Relationships between basal metabolic rate, body weight and body composition in a group of ninety women aged 18 to 30 years.

Thesis

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Abstract

The aim of the study was to investigate relationships between basal metabolic rate (BMR), body weight and body composition in a group of 90 women aged 18 to 30 years. Whole body basal metabolic rate /24 hours, referred to here as gross BMR (GBMR), was assessed by indirect calorimetry using the Douglas bag technique and body composition by the sum of skinfold thickness at four sites (Durnin and Womersley, 1974).

When values of GBMR were plotted against body weight (BW) and against fat free mass (FFM) (kg), the data gave covariance coefficients of 0.71 and 0.75 respectively, comparable with published values. Distributions of data points however indicated that the moderate covariance was due not simply to overall variability but to a tendency to curvilinearity. In each case the data showed both linear and polynomial trends.

Since GBMR is determined to a large extent by body weight, the effect of BW as a variable was removed by calculation of BMR / kg / min., referred to here as unit BMR or uBMR. uBMR values plotted against %FM showed a highly significant curvilinear distribution with lower values of uBMR in both lean and overweight sectors of the study population. While bearing in mind the problematic nature of BMR assessment, markedly low values were found for the leanest subjects. The metabolic rate of unit weight of composite tissue is determined not only by the proportions of FFM and FM compartments but also by the components of the compartments and the factors which regulate activity within any given component. These neural and endocrine factors can not only alter the rate of fuel consumption but the selection of the fuel. While it might be expected that unit weight of tissue of high %FM would have a lower overall energy expenditure, tissue with very low percentage fat might be expected to reflect the typically higher expenditure of FFM. In addition to the inherent variability due to composition and regulation, the low values of uBMR found for very lean subjects may be evidence of some adaptation, possibly to low intake.

To investigate the degree of departure from linearity as it was reflected in GBMR values, the study population was partitioned according to body size (by BMI) and body composition (by %FM). Three groups, 'overweight', 'standard' and 'lean' were identified in each grouping, the membership of each group being determined by the grouping criteria. Regression analysis of group data showed that trendlines of GBMR with BW had distinctly different slopes from group to group in each grouping. With FFM discontinuity was evident only at extremes of the range.

BMR is often estimated from linear regression equations. In order to assess the effect of this tendency to nonlinearity in the study population data on the prediction of GBMR, linear regression equations were constructed for the full range of the study population and for each group using BW, $BW^{0.75}$ and FFM. These equations were then used as 'prediction' equations to estimate the mean GBMR by substituting mean anthropometric parameters first in the full range equation then in the group specific equation. Where the extent of departure from linearity was large, the difference between an estimate obtained using a full range equation and one obtained using the group specific equation would be significant not only in statistical but in practical terms.

These estimates for each parameter were compared with the measured mean value and with one another. The estimates using BW, $BW^{0.75}$ and FFM were then measured against one another. The equation of Schofield (1985, 91) substituting BW was used as comparison (as a full range equation only)

The equation by Schofield overestimated the mean of the full range by 4.7%, but when quantified as units of energy, the discrepancy would not have been relevant in practical or clinical terms. For groups of standard BC, mean GBMR was closely represented by all full range equations including that of Schofield. The effects of non linearity became apparent, however, in the overestimates of mean GBMR for overweight and lean groups produced by the full range equations. Some of these, particularly those produced by the equation of Schofield, would have considerable practical significance. Full range equations developed from the study population data substituting FFM in the

case of the overweight and BW or $BW^{0.75}$ in the lean gave better representation than Schofield's equation. Apart from the leanest group, only marginal practical improvement was gained by the use of group specific equations.

The leanest subjects appeared to constitute a separate group. Overestimates of mean GBMR were produced by all full range equations ranging from approximately 9 to 16%, the greatest discrepancy produced by FFM. Although estimations of energy expenditure must always be viewed with caution, the study found evidence of low values of GBMR and uBMR in some very lean individuals and indicated a requirement for a predictive equation specifically applying to very lean subjects i.e. those below approximately 15% body fat. The best estimate was given by a group specific equation substituting group mean $BW^{0.75}$.

In order to assess the discrepancy of estimate which might occur for individuals within the population or groups, individual estimates of GBMR were made using the full range and group specific equations and each was compared with individual measured GBMR. All full range equations produced wide ranges of discrepancy, even where the mean had been closely represented. In most cases, the discrepancies were only marginally improved by the use of group specific equations, achieved mainly by redistribution of the range about zero.

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Chapter 1

Literature review

Chapter 1

Literature Review

1.0 Basal metabolic rate (BMR)

Basal metabolic rate (BMR) has been seen for many years as a cornerstone of understanding of chemical / biological energetics and, as such, the focus of much scientific investigation

Work began with the Lavoisier studies in chemical energetics in the late 18th century and in the 19th century was pursued as a kind of biological holy grail, with BMR regarded as a primary biological property which could be defined in terms of natural laws (Rubner 1883, Richet 1889). As biological curiosity was joined by realisation that this property might have some wider use, much time and effort went into the search for an association of BMR with some easily and reliably measured entity, so that predictions of BMR could be made simply and with reasonable accuracy.

BMR represents 60 - 75 % of total daily energy expenditure and, as such, its accurate prediction can be a planning tool of great social and political significance. Given estimates of the energy cost of activities, a prediction can be made of total energy requirement over a given period of time, e.g., 24 hours.

The use of BMR prediction has changed with time and circumstances. In some societies, the requirement is still to ensure sufficient intake, but in others the emphasis has shifted to estimation of the maximum energy intake in addition to basal which might be compatible with health.

The 'standard laboratory conditions' widely used for BMR assessment were laid down by Benedict in 1938 and these can be summarised as follows:

- there should be absence of gross muscular activity
- the subject should be in a post absorptive state, ideally 12 or more hours after a meal
- the ambient conditions should be thermally neutral
- the subject should be in a calm, unemotional state
- the subject's weight should be stable, indicating acceptable energy balance
- the phase of the subject's menstrual cycle should be known

BMR had been defined as 'the minimal energy expenditure compatible with life' (Mitchell, 1962), Benedict's conditions however do not represent a 'minimum energy expenditure' state since it has been shown that metabolic rate is reduced, for example, during sleep (Durnin and Passmore 1967), by anaesthesia (Mitchell, 1962) and by meditation (Farrell 1980). It may be that the term 'resting metabolic rate' (often used synonymously) may be more appropriate. Where BMR is assessed in clinical situations, the subject may be in a physiological state far removed from the 'standard' and may even be fed during assessment (Gibney and Leahy, 1996)
This study uses the term 'basal' to describe the value of that measurement obtained under the standard conditions described by Benedict and with the co-operation of healthy volunteers.

A review of data on BMR of human subjects reveals both its large amount and its variability. Large reviews have been carried out at intervals with the purpose of establishing predictive equations for BMR. A review of data from approximately 8,500 subjects (Quenouille *et al.* 1951) included not only BMR, age, sex, body weight and height but also data related to race and climatic conditions.

A more selective review of data of more than 2,500 subjects was carried out (Durnin, 1981) from which equations relating BMR to body weight (BW) were derived and a further review (Francois, 1981) of a similar but not identical body of information produced proposed further equations, in this case, relating BMR to both body weight and height.

Clearly, in addition to the inherent variability within and between the subjects which might be regarded as intrinsic variability, the detail of these large reviews indicates extrinsic influences due to diversity of method used and the level of care given to checking and calibration.

This has been a long standing criticism of BMR assessment. In 1937, Talbot (cited by Schofield, 1985) had estimated that (at that time) there were 'more than 10,000 pieces of portable equipment for measuring BMR in use in the United States' and - 'the result has been an enormous number of experiments, most of them with poor results' (Du Bois, 1936). Schofield also indicated that Durnin's review (1981) of data had selected studies of scientific merit with accurate data, suggesting that some studies available did not meet these criteria or at the very least, did not meet the requirement to compare like with like.

In a field such as the assessment of BMR where equipment is constantly being developed and modified and where the human is the subject, variety of technique is to be expected. A report of a workshop on measurement of energy expenditure (Gibney and Leahy, 1996) indicated the continuing diversity of method and the continuing requirement to pay regard to accurate calibration. Murgatroyd speaking at the workshop, urged those embarking on energy expenditure measurement to seek the advice and support of others experienced in the techniques.

Basal metabolic rate may be regarded as being dependent on a number of intrinsic factors, for example, the size and composition of the body, however, the interpretation

of the data requires examination of extrinsic factors such as methodological differences, considered below.

1.1 Extrinsic factors affecting published data

Methods of measurement of energy expenditure (EE) at basal level include those which can be defined as employing direct calorimetry, where metabolic rate (MR) is related directly to heat production, and indirect calorimetry where MR is related to some other parameter associated with EE such as oxygen consumption and / or carbon dioxide production. The assumption made is that metabolism must be aerobic.

Other methods of assessment of EE such as those representing bicarbonate turnover (doubly labelled water) or heart rate monitoring are unsuitable for work at basal level. The doubly labelled water technique, for example, is a useful if expensive method of assessing total EE which requires a long turnover period, while heart rate monitoring, useful as an indicator of a comfortable unstressed state prior to BMR estimation, is more suited to the assessment of the occurrence and magnitude of short term changes in EE rather than measurement of EE at basal level.

1.11 Diversity of measurement method

In the measurement of EE, apparent variability may be introduced by the influence of extrinsic factors, for example, by diversity in -

- apparatus
- conditions of use
- method of calculation
- selection of data

1.111 Apparatus

Apparatus used in indirect calorimetry has included a range of spirometers such as Beckman, Benedict Roth, Max Planck, gas collecting bags such as the Douglas bag, ventilated hoods, helmets and suits.
Estimation of oxygen consumption has similarly been done by a variety of means.

24 hour energy expenditure was measured (Webb, 1981) using an insulated suit as a calorimeter. Authors have used the ventilated hood method in some studies (Ravussin *et al.* 1982) and a respiratory chamber in others (Ravussin *et al.* 1986). One study of the effect of the menstrual cycle (Solomon, 1982) used Douglas bags with nose clip and mouthpiece, while another, also considering the effect of the menstrual cycle employed a chamber calorimeter (Bisdee *et al.* 1989i). Other authors (Curtis *et al.* 1996) in work on energy expenditure during the menstrual cycle carried out 2 independent studies, one using the Douglas bag technique, the other using the Deltatrac ventilated hood system (Datex Deltatrac Metabolic Monitor). (The study did not consider the effect of different method despite the fact that use was made of data combining the two studies) The ventilated hood system has the advantage over other systems in that it does not require the use of a mouth piece and nose clip making it more acceptable to the user particularly in a clinical situation. The use of masks or mouth pieces and nose clips disturbs the normal breathing pattern and if they are to be used, a period of adaptation is essential (Askanasi *et al.* 1980). Six subjects who volunteered for the author's study were unable to take part because of difficulty with the mouth piece.

The Deltatrac system is one example of a ventilated hood system widely used in experimental and clinical applications. It can be used over a range of EE rates and is more easily used than earlier instruments. (This method was not available at the time when the practical work for the author's study was carried out (1983 -86)

1.112 Conditions of measurement

Apart from the primary differences produced by use of different apparatus, the conditions under which the method was used may have varied.
Benedict's guidelines (1938) for the assessment of BMR, often referred to as 'standard laboratory conditions' may yet allow variation in the finer points of the assessment process.

Some assessments of BMR were made as a segment of 24 hour energy expenditure (24EE) (Astrup *et al.* 1992), or separately during the assessment 24EE (Ferraro *et al.* 1992), where a ventilated hood was used within a respiratory chamber.
Where BMR or 'sleeping energy expenditure' (SEE) were assessed as segments of 24EE, further variation might occur in the conditions during assessment.
Bisdee *et al.* (1989) in a study of changes in EE during the menstrual cycle, compared their results with those found by Webb (1986) but observed that Webb's subjects were 'extremely sedentary and wearing a calorimetric suit'.

