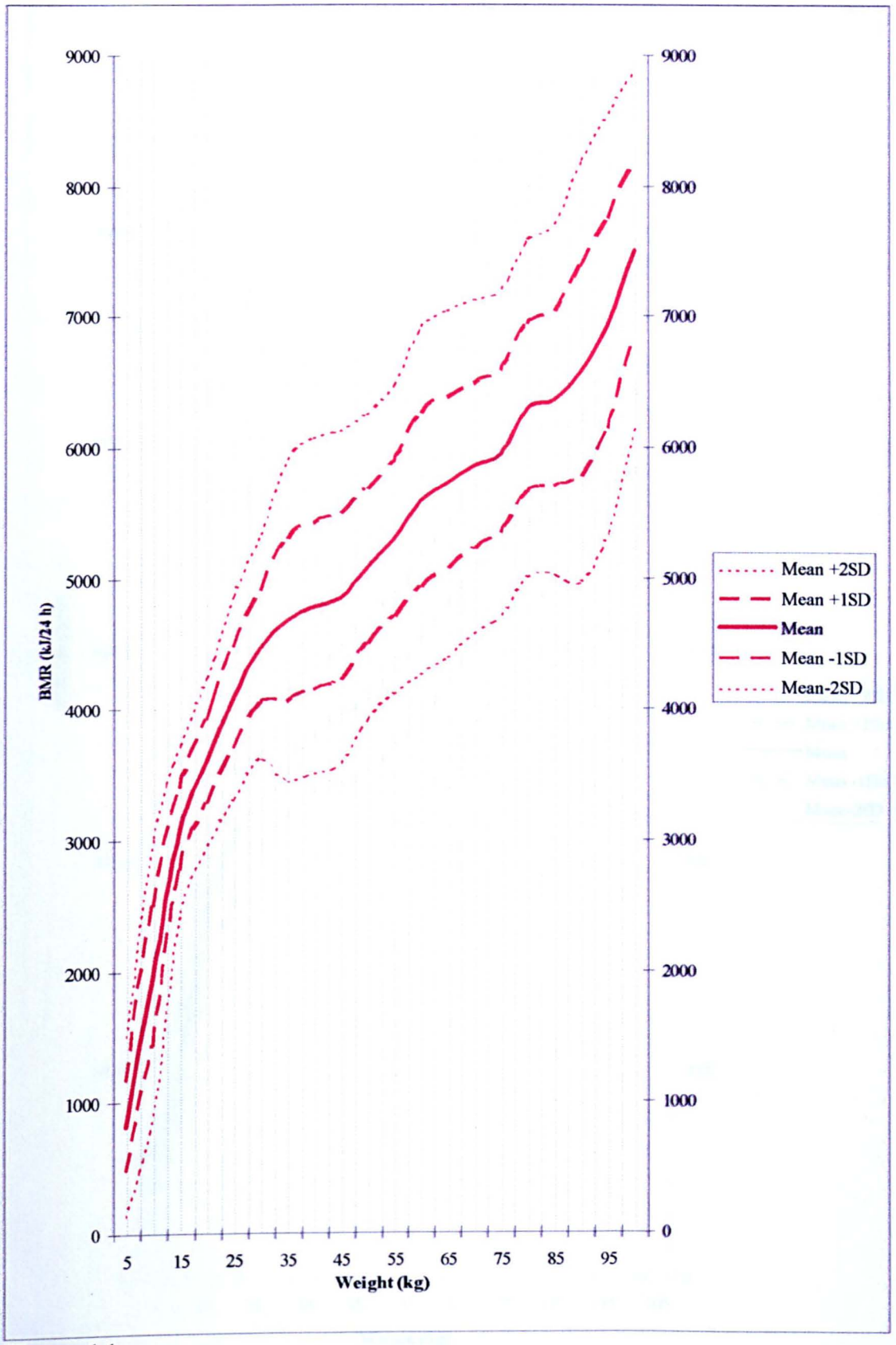


Figure 4.1
Normal BMR curve for females with weight

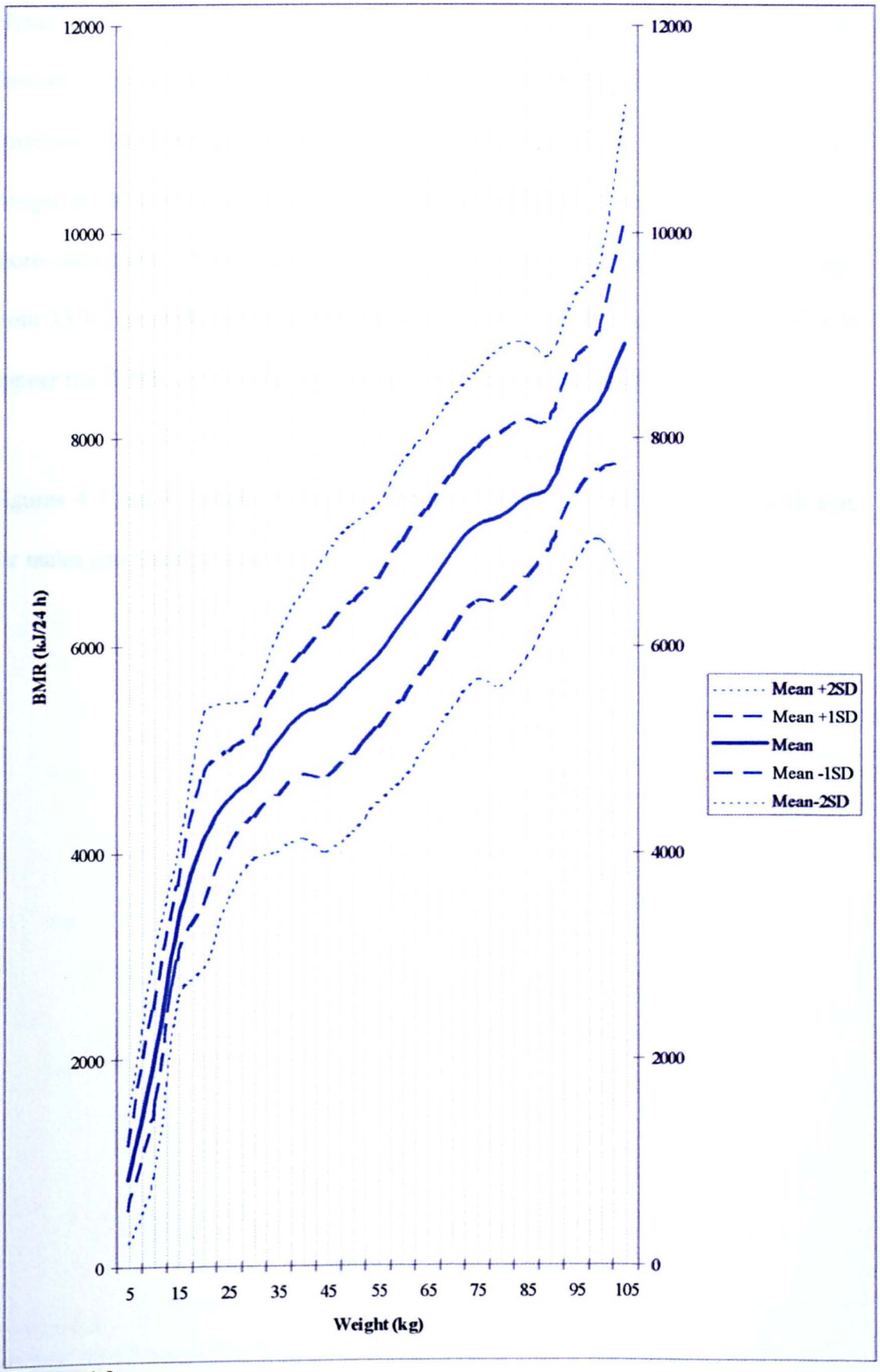


Figure 4.2
Normal BMR curve for males with weight

Figures 4.1 and 4.2 show how BMR increases with weight. BMR in both males and females increases most rapidly and linearly up until 35 kg of body weight. This corresponds with an age of about 10 years old and may be due to puberty From this weight onwards BMR continues to increases but a slightly lower rate and the trend is more curvilinear. The trends are similar for both the males and females, although from 35 kg onwards the female BMR is at a lower rate than male BMR. It would appear that BMR unconditionally increases with increasing weight.

Figures 4.3 and 4.4 depict normal curves which show how BMR changes with age, for males and females separately.

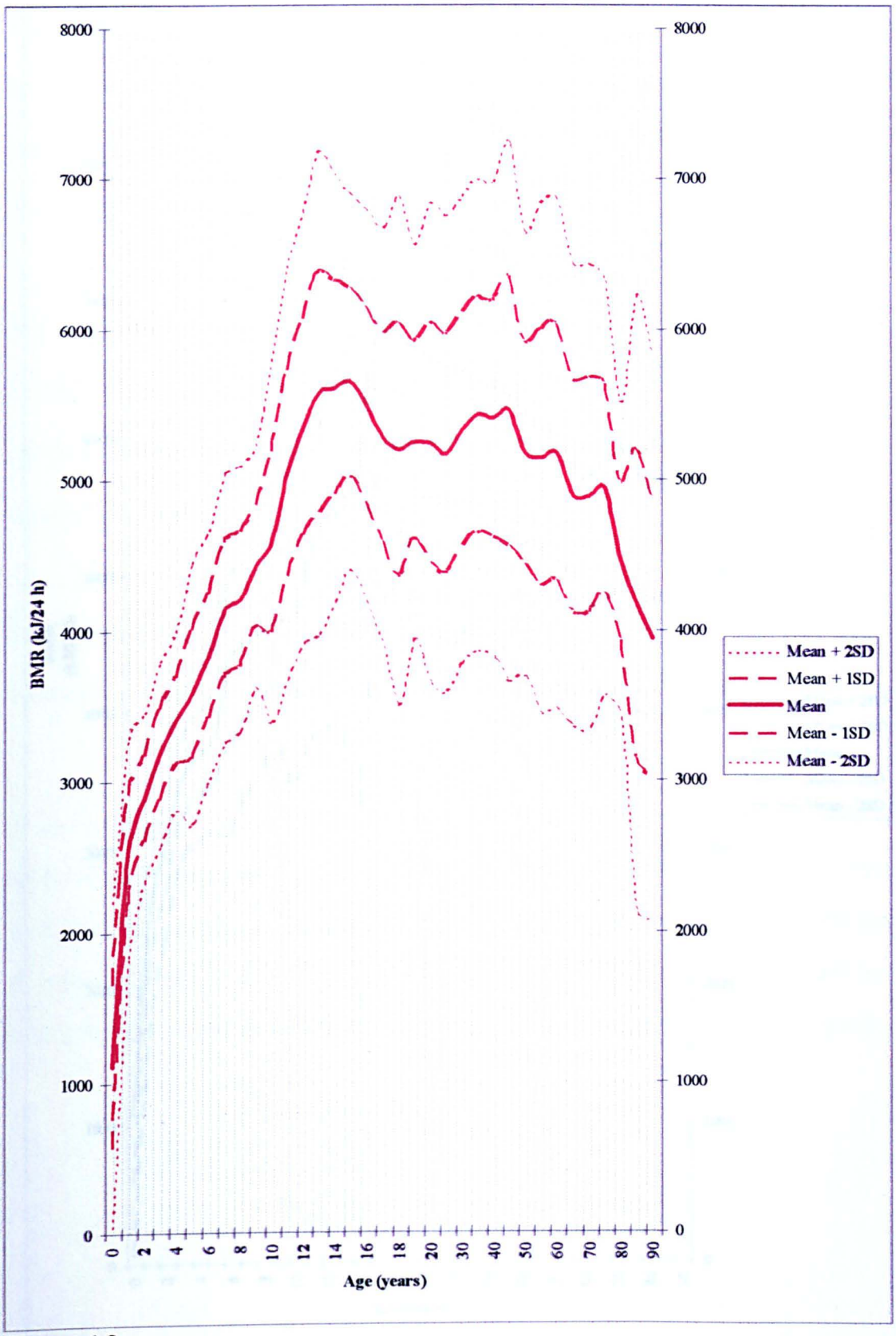


Figure 4.3
Normal BMR curve for females with age

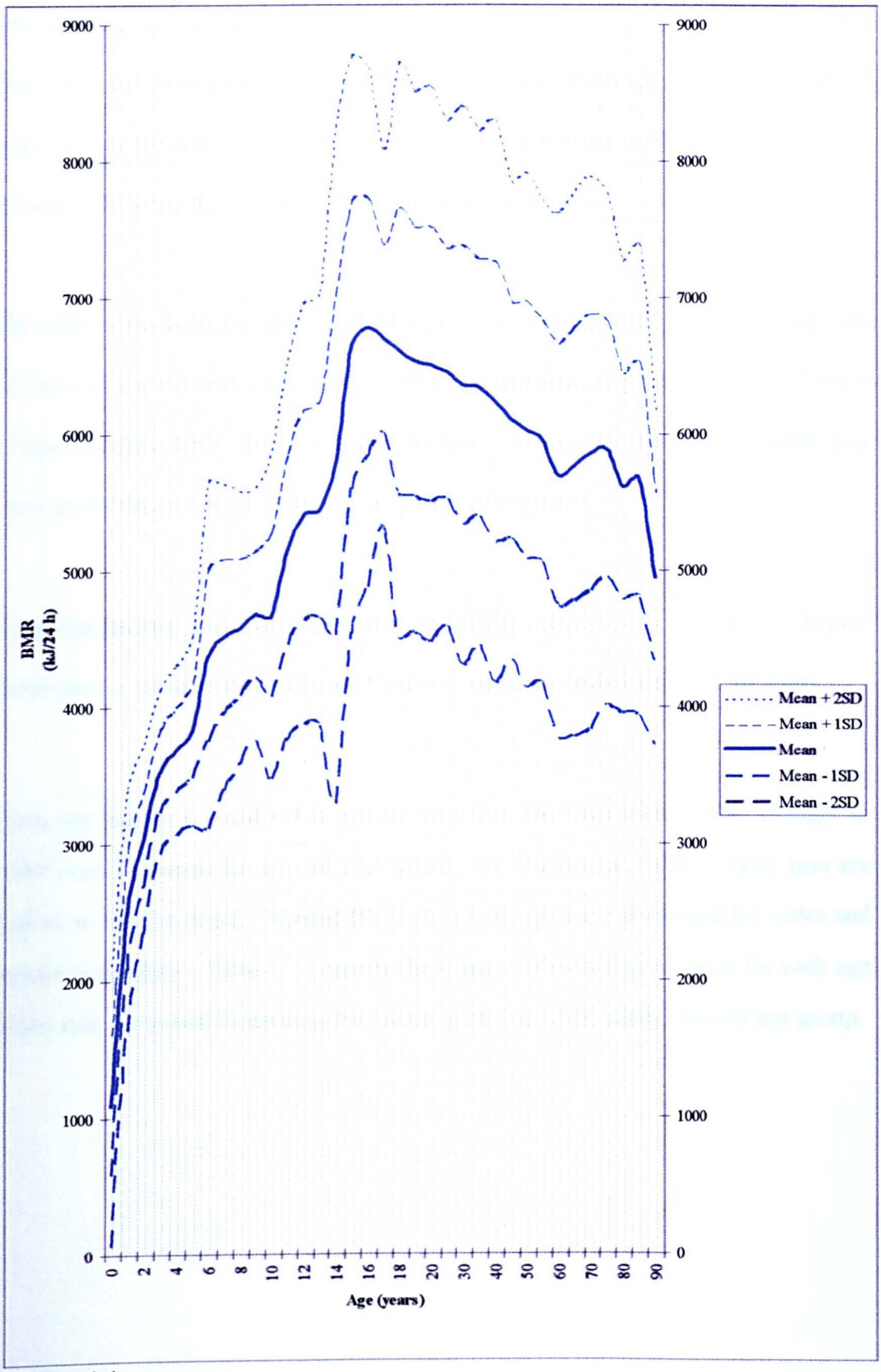


Figure 4.4
Normal BMR curve for males with age

The graphs above depict the changes in BMR with increasing age. With regards to figure 4.3, the females show a rapid increase in total BMR up until the age of 15 years. From the age of 16 years onwards there is a gradual decline in BMR. After the age of 75 years the decline in BMR becomes more rapid.

The males show a similar pattern, BMR rapidly increases up until age of 16 years. At 16 years of age the peak in evidence is probably indicative of puberty. From 17 years of age onwards, BMR shows a steady decline. Similarly to the females, males also show an increased rate of decline after the age of 75 years.

These figures may also enable us in time to identify subjects who are hypo- or hyper-metabolic i.e. those who are above or below 2 standard deviations from the mean.

From the figures 4.3 and 4.4 it can be seen that the most considerable changes in BMR occur between the ages of 0-20 years. For this reason BMR in these ages are looked at in more depth. Normal BMR plots with age were developed for males and females separately. Table 4.1 presents the number of individual subjects for each age group that were used to develop the normal plots for BMR within the said age group.

Table 4.1

Number of subjects used to create normal BMR curves in the 0-20 years age group

Age (years)	Male	Female
0	213	158
1	37	25
2	29	32
3	46	43
4	39	40
5	55	49
6	60	49
7	89	51
8	119	62
9	134	59
10	200	123
11	184	246
12	223	198
13	107	130
14	110	117
15	69	66
16	45	97
17	58	123
18	181	134
19	249	156
20	385	205
Total	**2632**	**2163**

Figure 4.5 depicts the normal curve for males subjects aged between 0-20 years. The mean and $\pm$ SD are plotted.

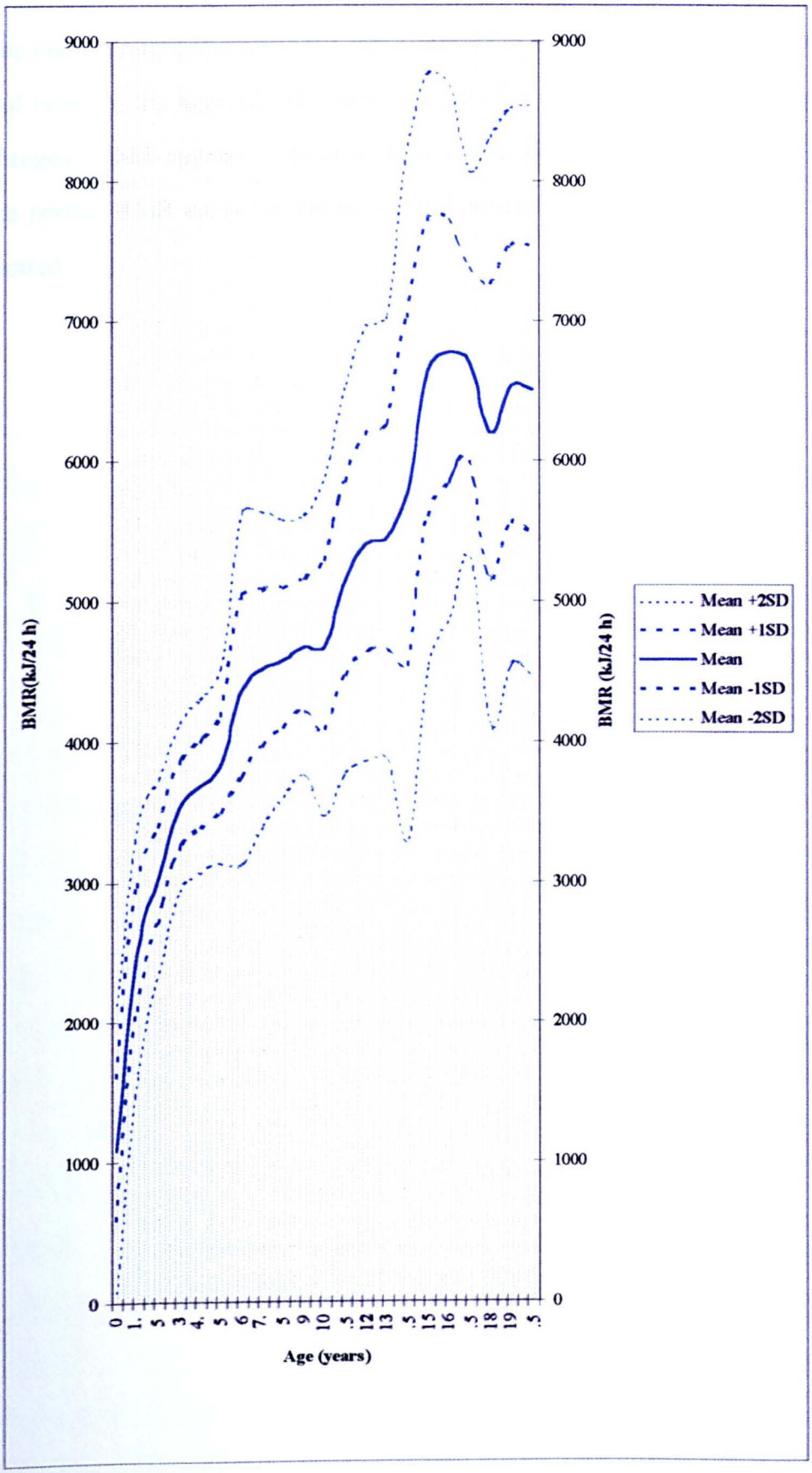


Figure 4.5

Normal BMR curves for males aged 0-20 years

The male normal curve show the rapid increase in BMR during the first 3 years of life and between the ages 12 -15 years. The peak at age 16 is a result of the pubertal changes. BMR appears to begin a decline after 17 years of age. Figure 4.6 depicts the normal BMR curve for females aged between 0-20 years. The mean $\pm$ SD are plotted.

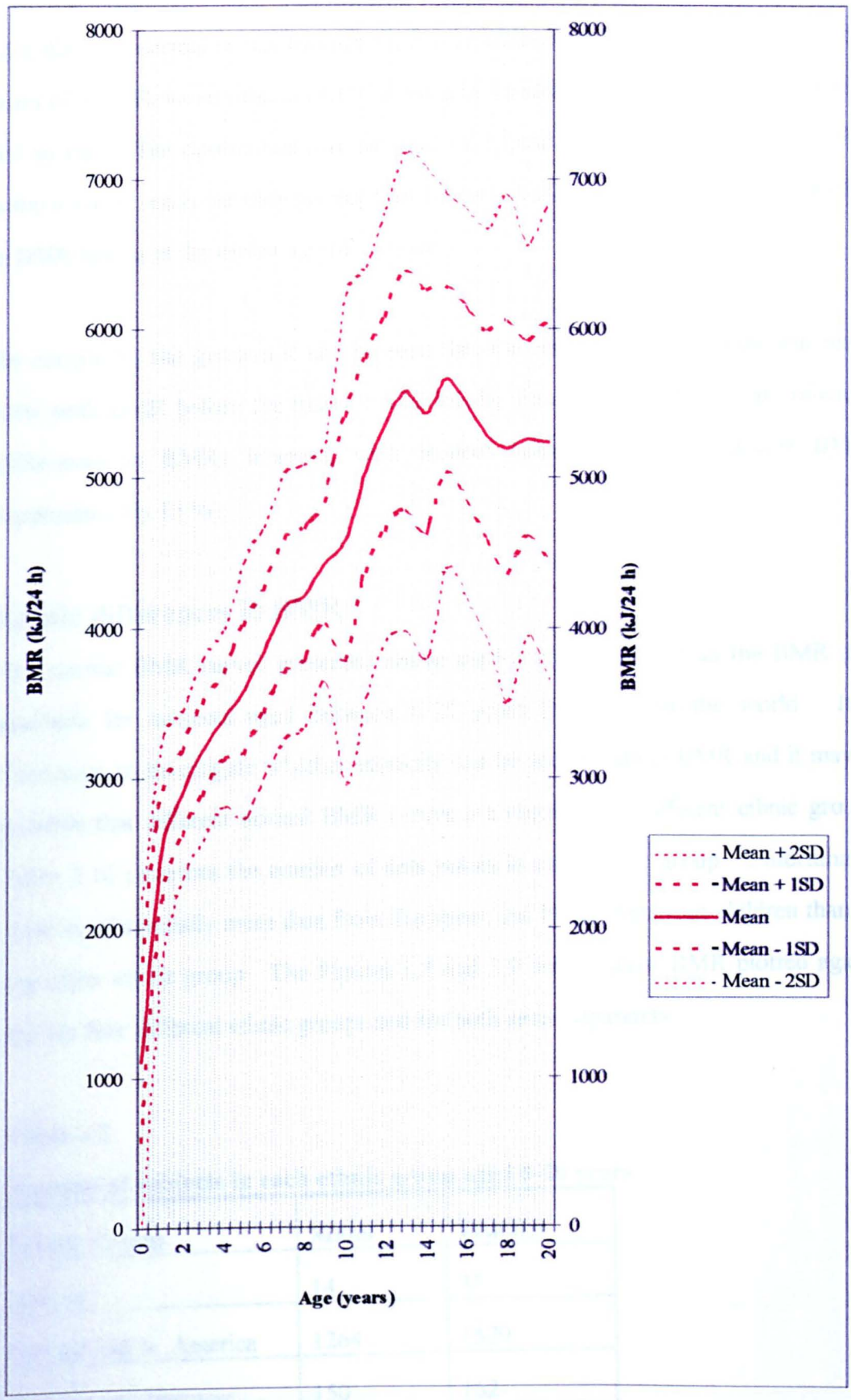


Figure 4.6

Normal BMR curves for females aged 0-20 years

Like the male normal curve, females show a rapid increase in BMR during the first 3 years of life. However, the pubertal increase in females appears to start earlier and is not so rapid. The double hump at the ages of 13 and 15 years depicts the fact that some subjects reach maturity sooner than others. Additionally the start of the decline in BMR begins at the earlier age of 16 years.