The period of rest or adaptation to the apparatus has varied. The small value for within subject coefficient of variance found in one study of 24 hour energy expenditure (de Boer *et al.* 1987) was attributed to the adaptation period of 1 day prior to the test and to a 5 day dietary adaptation period, while another (Astrup *et al.* 1992) described a 4 day instructional period (instruction by a dietician).
Webb (1981) measured for 36 and 46 hours 'to allow a certain settling of the data' and 'selection of the 24 hour segment which best represents a subject's metabolism'. In this case part of the measurement period was acting as preparatory time.

Where measurement of BMR only was carried out using apparently very similar methods, there are differences to be found in the detail.

Many authors used a 30 minute rest period immediately before the test period, but one, (Solomon *et al.* 1982) using this rest period, prefaced it by having the subjects sleep overnight in the laboratory. A 15 minute rest period prior to the first of the 15 minute test periods has also been used (Keys *et al.* 1973), the subject either driving or having been driven to the laboratory. It is conceivable that in Minneapolis in 1973, there may have been considerable difference between driving and being driven prior to an assessment of BMR.

1.113 Selection of data

The number of tests on one subject varies, with some workers opting for a single test and others double or triple estimations.

In his summary, Schofield (1985) noted that investigators who had opted for the single measurement technique would make additional tests if the first was thought to be unsatisfactory due to restlessness, nervous tension or elevated temperature (citing Boothby *et al.* 1936) and observed that there was no evidence as to the extent of this practice. Schofield had also analysed more recent relevant screened data and found that 37.3% of cases were said to be based on a single measurement, 49% were the mean of 2 or more values. In 1.4%, the lowest value was taken and in 12%, no information was given. Where a mean of several values was used, some studies used the complete range, while others selected from the lower end of the range. Comparison of these data had shown that when group means were calculated, that for the 'lowest measurement group' was lowest, but the means for the 'single measurement group' and the 'mean score group' hardly differed (Schofield 1985). He concluded that, although these inconsistencies had apparently made no difference at least to group means, the problem should be examined further.

Some studies unfortunately give no details as to whether a single assessment is carried out or whether the tests were multiples and no information on how the multiple tests were treated (Cuskelly and Younger, 1993)

Webb (1981) can be quoted again but in a different context- he noted that subjects were measured for 36 and 46 hours 'to allow a certain settling of the data' and 'selection of the 24 hour segment which best represents a subject's metabolism'. While his study involved assessment of total energy expenditure rather than BMR, his comment suggests a somewhat selective use of numerical data.

1.114 Methods of Calculation

In an account of a workshop on the measurement of energy expenditure, Gibney and Leahy (1996) reported a summary given by Macdonald of the equations used in the estimation of BMR by indirect calorimetry. A number of equations were identified (Weir, 1949, Consolazio *et al.* 1963, Ferranini, 1988, Simonson and DeFronzo, 1990), however the equations produced by Elia and Livesey (1992) were considered likely to be more accurate since they use more appropriate values for the energy content and respiratory quotient (RQ) of protein. The use of the Haldane (1935) correction which allows for the differences in volume between inspired and expired air was strongly recommended. Haldane found that the volume of (dry) air diminished in respiration with more oxygen taken up than carbon dioxide given off. Since nitrogen is not exchanged, it was possible to correct the volume of oxygen used by applying a factor derived from the apparent relative change in nitrogen. Expressed as a change in RQ, the difference approximates to zero when RQ = 1 rising to + 0.05 when true RQ is 0.7. Working from Haldane's own calculation, where true RQ = 0.8, the oxygen underestimate is approximately 5%.

A review of literature describing BMR measurement by indirect calorimetry indicates first that the method of calculation is not always identified. Data from a number of studies may be compared in a review without reference to the calculations used in each study. Cunningham (1991) reviewed studies carried out on healthy adults where EE had been measured with reference to body composition. Although his paper gave considerable detail regarding the methods used, the methods of calculation used for the

raw data had to be inferred as far as possible from the method employed, and it was unlikely that a common calculation could have been used for all studies being compared.

There are examples of the ventilated hood technique used with the Haldane correction (Ravussin *et al.* 1986) and without (Owen *et al.* 1987). Solomon's study (1982) of the changes in BMR during the menstrual cycle clearly described the use of the equation of Consolazio, while Bisdee *et al.* (1989i) also working on EE during the menstrual cycle used a whole body calorimeter and the method of calculation described by Brown *et al.* (1984) for use with open circuit calorimetry. de Boer *et al.* (1987) in their study of women, used the formula of Brouwer (1965), but neglected the protein factor in the formula for periods shorter than 24 hours i.e. for BMR. She also noted that oxygen consumption and carbon dioxide production by cigarette burning was subtracted (presumably this did not apply during assessment of BMR). Macdonald (Gibney and Leahy, 1996) has emphasised that anyone carrying out indirect calorimetry should fully understand the equations used. Where a number of studies are used comparatively, it might also be recommended that the equations employed should be identified.

1.2 Intrinsic determinants of BMR

While variations in the methods of measurement and calculation are likely to introduce apparent variability in BMR from published sources due to technical or measurement artefacts, the effects are likely to be outweighed by the effects of intrinsic factors within the subjects themselves.

These intrinsic factors which may be regarded as major determinants of BMR may be grouped under the following headings -

- body size
- the composition of the body tissue
- those neural and endocrine factors regulating the rate of tissue activity
- the fuel selection of the components of the tissue mass

1.3 Body Size - body surface area or body weight ?

The size of an object may be judged in a variety of ways, for example by a measure of its volume, perhaps derived from its surface area, or by its weight.

Body surface area (BSA) was suggested in the 19th century as a determinant of basal metabolic rate. Rubner (1883) and Voit (1901), who had been Rubner's pupil, proposed that metabolic rate was related to BSA and was determined by heat loss. Voit's study was concerned with metabolic rate across species and showed that the very large differences in heat production between different sizes of animal species, narrowed to about 20% of the mean when expressed as energy / unit BSA. Volt's proposal did not, however, explain the large differences which may exist between members of the same species.

Even in the very early days, there was continuing controversy on the relative validity of BSA and body weight (BW). Voit had attributed metabolic rate to the cell mass of the organism and in 1915, Benedict considered that weight and BSA were probably equally unsuitable theoretical indices of 'active protoplasmic tissue'. In 1919, Harris and Benedict stated that BSA produced no advantage as an index. The concept of BSA , however, continued to be widely held and Cunningham (1982) cited studies (Terroine and Roche, 1925, Graft *et al.* 1925) which showed that cellular energetics of in vitro samples of tissue from different sized animals were uniform among homeotherms. Those authors, however, had chosen not to challenge the primacy of BSA on the grounds that in vitro samples were not representative.

Eventually, Du Bois (1927) provided evidence and argument which discredited the view that surface area should be a primary determinant of BMR. With hindsight, the view of BSA as a determinant of metabolic rate in homeotherms is biologically unsound. Man has numerous temperature regulatory mechanisms and it seems unlikely that metabolic activity could ever have been thought of as primarily adjusted to keep the surface warm rather than as a series of integrated processes producing heat as a

product which can be dissipated or retained at a rate determined by responses initiated by core and shell thermorecepters to maintain core temperature.

Inspite of the arguments against it, BSA continued to be used. It was not usually measured. Measurement involved covering the subject with a thin film of paper or fabric which could then be removed and measured. This was done on relatively few subjects and the practical difficulties ensured that the technique was unlikely to become a common assessment procedure.

Surface area was therefore derived from height and weight (Du Bois and Du Bois, 1916) or from a nomogram (Fleisch, 1951). Although the concept of BSA as a useful parameter was outmoded by the 1927 publication of Du Bois' first edition of 'Basal Metabolism In Health And Disease' (Keys *et al.* 1973), BSA continued to appear in literature until much later. Cunningham (1982) wrote that BSA was clinically useful and routinely used to predict energy requirement, however argued that this was acceptable only because, within one sex, BSA was well correlated with lean body mass. Owen *et al.* (1986) observed that, in their study on 44 women, the combination of age and BSA gave the highest correlation but was not statistically different from that for weight alone.

1.31 Body weight

The 'quantity' of a body is denoted by the term 'mass' while the term 'weight' refers to the gravitational force exerted on that body, the values being numerically equal only at sea level. Use of the term 'body weight', with the SI unit of mass kilogram, rather than body mass, however, remains widespread and accepted in current (biological) scientific literature, including that cited. The term 'body weight' is employed in that sense throughout this document, despite the inconsistency created by use of the more recent terms fat mass and fat free mass.

The use of body weight (BW) as a parameter from which to predict BMR arose from the need to find some standard which could be easily and accurately measured. BW meets these requirements, subjects are accustomed to weighing themselves and being

weighed and there is usually no resistance to its assessment. BW, however, is not constant from day to day (Durnin and Passmore, 1967) and it had been demonstrated (Edholm *et al.* 1974) that changes of up to 1kg can occur due to intake and excretion of food and fluid.

The body of literature concerned with the relationship between BMR and BW is very large and now spans almost a century. Although the measurement of BW is straight-forward, the literature concerning the relationship of BMR with BW is complicated not only by biological variability of BMR but by the variation in the methods used for the measurement of BMR. Different methods were used with the same and different apparatus, different sample sizes, different standards applied to the assessment and the subsequent treatment of data (see sections under 1.11).

As a parameter related to BMR, the use of BW is biologically more soundly based than the use of BSA, however, it is apparent from a review of the literature involving BW shows that the relationship of BMR with BW, apart from methodological issues, is far from simple.

In 1973, the relationships were summarised by Keys *et al.* who had found that when correlations of BMR and weight (W), height (H), H and W, with and without BSA had been examined, the combination of H and W was found most closely correlated, H least correlated and that none of the values was high.

BMR and anthropometric records were reviewed and screened for FAO/WHO/UNU Expert Consultation on Energy and Protein Requirements, 1981 (Schofield, 1985, citing Durnin, 1981). Data were amassed for more than 2000 subjects who had taken part in studies which were regarded as being likely to have yielded valid results. These data were examined by several analysts.

The data analysis was summarised by Schofield. Francois (1981) had allocated the data to four age/weight groups and derived semilogarithmic regressions for each, thus fitting four regression lines along the curve. This, according to Schofield, resulted in discontinuity between the groups and required highly complex data manipulation. Rand

(1982), in an unpublished report (quoted by Schofield) on a study of observed and predicted BMR, constructed prediction equations, from log weight and log weight squared. He found that inclusion of either height or age did not increase the variation accounted for by the two terms and also that several combinations of all of the terms predicted more than 90% of the variability. Furthermore, where one or other of the two terms was used alone, the effect was of little consequence when the overall variability was considered and the addition of a second variable was unlikely to improve prediction. He also noted that all the equations gave a poor fit at the extreme ends of the scale, underestimating the very light and very heavy individuals.

Since weight and a profile of other factors appeared to demand not one linear relationship but several across the life span (Durnin 1981), data were subdivided according to age group, - under 3 years, 3-10, 10-18, 18-30, 30-60, over 60 years - and equations established for each group, male and female, based on weight alone.

The inclusion of height (H) as a variable did not improve prediction except for children in the 0-3 year groups and people over 60 years. This applied to both sexes.

Using the weight only equations, it was found that standard error (SE) was usually less than 2% of the mean of the observed data used to derive the equations, moving to 4% at the extremes of weight range for the oldest and youngest groups. For 18-30 year olds (the age range of the author's study) the 95% confidence limits for these predictions are less than ±3% of mean BMR at maximum.

The addition of multiple variables of ever increasing complexity apparently contributed little to the exactness of prediction and the use of the power factor $BW^{0.75}$ is likely to be just as representative. (Schofield 1985). Body weight for age, for sex and in some cases weight for height as representing body size appeared to be a major determinant of BMR although the precise relationship remained a matter of debate (Schofield, 1985).