By comparing the genders it can be seen that the females mature earlier and reach their peak BMR before the males. Additionally from the age of 13 years onwards differences in BMRs increase, with females having consistently lower BMRs (approximately 15 %).

Ethnic differences in BMR

The normal BMR curves presented above used a compilation of all the BMR data available for subjects aged between 0-20 years from around the world. It is interesting to investigate whether ethnicity can be seen to affect BMR and it may be possible that different normal BMR curves are required for different ethnic groups. Table 3.16 describes the number of data points in each ethnic group. Unfortunately there is substantially more data from European and North American children than for any other ethnic group. The Figures 3.8 and 3.9 below, show BMR plotted against age for four different ethnic groups and for both sexes separately.

Table 4.2

Number of subjects in each ethnic group aged 0-20 years

Ethnic Group	Males	Females
African	14	35
Europe and N. America	1264	1579
Chinese and Japanese	150	162
Indian	265	87

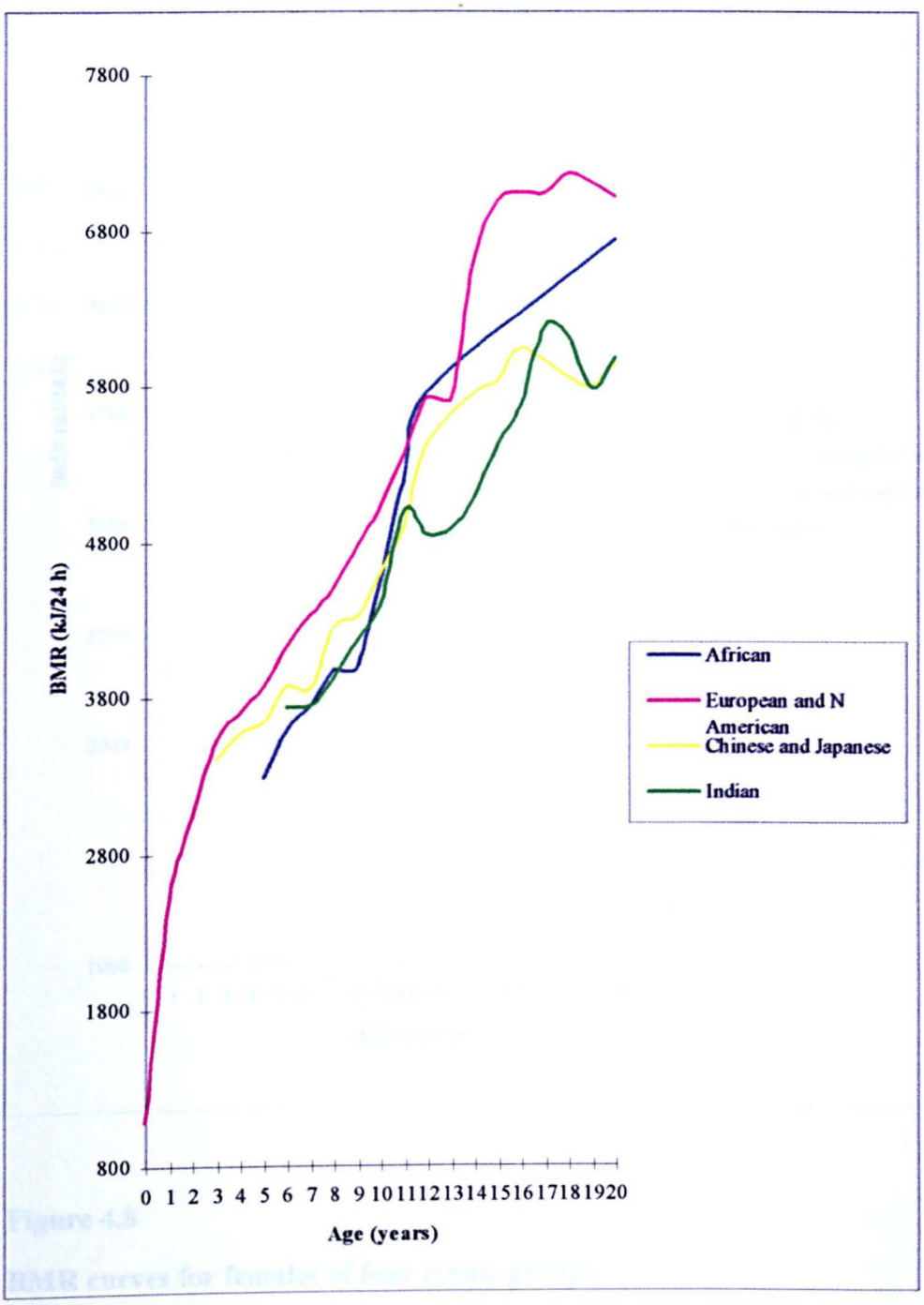


Figure 4.7

BMR curves for male subjects of 4 ethnic groups

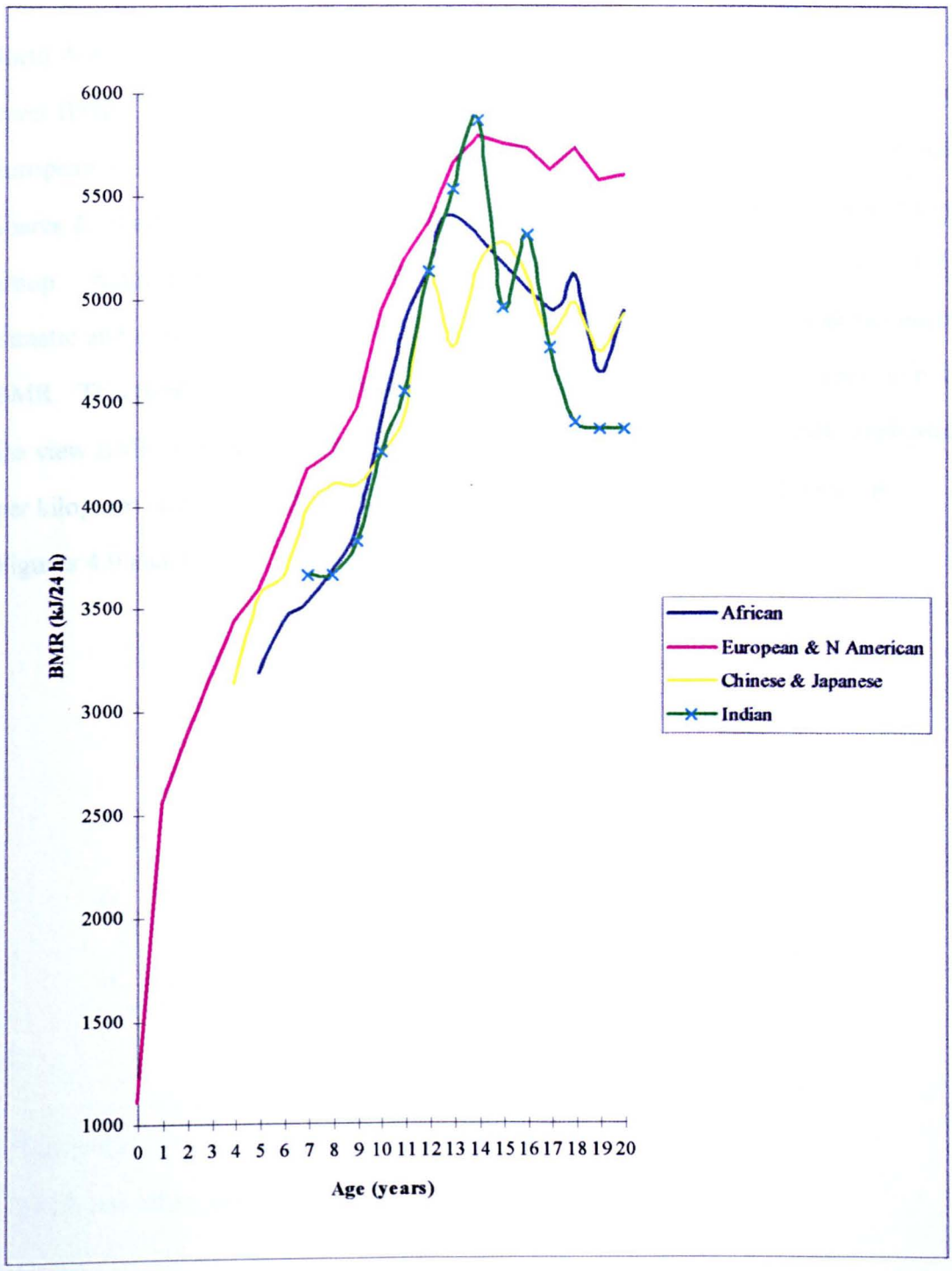


Figure 4.8

BMR curves for females of four ethnic groups

Unfortunately lack of data for some of the ethnic groups make direct comparisons difficult, but certain trends are visible. For both males and females the European and

North American group appears to have a higher BMR. Whilst the Indian group has a lower BMR. It has been established that Indian subjects have lower BMRs than their European and North American counterparts (Benedict, 1932; Bose & De, 1934 and Soares & Shetty, 1988). There are many possible reasons why BMR is lower in this group. Anthropometric factors, poor socio-economic status (Wilson *et al.*, 1938) climatic and nutritional factors (Soares & Shetty, 1988) all contribute to variations in BMR. This trend of lower BMR in tropical peoples even as children is supportive of the view BMR in general is lower in tropical people. However, when BMR expressed per kilogram of body weight a different picture is evident and this can be seen in Figures 4.9 and 4.10.

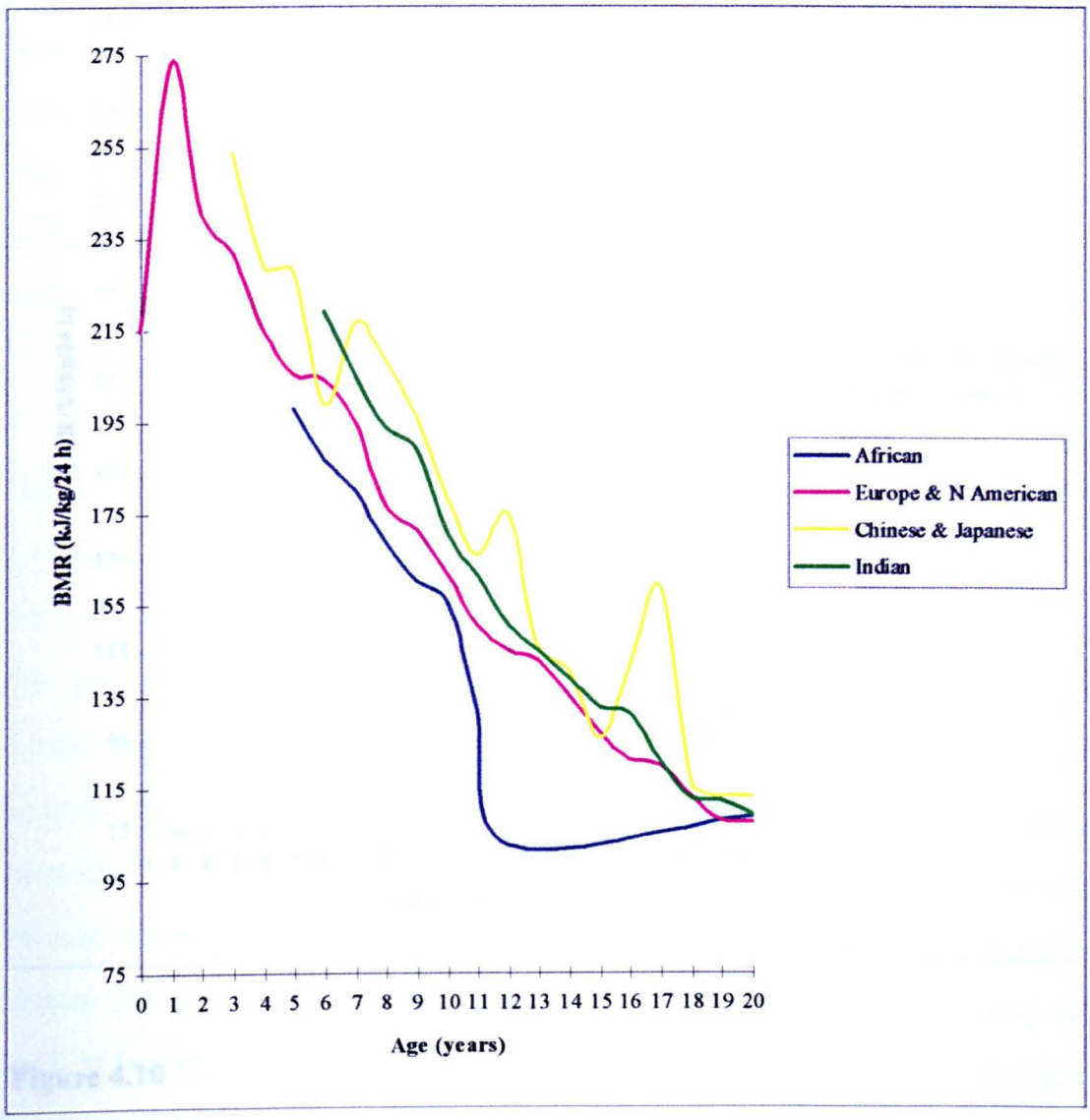


Figure 4.9

BMR per kilogram of body weight; male ethnic groups

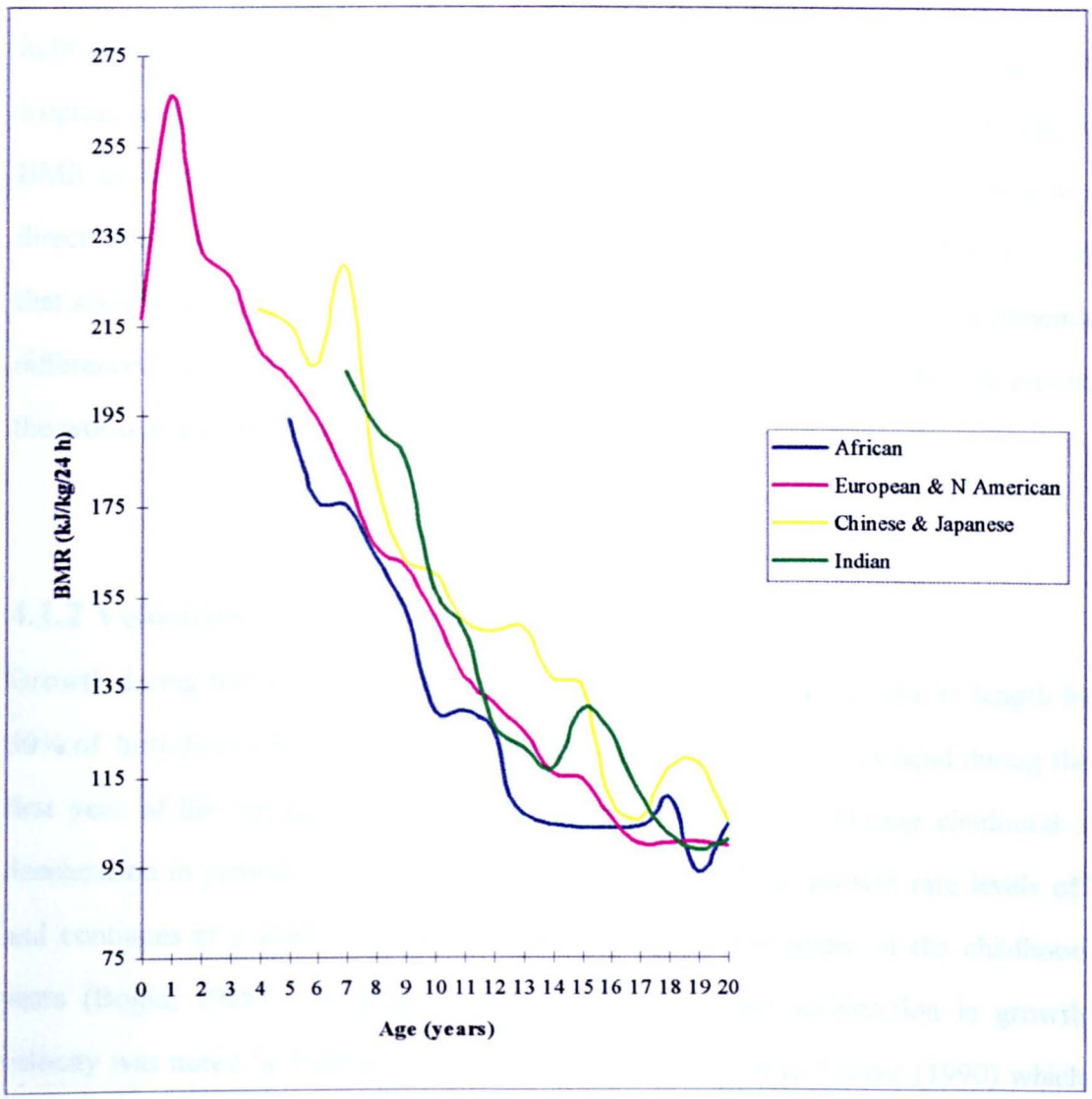


Figure 4.10

BMR per kilogram of body weight; female ethnic groups

When BMR is expressed per kilogram of body weight there is a far greater overlap between the ethnic groups. It would seem that differences in BMR between different ethnic groups are primarily a result of different body weights and organ size and weight. There are many factors that influence metabolism in any population which make comparisons between ethnic groups difficult. Starvation, disease and generally poor living conditions in some subjects exert a substantial influence on metabolism. Comparisons between ethnic groups living in similar conditions can help shed some

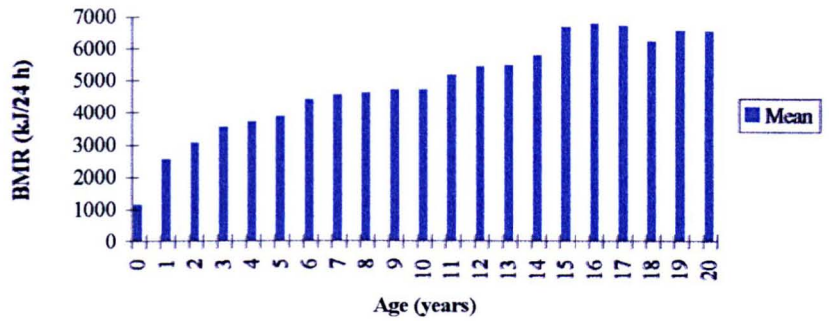
light on this problem. Hayter & Henry, (1993) compared subjects migrating from tropical to temperate countries with temperate residents and found no significant BMR differences. Therefore, it might be assumed that differences in BMR may be a direct result of climatic, nutritional factors and especially body weight. It is thought that standards for each ethnic group would be useful to compensate for environmental differences, however. Clearly there is a need for more BMR data for children around the world before this is possible.

4.1.2 Velocities

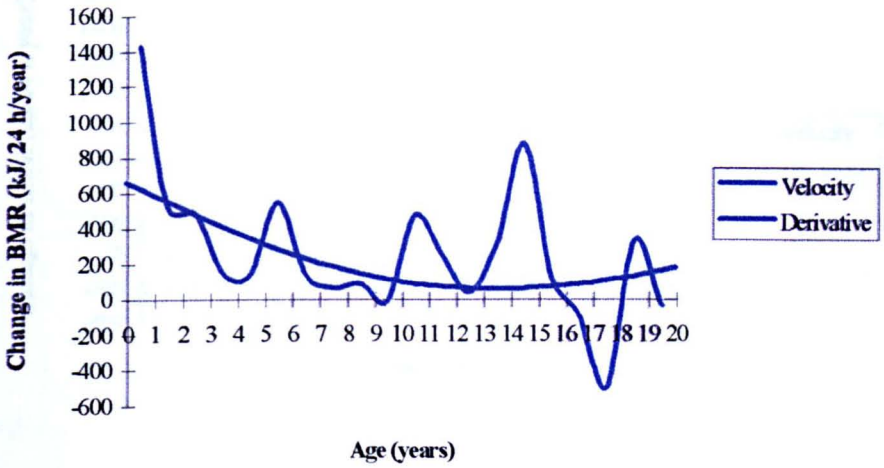
Growth during the first year of life is most rapid. Infants may increase in length by 50% of birth height and 200% of birth weight. Because growth is so rapid during the first year of life the rate of velocity decrease is very steep. During childhood a deceleration in growth velocity continues until 3 years of age growth rate levels off and continues at a slower but steadier pace during the remainder of the childhood years (Bogin, 1988). At about age 7-8 years a modest acceleration in growth velocity was noted by Falkner & Tanner (1985) and Eveleth & Tanner (1990) which became known as the mid-growth spurt. Another growth spurt is noted around the onset of sexual maturation, the adolescent growth spurt, Tanner *et al.* (1976) found this spurt to be greater in boys, which may be partly explained by the fact that in general males are taller and heavier than females. Whilst velocities are commonly plotted for height and weight, BMR velocities have not been widely used.

Just as there is a paucity of normal curves for BMR, no one has described BMR velocities, this is the aim of this section. Using the expanded Oxford Brookes data base, the BMR velocities was plotted against age for males and females separately and are presented below. Velocities were constructed manually, by finding the difference between BMR points at the beginning and the end of one year in time, and using the computer to construct a polynomial from the mean BMR values and differentiate this curve to find the velocity. Although the derivative curve is essentially the same as the

velocity, because the mean curve is smoothed somewhat, the derivative depicts more of the trends over time. Additionally by differentiating the mean BMR curve it is still possible to calculate the velocity even when several data points are missing.



a)



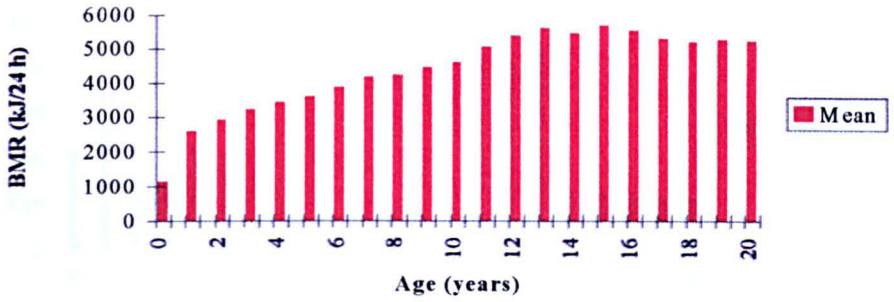
b)

Figure 4.11

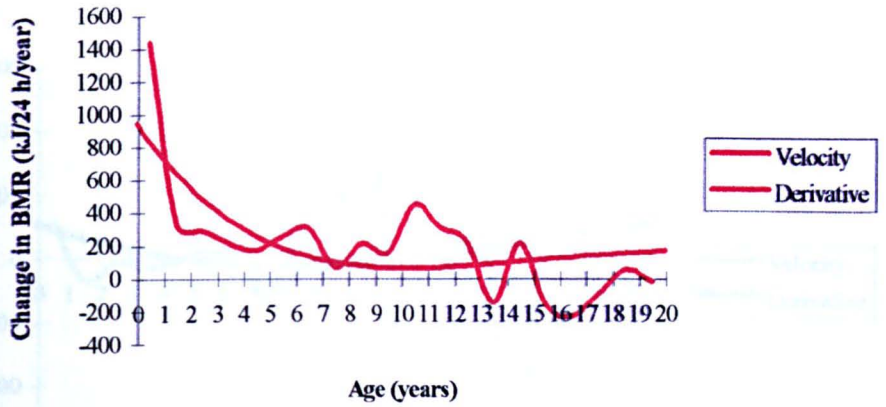
BMR with age in males. (a) mean plot of BMR achieved at each age. (b) Velocity plot of average velocities each year. The derivative of the fitted curves is shown.

From the velocities calculated by hand several peaks are evident. Velocity peaks are noted at the ages 0.5, 6, 10 and 14 years. Additionally there is a large decrease in velocity at the age of 17, the time after puberty. The line of the derivative shows that the general trend of BMR velocity with age is downwards. At the age of 15 years the

velocity appears to increase slightly, a time when mean BMR increases, this appears to be immediately after puberty.



a)



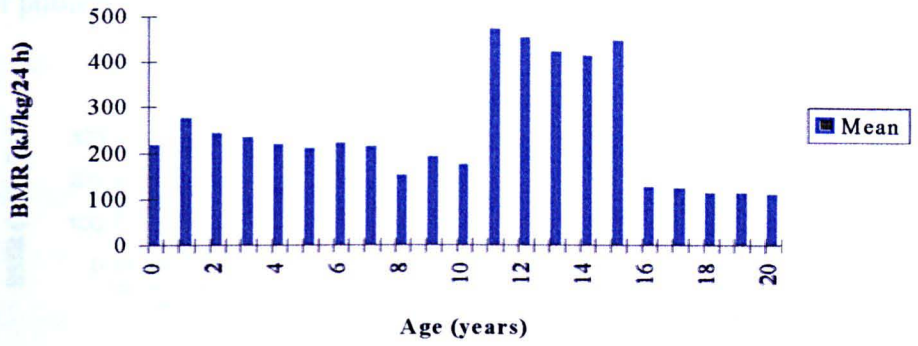
b)

Figure 4.12

BMR with age in females. (a) mean plot of BMR achieved at each age. (b) Velocity plot of average velocities each year. The derivative of the fitted curves is shown.

The BMR velocity of the females does not peak as greatly as the males, but significant peaks are noted at the ages 10 and 14 years. Females show the downward tend in BMR velocity with age but this appears to pick up again at the age of about 12, when mean BMR is seen to increase, coinciding with the onset of puberty. It would appear that BMR velocity is much more variable in males than in females.

To look at the effect of body weight on BMR, the follow figures present BMR per kilogram of body weight for males and females separately.



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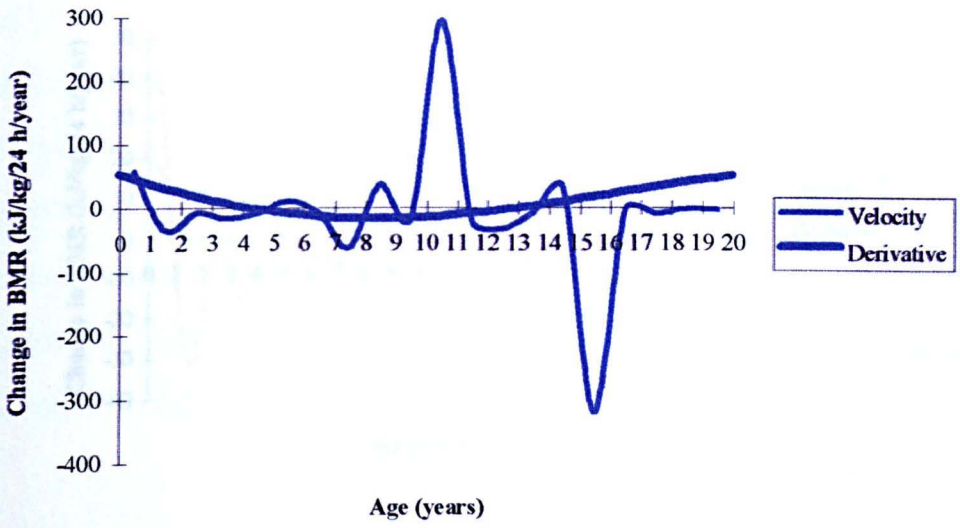
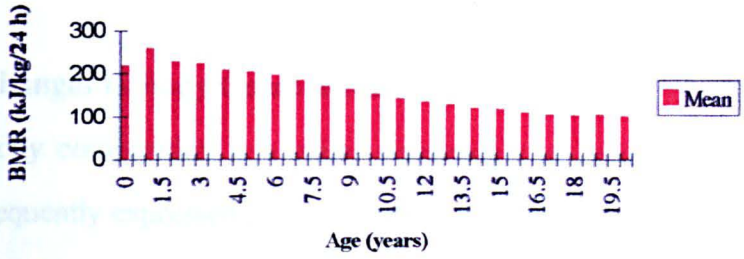


b)

Figure 4.13

BMR per kilogram of body weight with age in males. (a) mean plot of BMR (kJ/kg) achieved at each age. (b) Velocity plot of average velocities each year. The derivative of the fitted curves is shown.

When BMR is plotted per kilogram of body weight the velocity appears to be far more variable. The males show an increase in velocity around 11 years of age when a substantial increase in mean BMR is noted. The appears to be prior to puberty. Additionally there is a dip in mean BMR and velocity around age 15, towards the end of puberty.



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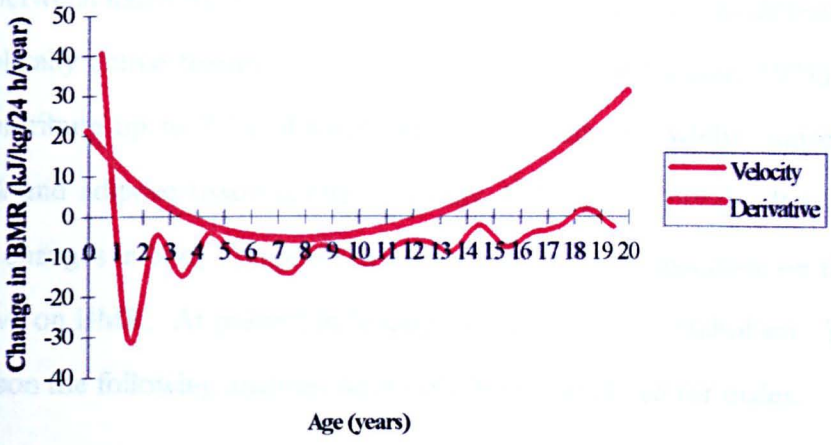

b)

Figure 4.14

BMR per kilogram of body weight with age in females. (a) mean plot of BMR (kJ/kg) achieved at each age. (b) Velocity plot of average velocities each year. The derivative of the fitted curves is shown.

Females show a continual decrease in mean BMR over time. After an initial decrease in velocity during the first year of life, BMR velocity does not seem to differ greatly

with age, although the derivative plot does show an increase in BMR velocity after 10 years of age and this continues right through to age 20 years. As with previous figures, BMR velocity in females seems to be less variable than in males.

It is hoped that BMR velocities will be used like growth velocities to understand what is happening in the human body.

Changes in Body Composition

Body composition is a major determinant of energy expenditure in man. BMR is frequently expressed per kilogram of body weight, yet people of similar body weights may have very different BMRs (Blaxter, 1989). BMR per kg of lean body mass may be more accurate (Cunningham, 1982) but it has been suggested that differences in BMR between individuals of similar weights may be explained by differing amounts of metabolically active tissues such as individual organs (Holliday, 1971). The organs may contribute up to 75% of total oxygen consumption, whilst muscle contributes 20-25% and adipose tissue contributes only 4-5% (Elia, 1992). It is interesting to look at changes in body composition with age in order to speculate on the effects this may have on BMR. At present little data exists on organ metabolism. Therefore, for this reason the following analyses have only been completed for males.

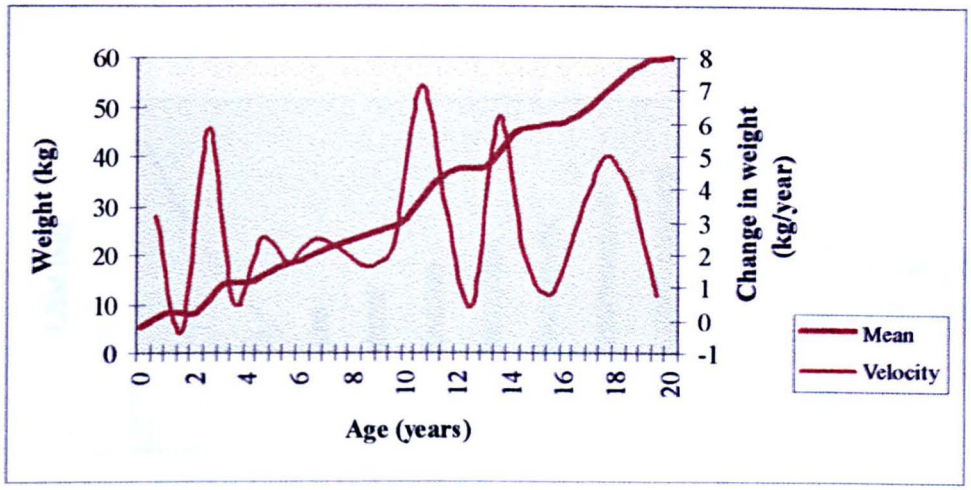

Figure 4.15

Mean weight and velocity with age in males

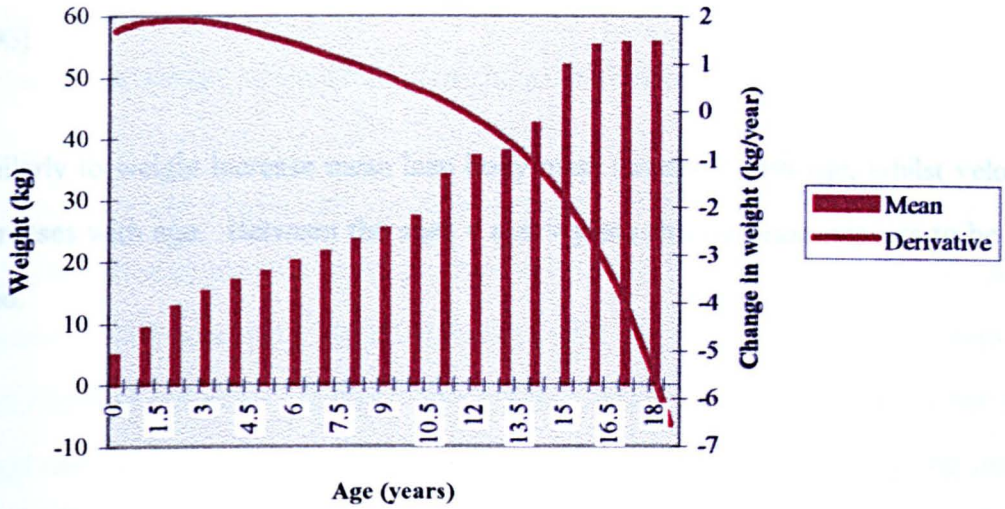

Figure 4.16

Mean weight and the derivative with age in males

As expected weight increases with age. Weight velocity can be seen to have several peaks at ages 3, 11, 14 and 18. However the derivative shows a decrease in velocity of weight increase with age.

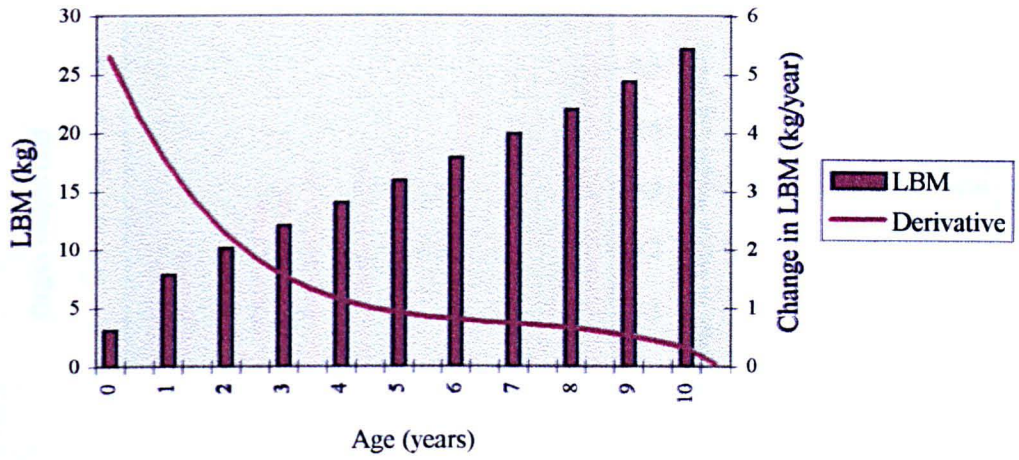

Figure 4.17

Mean Lean Body Mass (LBM) with age in males (data taken from Hunt & Groff, 1990)

Similarly to weight increase mean lean body mass increases with age, whilst velocity decreases with age. Between the ages 4 and 9 years this decrease appears to be less rapid.

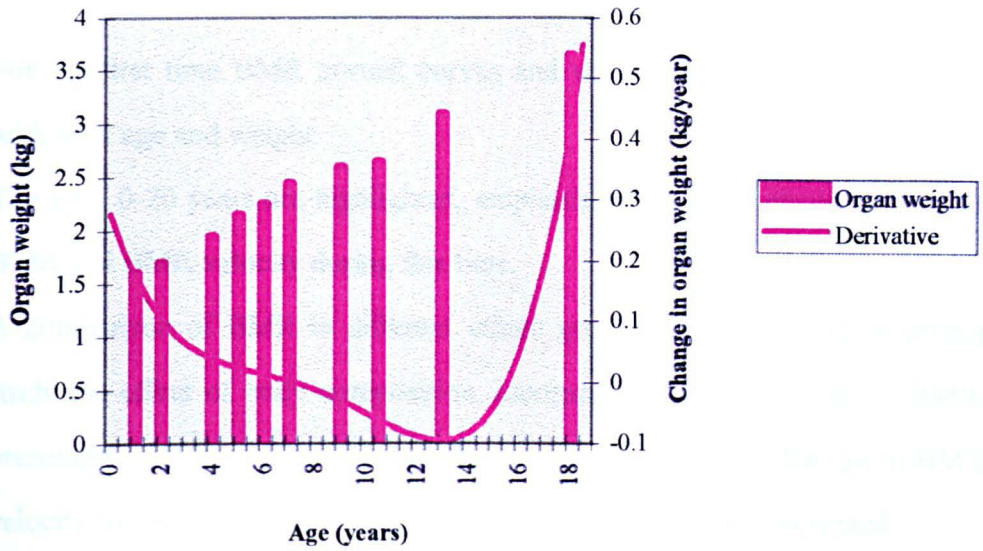

Figure 4.18

Mean organ weight and derivative with age in males (taken from Holliday, 1971)

Changes in organ weight with age also increase. Whilst the derivative of the mean data (the velocity) shows a rapid decrease in rate of change until 13 years of age, an increase is then apparent. However, lack of data for several of the age groups has contributed to this effect. Whilst organ weight change increases with age, it has been found that the metabolic rate of each organ appear to change very little during growth and development as oxygen consumption appears to be similar for children and adults. In children there is therefore a larger proportion of metabolically active tissue, and this partially explains the higher metabolic rate of infants and children compared to adults, when metabolism is expressed in relation to body weight or lean body mass (Elia, 1992). Studies have shown that loss of body weight, is closely coupled with the weight loss of organs (Spencer, 1996). It would seem that organ weight and organ metabolism varies with body size and has a significant effect on whole body metabolism.

Chapter summary

- For the first time BMR normal curves and velocities are presented for all ages with both age and weight.
- The ages 0-20 years are highlighted, emphasising the large changes that occur in BMR and BMR velocity during this time.
- A comparison of BMR in different ethnic groups was made and an attempt to study the effect of body composition, incorporating organ weight on BMR was presented. An attempt to describe the relationship between changes in BMR and velocity to changes in organ weight and body composition is presented.
- It can be seen that BMR is a highly variable component of energy expenditure. It would appear that no two individuals will have the same BMR. Reasons for these differences include differences in body weight, lean body mass, ethnic group and increasingly it would seem that organ weight and organ metabolism are significant factors.

Chapter

5

Variations in Energy Expenditure; the suitability of heart rate monitoring

5. Variation in Energy Expenditure; the suitability of heart rate monitoring

5.1 Introduction

Total energy expenditure is highly variable between individuals (Shetty *et al.*, 1996). Of the four components that comprise total energy expenditure, BMR, DIT, growth, and physical activity, it is physical activity that is the most variable component of energy expenditure. There are many factors to consider when selecting a method to measure total energy expenditure such as cost, validity, sensitivity and reliability. All the available methods have their own advantages and disadvantages. For example, the doubly labelled water technique is highly accurate and objective but may be considered too costly for large-scale studies (Melanson & Freedson, 1996). Whole-body indirect calorimeters are capable of providing accurate and precise measurements but they are expensive and create an artificial environment in which the subject performs (Murgatroyd *et al.*, 1993). Accelerometry techniques that measure activity involving movements of the trunk and limbs provide an objective assessment of the frequency of activity but fail to record the intensity of the movement (Shutz & Deurenberg, 1996). Indeed with regards to measuring energy expenditure it appears that the highest accuracy is only obtained at the cost of inconvenience to both the investigator and the subject (Garrow, 1974). A summary of the advantages and disadvantages of the different instruments available to measure total energy expenditure and physical activity are presented in Table 5.1. Whilst there are numerous methods for estimating total energy expenditure and physical activity (Murgatroyd *et al.*, 1993) few are inexpensive, socially acceptable and can be used in free-living subjects. Heart rate monitoring whilst seemingly able to fulfil the need for a cheap and convenient method has not been validated under a range of conditions and population groups. This analysis will form the basis of this chapter.

Table 5.1

Comparison of instruments used in physical activity research (Melanson & Freedson, 1996)

Instrument	Objectivity	Expense	Advantages (+) and Limitations (-)
Doubly labelled water	High	Moderate	(+) Highly accurate for assessment of energy expenditure of a group Physiological marker (-) Cannot assess activity patterns, intensity, duration, or frequency
Activity diaries	Low to moderate	Low to moderate	(+) Practical for large-scale studies Can assess activity patterns, (-) Requires co-operation and motivation
Activity recall	Low to moderate	Low to moderate	(+) Practical for large scale studies Can assess activity patterns (-) Memory and recall errors Interviewer may be needed
Observation	High	Low to moderate	(+) Can assess activity patterns (-) Not practical for large studies Requires trained observers
Caltrac accelerometer	High	Moderate	(+) Accurate when walking is predominant activity (-) Sensitive only to vertical accelerations and not speed EE equations may cause errors
Heart rate monitoring	High	Moderate	(+) Physiological marker (-) Influenced by other factors

Calculating energy expenditure using heart rates

The importance of finding a simple, reliable and cheap method to estimate TDEE spurred the use of heart rate monitoring. As early as 1910, Benedict reported that a change in the heat production of an individual can be correlated with pulse rate (Benedict & Carpenter, 1910). He then went on to suggest that pulse rate may be a way of measuring an individual's total energy metabolism. Other workers in the field including Murlin & Greer (1914) and Henderon & Prince (1914) went on to confirm this association. It was not then until the 1960's that there was a resurgence of interest in the use of heart rate monitoring as a means of measuring metabolic rate when Booyens & Hervey (1960) decided to test the relationship between pulse/heart rate and energy expenditure. Their method assumed that there was a linear relationship between heart rate (HR) and energy expenditure (EE), this relationship is depicted in Figure 5.1.

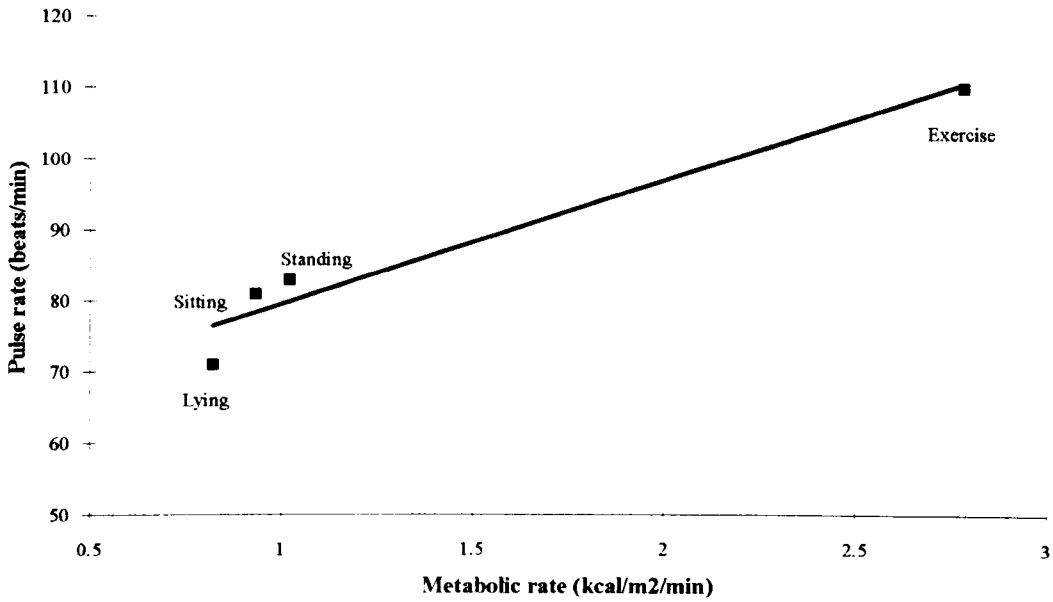

Figure 5.1

The relationship between pulse and metabolic rate (Booyens & Hervey, 1960)

To establish individual regression lines, simultaneous measurements of oxygen consumption and heart rate must be made with the subject at rest and several levels of activity. Booyens found a consistent relationship during moderate exercise but during "quiet occupations" such as sitting and very light activities pulse rate was found to be too variable.

By studying the HR and EE, Dauncey & James (1979) found that the relationship was in fact curvi-linear, as opposed to linear. Several methods of calibration were explored using data collected at rest and a range of activities. Several plots were then tried and fitted, such as linear regressions and logistic plots. However, the best calibration was that obtained over an entire 24 hour period in a room calorimeter. Heart rate readings at the low end of the calibration scale were found to be the least reliable, especially those values obtained during sleep. Unfortunately the relationship between HR and EE is not particularly accurate when studying sedentary activities. HR monitoring has been studied in subjects with low levels of energy expenditure.

Christensen *et al.*(1983) studied subjects with metabolic disorders such as anorexia and obesity. He found that the method was unsuitable for estimating low energy expenditures. Van Den Berg-Emons *et al.* (1996) tested the applicability of HR monitoring in children with spastic cerebral palsy displaying low levels of energy expenditure. Total energy expenditure was measured using doubly labelled water and the heart rate method. At the group level there was no difference between the two methods but was not deemed suitable for individuals. Early cross-validation studies of heart rate monitoring against whole-body calorimetry demonstrated poor levels of precision, probably attributable to the use of a mean HR value over long periods of low activity including sleep. It seems that is method may be of little use for monitoring individuals with low energy expenditures.

One of the main problems with heart rate monitoring is that pulse rate is affected by many factors including posture, environmental temperature, emotion, food, drink and smoking. Factors which affect the relationship between heart rate and energy expenditure according to Andrews (1971) can be categorised as follows:

1. Intrapersonal - state of training, state of fatigue, state of dietary absorption
2. Interpersonal - subject, age and sex
3. Situational - environment, site of muscular activity (static versus dynamic)

Heart rate during standing is often found to be significantly higher than during low intensity exercise. A high pulse rate whilst standing is most likely to be due to a combined psychologically driven tachycardic response (Livingstone *et al.*, 1992). Boredom, anticipation and or stress imposed by unnatural breathing apparatus may also result in emotionally induced tachycardia.

The relationship between HR and EE may be altered for different activities which employ different groups of muscles i.e. is the muscular effort dynamic or static? Training can lower the pulse rate at any level of metabolism for the particular type of work practised. Williams *et al.*(1961) noted the body's circulation is put under great stress when exposed to hot conditions. Blood vessels in the skin become dilated and

there is cardio-acceleration with an associated fall in stroke volume. This reaction could alter cardiac output in such a way that an individuals maximum oxygen uptake is reduced significantly, if there is no adjustment of the system. Spady (1980) found sleeping heart rate always fell unrealistically low suggesting the relationship between HR and EE when at sleep is not linear. Pharmaceutical agents can also affect the heart rate, Reynolds *et al* (1995) noted an even lower night time heart rate in sedated subjects.

HR monitoring is frequently used for exercise studies, because of the good relationship between HR and VO_2 at high levels of activity and this relationship has been tested in many athletes including female distance runners (Beidleman *et al*, 1995). Although it has been suggested that one of the inaccuracies of the minute by minute heart rate method is that there may be a slower return of HR to resting levels than the return of EE after bouts of activity.

The FLEX HR method

The main problem with HR at low levels of activity is pulse fluctuations caused by external factors such as climate and posture. This makes HR calibrations unreliable. Spurr & Reina (1988) tried to overcome this problem with the development of the FLEX HR method. The FLEX HR accounts for the fact that there are two ranges of HR, one for rest and one for activity. The idea of the FLEX HR is to determine a critical HR above which the slope and intercept of the calibration curve obtained at exercise can be used to calculate VO_2, and below which RMR can be used to estimate the energy expenditure. This critical HR may be referred to as FLEX HR. The FLEX HR is determined by finding the mean of the highest resting HR and the lowest exercise HR. Above the FLEX HR the calibration curve is used to calculate energy expenditure, below the FLEX HR, RMR is used to approximate EE. Although the FLEX method compensates for the unreliable relationship between HR and EE during sedentary activities one of the main problems is that it is unsuitable for

assessing the energy expenditure of inactive individuals, where heart rates seldom go above the critical FLEX HR. It may well be, that HR monitoring (particularly the FLEX HR method) is an unsuitable method for measuring sedentary subjects and should be restricted to use only in physically active people.