Since that time, a study of predicted energy expenditure of lean and obese women (de Boer *et al.*, 1987) found that BW accounted for 82% of the variance in 24 hour energy

expenditure. Another (Owen *et al.* 1986), found that, in women, BW was highly correlated with RMR (r = 0.74). The slopes of the regression lines for non-athletic lean and obese women were indistinguishable, the equation given as RMR(kcal / 24 hrs.) = (7.18 x W (kg)) + 0.795. The regression line for the female athletes in this study was different from the above, the equation given as RMR (kcal / 24 hrs) = (21.1 x W (kg) + 50.4 and the 95% confidence limits for the regression line were narrow, indicating that BW was not equally well correlated with BMR in all body compositions or that lean athletic women exhibited characteristics different from the rest of the females in Owen's study group.

Dore *et al.* (1982) found that BW was the most highly correlated variable for predicted resting energy. The women in this group, however, had been obese and had lost large amounts of weight, therefore, it is possible that correlation of BMR with BW had been affected by body composition changes or possible adaptation to reduced intake (Keys *et al.* 1950). This correlation may therefore not have been representative of a group not exposed to those changes.

!.32 Body mass index (BMI)

BW by itself gives some measure of size but little else. The use of anthropometric indices refines an estimation by the recruitment of other parameters such as height or height for age. The application of anthropometric indices allows the construction of an 'indicator' which gives information about the anthropometric or nutritional status of a community, for example, the proportion of children below a certain weight for age is used as an indicator of community status (WHO, 1995). Those indices relating BW to height are body mass index (weight / height^2) and the ponderal index (weight / height^3). The author's study involved measuring BW and H and calculation of BMI for the subjects in the study population.

BMI values, however, can be misleading. Ethnic groups may have different 'body build'.

Leg length may have considerable influence. WHO cite the example of Australian aboriginal people who have longer legs but the same sitting height and body weight as Europeans but have lower BMI and ethnic south Americans with shorter leg length who have higher BMI.

The same BMI may denote very different body compositions. Low BMI in some populations may indicate malnutrition (Shetty and James, 1994) or clinical disease (James and Ralph, 1994), however since BMI is highly correlated with FM (Norgan, 1994) and very low FM has been identified in long distance female runners (Maughan, 1994), low BMI in some populations may relate to athleticism. Both fat and lean tissue are lost as weight is lost, the greater the mass of adipose tissue, the smaller the loss of lean tissue in starvation (Ferro-Luzzi *et al.* 1994). In females, the greater percentage of fat has the effect of moderating the loss of lean tissue, which increases, however, as weight and BMI are reduced. Illness and the response to trauma are characterised by proteolysis and gluconeogenesis resulting in the preferential loss of lean tissue and, as muscle mass is reduced, work capacity is also reduced.(Desai, 1989). The low BMI and low FM mass of the athlete, however, is likely to be the result of a training regime which maintains muscle mass and a diet calculated to avoid the laying down of fat.

BMI of either low or high values would appear to have attendant risk.

WHO (1995) has described kg / m^2 values of -

- 17 to 18.49 as mild thinness
- 16 to 16.99 as moderate thinness -linked with clear- cut increase in illness in adults
- < 16 as severe thinness - associated with markedly increased risk of ill health and decreased physical performance, lethargy and death.

They identify the requirement for future research into the following aspects among others, the evaluation of a cut - off point for BMI for ages 18 - 25 years, for which lower cut - off may be appropriate (this is the age group included in the present study), and improvement in the understanding of the effect of low BMI on lean body mass e.g.

whether the integrity of the mass and composition of lean tissue is always compromised by low BMI (again an important consideration for some subjects in this study)

At the other end of the scale, overweight in 'consumer' societies has become a major health cost. Overweight is generally thought to be associated with an increase in the prevalence of cardiovascular risk factors (Manson *et al.* 1990). The increased risk appears to be compounded by abdominal distribution of fat. (Lapidus *et al.* 1988 cited by Han *et al.* 1995; Lapidus *et al.* 1994). The risk of hypertension, increased by overweight, can be reduced by weight loss (Schotte and Stunkard, 1990). Overweight increases the risk of type 2 diabetes. Down regulation of insulin receptors on insulin sensitive tissue is associated with overweight to the extent that the risk of type 2 diabetes is increased 60 fold with BMI over 35 kg / m^2 (Colditz *et al.* 1990 cited by WHO, 1995)

As with thinness, overweight as defined by BMI (kg/m^2) has been graded by WHO (1995) with

- 18.5 to 24.99 as normal
- 25.00 to 29.99 as overweight grade 1
- 30.00 to 39.99 as overweight grade 2
- ≥ 40.00 as overweight grade 3

Clearly, BMI values which are either low or high may have implications for states of health and therefore energy requirements which may be affected by that state of health. Furthermore, although BMI may be highly correlated with FM (the study by Norgan, 1994 concerned non -Europeans), BMI is more a measure of size than composition (Norgan, 1994)

In the absence of additional information on body composition, there are limits to the reliability of BMI. Just as underweight or low BMI may not necessarily be a reliable

indicator of negative or near negative energy balance, overweight, while usually a very good pointer to excess intake over output, may also be misleading. The original purpose of the study of BC by Behnke *et al.* (1942) was, after all, to show that draftees into the US navy, who had been professional football players, had been wrongly rejected on grounds of excessive weight for height.

1.4 Body composition

There are large and predictable differences in BMR between groups with similar mean BW. Females have lower BMR than males of the same BW and age group. The young have higher BMR than older members of the same sex and BW, and even differing states of fitness may produce different BMR in individuals who are apparently similar. Body weight, although a major determinant of BMR, can account for only a proportion of variance and much of the differences between male and female, young and old, fit and unfit, can be traced to differences in body composition (BC)

1.41 The components of body composition

The body is composed of cell masses using water, oxygen, substrates and energy, the total of which activity in basal conditions per unit time is expressed as basal metabolic rate. Different cell masses have different metabolic processes and requirements and could be regarded as separate but communicating compartments.

The methods of assessment of body composition may be based on the assessment of a total body parameter, for example relative density or body water or body potassium, from which can be derived information on the compartments relative to one another. The assessment may also be based on the measurement or assessment of one compartment, for example fat mass, from which a value can be derived for another compartment, making up the whole.

1.42 Two compartment models

The view of Benedict in 1915 was that BC compartments might be 'active protoplasmic mass' and 'metabolically inert fatty tissue', the latter a particularly inappropriate term now, but at that time, little was known of the properties of adipose tissue.

In subsequent years, the concept of compartments was developed and in 1953, Miller and Blyth first used the term fat free mass (FFM). Using their terminology, the major compartments of a two compartment model could then be regarded as fat mass (FM) and FFM.

The two compartment model was further developed to a four compartment model where the components of FFM, identified as water, protein and minerals, were regarded as separate compartments. This could then give rise to two three compartment models where first water and protein, then water and minerals were taken as single compartments. The protein component is difficult to measure, the three compartment models were not commonly used (Going *et al.* 1994) and two component models continued to be developed and used.

Using animal and human cadaver analyses it was possible to estimate the relative density of the separate compartments and from there to derive formulae relating body density to body fat. This gave rise to the densitometric techniques which established the relative density of the whole body by weighing in air and under water and estimating the contributions of lung and gut air.

Siri (1956, 61) and Brozek *et al.* (1963) both used the 2 compartment approach although their equations were differently derived. The Siri equation related variation in triglyceride to differences in body density while the Brozek equation used a 'reference body of specific density'. Variation from this reference body density was assumed to be due to differences in the amount of 'obesity tissue'. A comparison of the results given by the two equations (Lohman, 1981) found that at non-lean non-overweight i.e. 'standard' BC, the estimates of body fat were very close (citing Wilmore and Behnke,

1968) however where subjects were lean or obese, the equation of Brozek *et al.* gave better estimates.

1.421 Terminology of two compartment models

Although the anatomical analogy of the compartments FM and FFM might be regarded as adipose tissue and lean body mass (LBM), the composition of the compartments is not the same.

Adipose tissue contains protein and water and is approximately 80% fat. 'Fat' is the chemical term for the esters of glycerol and therefore applies to a particular and clearly definable class of lipid. Lipids, which include fat, may be classed as 'essential' and 'non - essential' (Wang *et al.* 1992). Densitometric assessment includes the non - essential lipid in the FM compartment and the essential lipid in the FFM compartment. FFM has been defined elsewhere (Miller and Blyth 1953) as 'active cell mass' i.e. living cells, these cells containing lipids as structural and functional components. FFM has also been defined (Going, 1994) as a heterogeneous compartment containing water, protein and minerals with the implication that it is fat free, which, provided the definition of 'fat' is adhered to, would be in agreement with the conditions applying in densitometry or equations derived from densitometry. Using the anatomical equivalent compartments, LBM must contain essential lipid, but in practice, also contains small amounts of fat as defined above.

The use of terms by some authors such as Cunningham (1991) is less than exact. He described LBM and FFM as not equivalent, LBM representing 'non adipose tissue' however FFM was described as 'non lipid mass'. Ravussin *et al.* (1982) used the terms FFM and LBM interchangeably, Astrup *et al.* (1992) used the term LBM for one compartment with the term FM for the other.

1.43 More complex models of body composition

There have been major advances in models relating anthropometry to body composition which extend the concepts of the two compartment model. The

multicomponent models envisage the body at different 'levels'. (Heymsfield *et al.* 1996, citing Wang *et al.* 1992)

The five level model visualises the body at increasingly complex organisational levels - atomic, molecular, cellular, tissue / system and whole body. The levels are distinct from one another and in each case, the total mass of the components equals body weight. At equilibrium in any level there is a steady state between specific identifiable components, providing predictable relationships which can be utilised to derive body composition expressed in the terms of that level.

Estimations made directly at one level may provide supporting evidence for a better estimate at another level. For example, total body calcium, estimated directly at atomic level, can be related to the predictable relationship between osseous and non - osseous calcium known to exist where there is a state of equilibrium at cellular level (level 3) or tissue / system level (level 4) (Wang *et al.* 1992)

1.44 Practicality of simpler models

The availability of samples and the methods of analysis may put assessment of some of the levels out of the reach of some investigators, although published data particularly at atomic and molecular levels are likely to provide useful information additional to more conventional anthropometry.

Because of its relative accessibility, the two component model continues to be widely used in practice, with BC being estimated by the measurement of one compartment e.g. FM and calculation of the other from body density, body weight or total body water.

A comparative study estimated % body fat in 389 Caucasians by eight methods, three of which gave the results, bio - impedance - 17.2%, skinfold thickness (Durnin and omersley, 1974) - 19.9% and densitometry, long considered the reference method, - 20.8%. (Ballor, 1996, citing Peirson *et al.* 1991)

1.5 Body composition as fat mass (FM) and fat free mass (FFM)

Although the titles of the compartments imply that the composition may be uniform and the characteristics may be predictable, neither compartment could be regarded as simple and each has an extensive literature field. For convenience, some methods of body composition assessment are considered under **Fat mass** at section 1.511 and following and others under **Fat free mass** at section 1.521 and following.

1.51 Fat mass

Fat mass is not the inert fatty tissue as described by Benedict (1915), and, to quote Pond (1992) neither is it a Cinderella tissue regarded as filling the spaces not occupied by other tissues. It has been described as the tissue most affected by diet (Frayn *et al.* 1992) and the ultimate reservoir for energy storage. It is a tissue which is well perfused and the site of numerous biochemical reactions.

Its role in energy exchange and management, operating through triacylglycerol (TAG), has been extensively studied (Frayn *et al.* 1995). It is sensitive to many mediators including insulin, insulin like growth factors (IGFs) and other hormones (see review by Abate and Garg, 1995).

It is not a homogeneous mass. The characteristics of the 'minor fat depots' which are associated with lymph nodes (Pond, 1996) make it clear that, while histologically alike, these deposits differ from the large depots and from one another. The functions may be entirely different, e.g. functions relating to the responses of the immune system and acting as the reservoir of particular rare but essential nutrients and Pond makes the reasonable contention that it would be biologically sensible to separate fat depots which serve to maintain the energy availability (Frayn *et al.* 1995) from these small depots.