Previous validations

Heart rate monitoring has been validated with many different methods of measuring energy expenditure with varying results. Spurr & Reina (1988) found that the maximum error of the HR method in measuring total daily energy expenditure ranged from -15% to +20%. Van Den Berg-Emons *et al* (1996) and Payne *et al* (1995) found no significant differences between HR and doubly labelled water when looking at a group of spastic cerebral palsy patients and children. Racette *et al* (1993) also found HR and physical activity questionnaires compared favourably with doubly labelled water. However, Ceesay (1989) found a non-significant underestimate in EE when compared to a whole body calorimeter. Conversely Emons *et al* (1992) found HR overestimated EE by 10.4% when compared with a calorimeter and 13.3% with doubly labelled water. Leonard (1995) found HR and the factorial method to be highly correlated to the factorial method (r = 0.759), the factorial method underestimated total daily energy expenditure (10.27 $\pm$2.54 compared with 11.91 $\pm$3.96 MJ/d, $P<0.001$).

Activity patterns

As well as quantifying energy expenditure in terms of calories, heart rate monitoring can also be used to show patterns and levels of exercise. Spurr *et al* (1996) looked at patterns of heart rate over 24 h in urban Colombian women to compare the habitual activity levels between housewives and those in employment. HR in children precisely mirrors changes in activity, more so than in adults because of the faster recovery of resting HR after exercise. Armstrong *et al* (1990) looked at the patterns of physical activity in British school children. The percentage of time the children spent above

140 beats/min was recorded (140 beats/min is approximately 70% of the maximal heart rate for a child). The children were found to exhibit low levels of habitual exercise, and in particular the girls were found to be less active than the boys.

Heart rate monitors also offer the potential to monitor training status and intensity in athletes. Selley *et al* (1995) found that although in non-competitive running, there is a good relationship between speed and HR in an individual but in a race situation this relationship is altered as fast and slow runners were found to have similar HR's during both 10 and 21 kilometre races. It appears that factors other than work influence HR during race situations including sympathetic arousal.

Experimental Work

5.2 Heart rate monitoring to estimate energy expenditure

This section looks at whether food intake effects heart rate, energy expenditure and the associated relationship between these 3 factors. In the previous discussion it was pointed out that numerous factors can independently influence HR. A factor that has been little explored is the influence of food intake on HR. It is well known that the consumption of food initiates DIT (Dulloo *et al.*, 1989). Whilst a body of information associated with diet composition exists (Rubner, 1883 onwards) there is sparse literature on the role of diet, HR and energy expenditure.

5.2.1 The effect of Food on heart rate

Many factors affect heart rate including the subjects age, sex and training status, this is the reason why heart rate and energy expenditure are calibrated separately for each individual. Other factors which affect heart rate are posture, environment, smoking, drinking and eating. The present experiment looked at the effect of a meal (breakfast) on heart rate, energy expenditure and the associated relationship. If food significantly alters this relationship then it may be that heart rate monitoring is not the ideal method for estimating energy expenditure in individuals for periods of 24 hours, or indeed for any time frame which incorporates meal times.

This experiment was designed to test the applicability of heart rate monitoring after the consumption of food.

The physical characteristics of the subjects in this experiment are shown in Table 5.2. All subjects were healthy male students with BMI's below 30.

Table 5.2
Subject characteristics

Subject	Age (years)	Weight (kg)	Height (cm)	BMI
1	29	70	174	23.12
2	29	81	177	25.85
3	24	50	170	17.30
4	24	74	183.5	21.98
5	26	92	181	28.08
6	24	78	194.5	20.62
7	20	81	198	20.66
8	24	49	171	16.76
9	23	61	169	21.36
10	23	72	183	21.50
11	29	81.5	191	22.34
12	22	94	180	29.01
13	22	72	183	21.50
14	23	74	18	22.59
15	25	76	177	24.26

The breakfast that was provided is shown in Table 5.3. The breakfast was composed of typical foods normally eaten by the subjects in the morning and consisted of cereals, milk, toast, margarine and jam.

Table 5.3
Macro-nutrient breakdown of breakfast consumed

Food	Portion Size (g)	Protein (g)	Fat (g)	Carbohydrate (g)	Energy	
					kJ	kcal
Cornflakes	30	2.37	0.21	25.77	460.5	110.06
Semi-skim milk	100	3.3	1.6	5.0	195	46.61
Toast	54	5.022	0.864	30.834	609.66	145.71
Jam	30	0.18	-	20.7	334.2	79.88
Margarine	10	0.02	8.16	0.1	303.9	72.63
Total	**224**	**10.892**	**10.834**	**82.404**	**1903.26**	**454.89**

In addition to the breakfast consumed, 7 of the subjects had a cup of coffee. No significant differences were found between the heart rates and energy expenditure in the subjects that had drunk coffee from those that had not.

Data was obtained to establish calibration curves for each subject individually. For this preliminary study, four calibration activities were performed before and after breakfast. The calibration activities for this experiment were:

1. Lying down at rest
2. Standing unaided
3. Cycling on a cycle ergometer with 1 kg of resistance at 60 rpm
4. Cycling with 3 kg of resistance, 60 rpm

Energy expenditure and heart rate were recorded simultaneously before and 30 min after breakfast. Individual calibration data can be seen in the appendix.

The mean energy expenditure and heart rate data obtained from all 15 subjects before and after breakfast is presented in Table 5.4.

Table 5.4
Group mean data

Activity		**Energy Expenditure (kJ/min)**		**Heart Rate (beats/min)**	
		Before breakfast	**After breakfast**	**Before breakfast**	**After breakfast**
Lying down	Mean	4.78	6.40	59.29	67.64**
	SD	1.28	2.24	8.90	9.60
Standing	Mean	6.72	8.06	75.29	87.50**
	SD	2.05	3.43	10.89	15.98
Light cycling	Mean	15.26	16.71	83.07	92.50**
	SD	5.87	7.40	9.82	15.04
Heavy cycling	Mean	41.19	43.56	139.29	146.36**
	SD	13.63	14.86	18.67	18.79

** HR significantly different before and after breakfast, $P < 0.01$

The results from paired t-tests show that the group mean data for energy expenditure after breakfast does increase, but not significantly. Heart rate however, is seen to increase significantly ($P < 0.01$) after the consumption of breakfast.

The percentage changes in both energy expenditure and heart rate after breakfast are shown in Table 5.5.

Table 5.5

Changes in energy expenditure and heart rate after breakfast

Activity	Change in Energy Expenditure (%)	Change in Heart Rate (%)
Lying down	33.89	14.08
Standing	21.43	16.22
Light cycling	9.50	11.35
Heavy cycling	5.75	5.08

A t-test showed no significant differences between the percentage changes in energy expenditure and the percentage changes in heart rate after breakfast.

The calibration data was used to plot linear regression lines for each subject individually, and for the group as a whole. The linear equations before and after breakfast, as well as the correlation coefficients and the standard error of estimates are presented in Table 5.6.

Table 5.6
Regression equations before and after breakfast

Subject	Before breakfast			After breakfast		
	Linear equation	***r***	**s.e.e.**	**Linear equation**	***r***	**s.e.e.**
1	EE = 0.37 * HR - 19.51	0.99	1.39	EE = 0.34 * HR - 19.52	0.99	3.05
2	EE = 0.54 * HR - 26.50	0.97	6.05	EE = 1.00 * HR - 64.90	0.97	10.2
3	EE = 0.26 * HR - 12.68	0.98	2.71	EE = 0.27 * HR - 13.73	0.97	3.20
4	EE = 1.00 * HR - 63.71	0.96	10.62	EE = 0.78 * HR - 51.47	0.98	5.42
5	EE = 0.56 * HR - 25.58	0.97	5.17	EE = 0.51 * HR - 30.34	0.95	6.80
6	EE = 0.41 * HR - 22.87	0.95	5.26	EE = 0.40 * HR - 23.14	0.92	6.23
7	EE = 0.55 * HR - 33.38	0.99	2.22	EE = 0.57 * HR - 36.42	0.99	3.37
8	EE = 0.27 * HR - 12.59	0.98	3.02	EE = 0.24 * HR - 12.70	0.96	3.38
9	EE = 0.50 * HR - 27.70	0.98	2.14	EE = 0.50 * HR - 28.80	0.99	1.36
10	EE = 0.51 * HR - 37.50	0.95	5.43	EE = 0.48 * HR - 41.30	0.84	10.7
11	EE = 0.46 * HR - 23.70	0.99	2.80	EE = 0.54 * HR - 36.20	0.98	4.88
12	EE = 0.58 * HR - 22.40	0.99	2.98	EE = 0.58 * HR - 24.90	0.99	3.21
13	EE = 0.37 * HR - 18.44	1.00	1.56	EE = 0.42 * HR - 22.21	0.98	3.50
14	EE = 0.45 * HR - 24.20	0.99	1.94	EE = 0.44 * HR - 24.99	0.99	3.14
15	EE = 0.38 * HR - 24.20	1.00	1.03	EE = 0.44 * HR - 30.43	0.98	4.09
Mean	EE = 0.48 * HR - 25.51	0.98	3.08	EE = 0.50 * HR - 30.52	0.97	4.36

Figure 5.2 graphically shows the relationship between energy expenditure and heart rate, before and after breakfast for the whole group.

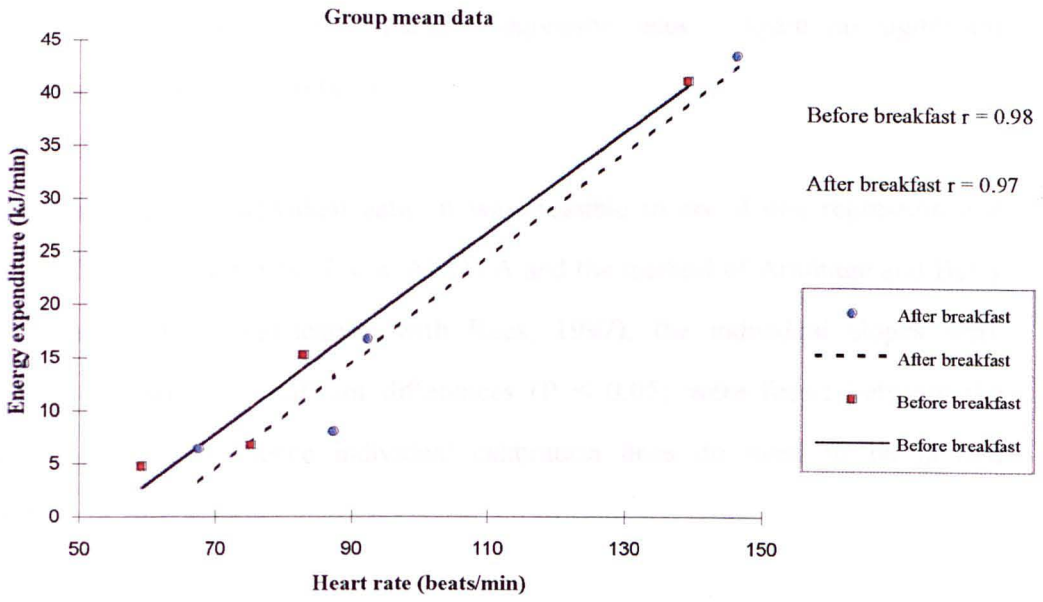

Figure 5.2

The relationship between heart rate and energy expenditure

To establish if the heart rate and energy expenditure relationship altered after breakfast the regression lines were compared. There are two ways of looking at this; firstly are the slopes different, i.e. are the regression lines parallel or not? If the slopes do not differ then it is interesting to ask whether the lines differ in height above the x-axis, by comparing the c values (where, $y = mx + c$).

The two regression lines for subject two showed the greatest gradient difference, therefore it was deemed that if there were no significant differences between the gradients of subject two's regression lines then the same would be true for all the other subjects. Using t-tests and the method according to Armitage & Berry (1987), (personal communication with Rees, 1997) no significant differences at the 5% level were found between the before and after breakfast regression gradients for subject two.

Having found no significant difference between the slopes of the regressions lines of subject two a similar technique was used to test for a significant difference between

the vertical heights of the two parallel regression lines. Again no significant differences were found ($P > 0.025$).

By comparing all the individual data it was possible to see if one regression line would suffice for all subjects. Using ANOVA and the method of Armitage and Berry (1987), (personal communication with Rees, 1997), the individual slopes were compared. However, significant differences ($P < 0.05$) were found between the individual slopes and hence individual calibration lines do need to be plotted separately for each person .

Although heart rate changes significantly after breakfast, and energy expenditure increases non-significantly, there were no changes in the regression lines created from the heart rate and energy expenditure regression lines. Therefore, it is possible to monitor heart rate during meal times and still produce appropriate estimates of energy expenditure. It was also proved necessary to establish the heart rate and energy expenditure in each individual subject separately.

The next stage was to collect HR data for periods of 24 hours in order to estimate total daily energy expenditure.

5.2.2 The use of heart rate to predict 24 hour energy expenditure

Heart rate monitors are capable of recording heart rates for long periods of time, in this case 24 hours. Once the data has been recorded it needs to be analysed in order to calculate the energy expended. There are a variety of ways of converting HR data into energy expenditure, the simplest method is to create a linear equation. Alternatively quadratic equations could be used to reflect the curvilinear nature of the HR and EE relationship. Much emphasis has been placed on the use of the FLEX HR

(Spurr & Reina, 1988 and Livingstone *et al.*, 1990) method but is this suitable in subjects whose energy expenditure rarely rise above resting levels?

This experiment was designed to investigate different methods of calculating energy expenditure from recordings of heart rate and activity diaries.

The physical characteristics of the subjects in this experiment are shown in Table 5.7. All subjects were healthy female students with BMI's below 30.

Table 5.7
Subject Characteristics

Subject	Age (years)	Weight (kg)	Height (cm)	BMI
1	17	87	171	29.75
2	17	44.6	144.5	21.36
3	20	81.9	168	29.02
4	21	62.5	172.3	21.05
5	22	47	149.5	21.03
6	23	70	174	23.12
7	23	73.7	159.1	29.12
8	30	48	160	18.75

Individual Calibration Data

Data was obtained to establish calibration curves for each subject. Six calibration activities were performed per person. The calibration activities were as follows:

1. Lying down at rest
2. Sitting comfortably in an upright chair
3. Standing unaided
4. Cycling on a stationary bicycle with no resistance, 60 rpm
5. Cycling with 1 kg of resistance, 60 rpm
6. Cycling with 2 kg of resistance, 60 rpm

Both energy expenditure and heart rate were recorded simultaneously and the results of the individual calibrations may be found in the appendix.

Linear equations to predict energy expenditure from heart rate

The individual calibration data was used to plot linear regression lines for each subject. These could then be used to predict energy expenditure from heart rate. The linear equations are shown in Table 5.8 along with the corresponding correlation coefficients and the standard error or estimates.

Table 5.8
Linear equations for predicting energy expenditure from heart rate

Subject	Linear equation	*r*	s.e.e.
1	EE = 0.37 * HR - 17.12	0.99	1.28
2	EE = 0.20 * HR - 12.43	0.99	1.03
3	EE = 0.30 * HR + 15.77	0.95	3.94
4	EE = 0.26 * HR - 11.31	0.97	2.71
5	EE = 0.23 * HR - 12.85	0.99	1.54
6	EE = 0.36 * HR - 21.64	0.98	3.41
7	EE = 0.26 * HR - 10.21	0.99	0.98
8	EE = 0.24 * HR - 13.87	0.99	0.88

Quadratic equations to predict energy expenditure from heart rate

In 1979, Dauncey & James stated that the relationship between heart rate and energy expenditure depicted a more curvilinear relationship than a linear one. For this reason, curved lines were also fitted to the subject calibration data. The quadratic equations and the corresponding correlation coefficients and standard error of estimates are presented in Table 5.9.

Table 5.9
Quadratic equations for predicting energy expenditure from heart rate

Subject	Quadratic equation	*r*	s.e.e.
1	EE = 0.00074 * HR^2 + 0.23 * HR - 11.09	0.99	1.28
2	EE = 0.00070 * HR^2 + 0.21 * HR - 2.40	1.00	0.54
3	EE = 0.00257 * HR^2 - 0.24 * HR + 11.20	0.96	3.72
4	EE = -0.0006 * HR^2 + 0.39 * HR 17.29	0.97	3.07
5	EE = -0.0007 * HR^2 + 0.40 * HR - 22.16	0.99	1.41
6	EE = 0.00154 * HR^2 - 0.001 * HR - 2.82	0.99	2.99
7	EE = 0.00062 * HR^2 + 0.24 * HR - 9.45	0.99	2.51
8	EE = 0.00086 * HR^2 + 0.42 * HR - 23.22	0.99	0.72

Figure 5.3 graphically shows both linear and quadratic curves fitted to subjects 6's calibration data in order to illustrate a direct comparison between the two methods of data analysis.

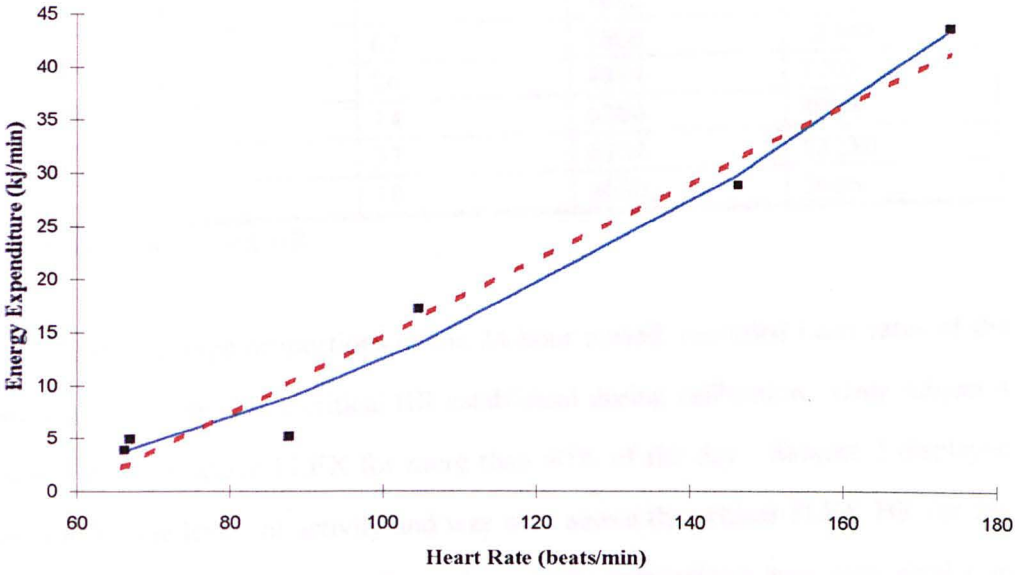

Figure 5.3
The linear and quadratic regression lines for subject number 6 during different activities

The FLEX HR method

The FLEX HR method of data analysis is a frequently used technique for estimating energy expenditure from heart rate. The critical FLEX (the mean of the highest resting and the lowest exercise HR) was determined for each subject. Resting energy expenditure (REE) was calculated from the initial calibration data and then the total estimated energy expenditure was calculated using the FLEX HR method. The FLEX HR results can be seen in Table 5.10.

Table 5.10
Estimation of energy expenditure using the FLEX HR method

Subject	Critical FLEX	Time spent above FLEX (%)	REE (kJ/24h) (when HR<FLEX)	FLEX EE (kJ/24h)
1	80	19	7366	10435
2	113	5	4752	4879
3†	85	-	7812	-
4	68	67	5666	12740
5	94	26	4424	7703
6	96	14	6386	8924
7	85	37	6124	13230
8	85	18	4630	5666

†Monitor failed to record HR

Unfortunately for large proportions of the 24 hour period, recorded heart rates of the subjects failed to rise above critical HR established during calibration. Only subject 4 remained at levels above FLEX for more than 40% of the day. Subject 2 displayed exceptionally low levels of activity and was only above the critical FLEX HR for 5% of the time. Therefore, subject 2's resting energy expenditure was very similar to energy expenditure estimated from the FLEX HR, a difference of only 127 kJ. It is for this reason that FLEX HR may not be suitable or necessary for all subjects, particularly those with very low activity levels where resting energy expenditure measurements will suffice.

Comparison of the different methods of estimating energy expenditure

Activity diaries were also completed by all 8 subjects in order to provide another means of comparing the different methods for estimating total energy expenditure. The estimated total energy expenditures calculated using the different methods are summarised in Table 5.11.

Table 5.11
Comparison of the different methods used to estimate total energy expenditure

Subject	Linear equation (kJ/24h)	Quadratic equation (kJ/24h)	FLEX HR (kJ/24h)	Diary (kJ/24h)
1	13585	11633	10435	10117
2	5682	5945	4879	4971
3†	-	-	-	11376
4	13272	13705	12740	11155
5	10929	11467	7703	7259
6	9954	10231	8924	8581
7	19259	15202	13230	8063
8	5524	5556	5666	5015
Mean	11172	10534	9082	8317
SD	4816	3648	3257	2507

† monitor failed to record HR
NB. no significant difference between methods

No significant differences were found between any of the methods used to predict total energy expenditure. It is therefore deemed that there is no superior method of analysing heart rate. It would then seem that for most purposes the HR method selected should be the most convenient method to both the subject and the investigator.

5.3 General conclusions

As with any method of energy expenditure of measurement there are many advantages and disadvantages of heart rate monitoring, these are summarised in Table 5.12.

Table 5.12

Relative advantages and disadvantages of heart rate monitoring

Advantages	*Disadvantages*
Simple and inexpensive	Needs individual calibration
Socially acceptable	Effected by environment, food, posture etc.
Non-intrusive	Uncertainty of prediction at sedentary activity levels
Provides activity data	Need electrode contact at all times

(Taken from a combination of Murgatroyd *et al.*, 1993 and Schutz & Deurenberg, 1996)

Summary

- Heart rate monitoring, does require individual calibrations.
- Food intake does not affect the HR and EE relationship.
- The FLEX HR method is not always suitable, particularly for subjects with low energy expenditure.
- The HR method is an important tool for measuring individual energy expenditure in moderately or heavily active subjects.
- Group mean values shows the activity diary method provides similar results to those obtained using HR monitors.
- Investigators should be aware of the limitations of the heart rate method for estimating total energy expenditure.

Chapter

6

Variations in Food Intake and Energy Density

6. Variations in Food Intake and Energy Density

6.1 Introduction

Energy balance is a complicated subject not least because of individual variations in energy intake and energy balance. Whilst this subject has been extensively studied in animal models such as rats, the results may not be applicable to the study of humans who are far more complex (Garrow, 1974). Passmore *et al.* (1952), found satisfactory agreement between estimates of energy intake and energy expenditure in three subjects, yet Hervey (1973) found no correlation between input and output during a single day, but over longer periods 4-14 days results showed a virtual balance. Body weight in most individuals may be constant for long periods of time suggesting that a balance between intake and expenditure is achieved. However, the consumption of high energy dense snacks have been known to cause a shift in energy balance and have been implicated in over consumption (Drummond *et al.*, 1996). Thus, it is suggested that energy balance is difficult to maintain in the face of energy dense foods. This formed the basis of our investigation.

Energy density of food consumed

It is well known that in countries such as Malaysia, the people consume foods of low-energy density. Their diets can be typically characterised by high-carbohydrate, high-fibre, low-fat foods (Yang & Read, 1996) such as rice, noodles and cassava. The carbohydrate fraction in these foods absorbs considerable amounts of water during cooking, leading to bulky foods with very low energy densities. In some South East Asian and African countries low-energy dense foods have been shown to contribute to low energy intakes. Even when *ad libitum* food is available, recommended energy intakes are difficult to achieve (Rutishauser & Frood, 1973). Similar effects have been found in Western countries. Hunt *et al.* (1975) suggested that people who eat low-energy dense food have lower energy intakes than those who eat high-energy dense foods. Since many low-energy dense diets are due to their low fat content, the

popularity of the low fat diet in those wishing to lose weight becomes apparent. However, in Western countries such as the UK the majority of the foods consumed are of high-energy density. Table 6.1 shows the energy densities of a selection of foods eaten in both Malaysia and the UK and demonstrates the relatively high-energy density of the diets consumed in the UK. The purpose of this study was to identify if it was possible to maintain energy balance when faced with high-energy dense food.

Table 6.1

The energy density of selected foods typical of Malaysian and UK diets

Malaysia		Oxford	
Food	**Energy density (kJ/g)**	**Food**	**Energy density (kJ/g)**
Fish balls	2.18	Roast potatoes	6.23
Tofu	2.93	White bread	9.83
Rice (cooked)	5.44	Chips	11.42
Sago (cooked)	5.48	Steak & kidney pie	13.51
Cassava	5.65	Cheese & pickle sandwich	13.60
Kwe Teow (noodles)	5.86	Crisps	20.92
Mee (fried noodles)	8.66	Chocolate	21.76

Because low-energy dense diets tend to be bulky and high in volume, Poppitt and Prentice, (1996) have suggested that large intakes of energy on a high carbohydrate diet are prevented by visual cues. These may be absent when presented with a small quantity of food rich in fat that has a very high energy content. Therefore we decided to investigate what happens when Malaysian students move from a country where the energy density of food is low to a country where the energy density of the majority of food consumed is high in order to find out if it is possible to regulate and maintain body weight and energy balance.

Food Intake

Food intake is affected by many factors. These can include geographical, social, psychological, religious, economical and political factors, but culture is one of the greatest determinants of what we eat. Just as there are many factors which affect our food intake, there are also many reasons why our food intake may change. Ecological and economic influences may lead to altered availability of certain foods, or the discovery, or innovation, of foods and the diffusion or borrowing of food habits from other cultures may occur (Fieldhouse, 1995). Food intake may be altered due to a conscious effort by an individual to change their dietary habits because of health and weight concerns. Whatever the reason for dietary change it may be useful to identify why and how people are prepared to make changes to their diets and then there may be greater chance of success if attempts are made to induce change (for example due to public health concerns).

One method for identifying the processes associated with dietary change is the examination of diets eaten by different generations, another is to look at the dietary changes of migrants. Whilst migrants generally tend to adapt to the food habits prevalent in the place of destination (Rao, 1986), many create their own culinary culture, making compromises and substitutions for ingredients no longer available in their new country. They may be come bipalatal and choose to eat local foods in public whilst retaining their own cuisine at home. Interestingly, not only do the actual foods consumed change but the accompanying beliefs, attitudes and social roles of food may also change (Fieldhouse, 1995). Overseas students who have left their home country to study in the UK make an interesting study group to look for changes in their food intake.

It is in young people that changes can be seen most rapidly as they are easily subjectable to peer influences at school and work. Additionally, they receive little cultural support for traditions when they are at university away from their families. The years between the ages of 18 and 24 years are established as being difficult. This is a transition stage when one ceases to be a child and begins to be an adult.

Nutritionally these are important years when young adults develop eating habits that are likely to be maintained for life (Jeffery-Hampl, 1995) and these are therefore interesting years to study. It is for these reasons we chose to study recently arrived undergraduate students mainly from the Malaysian Peninsula. The pattern of food selection and food intake in these newly arrived overseas students formed the basis of this study.

The Students

Oxford is a highly desirable place for education and hence is the destination for many international students. At Oxford Brookes University, approximately 16% of the students are from overseas. In particular there are 224 Malaysian students. Those that participated in this study were residents in Oxford for either one term or one year as part of an undergraduate degree exchange programme. All the students were placed in self catering halls of residence in close proximity to other Malaysian students. The majority of the students were from urban areas such as the Malaysian cities of Kuala Lumpar and Kuching.

The principle difficulties these overseas students have to face whilst studying in the UK, are social problems, financial problems, difficulties with the language and the British climate. Not all overseas students are wealthy, although many are from middle class backgrounds a few are scholarship students and are on very tight budgets. Additionally the students have to adapt to a different diet. All these factors combined can result in a phenomenon known as "culture shock" (Hamboyan & Bryan, 1995).

Malaysian Food

There are four main ethnic groups living in Malaysia:

1. Indigenous Malays
2. Immigrant Chinese
3. Trader Indians and Sri Lankans
4. Former invader Europeans

This rich racial mix has had a significant influence on the Malay cuisine. Traditional recipes from all four groups have been combined and adapted to suit different palates, and in some cases in keeping with religious taboos.

The most popular form of cooking is stir frying, a technique acquired from the Chinese. A kuali or a wok therefore tends to be the most important utensil in a Malaysian kitchen. Soy sauce is an indispensable flavouring agent, this also being acquired from the Chinese. Many Malaysian dishes are based on Indian curries, although not as hot and slightly sweeter than those from which they are derived. Malaysians like their food enriched with coconut milk and spiced with chilli peppers.

The main dietary staple is rice particularly nasi (steamed rice). Malaysians do not define food as a meal if rice has not been part of it. Rice is usually served with a number of side dishes which supply other needed nutrients, but are considered by the consumer as pleasing accompaniments to help the rice go down (Wilson, 1975). Rice or rice flour is the commonest constituent of cakes eaten daily or on special occasions such as circumcision, marriage or a house raising.

Because much of Malaysia is coastal, fish and other sea foods play a large and important part in the Malaysian diet. For many, fish is the chief source of protein and it is eaten in many ways - stewed, curried, fried or roasted. Small fish may be preserved by salting and drying and used as seasoning in other dishes. Fish products may also be preserved by making pastes. *Belachan* is made by fermenting and pounding together whole small prawns, it can be used in curries and sauces, as well as in side relishes (Wilson, 1975). Fruits tend to be snack foods although water melon and pineapple are eaten as a side relish with a meal. Malaysian food is also increasingly being subjected to Western influences. For example mayonnaise and salads are now regularly used as garnishes for cold dishes such as lobster (Lai, 1984).

Hot and cold (or Yin and Yang to the Chinese) foods are concepts widely adhered to in Malaysia. All food can be categorised as having either "heating" or "cooling" properties. For example meats are considered hot foods and all vegetables are classified as cold with the exception of raw papaya which is a hot food. Some foods

are in-between and are graded as being neutral. The most obvious example of a neutral food is rice. There are certain traditional ways of judging whether a food is hot or cold depending on its taste, its method of preparation and its physical effect on the body. Cooking can alter the properties of an ingredient. Foods that are refrigerated become cool, roasting and frying makes a food become hot. Steaming does not alter the property of any raw ingredient. All foods are considered to have a remedial or curative value and a nutritious diet should strike a balance between the two main categories of foods. A balanced meal should therefore include some foods that are cooling such as vegetables and some that are warming such as meat and a good amount of neutral food such as rice. Hot and cold foods can be used to generally stay healthy as well as to treat illnesses. Disease is said to occur when the body is out of balance. Balance is restored by treating a cold illness with hot or heating foods and vice-versa. Some illnesses are believed to be caused directly by what is ingested. Malaria is a result of eating sour fruit or drinking water that has not been heated and goitre swellings may be a result of eating excessive cold foods (McKay, 1980).

Many Malaysians consider the post-partum woman to have entered an unhealthy state and should therefore not eat cooling foods such as fruit and vegetables. Dietary restrictions are adhered to for 40 days after child birth (Wilson, 1980). Illnesses in children are often attributed to an injudicious diet of the mother during pregnancy. For example skin problems will afflict the child whose mother has broken the taboo against eating certain fish such as the *Ikan ayuh* (McKay, 1980). This classification of food has no scientific basis and opinions on certain cateorgorizations may vary from region to region and even person to person (Lai, 1984).

In general it is the mother who does the cooking, although in some families, family members take turns to cook. Daughters notably are expected to help at meal times. For some boys on arrival at a British University it is the first time that they have had to cook for themselves and are solely responsible for their own diets. An example of a typical days dietary pattern is shown in Table 6.2.

Table 6.2

A typical days food consumption of a Malay Malaysian

Meal	Food
Breakfast	Noodles Meat dish or Bread and butter
Midday	Rice Meat dish Vegetable dish
Dinner	Fried Rice Meat dish Vegetable dish Soup Pickles
Drinks	Chinese tea Soya milk Fruit juice Water
Snacks	Fruit e.g. guava

6.2 The study

Malaysian students were recruited at the beginning of the academic year when they were initially measured. Subjects were then requested to return after 3 months and again after 6 months of residence in Oxford in order for measurements to be repeated. The numbers in each phase of the study are shown in Table 5.3.

Table 6.3

Subjects numbers in each phase of study

	Females	Males	Total
On arrival	53	56	109
After 3 months	31	34	65
After 6 months	9	13	22

Although the figures indicate a high drop out rate this was due to the fact that many of the subjects were only at Oxford Brookes University for one term, and had returned to Malaysia before the end of the 6 month period.

Anthropometric results

Subjects were measured for the following anthropometric variables: weight, height, biceps, triceps, sub-scapular, supra-iliac skinfolds, percentage body fat, mid-arm, waist, hip and chest circumferences. A comparison between the anthropometric measurements was made to examine any changes that may have occurred during their time spent in Oxford.

Tables 6.4 and 6.5 show the mean values for each of the anthropometric variables measured, on arrival in Oxford, and after 3 and 6 months of residence in Oxford for males and females separately. Only subjects which completed all three phases of the study are presented here. Data for all the subjects measured may be found in appendix C.4 and C.5.

Table 6.4

Changes in the anthropometric measurements: Females

	On Arrival		After 3 months		After 6 months	
	Mean	SD	Mean	SD	Mean	SD
Weight (kg)	48.4	7.26	49.3	5.03	49.16	4.59
Body Mass Index (kg/m^2)	20.17	3.86	21.36	1.86	20.41	2.25
Bicep (mm)	9.8	3.03	13.83	2.02	13	2.82
Tricep (mm)	15.4	4.66	17.0	3.0	16.4	2.41
Sub- scapular (mm)	13	3.46	16.5	4.09	16.6	1.67
Supra-iliac (mm)	12.8	6.01	14.66	7.64	15.6	7.63
Body fat (%)	26.28	4.11	29.17	3.80	29.35	2.13
Mid-arm circ. (cm)	22.7	2.52	23.83	1.61	23.5	1.58
Waist circ. (cm)	62.4	5.32	64.33	3.78	64.2	4.43
Hip circ. (cm)	86	6.28	90.33	7.67	86.6	6.42
Waist : Hip Ratio	0.72	0.03	0.71	0.03	0.74	0.03
Chest circ. (cm)	76.4	3.36	79	2.64	77	2.12

Table 6.5

Changes in the anthropometric measurements: Males

	On Arrival		After 3 months		After 6 months	
	Mean	SD	Mean	SD	Mean	SD
Weight (kg)	57.2	8.43.	57.3	6.97	58.43	6.58
Body Mass Index (kg/m^2)	20.11	3.71	20.13	3.17	20.52	3.00
Bicep (mm)	5.65	2.63	6.6	2.79	6.15	2.49
Tricep (mm)	8.2	4.46	8.2	4.56	8.85	4.01
Sub- scapular (mm)	10.25	4.19	11.8	4.39	12.7	5.48
Supra-iliac (mm)	10.65	8.00	10.25	5.85	10.05	4.79
Body fat (%)	13.68	6.05	14.3	5.37	14.67	4.58
Mid-arm circ. (cm)	25.15	2.71	25.05	2.45	25.3	2.17
Waist circ. (cm)	70.4	6.53	70.2	5.57	70.1	5.27
Hip circ. (cm)	88.5	5.50	87.1	4.67	89.0	3.88
Waist : Hip Ratio	0.79	0.04	0.80	0.03	0.79	0.03
Chest circ. (cm)	83.3	7.02	84.0	5.65	85.1	6.19

No significant differences were found between any of the anthropometric measurements.

The measurements presented were compared with published anthropometric data for Malay estate workers resident in Kedah and Johor (Chee *et al.*, 1996). Table 5.6 shows a comparison between the data from Chee's study and the anthropometric data for the Malaysian student after 6 months in the UK. Mean values are presented.

Table 6.6

Comparison of anthropometric measurements with published data

	Chee (1996)		**Oxford Brookes (1997)**	
	Female	**Male**	**Female**	**Male**
Weight (kg)	55.3	63.5	49.16	58.43
Height (m)	1.51	1.63	1.56	1.68
Body mass index (kg/m^2)	24.2	23.8	20.20	20.70
Body fat (%)	34.1	22.3	29.35	14.67

As the Table shows, the subjects at Oxford Brookes were lighter in body weight, were taller, had lower BMI's and had less body fat than the Malay estate workers. These differences may be attributed to age. The average age of subjects in Chee's data were 44 years of age and the average age of subjects in the Oxford Brookes data were 22 years of age. It is well established that body fat increases with age (Westerterp, 1994).

BMR

BMR (kJ/24h) was also measured in 15 females and 11 males. The table below shows the average BMR measured in the 9 females and 11 males that were present in all three phases of the study. BMR was measured three times over the 6 month period.

Table 6.7

BMR measurements (kJ/24 h)

	On Arrival		After 3 months		After 6 months	
	Mean	SD	Mean	SD	Mean	SD
Females	5112.07	494.11	5267.59	804.51	4545.71	762.06
Males	6310.09	774.38	7091.25	948.03	5703.75*	773.51

*P > 0.05

No significant differences were found between the BMR measurements in the female subjects after 6 months in Oxford. However, in the male subjects a significant difference (P>0.05) was found.

The BMR measurements were compared with those measured in Singaporean medical students (Saha, 1985). On average male students had a BMR of 5861 kJ/24 h and females had a BMR of 3931.2 kJ/24 h. These values are distinctly lower than the BMR values identified in the Malaysian students measured in Oxford. This difference is possibly due to the different climatic conditions in which the subjects were measured. It is well established that in tropical climates BMR is lower than in more temperate climates such as in the UK (Castro, 1938; Henry & Rees, 1991).

Since there were no significant changes in weight, body fat or indeed any other anthropometric measurements this could mean that the Malaysian students are able to

remain in energy balance. To investigate this further we examined the differences in food intake and food selection.

Food diaries

Habit changes can be manifested in food selection, meal patterns, food preparation practices and beliefs associated with specific foods (McArthur *et al.*, 1989). Food diaries were kept in order to assess any changes in the habits of Malaysian students. Written records for recording food intake such as diaries are advantageous as they preserve a degree of privacy for the subjects, permit reinforcement of oral instructions with written ones and produce a measure of variety in selected foods (Schultz *et al.*, 1994). Additionally, food diaries provide a subjective measure of English literature, which is particularly useful in studies such as this where English is not the subjects' first language.

Food diaries enabled the examination of food selection and changes in the macro-nutrient composition and energy densities of the diets eaten in Malaysia and Oxford. The results for the 3 day recall diary for foods eaten in Malaysia and two 3 day food diaries completed after 3 and 6 months residence in Oxford are presented in Table 5.8 Whilst records of current food consumption are associated with fewer sources of error than estimates of past intake it was essential to ask subjects to recall food eaten previously, to establish a typical Malaysian diet with which to compare current dietary records kept in Oxford. However, it is acknowledged that all methods which assess habitual food intake in free-living individuals rely on information supplied by the subjects themselves, which may not be correct (Schultz, 1994). There is much debate over how long food diaries should be recorded to portray an accurate picture of food intake. Whilst Bingham and Nelson, (1991) advocate a need for 7 day diaries to account for individuals who substantially vary their intakes of food from day to day Basiotis *et al.* (1987) maintains the number of days required to estimate usual intake depends on the nutrient being studied. Whilst 41 days of records may be required to

assess vitamin A intake, 3 days are more than adequate to estimate food energy. Diaries were kept for 3 day periods in this study (one week day, one weekend day and one other day), longer lengths of study may cause boredom on the part of the subject and may result in less accurate records or greater drop out rates (Gersovitz *et al*, 1978).

Table 6.8

Differences in the energy density and macro-nutrient composition of the diets consumed in Malaysia and Oxford

	Malaysia		Oxford 3 months		Oxford 6 months	
	Mean	SD	Mean	SD	Mean	SD
Energy density kJ/g	4.98	1.55	6.19	1.84	6.49*	1.88
Energy kJ	6464	2041	6791	1548	5715	1866
Protein g	81.31	30.33	61.28	2.45	54.08*	26.45
Fat g	59.08	38.32	72.29	37.53	56.33	25.71
Carbo-hydrate g	191.39	60.18	211.03	63.79	171.77	63.46

* $P<0.05$

A significant difference in the energy density of the food consumed in Malaysia compared to Oxford was found. There was a significant drop in the amount of protein consumed. No significant changes were noted for fat, carbohydrate and energy intake.

Under-reporting

To ensure that the food intake data recorded here is accurate, the data was tested for under-reporting by the subjects. There are several methods which can be used to assess under-reporting and these include techniques such as 24-hour urine nitrogen analysis and doubly-labelled water. These techniques are expensive and require skilled personnel. However, a simpler method does exist which simply requires the

subjects BMR to be measured or calculated. Energy intakes of less than 1.2 x BMR can be excluded from analyses with certainty as erroneous estimates of habitual food intake (Bingham & Nelson, 1991). Under-reporting has been shown to be more likely in overweight individuals and this could be due to failure to report all food eaten, or because the subject decided to diet during the experimental period (Bingham & Nelson, 1991). However Livingstone *et al* (1990) found no such association between body mass index and the extent of under-reporting. Therefore the possibility of under-reporting should be taken seriously with respect to all subjects, regardless of body weight.

To test if the subjects were under-reporting in their 3 day food diaries, the average energy intake (EI) over 3 days was compared to measured BMR. The energy intake divided by BMR was on average 1.24 (SD 0.11).

Food frequency questionnaire results

Food frequency questionnaires (FFQ) have the advantage over food diaries because of their ease and uniformity of administration, their low cost and the fact that they require little effort on the part of the subject (Jenner, 1989). Subjects were asked to complete two FFQ's, one for foods eaten in Malaysia and one for foods eaten in Oxford. FFQ's were administered to the subjects prior to the food diaries in accordance with Bingham & Nelson, (1991) for two reasons. One, so the results did not mimic those presented in the diaries and two, because the diaries may have drawn the respondents' attention to their actual diets and thus biased the results.

In addition to the results obtained from the Malaysian students a group of Caucasian UK students were also asked to complete the FFQ. The results of which are presented in Table 6.9 and Figure 6.1.

Table 6.9

The number of times certain foods are consumed in 24 hours

Food	Malaysian Students in Malaysia	Malaysian Students in Oxford	Caucasian Students
Red Meat	0.6	0.3	0.33
White Meat	0.65	0.48	0.47
Sausages& Burgers	0.27	0.35	0.21
Fish	0.43	0.14	0.19
Bread	0.58	0.89	1.32
Potatoes	0.38	0.4	0.53
Rice	1.4	0.97	0.31
Noodles	0.46	0.29	0.43
Chips	0.29	0.22	0.17
Cereals	0.22	0.37	0.45
Fruit	0.66	0.47	0.73
Vegetables	1.13	0.82	0.86
Cheese	0.28	0.27	0.42
Eggs	0.57	0.62	0.2
Crisps	0.38	0.14	0.36
Biscuits	0.61	0.42	0.38
Chocolate	0.47	0.48	0.48
Coffee & Tea	0.82	0.92	1.14
Fizzy Drinks	0.3	0.22	0.56
Fruit Juice	0.44	0.35	0.72
Alcohol	0.06	0.06	1.01

*ANOVA showed no significant difference between the overall diets

The data in the table above can also be seen in Figure 6.1, presented in the form of a bar chart to graphically illustrate differences in the diets consumed by Malaysian students at home in Malaysia and whilst studying in Oxford, as well as a comparison with Caucasian students in Oxford.

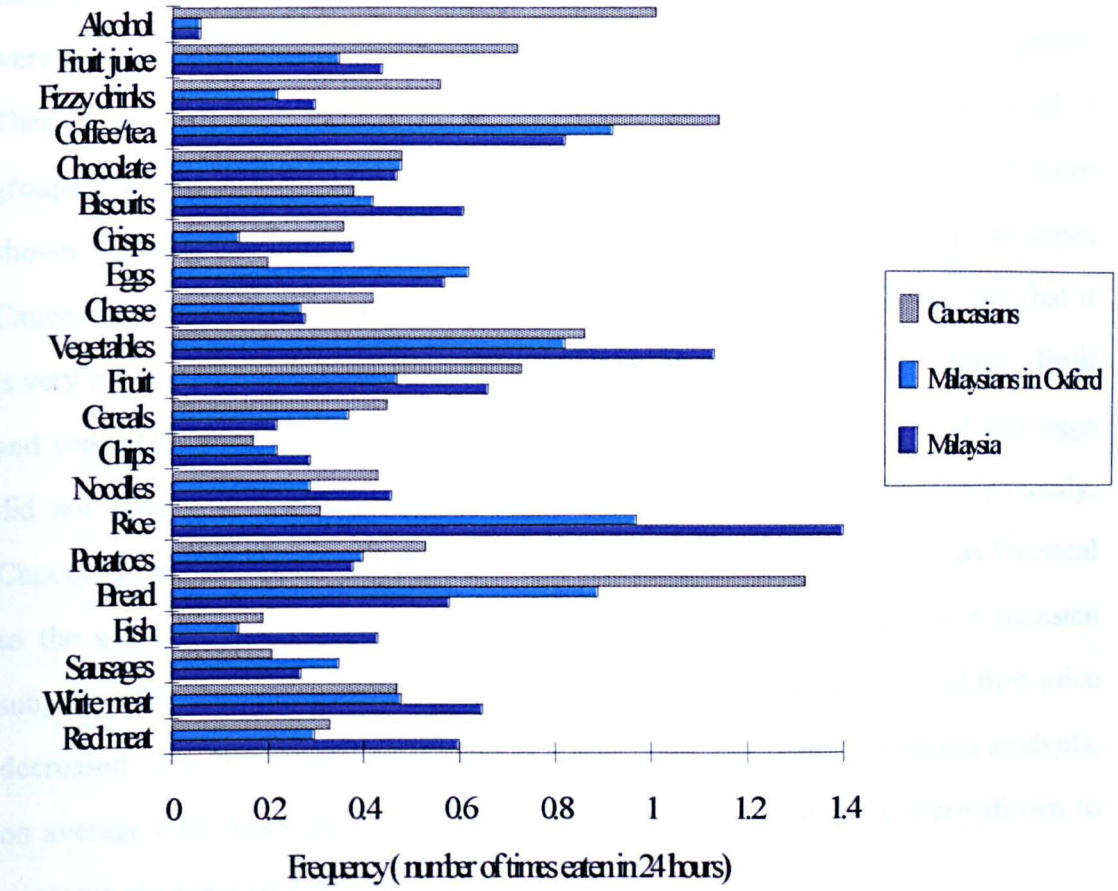

Figure 6.1

Frequency of consumption of different foods by Malaysian and Caucasian students

There was a decrease in consumption of both red and white meat by the Malaysian students in Oxford compared to what they ate at home in Malaysia. A decrease as great as 50% was demonstrated in the consumption of red meat in particular, bringing the consumption of meat down to similar levels to that exhibited by Caucasian

students. Sausages and burgers, however, were eaten more frequently in Oxford than Malaysia and more often in Malaysian students than Caucasian students. Fish was eaten less frequently in Oxford, although Caucasians ate a lot less. There was an increase in the consumption of bread but this was not eaten as regularly as by Caucasians. The frequency of consumption of rice decreased greatly, rice was rarely eaten for breakfast in Oxford as it regularly was in Malaysia, instead toast or cereals were eaten instead. Noodles followed a similar to pattern to that of rice consumption. There were very little differences in the consumption of potatoes between all 3 groups. The frequency of eating chips decreased although the Malaysians were shown to eat them more often than Caucasians. Cereals showed an increase, Caucasians were still shown to eat far more, this is thought to be due to the fact that it is very common for Caucasian students to eat some form of cereal for breakfast. Fruit and vegetables were both shown to decrease. The consumption of cheese and eggs did not greatly alter in any way. Crisps and biscuits were eaten less frequently. Chocolate remained practically the same and the amount eaten in Oxford was identical to the average consumption frequency of 0.48 times per day eaten by Caucasian subjects. Tea and coffee consumption increased but carbonated drinks and fruit juice decreased. Alcohol remained the same as it was rarely drunk by Malaysians students, on average 0.06 times per day compared to Caucasian students who were shown to consume alcohol 1.01 times per day.

FFQ validation

It is essential that FFQ's are rigorously tested and validated against standards of known accuracy. However all methods of measuring dietary intake include an element of bias and therefore only the "relative" validity of a questionnaire can be obtained with what is believed to be a more accurate measure of energy intake (Nelson, 1991), in this case a food diary. It is also essential that questionnaires are validated in the population in which they will be used (Bingham & Nelson, 1991).

To validate the food frequency questionnaire used in this study, correlation's were performed for protein, fat, carbohydrate, energy and the energy density of the food consumed, using data obtained from the FFQ and the food diaries completed by Malaysian students. The regression coefficients are given in Table 6.10.

Table 6.10

Regression coefficients of the relationship between macro-nutrients consumption assessed by food frequency questionnaire and a 3 day food intake diary

Macro-nutrient	***r***
Protein	0.352
Fat	0.48
Carbohydrate	0.67
Energy intake	0.66
Energy Density	0.21

Although these correlation coefficients may appear low, Nelson (1991) examined correlation's in 12 validation studies and found *r* values ranging from 0.08 - 0.94 demonstrating that there is no consistency in the strength of correlation for any given nutrient.

The FFQ in this study demonstrated interesting patterns of dietary changes for groups of students. The FFQ administered was in no way quantitative. The results merely showed changes in the frequency of consumption of different foods and not necessarily in the quantity of particular foods that were consumed.

Meal Patterns

When looking at the individual meals eaten by the Malaysian students it became evident that breakfast was the most likely meal to have changed. There was no evidence at all of the students eating a traditional Malaysian breakfast of rice or

noodles whilst they were resident in the UK. Instead the students were more likely to have toast or cereal or to skip breakfast altogether, in line with Caucasian students. Tong (1991) and Chau *et al* (1990) both noticed a mix of American and Chinese foods consumed at breakfast where-as afternoon and evening meals were predominantly composed of traditional Chinese food.