FM plays an important role in the energy economy acting as a large energy reserve. Since its rate of energy expenditure is very different to that of FFM, its mass relative to that of FFM significantly affects BMR and its range of metabolic activities is likely to contribute to the overall variability in BMR. Estimates have been made of the EE /kg of FM and FFM of 0.31 J/sec for FM and 1.35 J/sec for FFM.(Garby *et al.* 1988). The

authors had made observations of 104 women at rest and had also found similar values in other smaller studies and from other sources.

1.511 Fat mass measurement

In many individuals FM constitutes a very large mass. The highest %FM value in the author's study was 40%, considerably lower than subjects studied by Garrow and Webster (1985) some of whom were found to have 60%FM

1.5111 Skinfold thickness assessment

Body fat was estimated in the author's study by skinfold thickness measurement according to the method of Durnin and Womersley (1974)

The use of skinfold thickness measurement in the assessment of either BC or nutritional status (WHO, 1995) depends on the assumptions

- that skinfolds reflect the overall distribution of subcutaneous fat, this approaches validity only if measurements are made at several sites
- that the relationship between subcutaneous fat and total fat is sufficiently constant among populations to allow body fat to be estimated from skinfold thicknesses.

Skinfold thickness measurement has its limitations, for example where BC is changing. When measurements were made during a period of training (Sinning and Wilson, 1984), equations by Jackson, Pollock and Ward (1980) and Durnin and Womersley (1974) overestimated the densitometric value by 1 and 4 % respectively, the former difference however is likely to be within the repeatability limits of the densitometric methods. Also, where there has been weight loss, skinfold thickness assessment has been shown to overestimate the densitometric value by 4% to 8% (Scherf *et al.* 1986). Those with unusual distribution of fat, for example with thick triceps folds, are not

reliably assessed by skinfold, even where a total of four sites thickness is used. (WHO, 1995)

The technique is not recommended for subjects who are pregnant (WHO, 1995). There may be relocation of fat from limbs to abdominal area and skinfolds on arms, legs and even sub- scapular may not represent tot total body fat. The stretching of skin in the abdominal area may cause thinning of the fold and consequent underestimaton of the total fat. There may be a degree of generalised oedema which makes the folds difficult to measure reliably.

The apparently simple method of skinfold thickness assessment relies heavily on the skill of the observer. The inexperienced observer may introduce large errors simply by inexpert technique, however once a good technique has been established, reliability should improve (Walker and Kindlen, 1988). Calliper design should allow a precision of estimate of approximately 5 % (Edwards *et al.* 1955). Inter-observer variation has been found to be significant by Fuller *et al.* (1991). With 6 observers measuring 12 volunteers (6 male, 6 female) mean body fat was estimated to be 18.3 kg, residual SD - 0.9, residual coefficient of variation - 4.6 % ($p< 0.001$). Prior to this, Pullicino *et al.* (1990) had found skinfold thickness as one of the two best predictors of BC assessed by deuterium dilution and cited the study of Elia *et al.* (1990) which found skinfold thickness to be the best predictor where densitometry was the reference method.

Comparative studies of skinfold thickness and magnetic resonance imaging (MRI) (Barnard *et al.* 1995) found that the methods showed excellent agreement, 34.6 % mean body fat by skinfold thickness and 35.7 % by MRI, $r = 0.96$ $p<0.001$. MRI, which allows quantification of separate fat compartments, is considered at greater length under FFM (see 1.5216)

1.5112 Other methods of assessment of fat mass

Other methods of assessment are considered under the assessment of FFM where they provide either the primary assessment from which FFM is derived or assessment in parallel. Dual emission X ray absorptiometry (DEXA or DXA) has also been used to assess soft tissue mass and likewise is considered under FFM (see 1.5215) however, with reference to FM, it has been shown that, when compared with direct analysis of fat, DEXA substantially underestimated fat at physiological thicknesses and the authors suggest that their results raise serious questions about the validity of current algorithms for BC analysis (Jebb *et al.* 1994)

1.512 Fat mass and BMR

Fat mass, although a lower rate contributor to total expenditure, becomes an important factor in most large groups of women.

In obese subjects, it has been suggested that the contribution of FM increases as activity increases (Ravussin *et al.* 1982, de Boer *et al.* 1987, Garby *et al.* 1988) However, in basal conditions this does not apply and the effect in these circumstances may be due to increased thermal insulation (Garrow and Webster, 1985) or the increased cost of protein turnover caused by obesity (Welle and Nair, 1990). Ravussin *et al.* (1982) found a significantly lower respiratory quotient (RQ) in obese subjects indicating greater lipid oxidation and a possible shift in fuel selection and utilisation. Webb (1981), Ravussin *et al.* (1982) Astrup *et al.* (1992) and Ferraro *et al.* (1992) all found FM to be a significant determinant of BMR in the obese. The studies by Ravussin, Ferraro and Garrow found no difference in this respect between men and women.

1.5121 BMR and Fat Distribution

The regional distribution of fat has been found by some authors to be associated with effects on BMR. Such an effect, if valid, may be more closely related to the endocrine

or neuro-endocrine factors which resulted in the distribution rather than the distribution itself.

A study of obese female pre-menopausal subjects and non-obese controls (Westrate *et al.* 1990) showed that women who were non-abdominally obese had lower BMR adjusted for age, FM and FFM when compared with those who were abdominally obese and the non-obese controls. No difference in RQ was noted in the latter study. It was proposed that androgens such as free testosterone might play a part in fat distribution (Buemann *et al.* 1983) and the study reported that 24 hour energy expenditure adjusted for FFM and age was higher in obese women with android distribution than those with gynoid distribution. Pullicino *et al.*(1996) however found that, in a group of Maltese women with a high incidence of abdominal obesity, fat distribution had no effect on BMR. Abdominal obesity is linked with metabolic abnormalities which may result in diminished hepatic insulin clearance and insulin resistance (Vague and Raccah, 1992). The FFA rise, whether a cause or an effect on the above, is likely to have an influence on fuel selection and therefore on EE. (Barnard *et al.* 1995)

1.5122 BMR and low fat mass

A sharp decline was found to have occurred in resting EE of women who were severely anorexic (Scalfi *et al.* 1993), they had however retained a normal thermogenic response to food. Lean healthy women in the same study had higher resting EE but reduced thermogenic response to food. The very lean healthy women had retained greater body fat than the anorexic women, with about 5 % difference in the means. This finding may indicate that the reduced EE may only be found at very low %FM.

A study of energy intake, expenditure and activity (Maughan, 1994) found that in sports where women require a low body weight, particularly a low fat content, for example, gymnastics and distance running, many have a very low fat mass, less than 10% of BW is not uncommon in female long distance runners. Maughan also found that these women consistently show a lower than expected intake to maintain their weight.

The presence of FM whether small or large would appear to influence BMR. Where FM is small, possibly as a result of chronically low intake or intake aimed at maintaining a low body weight or low fat mass, there may be adaptive changes in tissues to reduce EE, although this would suggest that tissue was capable of becoming more energy efficient. At the least, the mix of fuel substrates available and the regulatory factors affecting their use must be affected. On the other hand, where FM is large, BW includes a large compartment of low EE, thus affecting BMR of the whole and again affecting the fuel substrates available.

1.52 Fat free mass (FFM)

Fat free mass has been described as that component in a two compartment system which is fat free but includes essential lipid (Wang *et al.* 1992). Using the molecular level, level 2, of their multicomponent model, it can also be described as that compartment including body water, bone and soft tissue mineral, protein and glycogen, or it may be simply defined in a two compartment model as FFM = BW - FM.

1.521 FFM estimation / measurement

As the higher energy compartment in a two compartment system, FFM is taken as the greater contributor to EE. BMR is frequently related to FFM rather than BW, however the methods of determination of FFM are complex and diverse and, as with BMR determinations, data relating to FFM measurement must be considered with care.
FFM can be estimated by a number of methods, which measure an entity which can be directly related to FFM.
Those considered below are -

- densitometry
- hydrometry
- bioelectrical impedance
- total body potassium

- dual emission X ray absorptiometry
- nuclear magnetic resonance / magnetic resonance imaging

1.5211 Densitometry

Densitometry, as discussed earlier, has been used to estimate FFM, but makes the assumption of constant relative densities for FFM and FM. The method also assumes that the components of FFM will have a fixed quantitative relationship with one another and that the density of each component is fixed. Density of FFM been found to be lower in elderly people (Deurenberg and van der Kooy, 1989), in obese people (Deurenberg *et al.* 1989) and in white males compared with black males. (Schutte *et al.* 1984). Body cell mass in FFM was also found to be higher in black females than in matched whites. (Cote and Adams, 1993)

1.5212 Hydrometry

The changes found daily in body weight may be as large as 1kg (Durnin and Passmore, 1967) and are likely to be due to changes in total body water (TBW) since primary changes in body solids would take much longer to achieve. Since at each of the levels of BC assessment, the components of the level are related to body weight (Wang *et al.*, 1992), BC is in turn closely bound up with TBW.

TBW has been estimated by a number of dilution techniques, e.g. tritium in a study of rat BC (Rothwell and Stock, 1979), bromide ion chromatography in an assessment of extracellular water volume (Wong *et al.* 1989i) and deuterium dilution where the results were compared with anthropometry (Wong *et al.* 1989ii)

Again a number of assumptions have to be made, for example that the tracer used is equally rapidly taken up by the components, is equally distributed and is not metabolised by any of the compartments.

The question of equilibration is central to the method and two concepts have been employed. The plateau method is based on the principle of collecting samples until it is

clear that a plateau for the tracer has been reached and TBW is estimated from the dilution. The plateau is not a constant because of the contribution of metabolic water and a slope intercept method has been used which avoids some of the effect of this variable (Coward, 1988). This involves measuring for up to 14 days after the dose, constructing a slope and extrapolating to find the zero time intercept. This method requires longer involvement of the subject and their extended co-operation

The methods of analysis of the tracer have also varied over the years and to some extent, the analytical methods have dictated the tracers used. The scintillation counter for example was convenient to use and was available from the mid 1950s (Vaughan and Boling, 1961), but this used tritium not deuterium. Deuterium was used in studies employing infrared spectrometry (Lukaski and Johnson, 1985) and nuclear magnetic resonance (NMR) (Khaled *et al.* 1987)

Pragmatic considerations such as cost affect choice of method. Oxygen 18, (^{18}O) closely represents TBW (Schoeller *et al.* 1985) but its cost far outweighs the gain in accuracy of estimation.

1.5213 Bioelectrical impedance / 'bioimpedance analysis' (BIA)

Measurement of electrical impedance and conductivity have given rise to several techniques of assessment of BC

In electrical terms, impedance is the opposition to (alternating) current flow in a conductor. It is frequency dependent and consists of resistance and reactance. Reactance in biological systems is usually very small compared with resistance. The equation -

$$\text{impedance} = \text{resistance}^2 + \text{reactance}^2$$

further reduces the effect of reactance and therefore impedance is often taken to mean resistance. Reactance, as the reciprocal of capacitance, would only become important where multifrequency systems were in use.

BIA has been used in diverse fields by many authors, for example, clinically (Pullicino *et al.* 1990), epidemiologically (Van Loan and Kophler, 1990) and in food animal husbandry and production (Boileau, 1988). The ability to detect relatively small changes in BC has made it a useful clinical indicator of the effects of trauma or wasting disease, however, the large number of equations available relating impedance to BC and including numerous other parameters such as electrolytes complicates interpretation of the results.

The relationship of impedance to FFM itself is even more complex. The ratio of TBW to FFM is not constant and the degree of hydration may vary without being clinically evident. While some studies showed good agreement between densitometry and BIA in young men (Lukaski *et al.* 1985), the studies using BIA on older subjects (Deurenberg and van der Kooy, 1989) and on young children (Deurenberg *et al.* 1990ii) indicated that the relationship between FFM water and TBW was not constant. BIA was shown to be not well related to FFM in obese subjects. (Segal *et al.* 1988)
As with all assessments, the care taken with conditions of assessment is important. Ambient temperature, body position, recent activity and stage of the menstrual cycle all affect *results* and Lukaski *et al.* (1985) advised that a strict protocol was required to ensure repeatability of conditions.