Lunch showed less changes than breakfast and where possible rice or noodles and a vegetable and/or a meat dish was consumed, fewer dishes were prepared than at dinner. On occasions when the students were not at home and unable to cook, burgers and French fries seemed to be the most popular foods.

Dinner showed the least changes and was similar to that consumed in Malaysia. Some direct exchanges were made dependant on the availability of certain foods in UK supermarkets. For example fish fingers were frequently eaten instead of fresh fish, crab sticks instead of crabs and sausages instead of pork or beef.

Overall it would seem that both Malaysian and UK food habits and practices were employed by the Malaysian students whilst living in Oxford.

6.3 Discussion

Anthropometric measurements

No significant differences were found between any of the measurements in either the male or the female groups in the 6 months of UK residence. It appears that despite differences in the Malaysian and British food and the energy densities of these foods, the subjects have been consuming the correct amount of energy to meet and not exceed their individual energy requirements. This would suggest that the subjects have been able to modulate their energy intakes and have been able to remain in energy balance and weight stable.

BMR measurements

There were no significant differences in measured BMR in the female subjects, in accordance with the corresponding stable body weights and lean body mass.

However the male subjects showed a significant decrease in BMR. There are no obvious reasons why this may have occurred as there were no significant changes in either body weight or body fat. One possible explanation for the reduction in BMR is a decrease in the daily activities of the male subjects, but this presumably would be reflected in their anthropometric measurements. Another possible explanation is a decrease in dietary energy. Keys (1950) demonstrated a decrease in the BMR of young men when placed on starvation diets. Nevertheless no significant decreases in energy were observed from the 3 day food records. However there was a significant decrease in protein intake. Protein intake had decreased from 81.3 g to 54.1 g whilst this is a significant reduction it is still with the limits proposed by the Department of Health (1991). Low protein intakes can depress BMR (Mitchell, 1964), this is because during starvation there is a decline in protein synthesis and degradation which limits bodily protein losses and hence the energy expenditure required to maintain these processes also declines. However Soares (1988) has shown that low protein intakes on days preceding measurements fail to influence BMR. Therefore any reduction in BMR due to reduced protein intake must be consistent over time. Nevertheless there were no changes in the anthropometric measurements so the reduction in BMR as a result of decreased protein intake cannot be confirmed. It is likely that the reduction in BMR is due to a training effect. Soares & Shetty (1986) noted a significant decline in BMR in subjects measured from week to week over a 6 week period. As the subjects become more familiar with the apparatus for the measurement of BMR they subsequently become less apprehensive. Of course the decrease in male BMR could be due to any combination of these factors or simply due to a reduction in the number of students involved in each phase of the study.

Variations in Food intake

Under-reporting

The EI of the subjects were expressed as multiples of observed BMR A mean EI:BMR ratio of 1.24 was found for the Malaysian subjects. The FAO/WHO/UNU (1985) state that total requirements for moderately active and active people should have an EI:BMR in the region of 1.5 - 2.1. Clearly the EI:BMR of our subjects was well below this level. Goldberg *et al.* (1991) in a study using fundamental principles of energy physiology calculated a cut-off point of 1.35 (1.45 in cases where BMR is calculated not observed). However she does go on to say that it is possible for exceptional individuals to exist on an EI of slightly less than 1.2 BMR, if the subjects are to remain virtually moribund. Whilst I would not describe the subjects in this study as moribund they were not particularly active. The majority of their time was spent studying, reading, playing computer games, watching television or shopping. When asked none of the subjects admitted to taking any form of regular exercise. Many of the Malaysian students hold the view that they are in England for one reason, and that is to study.

However, if 1.2 BMR was a correct reflection of mean food intake then a loss in body weight would be expected. No weight loss was revealed during the 6 months of this study. Therefore it must be assumed that the subjects are under-reporting.

Serious under-reporting has particularly been found in obese subjects (Prentice *et al.*, 1986). None of the subjects in this study were obese. There may be many reasons why subjects under-report their food intake. These reasons include; altered eating habits due to increased consciousness of what is being eaten, can't be bothered to record intake, subjects may be embarrassed or find it inconvenient (Macdiarmid & Blundell, 1997). The subjects in this study may have had additional problems recording their food intake because English is not their first language. In light of this it seems that the data presented here may be an underestimate of true food intake but was the best obtainable data possible in the circumstances.

Comparisons of food intake in this and other studies

Table 6.11 shows similar studies which have looked at dietary changes in subjects migrating from one country to another.

Table 6.11

A comparison of diets in similar studies

Reference	Nationality	Sex	Conditions	Protein %	Fat %	Carbohy-drate %	Energy kJ
Present study (1997)	Malaysian	m/f	Malaysia	24.5	17.8	57.7	64680
		m/f	Oxford after 3 months	17.8	21.0	61.2	6792.4
		m/f	Oxford after 6 months	19.2	20.0	61.0	5715.3
Yang (1996)	Chinese	m/f	Before immigration S.E. Asia	19.8	20.0	60.2	9111.9
		m/f	After immigration in USA	19.8	23.5	56.7	8944
Schultz (1994)	Chinese	f	After immigration	15	34	50	5803
	Chinese-American	f	1st generation	16	33	50	7535
	White American	f	Control group	14	34	49	6828
Anderson (1995)	South Asian	f	1st generation	13.1	42.4	44.5	7960
		f	2nd generation	13.7	39.8	46.3	7780
DoH (1991)	British	m/f	Recommendations	15	35	50	

As discussed in the relation to BMR a decrease in protein consumption was noted between the diets consumed in Malaysia and after 3 and 6 months in the UK by the subjects in this study. The main reason for this was due to a reduction in the amount of meat and fish eaten. Both red and white meats were eaten less frequently in the UK. This is presumed to be because of cost rather than dietary preferences as meat products such as sausages were still eaten regularly. Fish is much cheaper and easy to buy in Malaysia because of the close proximity of the sea and may explain why less of fish is eaten in the UK. There appeared to be no changes in the diary products such as eggs besides which many Asians are known to be lactose malabsorbers. Whilst protein intake has reduced it is still within limits stated by the Department of Health (DoH,1991). Interestingly Yang (1996) found no change in the consumption of protein in Chinese subjects migrating to the USA. Whilst both Schultz (1994) and Anderson (1995) found increased protein intakes between 1st and 2nd generation immigrants living in Western societies. Although the protein increases in both studies were very small.

Although the total grams of fat had not altered significantly in the diets of Malaysian students in this study, the amount of fat given as percentage of the whole diet had increased. Fat consumption after migration to the USA has been shown to increase in other immigrant studies (Yang & Read, 1996; Tong, 1991 and Chau *et al.*, 1990). The DoH recommends that no more than 35% of the energy content of the British diet should come from fat. Both the Malaysian and the Oxford results show percentage fat levels well below 35% and therefore the Malaysian students are not putting themselves at any risk of increased chances of coronary heart disease or other fat consumption related diseases.

Carbohydrate levels were not shown to alter significantly whether expressed in absolute terms or as a percentage of total dietary intake.

Total energy increased in the first 3 months but then decreased by the end of 6 months. No significant changes were found.

There was a significant increase in the energy density of the food consumed. This is a direct result of the Malaysian consuming a greater percentage of their total energy intake from fat, seemingly as a result of incorporating more British foods into their diets. Table 5.1 showed how typically British foods tend to be far more energy dense the foods consumed in Malaysia. Anderson *et al.* (1995) demonstrated an adoption of British foods into the diets of female Indian immigrants to the UK. She noted that many British convenience foods (often very energy dense) had been incorporated into the traditional Asian diet. Other studies have observed that people who leave their home country continue to adhere to certain ethnic dietary practices whilst simultaneously experiencing new foods (McArthur *et al.*, 1989). Whilst it is anticipated that the longer the students remain in the UK the greater their exposure to UK foods and the more UK food habits they will adopt, complete abandonment of native food habits are unlikely (Yang & Fox, 1979).

FFQ

Results from the FFQ suggest that increase in the consumption of bread and the decrease in consumption of rice is due to the fact that bread is used as a replacement for rice. In a similar study of South East Asian immigrants living in America Ho (1966) found that rice was frequently replaced with bread rolls. There was a decrease in the amount of fish eaten although fish was not eaten as infrequently as it is in Caucasian students. Again this is thought to be because in Malaysia the sea is always in close proximity making sea food much easier and cheaper to buy. Fruit and vegetables were both shown to decrease, this likely due to the fact that fruit and vegetables are more expensive in the UK and there is not as much variety as can be found in Malaysian market stalls. Ho *et al.* (1966) similarly found that there was a

decrease in the vegetables consumed and the variety of vegetables eaten on arrival in America but conversely found an increase in the consumption of fruit. Grivetti & Paquette (1978) in a study looking at dietary patterns of Chinese in China and America found that the same amount and diversity of vegetables were eaten in both countries, however diversity was maintained through a different spectrum of vegetables in each country.

When asked what, if any, native foods were unavailable in the UK that subjects "missed" the following foods were listed:

Fresh fish

Variety of vegetables

Pickles

This naturally accounts for the decrease in the consumption of these foods shown in the FFQ. Grivetti & Paquette (1978) asked the question are increases in food frequencies actual increases or could they be better explained as food substitutes or adaptations? It would appear that the availability of certain foods in UK supermarkets influenced the frequency of how often certain foods were eaten. The students were not intentionally trying to alter their native diets but typically Malaysian food was not available and so UK substitutes were purchased. Yang & Fox (1979) noted similar practices in Chinese people living in the USA, where American foods were not always eaten in their natural style, instead modified according to the flavour or texture preferences of the Chinese and accepted as new "Chinese-like" foods.

It needs to be recognised that during the last few decades Asian countries have been undergoing industrialisation and rapid economic change. Concurrent with this has been a Westernisation of the dietary pattern (Yang & Read, 1996). Therefore changes in diets as a result of migration will become less pronounced with time.

6.4 Conclusions

There was a significant decline in the amount of protein eaten by Malaysian students residing in Oxford and a significant increase in the energy density of the food consumed. Despite this there are no significant weight or any other anthropometric changes in the Malaysian students. It would appear that in this case, it is possible for changes in energy density to be recognised by the body, although at first sight it would seem, that from data in the literature, that this is not always the case. Whilst animal models have shown accurate detection of foods with differing energy densities and are able to adjust their food intakes to maintain constant energy intakes (Cowgill, 1928; Janowitz & Grossman, 1949) human studies are less reliable. Wooley *et al.* (1972) elegantly demonstrated how unreliable humans were at detecting changes in energy intake. He supplied volunteers with one liquid meal per day. For one week subjects were provided with exactly the same amount of energy as would normally be consumed at lunch, but then for the following 2-3 weeks the subjects were provided with 50% less or 50% more than their usual amount. Subjects were then asked to guess if they had received more or less energy than usual. Only 55% of the subjects guessed correctly (similar to an entirely random prediction). Therefore it can be deemed that humans are not very good at recognising the energy contents of meals they have just eaten.

Whilst humans are unreliable at predicting energy consumed at one meal it is possible that adjustments may be made over longer time intervals such as a day or several days. Duncan *et al.* (1983) demonstrated that when subjects received meals identical in volume but with high and low fat contents and hence high and low energy densities for 5 days each, those consuming high energy diets were found to consume high calorie intakes and thus were not able to remain in energy balance when presented with energy dense foods. However, Lissner *et al.* (1987) in a similar experiment failed to show this effect and equal calories were eaten regardless of whether low or high energy density diets were being consumed. Whilst these results may appear confounding greater clarity is obtained when a time factor is involved. Duncan's

experiment only asked the subjects to adhere to each of the low and high energy density diets for 5 days, whilst Lissner's subjects were required to continue each of the diets for two weeks. It may appear that the body can adapt to changes in energy density, if not immediately, then over time.

The subjects in this study were resident in the UK for a period of 6 months and thus it would appear in the given time frame they were able to adjust their intakes accordingly to prevent any significant increases in body weight.

Summary

To summarise it appears that Malaysian students are able to remain in energy balance and are weight stable at least during the first 6 months of residence, despite the choice of energy dense food available to them in the UK. When it is considered that if a person was to be in positive energy balance, where energy intake was greater than energy expenditure by as little as 50 kcal per day, in 10 years time this would lead to serious obesity (Passmore, 1971), the ability of man and indeed the Malaysian students in this study, to remain in energy balance is quite remarkable and exhibits proof of a very precise mechanism by which the human body can maintain energy balance. In many cases energy balance may be retained for several years (Garrow, 1974). This suggests that the subjects in this study are able to modulate their food intake in response to the changes in the energy densities of the food available. However, whilst there is so much contradictory data in the literature more extensive studies are needed to fully develop a model for energy balance in different population groups.

Chapter

7

Variations in Arm-span and Height with Special Reference to Ethnicity and Gender

7. Variations in Arm-span and Height with Special Reference to Ethnicity and Gender

7.1 Introduction

Height is one of the easiest anthropometric measurements to make, however, its simplicity should not detract from its importance as an anthropometric measurement. Height is habitually used in conjunction with weight to assess nutritional status. Height is used for "acceptable" weight tables and BMI. Since height is a simple indicator of body size, it is also used when standardising other measurements such as muscle strength or lung volume and peak flow which may vary with body proportions. Unfortunately it is not always possible to measure height; this may be due to disability or deformity, and notably in elderly subjects whom may show extensive spinal curvature. It is well established that height in old age is less than it was in youth. Trotter & Gleser (1951) suggested there was a progressive loss of height from 30 years of age onwards. This is largely due to changes in the spine, flattening of cartilaginous discs between the vertebrae and even the flattening of the vertebrae bodies themselves, resulting in an increased curvature of the spine (kyphosis). Brown and Wigzell (1964) went on to confirm that there is a significant loss of stature with ageing and this has been estimated to be in the region of 0.5 inches for every 20 years of adulthood. It has been suggested that because of this loss of height with ageing, BMI and other similar indices which use height may be inappropriate for use in elderly populations (Rabe *et al.*, 1996).

It is possible that height may be substituted with other anthropometric variables. Other suitable anthropometric measures include knee height, arm length, subischial length, demi-arm-span and arm-span. Hertzog *et al.* (1969) used radiographs of tibia length to estimate the statural loss due to a result of ageing. Chumlea *et al.* (1985) in a study of 236 men and women aged 65-104 years also found knee height to be highly correlated with stature ($r = 0.67$ for male and $r = 0.65$ females) and presented

equations for predicting total height from knee height. Sethi *et al.* (1995) studied total arm-length and subischial length in women. Subischial length or long bone lengths are mainly affected by the secular changes and are least affected by age associated shrinkage which is frequently found to affect height. Bassey (1986) reported that demi-span may be used in clinical assessment as an alternative measure of skeletal size, since height and demi-span are highly correlated ($r = 0.74$) in European subjects.

Arm-span is another alternative measure which may be used as a proxy indicator for height. Aside from estimating height, arm-span has other uses. By knowing the normal arm-span : height relationship, disorders such as Marfan's syndrome where arm-span exceeds height can be recognised (Scott, 1992) and children with growth abnormalities identified (Engstrom *et al.*, 1981).

The stature of a "well made man" is held to be equal to his arm-span (Pheasant, 1997). Work connecting arm-span and height has mostly stemmed from the famous Leonardo da Vinci picture entitled "The proportions of the human body according to Vitruvius". Vitruvius was a Roman architect who believed the perfect proportion of man to be the template for perfect proportion in architecture (taken from Schott, 1992). Da Vinci's picture illustrates the concept of arm-span being the same length as height, although this is a widely held assumption, in practice this is not necessarily the case.

In 1930, Harris and co-workers reported a close relationship between arm-span and height. Much of the early anthropometric work relating the association between arm-span and height was confined to Caucasian subjects. Steele & Mattox (1987) reported a significant relationship between arm-span and height in black and white females. Although both correlation's were high, arm-span and height was more highly correlated in white subjects than black ($r = 0.894$ for white females and $r = 0.776$ for black females). Further analyses of co-variance indicated there was a significant interaction between race and the relationship between arm-span and height ($P<0.01$). Such results indicate that the arm-span and height relationship is different for black

and white subjects and analyses for each race should be done separately. Furthermore the difference in the relationship between arm-span and height between black and white subjects is also known to differ with age. McPherson *et al.* (1978) found that black populations show a greater decrease in height with age than white subjects, thus altering the arm-span : height relationship.

Not only would it appear that there are variations in the arm-span : height relationship between different ethnic groups but it has also been suggested that there are sex differences. Engstrom *et al.* (1981) measured arm-span and height in 160 white children and found that in boys the mean arm-span always to be greater than the mean height. The difference in girls was always <1 cm, but the sign changed from negative to positive at 11.5 years of age. McPherson *et al.* (1978) also found a sex difference when looking at age changes in black and white Americans. Black males were found to lose 4.2 cm of height for every 20 years of age whilst black females were reported to lose 3.4 cm of height. It should be noted that skeletal disease is more noticeable in females and this increases with age and will of course affect the arm-span to height relationship.

It is endeavoured to examine the relationship between arm-span and height between the sexes and within four distinct ethnic groups. This will allow an assessment of the validity of arm-span and height, and the practical usage of these as clinical measures for both sexes and different ethnic groups.

7.2 The subjects

Young, free-living, healthy persons who show no age related changes in skeletal composition are the ideal subjects to test this relationship, therefore the subjects recruited were on average 23.3 (SD 5.5) years of age and were all below 40 years of age.

Subjects were divided into four broad ethnic groups: a) Afro-Caribbean, b) Asian, c) Caucasian and d) Oriental. This arbitrary classification enabled us to categorise

residents from many countries around the world into easily definable groups depicting ethnic origin. Table 7.1 shows how the different nationalities represented in this study were divided into the four ethnic groups.

Table 7.1

Classification of the ethnic groups

Ethnic Group	Countries Incorporated
a) Afro-Caribbean	Afghanistan, Jamaica, Kenya, Nigeria, Tanzania, Uganda, Zambia
b) Asian	India, Pakistan, Sri-Lanka
c) Caucasian	Australia, France, Germany, Greece, United Kingdom
d) Oriental	China, Hong Kong, Japan, Korea, Malaysia, Singapore, Taiwan, Thailand

7.3 The results

The arm-span and height data was collated for each sex and ethnic group and was tested for normality. Low levels of skewness and kurtosis indicated that parametric tests were appropriate. Table 7.2 shows the arm-span and height measurements for males and females in the four ethnic groups. Data is presented for each of the four ethnic groups which have been sub-divided to show the male and female data separately. Mean data values are presented with the corresponding standard deviations.

Table 7.2

Arm-span and height data for males and females of four ethnic groups

Ethnic Group	Sex	n	Arm-span (cm)	SD	Height (cm)	SD
Afro-Caribbean	m	50	182.4	10.20	175.3	7.55
	f	50	168.3	9.11	162.3	6.44
Asian	m	50	177.6	8.00	172.7	6.42
	f	44	160.0	7.67	158.0	4.92
Caucasian	m	103	181.3	8.28	179.2	7.19
	f	116	163.6	7.78	164.6	6.97
Oriental	m	69	172.8	7.46	170.9	6.49
	f	71	159.8	7.42	159.8	6.24

Height

The height data collected at Oxford Brookes University was compared to the anthropometric standards of Frisancho (1990), Chee *et al.* (1996) and the Department of Health and Social Security (DHSS, 1986). Table 7.3 directly compares our results for height with Frisancho's standards for black and white, male and female subjects, the DHSS standards of adults in Great Britain, and Chee's data heights of Malay and Indian subjects.

Table 7.3

A comparison of height (cm) between two studies in two ethnic groups

Study	Ethnic group	Male	Female
Frisancho (1990)	Black	175.8	162.6
Oxford Brookes (1997)	Afro-Caribbean	175.3	162.3
Chee (1996)	Indian	164	152
Oxford Brookes (1997)	Asian	172.7	158
Frisancho (1990)	White	176.9	163.3
DHSS (1986)	Great Britain	176.0	161.5
Oxford Brookes (1997)	Caucasian	179.2	164.6
Chee (1996)	Malay	163	151
Oxford Brookes (1997)	Oriental	170.9	159.8

For the Afro-Caribbean/black ethnic group the figures measured at Oxford Brookes are very similar to Frisancho's. However, our subjects are very much taller than Chee's results for Indian and Malay subjects and the Caucasian/white subjects appear to be slightly taller than those presented by Frisancho. When the Oxford Brookes data are compared to the British population (DHSS, 1986) the difference is even greater. It is a widely held belief that university students are taller on average than the general population, since positive correlations have been found between I.Q. and height (Downie *et al.*, 1997) it is suggested that the sample presented is typical of university students and not the British public at large.

Using the data from the present study, differences in height between the sexes and within the ethnic groups were investigated.

With respect to the female subjects, on average the Caucasian ethnic group was the tallest, being 6.6 cm taller than the Asian subjects who were the shortest of all the ethnic groups. There were very significant differences in height between the female

ethnic groups. The P values indicating the significance of the height differences between the ethnic groups are presented in Table 7.4.

Table 7.4

Significant differences in height between the female ethnic groups

	Afro-Caribbean	Asian	Caucasian
Asian	P<0.001		
Caucasian	NS	P<0.0001	
Oriental	P<0.05	NS	P<0.0001

Likewise in the male subjects the Caucasians were the tallest of the ethnic groups and were 8.3 cm taller than the Oriental ethnic group who were the shortest. There were again significant differences in height between the male ethnic groups. The P values indicating the significance of the height differences between the ethnic groups are presented in Table 7.5.

Table 7.5

Significant differences in height between the male ethnic groups

	Afro-Caribbean	Asian	Caucasian
Asian	NS		
Caucasian	P<0.005	P<0.0001	
Oriental	P<0.001	NS	P<0.0001

There were highly significant differences in height (P<0.00001) between males and females. However the degree of sexual dimorphism did vary between the ethnic

groups and this is exhibited in Table 7.6 The sex height difference is given as the mean male height minus the mean female height.

Table 7.6

The degree of sexual dimorphism in height

Ethnic Group	Sex difference in height (cm)
Afro-Caribbean	13
Asian	14.7
Caucasian	14.6
Oriental	11.1

As the Table shows there is a greater gender difference in height amongst the Asian ethnic group than any other group. The Oriental group exhibited the least gender difference for both height and arm-span measurements, although there were still significant differences between the heights of male and female Orientals ($P<0.00001$). It has been suggested that better nourished populations show a greater degree of sexual dimorphism (Eveleth, 1975), but since all subjects were of similar socio-economic class this suggestion is considered unlikely in this case.

Arm-span

Arm-span is unaffected by vertebral collapse or distortion of inter-vertebral discs associated with age and injury and therefore is particularly suitable to use as a proxy for height. Arm-span is also studied as an independent variable in ergonomics, when research is undertaken to estimate optimum work space and zones of convenient reach (Pheasant, 1997). The arm-span results indicate that whilst Caucasian females were the tallest ethnic groups, we can see that the Afro-Caribbean group had significantly longer arm-spans than all other ethnic groups. The Asian and Oriental

groups had similar length arm-spans that were significantly shorter than the Caucasian and Afro-Caribbean females. The P values indicating the level of significance of the arm-span differences between the female ethnic groups are presented in Table 7.7.

Table 7.7

Significant differences in arm-span between the female ethnic groups

	Afro-Caribbean	**Asian**	**Caucasian**
Asian	P<0.0001		
Caucasian	P<0.001	NS	
Oriental	P<0.0001	NS	P<0.01

The male ethnic groups exhibited the same pattern as the females, with the Afro-Caribbean's having the longest arm-spans. The Oriental males had arm-spans that were significantly shorter than all other ethnic groups. The P values indicating the significant differences between the arm-spans of the male ethnic groups are presented in Table 7.8.

Table 7.8

Significant differences in arm-span between the male ethnic groups

	Afro-Caribbean	**Asian**	**Caucasian**
Asian	NS		
Caucasian	NS	NS	
Oriental	P<0.0001	P<0.005	P<0.0001

The difference between arm-span and height between the sexes was highly significant ($P<0.00001$). The arm-span differences between the sexes and in different ethnic groups is shown in Table 7.9.

Table 7.9

The degree of arm-span sexual dimorphism

Ethnic Group	Sex difference in arm-span (cm)
Afro-Caribbean	14.1
Asian	17.6
Caucasian	17.7
Oriental	13

The Asian and Caucasian groups clearly exhibited the greatest sexual dimorphism in arm-span lengths. Whilst there were still significant differences in the length of arm-spans between Oriental males and females, this group showed the least sexual dimorphism.

Comparing arm-span and height

Comparison were then made between height and arm-span. If no significant differences were found then arm-span could be assumed to be a suitable substitute measurement for stature in situations when height measurements cannot be accurately measured .

Table 7.10

Differences between arm-span and height

Ethnic Group	Sex	Arm-span (cm)	Height (cm)	Mean difference arm-span - height (cm)
Afro-Caribbean	m	182.4**	175.3**	7.1
	f	168.3**	162.3**	6.0
Asian	m	177.6**	172.7**	4.9
	f	160.0	158.0	2.0
Caucasian	m	181.3	179.2	2.1
	f	163.6	164.6	-1
Oriental	m	172.8	170.9	1.9
	f	159.8	159.8	0.0

** Arm-span measurements significantly different from height measurements, $P<0.01$

In 5 out of the 8 groups no significant differences between arm-span and height were found. However in the remaining 3 groups, namely the male and female Afro-Caribbean's and male Asians, arm-span was found to be significantly different from height ($P < 0.01$). Because of the statistical difference between arm-span and height in the Afro-Caribbean's and Asian male groups a direct substitution of arm-span for height in these groups would be deemed inappropriate.

The relationship between arm-span and height

Despite the significant differences between arm-span and height in three of the groups we cannot rule out the possibility that the two measurements may be highly related. Regression lines were plotted and correlation coefficients were calculated to find the degree to which arm-span and height were related to each other in the different ethnic and gender groups.

Figures 7.1 and 7.2 graphically display height plotted against arm-span for both sexes. Separate regression lines have been drawn to denote the different ethnic groups. The correlation coefficients and the regression equations for each group are presented in Table 7.11.

Table 7.11

The relationship between arm-span and height

Ethnicity Group	Sex	Regression Equation	s.e.e.	r
Afro-Caribbean	m	height = 0.66 * arm-span + 54.9	3.46	0.89
	f	height = 0.57 * arm-span + 66.9	3.88	0.80
Asian	m	height = 0.67 * arm-span + 53.4	3.55	0.84
	f	height = 0.48 * arm-span + 81.0	3.30	0.75
Caucasian	m	height = 0.76 * arm-span + 41.9	3.53	0.87
	f	height = 0.80 * arm-span + 34.3	3.20	0.84
Oriental	m	height = 0.74 * arm-span + 42.7	3.41	0.85
	f	height = 0.70 * arm-span + 47.2	3.43	0.73

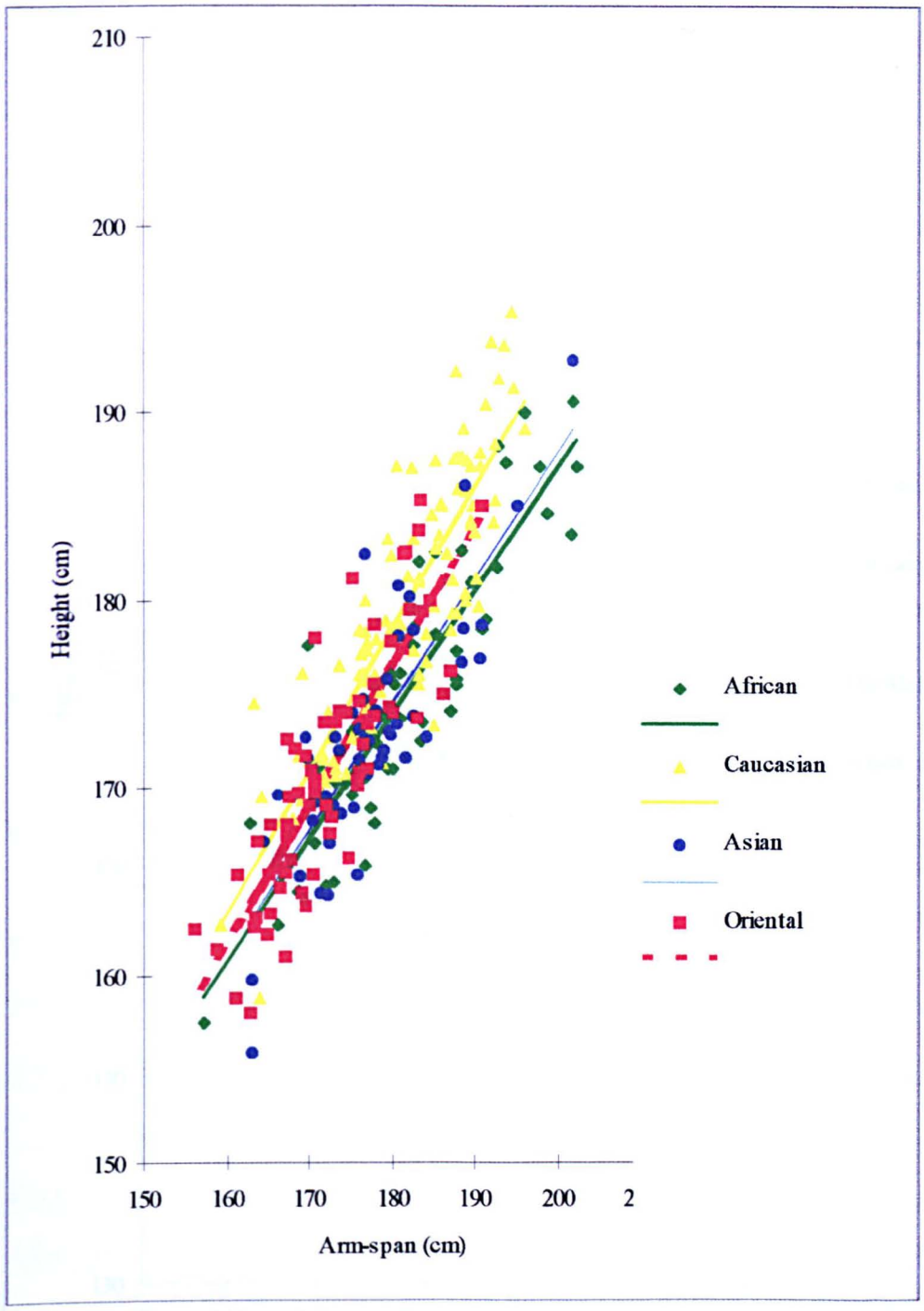

Figure 7.1
The relationship between arm-span and height in males of different ethnic groups

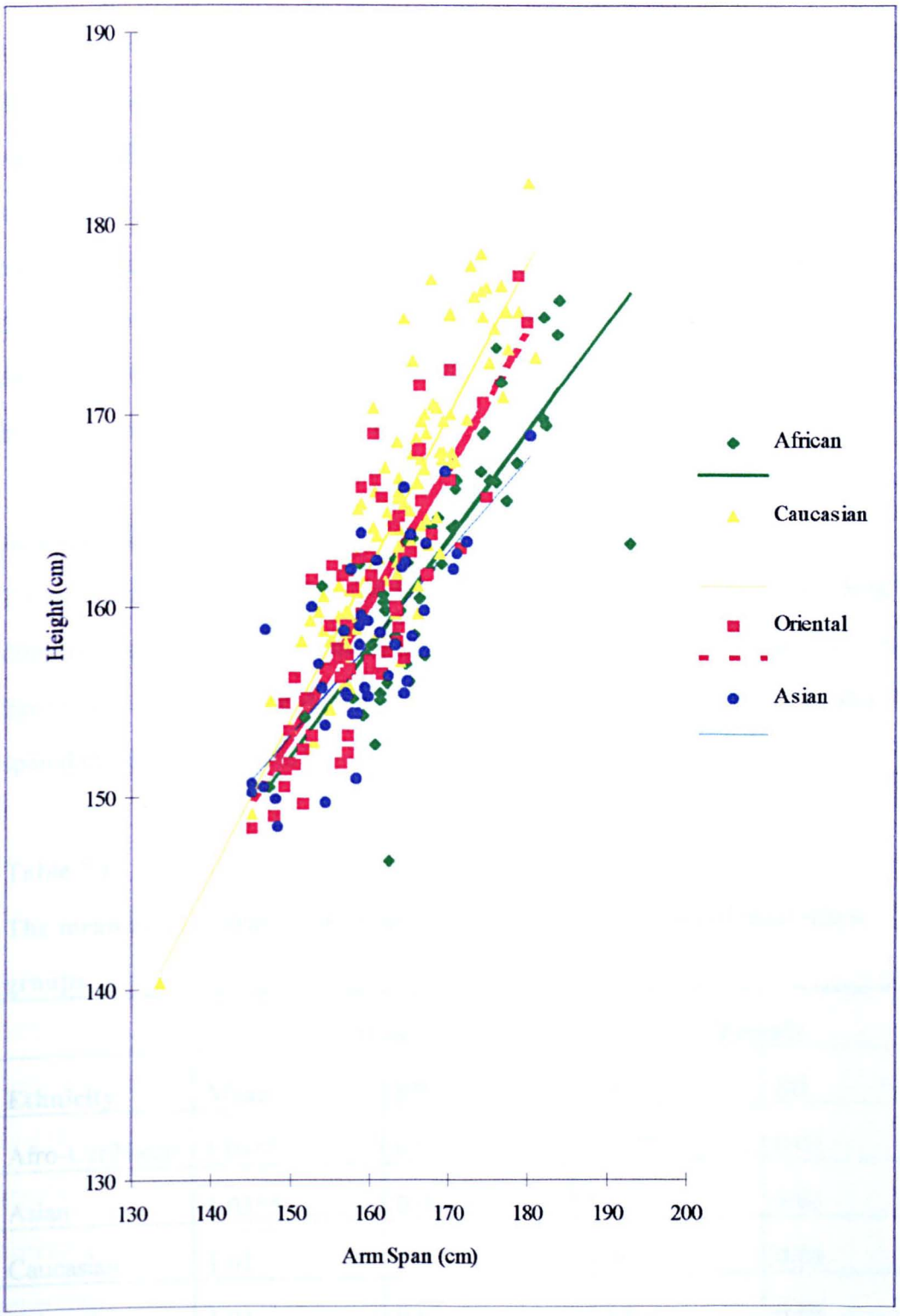

Figure 7.2
The relationship between arm-span and height in females of different ethnic groups

The correlation coefficients (r = 0.73 - 0.89) indicate a strong relationship between the arm-span and height measurements for all groups including the three groups where significant differences were found between the two measurements. Arm-span and height may not always be consistent with each other regardless of ethnic group, however, good arm-span and height relationships exist. In cases where it is not deemed appropriate to substitute arm-span for height it is possible that a regression equation corresponding to the appropriate ethnic groups may make use of arm-span measurements as a tool to predict height.

Arm-span and height ratios

To enable a direct comparison of the relationship between arm-span and height in different groups it is convenient to analyse the arm-span and height data as a single figure. For this reason the data in Table 7.12 is presented in the form of a ratio (arm-span divided by height).

Table 7.12

The mean ratio of arm-span to height for males and females of four ethnic groups

	Male		Female	
Ethnicity	**Mean**	**SD**	**Mean**	**SD**
Afro-Caribbean	1.04**	0.03	1.04**	0.03
Asian	1.03**	0.02	1.01	0.03
Caucasian	1.01	0.02	1.00	0.03
Oriental	1.01	0.02	1.01	0.03

** Ratios significantly different amongst the ethnic groups, $P < 0.01$

To look for differences between the arm-span and height ratios ethnic groups an analysis of variance (ANOVA) was performed using the computer package Excel 4.0.

Results show that there are significant differences in the ratios between the ethnic groups. The ratios of the Afro-Caribbean's and the Asian male groups were found to differ significantly ($P < 0.01$) from the other ethnic groups.

Interestingly the arm-span and height ratios of the Afro-Caribbeans and the Asian males are much larger than 1.0, indicating arm-span measurements that are greater than height measurements. The ratios of the Caucasian and Oriental groups and Asian females were found to be very close to 1.0, indicating similar arm-span and height measurements.

No significant differences ($P > 0.05$) were found between the sexes when the arm-span to height ratios were compared for all subjects. However when looking at each particular ethnic group in turn a significant difference ($P < 0.01$) was found between the arm-span and height ratios of males and females of the Asian ethnic group. All other ethnic groups showed identical or highly similar arm-span and height ratios for both sexes.

7.4 Discussion and summary

Arm-span measurements and height measurements were found to be significantly different ($P < 0.01$) from each other in male and female Afro-Caribbeans and male Asians. Additionally, in these groups the arm-span and height relationship was found to differ significantly from the other gender and ethnic groups ($P < 0.01$). The results are therefore indicative of ethnic anthropometric differences. Furthermore there were distinct differences between the ethnic groups when height and arm-span were studied separately. Caucasians were found to be the tallest ethnic group but Afro-Caribbeans were found to have the longest arm-spans. In another anthropometric study, Malina (1996) found American white and black subjects to be taller and have longer extremities i.e. legs and arms than Asian subjects. Whether these anthropometric differences are due to cultural differences such as nutrition and lifestyle factors or due

to underlying biological factors such as genetics is debatable and subject to further research.

Gender differences in the arm-span and height relationship were only found within the Asian ethnic group. The other ethnic groups showed no signs of any gender dimorphism in this relationship. However there were distinct gender differences in height alone and arm-span alone, male subjects being taller and having longer arm-spans, in all ethnic groups. Whilst in all populations males are taller than females, the degree to which the sexes differ is not the same in different ethnic groups. The Asian and Caucasian subjects showed the greatest sexual dimorphism's and Orientals the least. Eveleth (1975) in a study comparing Negroid, European and Amerindian populations found that Amerindians had the greatest sexual dimorphism with respect to height and that the Negroid populations showed the least. It is loosely suggested that the greater dimorphism in the Amerindians could possibly be due to this society's preferential treatment of boys over girls. In the case of the Negroid populations poor nutrition may have meant that many of the males did not meet their full height potential. But since all subjects in this study were of similar socio-economic status, differences in sexual dimorphism cannot be attributed to inadequacies in lifestyle such as malnutrition.

Due to differences in the relationship between arm-span and height in different ethnic groups and between the sexes, the use of arm-span as a proxy for height should be used cautiously. In the future, studies related to arm-span and height must consider the ethnic and gender implications in order to decrease the risk of inaccurate assumptions being made.

Chapter

8

General Discussion and Conclusions

8. General Discussion and Conclusions

8.1 Biological Variation

The studies presented in this thesis illustrate biological variation in man. In particular, the way biological variation manifests itself in relation to energy metabolism is emphasised. Possible reasons for the highly variable nature of energy metabolism are discussed.

In chapter one a review of the literature shows how biological variation has been reported to be evident in aspects of total daily energy expenditure and BMR, food intake, anthropometry and ethnicity, the findings are summarised below:

Whilst the human species consists of a large number of diverse populations, it is has not been necessary to subdivide *Homo sapiens* into sub species or "races". Instead within this thesis it has been considered appropriate to talk of ethnic groups, a term which is used in a geographical sense. It is acknowledged that there is a large amount of inter-gradation and overlap between these so called ethnic groups.

Variation in BMR of individuals and populations may be attributed to many factors including age, body size and composition, dietary factors, such as under- and over-nutrition, hormonal factors, disease, climate, physical activity, pharmacological agents, psychological state, genetics and ethnicity. A review of various equations that have been used to predict BMR are presented. These highlight a need for an unbiased and extended data base in order to create new equations that are suitable to predict BMR in populations world wide. New Oxford Brookes predictive equations for BMR are presented in chapter three. The new Oxford Brookes equations, which use body weight were compared with those of Schofield (1985) and were found to predict BMR to different from that calculated using the Schofield equations. Equations to predict BMR from weight and height were also created. Additionally equations were

developed for a new set of age bands, these new age bands reflect the biological and physical changes that occur throughout the life span. The effect of ethnicity was also investigated. BMR was not consistently found to be different between the groups studied. It is hoped the equations produced will be used to accurately predict BMR in populations world-wide.

Actual BMR measurements of 77 females aged between 18 and 30 years of age were compared with 7 different equations. Out of all the equations, the Henry & Rees (1991) equations and the newly developed Oxford Brookes equations were found to approximate measured BMR the most closely.

In chapter four, for the first time normal curves were plotted for BMR with weight throughout the life-span. The years through childhood from 0-20 years were highlighted as a time of particularly rapid changes in BMR. Normal curves for BMR were compared for 4 different ethnic groups for males and females aged between 0-20 years. Whilst there appeared to be ethnic differences in total BMR between the groups, when BMR was expressed per kilogram of body weight these differences largely disappeared. Velocity or the rate of change in BMR with age was also investigated for the first time, and compared to velocities of growth, body composition and organ weight. It is accepted that body composition, and in particular the major organs, significantly affect BMR and may account for metabolic differences between children and adults when BMR is expressed per kilogram of body weight.

Physical activity has been argued to be the most variable aspect, and at the very least the most adaptable component, of energy expenditure. Whilst many methods exist to evaluate total energy expenditure, such as activity diaries or doubly labelled water, they are either laborious or expensive. For this reason in chapter five, the use of heart rate monitoring was investigated.

Results to test the effect of food on heart rate and energy expenditure showed that whilst heart rate changes significantly after breakfast, energy expenditure increases

non-significantly. There were no changes between the regression lines created from the heart rate and energy expenditure relationship. Therefore, it is possible to monitor heart rate during meal times and still produce appropriate estimates of energy expenditure. It was also proved necessary to establish the heart rate and energy expenditure in each individual subject separately.

No significant differences were found between any of the methods to predict total energy expenditure (linear equations, quadratic equations, the Flex HR method or activity diaries) when subjects have very low energy expenditures. It was therefore deemed that there is no superior method of analysing heart rate. It would then seem that for most intensive purposes the HR method selected should be the most convenient method to both the subject and the investigator. However, heart rate monitoring may not always be suitable for subjects with very low levels of energy expenditure. The HR method can be used in free-living subjects, is relatively inexpensive, socially acceptable and non-intrusive and can provide useful activity data even without calculating energy expenditure. It is for these reason HR monitoring will remain an important accessory in the field measurement of the energy expenditure and as an activity monitor of individuals and different populations.

Food intake is another highly variable component of energy expenditure between populations (Norgan, 1981) and amongst individuals (Beaton *et al.*, 1983). Intake may be affected by many factors such as culture, physiological and endocrinological factors, psychology and palatability and sensory preferences. When faced with new and novel foods of a different culture it is possible that energy balance may be difficult to maintain. This was researched in a study concerning international students who had migrated to the UK and presented in chapter six.

It was found that Malaysian students are able to remain in energy balance and are weight stable at least during the first 6 months of residence, despite the choice of energy dense food available to them in the UK. When it is considered that if a person was to be in positive energy balance, where energy intake was greater than energy

expenditure by as little as 50 kcal per day, in 10 years time this would lead to serious obesity (Passmore, 1971). The ability of man and indeed the Malaysian students in this study, to remain in energy balance is quite remarkable and exhibits proof of a very precise mechanism by which the human body can maintain energy balance, at least in the short term. In many cases energy balance may be retained for several years (Garrow, 1974). This suggests that the subjects in this study were able to modulate their food intake in response to the changes in the energy densities of the food available. However, whilst there is so much contradictory data in the literature more extensive studies are needed to develop a model for energy balance in different population groups.

Body composition differences between the ethnic groups are widely acknowledged (Forbes, 1987, Pollitzer & Anderson, 1989, Malina, 1996). For this reason the use of arm-span in clinical settings as a substitute for height in different ethnic groups was investigated in chapter seven.

Arm-span measurements and height measurements were found to be significantly different ($P < 0.01$) from each other in male and female Afro-Caribbeans and male Asians. Additionally, in these groups the arm-span and height relationship was found to differ significantly from the other gender and ethnic groups ($P < 0.01$). The results are therefore indicative of ethnic anthropometric differences.

Due to differences in the relationship between arm-span and height in different ethnic groups and between the sexes, the use of arm-span as a proxy for height should be used cautiously. In the future, studies related to arm-span and height must consider the ethnic and gender implications in order to decrease the risk of inaccuracies.

8.2 Conclusions

Variation in BMR can be attributed to many factors such as diet and body composition. However at present, there is no clear evidence that ethnicity is one of these factors. Whilst many authors have found that BMR is lower in Indians (Shetty, 1984; Schofield, 1985 and Soares & Shetty, 1988...) other authors have not found this. Durnin (1981) found the BMRs of Egyptians, Burmese, Thai's, Japanese, Korean and Indians to be compatible with those of the accepted standards for North American and European populations. It is possible that low BMRs are a result of lower body weights and lower levels of fat free mass (De Boer *et al.*, 1988). Alternatively, it has been suggested ethnic differences may be due to varying racial abilities in producing differing degrees of muscular relaxation and muscular activity may be induced by environmental temperatures which appear to be comfortable (Durnin, 1981). The elevated BMRs of Eskimos have even been attributed to apprehension and a high protein diet (Heinbecker, 1931). Whilst there are so many confounding factors such as climate, body weight, muscular relaxation and diet, it is exceedingly difficult to attribute differences in BMR purely to ethnicity.

Ethnic differences have however, been recognised with regards to body composition. Differences in bone mass in black and white Americans have been identified (Pollitzer & Anderson, 1989), Orientals have been found to have a lighter lean body mass than Caucasians and Afro-Caribbeans (Forbes, 1987), Asians have been shown to have more subcutaneous fat but lower body mass index than Caucasians (Wang *et al.*, 1994) and there are differences between the arm-span and height relationship in different ethnic groups (Reeves *et al.*, 1996). Possible reasons for differences in body composition between ethnic groups can be attributed to adaptation to geographical areas i.e. there is a general relationship between body size/shape with distance from the equator, and cultural factors such as the suggestion by Frayer (1980) that our ancestors body size was dependant on the size of game animals (from 35,000 years ago, more aggressive game was hunted less and our ancestors adopted a more

sedentary way of life). Body size and composition are strongly influenced by genetic mechanisms. Shifts in bodily dimensions probably come about as a result of adaptations and are passed onto subsequent generations.

Genetic deviation has a highly significant effect on biological variation in man. Studies on monozygotic twins have shown that there are definite genetic components in BMR and body composition (Fontaine *et al.*, 1985 and Bouchard *et al.*, 1985). Multifactorial traits such as those involved in metabolism and body composition cannot be reduced to a simple Mendelian phenotype. Traits such as these have evolved under the interactive influence of social, behavioural, physiological, metabolic, cellular and molecular mechanisms. In any group of individuals there are many possible allelic permutations at several gene loci which in any particular environment may produce many different phenotypes and biological variations.

It is exceedingly difficult to attribute human variation to ethnic differences when high levels of individual variations are manifest. Whilst biological variation is a true phenomenon, reasons for variation are numerous; environmental agents, lifestyle influences, including dietary factors, and genetics are all implicated.

8.3 Further work

A lack of data for BMR in different ethnic groups particularly children aged 0-20 years has been made evident. More BMR data would allow further investigations into the subject of ethnicity and energy metabolism. In order to establish if there are true population variations, or if in fact differences in BMR and body composition are simply a result of environmental and lifestyle factors.

Work in the future will be able to study the metabolism of the different organs in the body and will produce data for males and females throughout the age range. At present the techniques, technology and methodology are limited in scope to accurately predict organ size and metabolic activity. As technology improves it is probable that more data on organ metabolic rates will become available. It may then be possible that further reasons for metabolic differences in seemingly identical individuals will be identified.

At present it is clear that the concept of energy balance and food modulation is not clearly understood. Whilst, the use of overseas students migrating from societies where food is of low energy density in comparison to Western societies, as presented here, is a useful study model with which to examine energy and body weight regulation, further studies are required to attempt to understand the nature of how energy balance is maintained in different population groups.

Appendix A

Summary of the papers included in the Oxford Brookes data base.