1.5214 Total body potassium

Total body potassium (TBK) has been used as a measure of BC since the development in the 1950s of the scintillation counter (Ellis and Eastman, 1993; Ellis, 1996). He described as the basis of the technique the measurement of γ rays detectable in the decay of ^{40}K . This gives a measure of ^{40}K which makes up a fixed percentage 0.0118% of total potassium and in turn can be related to body cell mass. Ellis cited early studies (Kulwich *et al.* 1958) as identifying the correlation of ^{40}K with FFM and the technique has developed to take account of factors such counting times and other emissions for

examples from clothing and jewelry. Ellis quoted Watson (1987) who described the effect on measurement of ^{40}K of the Chernobyl accident which released enough radioactivity into the environment to produce transient background interference.
Ellis described the principles of calibration of the method, one of which is to construct a 'phantom' of anthropometric shape from ground meat which has been chemically assayed for potassium. This 'phantom' approach has been used (Fenwick *et al.* 1991, cited by Ellis) to compare ten instrument systems. The trial showed good agreement between the median estimate of the counters and the known assays of the phantom. Although a costly, mainly research technique, it is non invasive and does not require the subject to fast. It links directly with level 1 (atomic level) in the five level BC model

It has been used clinically in the assessment of BC changes in trauma and sepsis. It has been demonstrated that TBK is not always an accurate measure of lean body mass (Jeejeebhoy *et al.* 1982). The study found that although in control subjects there was an overall relationship of TBK and total body nitrogen (TBN) to anthropometrically derived lean body weight, in patients who had been malnourished TBN was reduced more than TBK although both parameters were reduced. Short term repletion produced an acute rise in TBK but not TBN, indicating a change in cell potassium independent of nitrogen. The authors did not consider the mechanisms underlying this effect, however the changes in intracellular potassium produced by insulin in response to refeeding might have made this predictable. With longer term refeeding, nitrogen retention had occurred, with the implication that the relationship between TBK and either TBN or lean body mass is not constant.

1.5215 Dual emission X-ray absorptiometry (DEXA or DXA)

This technique has been used clinically for some years to measure the density and mineral content of bone. Its use allows the detection of osteoporotic changes in bone much before they become evident when conventional X-ray imaging is used.

Parallel to this development, DEXA has become a useful technique in the assessment of soft tissue i.e. FM and FFM. FM is estimated as fat and not as adipose tissue and FFM is derived from lean tissue mass and total body bone mineral.

The size and shape of the subject may affect the validity of DEXA assessment. Analysis of %fat in layers of pork shoulder assembled to varying thicknesses and occupying the area of a human trunk showed that at physiological tissue thickness, DEXA underestimated % fat (Jebb *et al.* 1994). Since fat content of the specimen is expressed in percentage terms, it may be assumed that non fat tissue might be overestimated at physiological thickness. Because of subject/sample size and degree of hydration, the software required must include adult and paediatric versions.

1.5216 Nuclear magnetic resonance (NMR) / magnetic resonance imaging (MRI)

NMR may be used in either the image or assay mode. For imaging, the term used is magnetic resonance imaging (MRI).

When an electromagnetic wave is applied to a subject or sample, energy is absorbed by the nuclei of specific chemical species. When the energy source is removed, the absorbed wave energy is emitted.

When relationships between anthropometric predictions and MRI assessment were compared (Ross *et al.* 1992), it was found that in women, variability was approximately .5% and in men 3.6%. MRI has been used more extensively to assess FM (See 1.511)

1.5217 Comparison of method

There are fewer studies of comparison of method. Assessment of BC of 28 healthy subjects by DEXA, deuterium dilution, densitometry and ^{40} potassium was compared and four prediction methods were also used, skinfold thickness, BIA, BMI and near infra-red reactance (Fuller *et al.* 1992).

When three and four component models were constructed using the different assessment techniques, the authors found that the models were not compromised by

errors arising from the techniques. It was also found that the agreement was higher within the assessment methods than between assessment and prediction methods.

BC was assessed in elderly people using BMI, skinfold thickness, densitometry, TBW and BIA (Reilly *et al.* 1994). The study found % body fat determined by the various methods to be highly correlated with one another, however the equations used for prediction of % body fat from the various indices were less reliable, a finding supporting that from the study of Fuller *et al.* Reilly *et al.* found that the age specific regression equations used to predict % body fat from BIA and from BMI (Deurenberg *et al.* 1990i) both overestimated % body fat compared with other methods. The authors observed that the differences between methods were slightly greater than those reported in studies in younger subjects.

Many of the techniques available for estimation of BC may be inappropriate for the purpose or population group, too costly, technically too elaborate for field studies or providing no more useful information than could be gained otherwise. M^{c}Laren (1988) made the observation that the value of BC assessments, however accurate, is bound to be limited (in practical or clinical contexts) unless related to the wide range of body build of healthy as well as diseased human beings.

The caveat relating earlier to interpretation of results of BMR assessment apply equally to assessments of BC. When data from more than one source are to be considered, the differences in method must be considered as yet another factor contributing to variability.

1.53 Fat free mass and BMR

The relationship of BMR with FFM, as with FM, is complicated not only by variability introduced by extrinsic methodological influences but by intrinsic factors such as endocrine regulators, state of fitness, age and differences in the relative components of the compartment

In a discussion of measured energy expenditure (Gibney and Leahy, 1996) Stock queried whether BMR should be related to FFM rather than BW as, for example, had been done in the predictive equations of Schofield (1985, 1991). Since the relationship between BW and BC changes from population to population, interpretation of predicted BMR may be confused by secular changes in BC. It was observed however that unfortunately measuring FFM created further difficulties.

1.531 Female body composition and BMR

Body composition in young males and females, up to an age of about 10 years, is similar enough to make no difference to BMR. After this, the relationship between BMR and BW shows increasing divergence of males and females. Near and post puberty, hormonal influences determine the secondary sexual characteristics, one of which is extra adiposity in the female, with the typical female anatomical distribution.

The relatively higher FM and lower FFM in the female produce significant effects on BMR which are attributable to body composition.

The subjects under consideration in the author's study were females aged 18 - 30 years, mainly students and all Caucasian.

A study of Edinburgh medical students of similar age (MacMillan *et al.* 1965, cited by Durnin and Passmore, 1967) yielded data which showed that whole body oxygen consumption and body composition are strikingly different in men and women, with resting oxygen consumption 28 % lower in women. When expressed per unit FFM (LBM in study), the difference was not significant.

In exercise studies, $VO_{2\ max}$ / unit tissue described as LBM was found to be not significantly different in men and women (Diaz *et al.* 1978). Training, which increased muscle usage and therefore increased muscle mass, moved female $VO_{2\ max}$ closer to the male value even when expressed as unit BW.

Although these data do not relate directly to the basal state, it might be assumed that, under basal conditions, male and female FFM might be capable of similar performance.

With the acceptance of the similarity of metabolic rate of FFM in males and females, many investigations on mixed groups and recalculations of previous investigations were carried out. Correlations of BMR with anthropometric indices from recalculation of other papers (Quenouille *et al.* 1951; Durnin, 1981; Cunningham, 1982, 1991; Owen *et al.* 1986) and in measured studies (Ravussin *et al.* 1982; Astrup *et al.* 1992) showed that FFM was most closely correlated with BMR in males and females.

The following studies involving mixed sex or mixed BC groups also support the view that FFM is highly correlated with BMR. The large studies of greater than 100 subjects (Cunningham, 1980; Bernstein *et al.* 1983; Garrow and Webster, 1985ii; Mifflin *et al.* 1990) indicate that FFM and BMR are highly correlated, although Cunningham used predicted rather than measured FFM. In the work of Bernstein the subjects were obese males and females ($r = 0.67$) and in that of Garrow the subjects were involved lean and obese but female only ($r = 0.69$). The results for Ravussin's 30 subjects (1982) (16 female, 14 male) showed FFM to be most highly correlated ($r = 0.886$) for this small mixed group. The authors quoted an RMR value of 125 kJ/ kg FFM / day and noted that this was similar to that found by other studies (James *et al.* 1978).

While most authors share the view that FFM in males and females exhibits similar EE, there is less agreement on the primacy of correlation of BMR with FFM in females.

A study of 44 lean and obese women (Owen *et al.* 1986) found that BW was highly related to BMR and stepwise inclusion of other variables did not improve predictions.

BW in women was found to be more closely related to BMR (described as RMR) (Dore *et al.* 1982, Mifflin *et al.* 1990). Although Mifflin's data indicated that BW was more closely related than FFM in women, FFM was more closely related in male subjects. Dore's group of women had been obese and had undergone massive weight loss, therefore had undergone marked compositional change.

The studies which show BW more closely related than FFM to BMR may reflect the fact that in some groups FM is large enough to make a significant contribution, (discussed under fat mass) or that the difference in correlation of FFM and BW with BMR is not large or that no single parameter represents BMR equally well throughout a wide range of body compositions. There may also be a contribution to variability from the effect of the menstrual cycle, (discussed under neuro-endocrine regulation.)
The balance of opinion would appear to be agreement that FFM energetics are similar in males and females, complicated by the non (menstrual) cyclic characteristic of the male and that correlation of BMR with FFM is closer than or at least as close as with BW. The measurement of BW however presents fewer difficulties and may be more reliable.

1.532 Individual diversity and variability of FFM related to BMR

In addition to differences in BC from group to group, differences in BC between individuals and changes in BC in one individual are likely to affect BMR

1.5321 Anatomical diversity

Although FFM and BMR are closely related, with FFM as probably the best single determinant, it still represents only 60 - 80% of the variability between subjects (Zurio *et al.* 1990), leaving a considerable margin. After correction for body weight and body composition, the coefficient of variation between subjects in 24 EE was determined as 6 - 7% in male and female subjects (Ferraro *et al.* 1992)

There is considerable anatomical variation between subjects in any group it was suggested that part of this variation in energy expenditure must be due to variations in the FFM compartment, particularly those organs which have high rates of energy expenditure e.g., brain and liver (Ferro-Luzzi, 1986)

Data an organ weight were used this to calculate variation in EE with this as the only variable (Garby and Lammert, 1994). From these data, it was proposed that variation from this source is approximately 5% and that this contributes a large part of the total variation.

Where subjects are very lean and FFM constitutes a large very component, the effect of anatomical variation may become significant, since the sub-units with their own regulatory factors and fuels of choice may affect the EE of the whole.

1.5322 Effects of changes in fitness

The age group of the study population is likely to be affected by differences in BMR or BC due to differences in their state of fitness. These differences present difficulties in analysis, since fitness has many more dimensions than simply body composition Previous dietary intake and activity patterns themselves have influences which are inseparable from the effects produced by changes in mass, perfusion and tone of the contributing tissues. Increases in BMR and higher FFM either with training or in subjects who were already trained athletes have been noted (Tremblay *et al.* 1986; Ravussin and Bogardus, 1989). These women were significantly different from 'untrained ' non obese subjects in those studies. Changes in BC have been recorded during training programmes where FFM (identified as muscle mass) increased while FM decreased, with only some subjects showing a gain in BW overall. (Vercruysen and Shelton, 1988; Meijer *et al.* 1991)

The effects of a training programme on 16 men and 16 women were compared. (Westerterp and Saris, 1991; Westerterp *et al.* 1992) That investigation found that body fat was decreased by the activity, but that the women tended to compensate for the

increase in EE by an increase in intake, therefore the effect was smaller in female subjects.

It is worth noting that, in the latter study, sleeping MR decreased although average daily MR increased, a finding analogous to that in which brisk walking was found to have had the effect of reducing resting heart rate (Hardman *et al.* 1992).

1.5323 Effects of gross changes in skeletal muscle and organ mass

The components of FFM do not have a constant mass relationship.