Paper No	Investigator	Year	Race	Location	n	Sex	Age	Technique
1	Adam	1957	Cauc	UK	56	m	18to23	B.R.
2	Adam	1951	Cauc	Singapore	103	m	22to25	B.spirometer
3	Ahmad	1938	Indian	India	9	m	19to32	Douglas bag
4	Arciero	1993	Cauc	USA	522	m/f	17to81	Ventilated hood
5	Aub	1917	Cauc	USA	6	m	77to83	Sage calorimeter
6	Bailey	1973	Cauc	USA	8	m/f	19to39	Tissot gasometer and Beckman analyser
7	Banerjee	1967	Indian	India	43	m/f	18to20	Kofranyi-Michaelis
8	Banerjee	1964	Indian	India	891	m	6to20	Haldane-Bailey
9	Bedale	1923	Cauc	UK	1	m	12	Douglas bag
10	Benedict	1921	Cauc	USA	9	f	12to17	Benedict
11	Benedict	1921	Cauc	USA	75	m/f	8dto15	Respiration chamber
12	Benedict	1928	Cauc	USA	4	m/f	24ti59	Benedict
13	Benedict	1928	Cauc	USA	60	m/f	18to58	Benedicts
14	Benedict	1935	Cauc	USA	15	m/f	69to88	Field respiration apparatus
15	Benedict	1914	Cauc	USA	157	m/f	16to58	Universal
16	Benedict	1936	Chinese	Manchuria	20	m	16to36	Benedicts field apparatus
17	Benedict	1933	Chinese	USA	18	f	12to22	Helmet respiration apparatus
18	Benedict	1919	Cauc	USA	14	m	19to44	Respiration apparatus
19	Benedict	1914	Cauc	USA	38	m/f	17dto17m	Benedicts
20	Bianca	1994	Gambian	Gambia	54	m	28	Ventilated hood
21	Biering	1931	Cauc	Sweden	133	m	7to18	Krogh
22	Bingham	1989	Cauc	UK	6	m/f	24to33	whole body calorimeter
23	Blunt	1921	Cauc	USA	14	f	24to44	Benedict portable
24	Blunt	1926	Cauc	USA	46	f	8to18	Benedict portable
25	Bond	1992	Cauc	UK	152	m/f	5to15	Deltatrac
26	Boothby	1922	Cauc	USA	102	m/f	21to61	Gasometer
27	Bose	1934	Indian	India	60	m/f	15to72	Sanborn graphic
28	Bowen	1935	Cauc	USA	12	m/f	16to56	Tissot gasometer
29	Burke	1993	Cauc	USA	23	f	18to35	Ventilated respiratory canopy
30	Butte	1994	Cauc	USA	128	m/f	0to42	Room respiration calorimeter
31	Calloway	1980	Cauc	USA	6	m	63to77	Douglas bag
32	Cathcart	1919	Cauc	UK	16	m	18to25	Douglas bag
33	Chitre	1959	Burmese	Burma	116	m	16to40	Sanborn metabolator
34	Clagett	1941	Cauc	USA	8	m/f	<1	Higgins and Bates open circuit
35	Collins	1930	Cauc	USA	6	m	3to5	B.R.
36	Coons	1931	Cauc	USA	101	f	17to39	B.R.
37	Cross	1957	Cauc	UK	56	m/f	0	Body plethysmograph

38	Cullumbin e	1950	Tropic al	Ceylon	225	m/f	10to25	Douglas bag	
39	Dahlstrom	1950	Cauc	Sweden	22	m/f	21	Douglas bag	
40	Dakshayan i	1964	Indian	India	232	m/f	8to40	B.R.	
41	Dalderup	1971	Cauc	Holland	61	m	70to92	Benedict app	
42	Dalderup	1966	Cauc	Holland	123	m/f	64to10 1	Benedict app	
43	De	1976	Indian	India	330	m/f	7to18	Collins	
44	De Almeida	1924	Brazili an	Brazil	8	m	21to46	Tissot	
45	De Almeida	1920	Brazili an	Brazil	10	m	23to40	Tissot	
46	De Guzman	1978	Filipin o	Philippin es	20	m/f	20to42	Sanborn basal metabolator	
47	De Bruin	1939	Cauc	Holland	243	m/f	1to17	Dusser deBarenne & Burger app	
48	Diaz	1991	Gambi an	Gambia	16	m	20to45	Douglas bag	
49	Dubois	1916	Cauc	USA	8	m	12to14	Sage calorimeter	
50	Earle	1928	Chines e	China	253	m/f	18to46	Sanborne Benedict	
51	Eaton	1939	Cauc	USA	160	m/f	15to98	Tissot and Haldane	
52	Fariduddin	1975	Indian	India	39	m	21to30	Douglas bag	
53	Felloni	1936	Cauc	Italy	532	m	19to25	B.R.	
54	Frigerio	1991	Gambi an	Gambia	32	f	17to39	Ventilated hood	
55	Fukagawa	1990	Cauc	USA	68	m/f	21to72	Open circuit indirect calorimeter	
56	Galvao	1948	Brazili an	Brazil	50	m	20to43	Tissot spirometer	
57	Garby	1984	Cauc	Denmark	8	m	19to50	Douglas bag	
58	Garn	1953	Cauc	USA	145	m/f	6to18	Jones-basal	
59	Gemmill	1929	Cauc	USA	3	m	23to27	Douglas bag	
60	Gephart	1915	Cauc	USA	7	m	21to47	Cornelle and Sage calorimeter	
61	Goldberg	1993	Cauc	UK	273	m/f	16to48	Whole body calorimeter	
62	Granati	1941	Cauc	Italy	186	m	16to55	B.R.	
63	Grande	1958	Cauc	USA	25	m	19to26	B.R.	
64	Griffiths	1928	Cauc	USA	5	m/f	19to30	Tissot open circuit	
65	Gustafson	1928	Cauc	USA	20	f	18to22	Benedict portable app	
66	Hafkesbrin g	1926	Cauc	USA	9	m/f	19to35	Haldane	
67	Hafkesbrin g	1924	Cauc	USA	2	f	27to35	Krogh mouth piece and Haldane	
68	Hamberger	1965	Cauc	Sweden	83	m/f	19to24	Krogh spirometer	
69	Hannon	1973	Cauc	USA	8	f	18to23	Douglas bag	
70	Harris	1919	Cauc	USA	333	m/f	0to73	Benedict	
71	Hicks	1931	Aborig inee	Australia	42	f	9to41	B. portable	
72	Hobson	1923	Cauc	UK	46	m	9to40	B. calorimeter	
73	Jones	1990	Gambi an	Gambia	52	m/f	20to41	Ventilated hood	
74	Karlberg	1952	Cauc	Sweden	60	m/f	<1	Krogh spirometer	
75	Keys	1950	Cauc	USA	32	m	25	Benedict Roth	
76	Keys	1973	Cauc	USA	373	m	21to71	Sanborn metabolism	

77	Khan	1973	Indian	India	530	m/f	2to30	B.R.		
78	Kilborn	1937	Chinese	China	68	m/f	17to59	B. field apparatus		
79	Kilborn	1937	Miao	China	24	m	18to51	B. field app		
80	Kise	1933	Japanese	Japan	94	m/f	50to100	Benedicts respiration apparatus		
81	Krishnan	1932	Indian	Madras	76	m/f	18to25	B.R. with Collin kymograph		
82	Kumar	1961	Indian	India	339	m	18to80	Douglas bag		
83	Lamb	1945	Cauc	USA	8	m/f	2to5	Collins Benedict Roth		
84	Lamb	1954	Cauc	USA	19	m/f	2to10	Collins Benedict Roth		
85	Lewis	1943	Cauc	USA	43	f	17to26	B.R.		
86	Lewis	1937	Cauc	USA	93	m/f	2to12	Higgins and Bates chamber		
87	Lusk	1924	Cauc	USA	1	m	30to40	B.R.		
88	MacGregg or	1941	Cauc	Singapore	70	m	22-23	B. spirometer		
89	MacGregg or	1940	Mix	Singapore	70	m	20to23	B. spirometer		
90	MacLeod	1925	Oriental	USA	9	f	21to29	Carnegie respiration apparatus		
91	Magnus-Levy	1942	Cauc	USA	1	m	26to76			
92	Malhotra	1960	Indian	India	7	m	20to36	Sanborne metabolator and Douglas bag		
93	Mason	1934	Cauc	India	34	f	20to54	B. spirometer		
94	Mason	1934	Indian	India	7	f	20to54	Closed circuit respiration helmet		
95	Mason	1931	Indian	India	54	f	17to54	Spirometer		
96	Mason	1964	Ind/Cauc	India	198	f	25to78	B.R.		
97	Mason	1972	Indian	India	24	m/f	19to72	B.R.		
98	Mason	1963	Indian	India	124	f	15to24	B.R.		
99	Matson	1934	Cauc	USA	14	m	74to92	B.R.		
100	McKay	1930	Cauc	USA	251	m/f	14to18	B.R.		
101	McKay	1936	Cauc	USA	73	f	53to70	B.R.		
102	McKrittrick	1935	Cauc	USA	100	f	17to26	B.R.		
103	Miller	1937	Mix	Hawaii	258	m/f	16to58	B. field apparatus		
104	Miller	1937	Polynesian	Somoa	21	m	22to35	B. field apparatus		
105	Miller	1957	Japanese	Hawaii	34	m/f	60to79	B.R.		
106	Minghelli	1990	Gambian	Gambia	36	m	18to32	Respiration chamber		
107	Montoro	1921	Cuban	Cuba	18	m/f	22to38	Benedict appartus		
108	Moore	1966	Cauc	USA	12	f	9to12	Kofranyi-Michaelis		
109	Morgan	1984	Cauc	UK	6	f	22to28	Open circuit indirect calorimeter		
110	Muhilal	1993	Javanese	Java	103	m/f	16to19	Douglas bag		
111	Mukherjee	1931	Indian	India	18	m	20to29	Douglas bag		
112	Munro	1950	Cauc/Ind	India	118	m	21to27	B. field app		
113	Nakagawa	1934	Japanese	Japan	31	m/f	3to7	B. resp app with cot chamber		
114	Nakagawa	1934	Japanese	Japan	25	m/f	6to12	B. resp app with cot chamber		

115	Nakagawa	1935	Japanese	Japan	26	m/f	3to11	B. resp. app.	
116	Nakagawa	1937	Japanese	Japan	23	m/f	12to15	B. resp app	
117	Niyogi	1939	Indian	India	76	m/f	18to35	Sanborn graphic metabolism tester	
118	Niyogi	1940	Indian	India	35	m	11to16	Benedict Sanborne	
119	Noor	1993	Malaysian	Malaysia	139	m/f	10to12	Deltatrac	
120	Noor	1994	Malaysian	Malaysia	707	m/f	18to60	Douglas bag	
121	Nylin	1935	Cauc	Sweden	12	f	8to12	?	
122	Oberlin	1990	Cauc	USA	16	f	25	ventilated canopy	
123	Ocampo	1930	Filipino	Phillippines	123	m/f	14to48	B.R.	
124	Odin	1934	Cauc	Sweden	23	m/f	6to60	Benedicts	
125	Okada	1926	Japanese	Japan	53	m/f	20to28	Open gasometer	
126	Oliveira	1940	Brazilian	Brazil	60	m	21to46	Aneroid chamber	
127	Oliveiro	1937	Malaysian	Singapore	28	m	19to51	Douglas bag	
128	Oliveiro	1939	Malaysian	Singapore	84	m	8to14	Douglas bag	
129	Olmstead	1918	Cauc	USA	7	m	12to13	Sage calorimeter	
130	Owen	1986	Cauc	USA	44	f	18to65	Beckman metabolic rate	
131	Palmer	1914	Cauc	USA	17	m/f	20to32	Benedicts universal apparatus	
132	Park	1969	Korean	Korea	17	m/f	19to40	Collins spirometer	
133	Passmore	1952	Cauc	U.K.	5	m	19to25	B.R. and Kofranyi-Michaelis	
134	Piers	1993	Indian	India	60	f	18to30	Hartman and Braun metabolator	
135	Pochlman	1993	Cauc	USA	115	m/f	56to90	Deltatrac	
136	Poppitt	1993	Gambian	Gambia	20	f	17to39	Open circuit indirect calorimeter	
137	Prentice	1985	Cauc	UK	12	f	23to40	Calorimeter	
138	Radsma	1932	Cauc	Java	24	m	18to23	Knipping apparatus	
139	Rahman	1936	Indian	India	32	m	19to32	Sanborn motor-grafic	
140	Rajagopal	1938	Indian/cauc	India	46	m	21to52	Benedict Roth	
141	Ravussin	1982	Cauc	Switzerland	30	m/f	20to46	Open circuit ventilated hood	
142	Reilly	1993	Cauc	UK	10	f	21to27	Open circuit indirect calorimeter	
143	Reilly	1995	Cauc	UK	59	m/f	66to74	Ventilated hood	
144	Remington	1931	Cauc	USA	133	m/f	18to34	B.R. with Collins	
145	Richardson	1965	Cauc	USA	24	f	20to53	Muller Franz respirometer	
146	Richardson	1960	Cauc	USA	6	f	35to46	Muller Franz respirometer	
147	Reiper	1993	Cauc	Germany	11	f	14to15	Kofranyi-Michaelis	
148	Roberts	1994	Cauc	USA	35	m	18to76	Deltatrac	
149	Robertson	1958	Cauc	UK	5	m	91to100	B.R.	
150	Rochelle	1969	Cauc	USA	7	m	23to30	Open circuit	
151	Shattuck	1931	Maya	Yucatan	26	m	17to32	Benedict helmet with blower	

152	Shaw	1933	Cauc/Ind	USA	11	f	18to22	B.R.		
153	Siddall	1937	Chinese	China	100	f	15to36	Sanborne Bendict		
154	Soares	1991	Indian	India	46	m	20to24	Hartman and Braun metabolator		
155	Soares	1993	Indian	India	130	m	18to30	Hartman and Braun metabolator		
156	Sokhey	1939	Indian	India	60	m	20to49	Chain-compensated spirometer		
157	Spurr	1994	Colombian	Colombian	21	f	20to42	Meteorological balloon		
158	Stark	1933	Cauc	USA	97	f	17to20	Sanborn grafic and B. portable		
159	Stark	1935	Cauc	USA	62	m	17t021	Sanborn Benedict		
160	Steggerda	1928	African	Jamaica	50	m/f	19to40	B. field		
161	Stedderda	1932	Maya	Mexican	32	m	18to40	B. field		
162	Sundstroem	1926	Cauc	USA	14	m/f	24to58	Zuntz portable respiration outfit		
163	Takahira	1925	Japanese	Japan	50	m/f	20to49	Respiration apparatus		
164	Talbot	1932	Cauc	USA	29	m/f	10dto10	Benedict portable		
165	Tame	1994	Cauc	UK	496	m/f	9to13	Deltatrac		
166	Tangni	1994	Benese	Benin	200	m/f	5to9	Douglas bag		
167	Thompson	1948	Cauc	USA	218	f	14to23	Indirect calorimetric techniques		
168	Thompson	1959	Cauc	USA	7	f	19to62	?		
169	Tilt	1930	Cauc	USA	52	f	17to25	Sanborn-Benedict		
170	Tilt	1948	Vauc	USA	38	f	17to26	B.R.		
171	Topper	1932	Cauc	USA	38	m/f	10to16	Krogh and B.R.		
172	Turner	1935	Oriental	USA	22	f	19to35	Closed circuit respiration apparatus		
173	Valencia	1994	Mexican	Mexico	32	m	19to40	Deltatrac		
174	Vogelius	1945	Cauc	Denmark	150	f	7to18	Krogh		
175	Voorrips	1993	Cauc	Holland	57	f	41to72	Ventilated hood system		
176	Wakeham	1923	Cauc	USA	24	f	18to35	Sanborne Benedict		
177	Wang	1939	Cauc	USA	70	m/f	4to17	Benedict cot chamber		
178	Wang	1936	Cauc	USA	34	f	10to20	Tissot		
179	Wang	1926	Cauc	USA	52	m/f	4to13	Benedicts cot chamber		
180	Wang	1934	Chinese	USA	32	f	12to22	Benedicts		
181	Wang	1932	Chinese	USA	21	m/f	5to17	Tissot gasometer		
182	Wardlow	1934	Austr/Abo	Australia	14	m	17to65	Haldane-Douglas		
183	Wardlow	1928	Aborigine	Australia	9	m	36to65	Haldane-Douglas		
184	Wardlow	1932	Aborigine	Australia	11	m	19to67	Haldane-Douglas		
185	Warwick	1987	Cauc	Australia	15	m/f	18to29	Ventilated hood		
186	Warwick	1993	Cauc	Australia	14	m/f	20to32	Ventilated hood		
187	Warwick	1988	Cauc	Australia	13	m/f	20to44	Ventilated hood		
188	Webster	1941	Cauc	USA	21	m/f	9to16	B.R.		
189	Wedgewood	1953	Cauc	USA	17	m	18to29	Open with Haldane		
190	Welle	1992	Cauc	USA	50	f	21to47	Open circuit ventilated mask		

191	Williams	1928	Maya	Yucatan	50	m/f	19to42	Field respiration apparatus	
192	Wilson	1938	Indian	India	62	m	6to16	Douglas bag	
193	Wising	1934	Cauc	Sweden	77	m/f	18to30	Krogh spirometer	
194	Wong	1994	Cauc	USA	154	f	9to16	Room respiration calorimeter	

Appendix B

Heart rate Calibration data

A.B.1 Individual calibration data for male subjects before and after food.

For subjects physical characteristics please see p177.

Subject 1m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	3.91	61	5.15	68
Standing	4.65	70	4.47	80
Light cycling	10.55	80	13.21	89
Heavy cycling	41.62	166	41.20	177

Subject 2m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	4.92	49	7.01	66
Standing	6.10	73	8.80	88
Light cycling	16.24	80	22.30	83
Heavy cycling	51.60	142	79.50	142

Subject 3m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	3.00	54	3.94	61
Standing	3.63	75	4.90	84
Light cycling	6.46	69	12.32	90
Heavy cycling	28.00	154	28.39	157

Subject 4m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	5.31	65	11.60	78
Standing	9.53	86	17.70	97
Light cycling	25.83	83	22.60	91
Heavy cycling	76.21	138	59.22	140

Subject 5m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	6.66	59	7.96	66
Standing	11.18	74	7.79	91
Light cycling	23.60	78	12.94	85
Heavy cycling	44.00	126	43.40	141

Subject 6m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	5.31	60	7.04	65
Standing	6.95	88	8.08	96
Light cycling	15.00	93	17.80	105
Heavy cycling	33.98	134	35.66	140

Subject 7m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	7.56	75	10.07	76
Standing	9.18	81	12.57	90
Light cycling	20.12	93	37.70	133
Heavy cycling	57.35	166	60.42	166

Subject 8m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	3.00	50	3.97	64
Standing	3.65	72	5.12	93
Light cycling	16.40	100	11.50	95
Heavy cycling	32.00	163	26.27	163

Subject 9m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	3.57	60	4.78	70
Standing	4.61	70	5.90	67
Light cycling	8.94	72	8.74	74
Heavy cycling	24.46	104	23.43	104

Subject 10m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	4.87	76	5.04	90
Standing	6.35	99	7.74	129
Light cycling	13.64	100	15.53	112
Heavy cycling	36.98	143	40.06	156

Subject 11m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	5.165	57	5.80	71
Standing	7.13	73	7.67	92
Light cycling	12.15	80	15.72	96
Heavy cycling	41.72	141	46.28	151

Subject 12m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	5.16	44	6.69	49
Standing	6.59	52	8.13	60
Light cycling	22.44	83	20.01	81
Heavy cycling	45.62	115	45.44	118

Subject 13m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	4.39	58	5.68	59
Standing	5.54	69	6.88	78
Light cycling	9.73	74	9.95	76
Heavy cycling	31.8	134	39.08	143

Subject 14m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	4.09	62	4.83	64
Standing	6.05	72	7.12	82
Light cycling	12.54	78	13.63	85
Heavy cycling	31.35	124	41.43	151

Subject 15m

Activity	Before breakfast		After breakfast	
	Energy expended (kJ/min)	Heart rate (beats/min)	Energy expended (kJ/min)	Heart rate (beats/min)
Lying down	4.50	61	5.26	77
Standing	5.52	69	6.07	93
Light cycling	24.25	115	23.37	115
Heavy cycling	42.60	165	37.96	157

A.B.2 Individual calibration data for 24 h Heart rate monitoring

Subject 1f

Activity	Energy expended (kJ/min)	Heart rate (beats/ min)
BMR	5.24	57
Sitting	4.99	58
Standing	4.54	62
Light cycling	17.65	97
Moderate cycling	28.65	122
Heavy cycling	36.30	143

Subject 2f

Activity	Energy expended (kJ/min)	Heart rate (beats/min)
BMR	2.92	73
Sitting	3.69	78
Standing	4.31	88
Light cycling	14.10	138
Moderate cycling	22.30	176
Heavy cycling	25.90	186

Subjects 3f

Activity	Energy expended (kJ/min)	Heart rate (beats/min)
BMR	5.00	65
Sitting	5.85	70
Standing	6.05	81
Light cycling	14.30	90
Moderate cycling	16.30	126
Heavy cycling	34.55	156

Subject 4f

Activity	Energy expended (kJ/min)	Heart rate (beats/min)
BMR	3.92	62
Sitting	3.95	65
Standing	4.19	67
Light cycling	11.25	69
Moderate cycling	19.25	117
Heavy cycling	28.25	153

Subject 5f

Activity	Energy expended (kJ/min)	Heart rate (beats/min)
BMR	2.83	70
Sitting	3.32	71
Standing	3.31	76
Light cycling	15.22	112
Moderate cycling	22.29	158
Heavy cycling	28.15	181

Subject 6f

Activity	Energy expended (kJ/min)	Heart rate (beats/min)
BMR	3.93	66
Sitting	4.94	67
Standing	5.20	88
Light cycling	17.30	105
Moderate cycling	28.90	146
Heavy cycling	43.70	174

Subject 7f

Activity	Energy expended (kJ/min)	Heart rate (beats/min)
BMR	4.10	49
Sitting	4.41	53
Standing	4.84	72
Light cycling	15.90	98
Moderate cycling	28.84	145
Heavy cycling	38.80	190

Subject 8f

Activity	Energy expended (kJ/min)	Heart rate (beats/min)
BMR	2.96	71
Sitting	3.47	72
Standing	3.38	77
Light cycling	8.598	92
Moderate cycling	13.44	110
Heavy cycling	20.79	148

For group mean values please refer to p178.

Appendix C

A.C.1 General Information for International Students

Name:

Course:

Term Time Address: Home Address:

Tel:

Date of birth:
Place of birth:
Mothers place of birth:
Fathers place of birth:

Number of brothers and sisters:

Fathers occupation:
Mothers occupation:

Initial height:

Initial weight:

Other relevant information:

A.C.2. Food Intake Questionnaire

This questionnaire is to find out a bit about the foods you eat. Please complete as much as you can. Thank you for your time and help.

1. Are you vegetarian?

yes ☐
no ☐

2. Do you take vitamin tablets?

yes ☐
no ☐

If yes, what _____

3. a) Have you ever tried to lose weight?

yes ☐
no ☐

b) Have you ever tried to gain weight?

yes ☐
no ☐

4. How many days a week do you have:

breakfast _____
lunch _____
dinner _____

5. How many snacks do you usually eat in one day (e.g. crisps, chocolate, fruit) and what food do you usually eat for a snack?

_____
_____
_____
_____

6. What sort of bread do you eat? _____

7. What sort of milk do you drink? _____

8. Do you use butter, margarine or a low fat spread? _____

9. Do you smoke?_____

A.C.3 Food Frequency Questionnaire

Please tick the boxes to show which foods you eat and how often.

	More than once a day	Once a day	More than once a week	Once a week	Once a month	Never
Red meat						
White meat						
Sausages / burgers						
Fish						
Bread						
Potatoes						
Rice						
Pasta or Noodles						
Chips						
Cereals						
Fresh fruit						
Tinned fruit						
Fresh vegetables						
Tinned or frozen vegetables						
Beans						
Pulses						
Cheese						
Eggs						
Yoghurt						
Cream						
Crisps						
Biscuits						
Chocolate						
Nuts						
Coffee or tea						
Milk						
Fizzy drinks						
Diet fizzy drinks						
Squash						
Fruit juice						
Alcohol						

Please list any other foods you eat frequently that deserve a mention

_____

A.C.4 Changes in the anthropometric measurements: Females

	On Arrival		After 3 months		After 6 months	
	Mean	SD	Mean	SD	Mean	SD
Weight (kg)	51.78	5.21	52.67	4.87	53.22	4.67
Body Mass Index (kg/m^2)	21.16	3.06	21.47	2.48	21.67	2.19
Bicep (mm)	11.83	4.2	14.00	4.75	11.94	3.71
Tricep (mm)	16.11	4.88	17.94	4.30	16.33	5.76
Sub- scapular (mm)	16.00	6.14	19.89	6.20	19.33	6.30
Supra-iliac (mm)	15.44	4.18	20.33	6.57	19.00	6.02
Body fat (%)	28.52	3.58	31.27	3.52	30.50	3.07
Mid-arm circ. (cm)	23.72	1.73	24.17	1.46	24.22	0.87
Waist circ. (cm)	65.44	5.29	66.44	4.36	66.33	4.06
Hip circ. (cm)	89.00	5.54	90.78	5.69	88.89	5.39
Waist : Hip Ratio	0.74	0.03	0.73	0.03	0.76	0.03
Chest circ. (cm)	80.78	3.80	80.56	3.32	81.11	4.28

A.C.5 Changes in the anthropometric measurements: Males

	On Arrival		After 3 months		After 6 months	
	Mean	SD	Mean	SD	Mean	SD
Weight (kg)	58.08	7.56	58.31	6.40	59.48	6.17
Body Mass Index (kg/m^2)	20.51	3.35	20.58	2.91	20.98	2.82
Bicep (mm)	6.42	2.74	7.54	3.33	6.58	2.70
Tricep (mm)	8.54	4.09	8.46	4.19	9.62	3.87
Sub- scapular (mm)	11.81	5.92	12.54	4.31	14.23	5.92
Supra-iliac (mm)	12.12	8.30	11.35	5.89	11.81	5.73
Body fat (%)	14.72	5.72	15.42	5.40	16.02	4.83
Mid-arm circ. (cm)	25.5	2.51	25.42	2.32	25.92	2.26
Waist circ. (cm)	71.77	6.79	71.46	5.60	71.54	5.42
Hip circ. (cm)	88.54	5.10	88.38	4.75	89.08	3.40
Waist : Hip Ratio	0.81	0.05	0.81	0.04	0.81	0.04
Chest circ. (cm)	83.69	6.61	84.08	5.43	85.96	6.15

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