Organ mass is preserved for some time in chronic negative energy balance at the expense of muscle mass (Barac - Nieto *et al.* 1978). Earlier studies (Keys *et al.* 1950, Grande *et al.* 1958) showed progressive losses of muscle over a period of 6 months. The reduction in BMR however did not match the loss of FFM, indicating some preservation of organ mass. Much later work (Soares and Shetty, 1991) was also able to show that in subjects who were semi starved, organ mass was spared at the expense of muscle mass and, as muscle decreases, the contribution to EE of organ mass increases proportionately (Garby and Lammert, 1994)

Trauma units are well accustomed to the phenomenon of loss of muscle, as evidenced by creatinine output in severely injured patients, while organ proteins are spared. While acute deprivation or traumatic catabolism may allow the preservation of protected proteins and produce certain compositional changes within FFM, prolonged positive or negative energy or nitrogen balance are also likely to produce changes. Organs of concentration camp prisoners and famine victims, estimated to have lost 25 to 45% of their original weight, weighed between 52% (spleen) and 80% (heart) of normal (Keys *et al.* 1950). Evidence from the Dutch famine, quoted by Elia (1994), showed gut mucosal thickness to be reduced, poorly perfused and contributing to reduced gut weight.

Since FFM is not of constant composition, while its EE is likely to more closely represent that of the whole body, its expenditure is likely to be variable on compositional grounds alone.

1.6 Neuro-endocrine regulation

In addition to the effects due to the overall size and composition of the body, BMR must also be affected by numerous factors which regulate the rate of fuel use and the selection of particular fuels.

Neuro-endocrine effects on BMR have been known in clinical context for many years, for example, before the development of sensitive assays, the estimation of BMR was used in the diagnosis of thyroid dysfunction.

Under standardised laboratory conditions which would meet the requirements for estimation of basal metabolic rate, it might be expected that regulatory systems and differences in fuel use would contribute little more to the variability already attributed to factors such as body weight and composition. By their very nature, however, regulatory systems maintain homeostasis not as a constant state but as a variable but constantly adjusted state. In this 'basal' state in any group of individuals there will variation within a 'normal' range. These chemical mediators may alter directly metabolic rate by altering the rate of fuel consumption or the fuel mixture, or indirectly, by altering BC or BW.

1.61 Sympathetic and sympathomedullary effects

In 1915, Benedict laid down that the condition of 'emotional repose' was required i.e., absence of excess sympathetic discharge, since activity of tissues increases in response to nonadrenaline and / or adrenaline (for review see Young and Macdonald, 1992). When the sympathetic thermogenic response to cold was blocked using the non -selective β blocker propranalol, it was found that daily EE was reduced and weight gained (Astrup *et al.* 1990) The authors commented that this may explain the weight gain reported in patients receiving β blocking agents.

Reduced MR in skeletal muscle was also shown with adrenoceptor blockade, although the study involved the use of biopsied skeletal muscle rather than in vivo (Fagher *et al.* 1993, Christin *et al.* 1993.) Skeletal muscle was identified as the site of part of the facultative thermogenesis due to carbohydrate feeding acting via β_2 receptor stimulation by adrenaline (epinephrine) (Astrup *et al.* 1989) . Muscle sympathetic nerve activity (MSNA) was measured in 19 Caucasian and 25 Pima Indian males (Spraul *et al.* 1993). MSNA correlated with EE adjusted for FFM in both groups (r = 0.51) and body fat in Caucasians (r = 0.53). Body fat was 24± 9% in Caucasians, 28± 10% in Pima. Pima subjects had lower MSNA than Caucasian subjects, 23± 6 vs 33±10 bursts / minute (all values are quoted as means ± SD)

It was suggested by the authors that low MSNA may be a factors in the aetiology of obesity in Pima Indians, however it must be considered that neither of these values could be considered as indicating close correlation. Skeletal muscle, however, constitutes a large proportion of lean body mass and has a wide range of energy expenditure, a small change in tone is likely to have a large effect on the overall variability of EE.

It is clear from the literature that the methods employed to study sympathomedullary effects are no more uniform than those in areas previously considered.

A review of studies relating to sympathomedullary effects reported in studies carried out between 1982 and 1991(Young and Macdonald, 1992) indicated some lack of agreement between the studies, for example, in the association with obesity. The studies considered very different subjects and groups of subjects and employed a variety of methods making it unlikely that true comparability could be achieved.

Consideration of recent studies of noradrenaline turnover in relation to RMR (Ravussin and Tataranni, 1996, (citing Toth and Poehlman, 1994 and Poehlman *et al.* 1995) has suggested that much of the variability in RMR not attributable to body size and composition can be associated with variability in sympathetic activity. These studies,

taken in conjunction with that of Spraul *et al.* (1993) on muscle activity (above), were considered by the authors to indicate that RMR was modulated by sympathomedullary activity.

1.62 'Thermogenic' hormones

Hormones other than circulating catecholamines have wide ranging effects on metabolic rate. The area is complex, since the hormones act singly and in concert and have their own positive and negative mediating factors. The thyroid hormones, growth hormone, androgens and insulin have been described as 'thermogenic' (Astrup *et al.* 1992). Related to these are the hypothalamic axis hormones regulating the anterior pituitary output, each open to a wide range of neural and systemic influences. Each hormone may have multiple influence on energy metabolism, e.g., cortisol influences insulin secretion, affects fuel utilisation and body composition. The thyroid hormones, triiodothyronine (T_3) in particular, affect fuel utilisation, body composition and the number and affinity of adrenoceptors.

Insulin, free thyroxine (T_4) index, testosterone and dehydroepiandrosterone (DHEA) were found to be positively related with BMR and sleeping MR and that growth hormone (GH), cortisol and dehydrotestosterone (DHT) were inversely related, however regression analysis showed that only a small part of the variance could be accounted for by the latter hormones.(Astrup *et al.* 1992)

1.621 Thyroid hormones

Thyroid hormones have a profound effect on MR. In thyrotoxicosis, MR can be doubled or more and, at one time, estimation of BMR was used in the diagnosis of thyroid dysfunction. As part of an investigation into suppression of thyroid axis activity, T_4 was found to have increased sleeping energy expenditure (SEE) by 4.1% on 180μg / day over 3 weeks and 8.5% when the dose was doubled over a further 3 week period.(Braco

et al. 1993) All subjects showed a normal thyroid stimulating hormone (TSH) suppression.

Although T_3 and T_4 effects on energy expenditure can be seen clearly at clinically abnormal levels, at normal levels, the position is less clear and it has been found that . although catecholamine levels were reduced in some obese subjects, there was no difference in thyroid hormone levels in obese and control subjects (Ravussin *et al.* 1982).

Fat oxidation was examined in skeletal muscle in non -obese, obese and post -obese subjects (Astrup *et al.* 1996). The authors have suggested that, although some studies have proposed that the proportion of type I and II muscle fibres may differ in obese subjects and that this may be associated with obesity (citing Wade *et al.*, 1990) other better controlled and larger studies (citing Simoneau and Bouchard, 1995) had shown no significant relationship between muscle fibre type and body fatness.

The authors, however, quoting unpublished results from Raben *et al.* found evidence of varying enzymic activity in the muscle of post obese subjects compared with controls and suggest that 'some neuro hormonal influence may be responsible' such as lower hormone status . The authors cited studies showing that a low free T_3 and low sympathetic activity could both be responsible for lower fat oxidation capacity in skeletal muscle and that both are risk factors for weight gain (citing unpublished results of Toubro *et al.*).

1.622 Growth hormone (GH)

GH is the subject of much literature. Although some authors (Astrup *et al.* 1992) have found that statistically its contribution to variably in EE is small, it has widespread and important physiological effects. Apart from its anabolic and hyperglycaemic effects, it affects the conversion of T_4 - T_3 peripherally therefore synergising with T_3.

In addition to affecting BC, GH therefore may affect MR directly via T_3 effects. It is secreted in bursts throughout 24 hours, without tonic secretion between bursts (Hartman

et al. 1993), it could therefore be suggested that it could contribute to within subject variability.

1.623 Androgens

It has been proposed that androgens may possess thermogenic properties and that variations within normal range may have a regulatory role in energy metabolism. (Astrup *et al.* 1992)

When 24 EE was adjusted for FFM, FM and age, it was found to be higher in women with android fat distribution compared to these with gynoid distribution i.e., indicating higher levels of androgens (Buemann *et al.* 1990) and it has also been suggested that post menopausal hormone replacement therapy (HRT) may prevent deposition of excess abdominal fat without any significant effect on total FM or FFM. (Haarbo *et al.* 1991)

1.624 Insulin

Insulin has been included in the list of 'thermogenic hormones' (Astrup *et al.* 1992) and to this must be added the effects of insulin like growth factors such as IG1 and IG11. Insulin will affect EE in the short term by affecting fuel availability and in the long term by affecting BC. Further consideration is given to insulin under 'Fuel utilisation' (see section 1.7)

1.63 The effects of the menstrual cycle

An important consideration with subjects such as those in this study, i.e. women aged 18 to 30 years, would be the effects of the menstrual cycle.

Studies of metabolic rate during the menstrual cycle have been carried out since the 1910's. Wakeham (1923), Hafkesbring and Collett (1924) were among the early workers. Wakeham quoted Gephart and Du Bois (1916) and Blunt and Dye (1921) as finding that no variation of basal metabolism within the menstrual cycle can be established, whereas other authors found to the contrary (Snell *et al.* 1920).

The early studies did not control energy intake and most studied only one cycle.

More modern work has however established that there are complex patterns of change during the menstrual cycle, for example, changes in food intake (Dalvit, 1981), body weight (Robinson and Watson, 1965; Pliner and Fleming, 1983), and metabolic rate (Solomon *et al.* 1982; Bisdee *et al.* 1989i and Bisdee *et al.* 1989ii).

Solomon's subjects consumed a defined diet, physical activity was constant and several cycles were examined allowing it to be established that, not only had changes in BMR occurred, but that the changes were cyclic. BMR was found to increase significantly during the luteal phase. This finding was supported by Bisdee *et al.* (1989ii) who found that EE decreased in late follicular phase and increased to a maximum in luteal phase. The changes were small (1.5%) for day time activities and larger (6.0%) for SMR. The difference in 24 EE in approximately 2.5% between late follicular and late luteal phases. In comparison with this, a much larger difference, 9%, in a study of different method (Webb, 1986) where subjects wore a calorimetric suit and were kept inactive for long periods, conditions likely to introduce other variables.

Solomon attributed the increase in MR to progesterone however, Bisdee has suggested that the change may be related to more subtle hormonal changes occurring during hypothalamic regulation of the cycle.

Bisdee also suggested that there is a biphasic change in energy balance, positive in luteal and negative in follicular phase, there may be therefore, further effects produced by changing BC during the menstrual cycle. Two parallel studies, one using the Douglas bag technique, the other using the Deltatrac (Curtis *et al.* 1996) have also found a reduction in BMR in early follicular phase and a rise in late luteal phase.

1.7 Fuel selection and utilisation

Energy expenditure, while dependent on the size and composition of the body, must also be affected by the activities of the regulatory factors and the nature of the fuels being used. Different metabolic fuels have very different heats of combustion, for example, that of glucose (2.80 MJ/mol) is about 50% higher than that of ketone bodies

(1.78 MJ/mol acetoacetic acid and 2.01 MJ/mol 3 - hydroxybutyric acid) but 4 times less than that of NEFA (10 - 79 MJ/mol) (Elia and Livesey (1992), cited by Elia (1995), the former referring to Livesey and Elia (1988)). The heat of combustion of glucose was taken from published sources (Weast *et al.* 1984), those for ketone bodies and NEFA from heats of combustion of the chemical groups. Livesey and Elia (1988) point out, firstly, that the values obtained above by compositional analysis had been found to agree with those obtained by bomb calorimetry, the estimate for fatty acids represented 99.6 ± 0.7% (SD, n = 10), and, secondly, they emphasise the point that they considered that estimates of substrate utilisation by indirect calorimetry were, at best, within 5% of the true value and, under some circumstances, considerably poorer. Energy values obtained from bomb calorimetry do not take account of the simultaneous use of several fuels, by pathways which are unequally efficient, or the partial use and excretion of fuels. This does not invalidate the original aim of indirect calorimetry (Livesey and Elia, 1988), but it demonstrates that the complexity of fuel selection and fuel use is likely to add to variability in MR.

1.71 Diversity of fuel use

Most tissues must be able to use a variety of fuels and to change fuel depending on circumstances. If dietary intake is acutely restricted, BMR is increased in the first few days prior to the reduction which is likely to follow. (Webber and Macdonald, 1994) In the review by Randle (1995) it has been estimated that in a Western diet, the fuel mix is approximately 50% carbohydrate, 33% fat and 17% protein in the fed state, shifting to 12% carbohydrate, 70% fat and 18% protein after an overnight fast and 0% carbohydrate, 95% fat and 5% protein after 40 days starvation. In prolonged starvation, glucose oxidation is replaced by lipid oxidation in tissue other than brain and in the brain by ketone bodies to about 90% of total. The effects on assessment of metabolic rate of such changes in fuel use may be assumed to be kept to a minimum by paying close regard to the conditions which apply to measurement of BMR i.e. that the subject

should be comfortable and in a fasted and rested state, however, since the fasted state is progressive rather than constant, changes in fuel availability are likely to contribute to variability.

Tissues have fuels of choice, although an important factor must be the level of availability. The fuel of choice of the brain is glucose but in starvation it will use ketone bodies and lactate, the degree of use probably depending mainly on their circulating concentration (Elia, 1995).

Skeletal muscle is a tissue of very large mass in the normal healthy human and at rest it uses predominantly non esterified fatty acids (NEFA), corresponding to about 80% of oxygen uptake.(Havel *et al.* 1967, cited by Henrikkson, 1995). Only a small proportion of the total is derived from carbohydrate and this is derived mainly from plasma glucose (Wahren *et al.* 1971, cited by Henrikkson, 1995). This would apply at basal level however as activity levels rise, the dependence on carbohydrate would increase.

1.72 Body composition, fuel availability and utilisation

Fuel usage is influenced by the effects of gross changes in BC. In the fasted state, the supply of fuel to tissue is mounted from endogenous sources which will quantitatively and qualitatively depend on BC. The substrates themselves may act as regulators of consumption by e.g. enzyme induction, or receptor site regulation or even by simply altering perfusion (Elia, 1995).

BMI has been associated with fuel selection. Stimulation of glucose transport has been found to be negatively correlated with BMI ($r = 0.765$) and that the continuous decline in glucose transport as BMI increases reaches a stage where, after BMI 30 kg/m^2, insulin, IGF 1 and IGF 11 (insulin like growth factors) no longer stimulate glucose transport (.Elton *et al.* 1994), although the latter study was carried out on biopsied tissue where there are no contributions from intermediary metabolism.

Obesity is associated with hyper insulinaemia but increased insulin resistance. Insulin itself is not thermogenic, it does however, promote glucose uptake and inhibit lipolysis,

therefore influencing both fuel use and BC. A threshold BMI (26.8 kg /m^2) has been proposed (Campbell and Gerich, 1990) up to which insulin sensitivity was not affected. The authors also reported that there appears to be a linear relationship between BMI and insulin sensitivity in Type II diabetes which is not shown in non-diabetic control subjects. In the fasted state, with fuel supply dependent on endogenous sources, insulin mediated glucose usage is likely to be depressed.

It has been speculated (Randle, 1995) that the mechanism of glucoreceptors may be similar in the brain to that of the pancreatic β cell and therefore that (the author was considering this possibility in the context of starvation) long term effects of lipid fuels might be central to the control of catecholamines, growth hormone and the hormones of the HPA axis which in turn manipulate fuel availability and the rate of use and hence influence metabolic rate.

1.8 Summary and aims of study

Review of the literature has indicated that BMR is affected by numerous intrinsic physical and biological factors, the complexity compounded by extrinsic factors such as degree of experimental error, differences in assessment method and data interpretation.

Assessment of BC is similarly complex. The level of covariance of BMR with BW and /or BC cited in the literature suggests that the effect may be scatter or that there may be some degree of organised nonlinearity in distribution.

This study, of a group of 90 women aged 18 to 30 years, had the aims of

- assessment/ measurement of BMR, BW and BC of the subjects
- exploration of the mathematical relationships of BMR with BW and BC
- investigation of the effects of scatter or degree of nonlinearity on the accuracy of prediction of BMR from linear regression equations (the form of equation frequently used) constructed from the study population data or in current use.
- evaluation of the practical relevance of any discrepancy between measured and predicted values of BMR

Chapter 2

Method

Chapter 2

Method

This section includes four sub-sections :- those methods relating to -

2.1 recruitment and preparation of the subjects

2.2 assessment of metabolic rate

2.3 anthropometric assessment.

2.4 recording of results

2.1 Recruitment and preparation of the subject

The subjects, all females aged 18-30 years, voluntecred for assessment.
Since assessment could only be carried out when working space and other time commitments allowed and only 2 or 3 assessments were usually possible in any one week, 10 to 12 subjects were recruited at any one time so that the interval between recruitment and assessment could be kept as short as possible.

Notices were posted on the general notice board and on the boards specific to individual courses indicating briefly the aims and requirements of the study, i.e. that subjects must be female, between 18 and 30 years and would require to fast overnight and until the test was completed, and be weighed and measured.
Leaflets outlining the aims and methods BMR and anthropometric assessment were available at the notice boards and at 2 designated offices and 1 designated laboratory.
Subjects who expressed an interest were given information on any questions asked. They were shown the room where the assessment would take place and the various pieces of equipment involved. Many of the subjects were already familiar with the laboratories and their facilities.

The subjects were recruited almost entirely from the student population with no attempt to select or exclude any particular body type, only to ensure that lean, overweight, and the non- lean non-overweight referred to here as 'standard' types were represented.

No medical history could be verified (none was pregnant, diabetic, or replied negatively to 'are you well ?' or 'do you feel well ?'). If the subjects were attending classes and did not have a current acute medical condition (when they would in any case be unlikely to present themselves for test) they were assumed to be 'normal, healthy' members of the young female population.

2.2 Assessment of basal metabolic rate

Subjects were asked to come for assessment on a day within day 5 to day 10 in the menstrual cycle, i.e. follicular phase, day 1 being the commencement of bleeding. No assessments were made on Fridays and Mondays to eliminate the effect of the weekend.

The subjects were requested to fast for a period of approximately 10 hours prior to assessment, i.e., overnight, although they could have tea or coffee in the morning if they were in the habit of doing so. Coffee and tea have a variable effect on MR in a group of subjects, Koof and Deurenberg (1995) found that 200 mg caffeine raised MR by a mean of 7% ± 4% in 6 male subjects. 'Tea or coffee', as beverages, are highly variable in composition, volume and concentration and their consumption by some of the subjects, while offsetting the effect of stress due to disturbance of habit, must be considered as contributing to the degree of experimental error. The addition of approximately 150 mls or grams to body weight would be within the limits of normal day to day weight variability. As an example, the addition of 0.15 kg to the weight of the lightest subject (40.1 kg) was an increase of 0.25%. It was recognised however that this factor could also add to the overall experimental error.

The subjects were requested not to undertake heavy physical activity in the 24 hours preceding the assessment and not to expend excess energy in coming to the laboratory. Most of the volunteers were students, living in Halls, a few minutes walk from the laboratory.

The assessment was carried out in a small room outfitted for the purpose, off the main laboratory. On arriving in the laboratory, the subject was weighed, without shoes, wearing a light wrap and having previously emptied the bladder. Other body measurements were made following BMR assessment.

The subject rested for 30 minutes in a comfortable supine position on a couch with the head raised slightly on a pillow.

The temperature of the room was maintained at 20 - 22°C.

The assessment of BMR took place in triplicate, each expired air collection over a period of 10 minutes (see section 2.23 for method of calculation).

The subject, who had previously been instructed in the use of mouthpiece and nose clip, breathed from air to air for a few minutes, via a Hans Rudolf non-return breathing valve and 3-way closure valve attached to a Douglas bag, so that she could become accustomed to the apparatus. During this time, the mouthpiece, nose clip and breathing valve were all checked for leaks by holding close to the joints a narrow strip of 'cling film' which had proved very responsive to air movement. Just prior to beginning the assessment, a final check was made on the comfort of the subject, her pulse rate was recorded and then the 3-way stopcock was opened to the Douglas bag. Immediately timing began.

A check was made for leakage between stopcock and bag using 'cling film' as before.

During the period of assessment, the subject used a cassette tape player with headphones to cut out external noise and to minimise concentration by the subject on her own breathing.

The subject had a choice of tapes, but the choice precluded tapes which might encourage 'moving in time with the music' and the volume was kept at a moderate level. Each subject was asked to lie as still as possible during the 10 minute assessment periods.

At the end of each 10 minute period, the Douglas bag was closed and removed and a few minutes rest period following during which the subject was told that she could move to a limited extent, e.g., to adopt a more comfortable position. Iced water was available to drink if required.

As each Douglas bag was used, it was removed to the main laboratory for measurement and analysis (see sections 2.21 and 2.22).

On completion of the expired air collection, anthropometric assessment was carried out. If any subject preferred at this point to have something to eat or drink, this of course was allowed and the subject returned as soon as possible following this to have height and skinfold thickness measured.

Very few subjects (6) found the mouthpiece and nose clip uncomfortable and having unsuccessfully tried several slightly different shapes and sizes, had their assessment terminated.

2.21 Gas collection and volume measurement

2.211 Gas collection

The method of assessment chosen was the Douglas bag method.

The equipment consisted of a 100 litre Douglas bag, a 3-way (T form) Hans Rudolf closure valve, a non-return Hans Rudolf breathing valve and delivery hosing of light weight ribbed PVC tubing fitted with soft extensible rubber connectors which ensure a good fit between hose and valves. The bag was fitted with a sampling tube, closed by a clamp of the artery clamp type.

Prior to use, the bag was evacuated using a vacuum pump which was fitted on the outlet side of a volume meter .The Douglas bag, with its closure valve and hose, was attached on the input side of the meter. A rheostat was used to regulate the vacuum pump so that it evacuated at a rate of 20 litres/min.

The bag was evacuated until a steady reading was obtained on the volume meter, indicating complete evacuation and a leak proof assembly. (The meter was a non-digital multi-dial type which recorded the volume in litres to 4 decimal places.)

The closure valve on the bag was then closed.

The Douglas bags were serially numbered, the numbers matching those on a set of gas sample bags.

At the beginning of the assessment, the subject was fitted with a suitable nose clip and mouthpiece and the evacuated bag was attached by a short length of hose to the expired air port of the breathing valve.

For the next few minutes, the closure valve remained in the 'open to air position' with the subject breathing to air through the closure valve, the Douglas bag remaining closed by the closure valve.

Time was allowed for the subject to become accustomed to the apparatus and for the detection of any leaks around the nose clip, mouthpiece or breather valve. The nose clip was the soft spring type set at a tension enough to close the nostrils and not permit nasal breathing, but not enough to cause distress.

The mouthpiece was the soft rubber type with a deep flange fitting between gums and the surface of the buccal cavity. (Subjects were given the opportunity to practise with nose clip and mouthpiece at the time of recruitment to the study and a suitable size was identified).

The subject lay in a comfortable supine position with the head and shoulders slightly raised by a pillow, and wearing light clothing. Headphones for a cassette tape player

were fitted.

Immediately preceding the start of the assessment, pulse rate was recorded, and a check made on the comfort of the subject. The stopcock to the Douglas bag was then opened and at the same time, a stop watch was started, thus beginning the timed period.

During the timed period, the subject and apparatus were observed intermittently.

At the end of the timed period, the closure valve was rotated, closing off the bag. The subject was informed of the end of one assessment and could move to a small extent, remove the mouthpiece and nose clip, and drink some water.

The procedure was repeated with the second and third Douglas bags.

The Douglas bag was removed to the main laboratory and gently manipulated to ensure that the contents were homogenous.

2.212 Removal of sample for analysis

A small non-diffusible sample bag (see calibration section 2.215) was evacuated and clamped. It was then attached to the Douglas bag sampling the tube and both clamps, i.e., that on the sampling tube and that on the sample bag, were removed so that expired air could be passed from the Douglas bag to the sample bag. This was achieved by exerting a gentle pressure on the Douglas bag. The sample bag was filled then the sample was passed back into the Douglas bag by pressing on the sample bag. This was repeated 3 times until a homogenous sample was obtained and the effect of any residual air in the sample bag could be said to be negligible. The sampling tube and the neck of the sample bag were re-clamped and the sample bag removed.

The sample bags had been shown to contain 1.75 litres (see section 2.152).

Although in most cases, the time taken to obtain the gas sample was enough to allow the temperature of the gas in the Douglas bag to equilibrate with the ambient temperature, a further 10 minutes was allowed, during which gas analysis was completed, before the volume measurement was made.

2.213 Measurement of expired air volume

The Douglas bag, with the closure valve in the closed position, was attached via the hose to the inlet port of the volume meter. A reading was taken of the volume on the dials (these dials should not be zeroed) and the closure valve opened. The gas was evacuated from the bag using the vacuum pump. As the bag was being emptied, the folds were smoothed out so that air was not trapped in the bag. A constant value on the volume meter indicated that no more gas could be withdrawn.

A second meter reading was taken and the difference between the two readings was a measure of the volume in the Douglas bag.

A reading was taken of ambient temperature and pressure and the total volume (i.e., Douglas bag + sample bag) of expired air converted to a value at standard temperature and pressure, dry (STPD)

2.214 Inspection of breathing and closure valves and Douglas bag

At the end of every session, the valves were stripped down to their component parts. The breathing valves were rinsed, sterilised, dried and the O-ring seals and the integrity of the spiral were inspected before re-assembling.

The closure valves were stripped, cleaned and inspected weekly. Valves and bags were checked for leaks during use by evacuating the bags and examining the meter pointer for movement. No movement occurs with an intact system.

Breathing valves were tested by attaching them by a short length of hose to the inlet port of the meter and evacuating as previously described. By blocking the ports of the breathing valve, it is possible to check the integrity of the seals and rings.

2.215 Calibration of volume measurement

This included calibration of the meter and of the volume of the sample bags.

2.2151 Calibration of meter

The instrument was mechanical, multi-dial and direct reading.

It had a heavy cast metal body and, in order to avoid any discrepancies arising from changes due to expansion or contraction of the body or component parts, the meter was maintained within the range 19 - 23°C, the temperature normally being 20 - 22°C.

It became apparent early in the calibration study that the instrument's performance was, to a small extent, flow rate dependent and to avoid this, gas flow rate through the meter was set by running the vacuum pump at a rate controlled by a rheostat. A flow rate was chosen which was fairly similar to that obtained in the classic technique of manually emptying the bags, i.e., about 20 litres / min. The flow rate and rheostat setting were correlated by drawing air through the meter over a timed interval until a consistently reliable rate was obtained and a fixed point was established on the rheostat. This was rechecked at intervals to maintain this performance.

During the period prior to the study when the reliability of the method was being tested, it was found that the volume calibration was difficult to establish. The laboratory instrument was customarily checked against a Parkinson Cowan gas meter in the University of Edinburgh Physiology Department which was in turn calibrated against a Tissot spirometer (Edinburgh University Medical Physics). On closer investigation it

was found that this instrument was calibrated against a hand-operated 7 litre syringe (Cranlea) at the City Hospital, Edinburgh.

With the co-operation of the scientific staff of the City Hospital who sanctioned the use of their syringe, a technique for volume calibration of the study meter was developed as follows.

The output port of the syringe was fitted with a non-return valve (Hans Rudolf) which allowed air to be drawn into the syringe and expelled without loss into a previously evacuated Douglas bag fitted in the conventional manner with a closure valve. 70 litres of air was passed into the Douglas bag, (10 strokes x 7 litres) and the bag closed. The bag was then evacuated by the method previously described. The procedure was repeated 5 times.

For comparison the procedure was repeated using a volume of

35 litres (5 x 7 litres)
42 " (6 x 7 ")
49 " (7 x 7 ")
56 " (8 x 7 ")
63 " (9 x 7 ")

the lower volumes 35, 42, 49 litres being similar to 10 minute volumes at basal ventilation.

For calibration purposes, in practice, it was decided to use 35 litres (5 strokes) and 70 litres (10 strokes) as calibration volumes.
The method had the advantage of calibrating the meter in conditions exactly duplicating those in which it would be used in practice and over approximately the same volume.

During this period of time, the volume of respiratory and metabolic work undertaken by the laboratory grew considerably and a grant of money enabled the purchase of a 7 litre certificated syringe of the same type as that owned by the City Hospital.

A calibration study using the 2 instruments in parallel was carried out and a further study using each syringe matched against the Tissot spirometer.
Regular calibration of the meter was then carried out using the Queen Margaret College 7 litre syringe at approximately 6-week intervals.

2.2152 Calibration of sample bag volume

The bags were small non-diffusible bladder bags of a uniform type. They were numbered serially as were the Douglas bags. Each in turn was filled from a Douglas bag by the method described previously, to a point where the 'rib folds' were extended and smooth but not under any degree of stretch. (It would be difficult to achieve any degree of stretch without risking damage to the Douglas bag).

The sample bag was then closed using a clamp, the Douglas bag evacuated according to the method described and a volume reading taken.

The clamp was removed from the sample bag tube, the sample bag evacuated and the sample bag volume thus obtained.

The technique of filling the sample bag and the volumes of the bags themselves proved to be surprisingly consistent provided only one type of bag was used. The volume of the gas sample was found to be approximately 1.75 l (± 10 ml)

2.22 Analysis of expired air

2.221 Gas analysis

Oxygen and carbon dioxide were measured in expired air, the oxygen by infrared analysis and carbon dioxide using the paramagnetic method, both analysers part of an exercise test system by P K Morgan.

The self-indicating soda lime was changed regularly and always before the indicator showed exhaustion. The calcium carbonate was also changed regularly and between periods of use was kept dry in a desiccator.

The seals and sinters were inspected each day for tightness of fit and regularly cleaned and seals greased.

When not in use, the inlet to the analysers was prefaced by a small tower containing soda lime.

The gas to be analysed was drawn from the sample bag by the analyser pump set at a flow rate of 500 ml / min.

The result for carbon dioxide was taken at 30 seconds from the entry of the sample and that for oxygen at 90 seconds from entry. The result for CO_2 was given to 2 decimal places and that for oxygen to one decimal place on the analyser display, however, by using the data check facility on the Morgan exercise system of which these analysers are part, it was possible to obtain the result for oxygen to 2 decimal places and use this to confirm the result corrected to one place.

2.222 Calibration

The system was calibrated against a certificated gas mixture

The following routine was observed prior to every batch of analyses.

The analysers were allowed to attain an oxygen figure of 20.9% and a figure of 0.00% for carbon dioxide with air being drawn in over a soda lime tower.

A sample of the calibration mixture was then attached and the analysers adjusted to the calibration gas figures at 30 and 90 seconds as described above (usually only small adjustments were required).

A sample of CO_2 free air was then drawn in and the analysers allowed to re-attain 0.00% CO_2 and 20.9% O_2. A second sample of the calibration mixture was attached and any adjustments required were made. This alternation of carbon dioxide free air and calibration gas continued until 3 measurements of the calibration gas were in agreement.

At the end of every batch of analyses, a sample of calibration gas was analysed as a further check on the system.

The calibration gas, although bought with a certificate of analysis, was checked by analysis using a Lloyd Haldane analyser. Since this method requires skill and practice, which the author does not have, the calibration gas was checked at each purchase and at intervals between purchases by an experienced technician in Edinburgh University.

2.23 Method of calculation of basal metabolic rate

The method of calculation elected was the method of Weir first described in 1949.

Where V = the volume of expired air in litres/min. (STPD)

and c = % oxygen in expired air

$$E\ (kcal./min.) = \frac{4.92V}{100}\ (20.93 - O_2 c)$$

The mathematical basis of the above was given by Passmore and Draper (1965)

This method avoids the necessity of estimating urinary nitrogen and expired carbon dioxide. The equation by Weir makes the assumption that 12.5% of energy is derived from protein and that RQ =1. If RQ is, in fact, less than 1, the dominator term of the ratio i.e. the volume of oxygen used (therefore MR) will have been under-estimated. As RQ values decrease from 1, the energy equivalent of oxygen is also decreased, therefore, if RQ is assumed to be 1, the underestimated volume has been related to an overestimated energy equivalent of oxygen. The two errors therefore offset one another.

The assessment of metabolic rate was carried out in triplicate. In order to be regarded as representative of the subject's BMR, two results were required to be within 3% of each other (Durnin, personal communication). Where this applied, the arithmetic mean of the two was used, where all three results were within 3%, the arithmetic mean of the three was used.

Carbon dioxide concentrations, although not used in this calculation, are a useful indicator of hyperventilation sometimes produced when breathing is interfered with as, for example when a nose clip and mouth piece are worn. It was also possible to calculate respiratory quotient as an indicator of the fasted state and this was done on an occasional basis.

The error produced by ignoring urinary nitrogen is unlikely to be more than 1%

(Durnin, personal communication)

2.3 Anthropometric assessment

2.31 Weight

2.32 Height

2.33 Skinfold thickness

2.31 Weight

The subject, having first emptied the bladder, was weighed in a light wrap and without shoes. Weight was recorded to the nearest 0.1kg. The scales used throughout were Avery beam balance type certified by a Weights and Measures Officer.

2.32 Height

This was measured using a staediometer. The subject was measured, without shoes, with feet flat on the platform and with the heels together.

The head was held with the Frankfurter plane in a horizontal position.

The subject was asked to breathe deeply and reach up to maximum height.

2.33 Skinfold thickness

The method of skinfold thickness assessment used was that of Durnin and Womersley (1974) In this study, the calliper was of the Harpenden type. A calibration certificate was obtained for one calliper which was used throughout and solely by the author.

2.331 Sites of measurement

Since the author is right handed, these sites are all on the subjects' right sides.

I) Biceps site

The skinfold was taken over the belly of the muscle when the arm was hung in a relaxed position with the palm of the hand out. The belly of the muscle was identified by previously asking the subject to flex the arm and raise the biceps muscle, the middle of which was then marked with a soft cosmetic pencil.

ii) Triceps site

The skinfold was taken on the dorsal side of the upper arm over the belly of the triceps muscle at a level mid-way between the acromion and the olecranon. The tip of the olecranon can be identified by asking the subject to flex the arm and the distance between the two measured using a steel tape. The mid-point was again marked using a cosmetic pencil.

The skinfold measurement was made, the arm hanging freely, with the crest of the skinfold parallel to the long axis of the arm.

iii) Subscapular site

The skinfold was taken below the tip of the scapula with the subject standing in a relaxed position.

A fold was lifted at a angle of 45° to the horizontal by the operator placing 2 fingers of each hand under the 2 lower planes of the scapula, pushing upwards towards the scapula, then pulling down the fold towards the thumbs. It was found to be possible to do this while holding the calliper in the right hand and a consistent technique was developed.

iv) Suprailiac site

This skinfold was taken just above the iliac crest in the mid-axiliary line. In some cases, it was necessary to ask the subject to lean away from and then towards the operator in a side-to-side plane to expose the position of the crest.

2.332 Method of raising the skinfold

The skinfold was lifted at a distance of about 1 cm from the point of measurement. The fold was raised as a crest with the sides approximately parallel. A degree of subjective

judgement enters the technique in the placing of the calliper jaws on the fold. If the jaws are positioned too close to the top of the fold, the reading obtained is low and conversely if the jaws are positioned too close to the base of the fold, underlying tissue can be included in the fold making the reading obtained too high. A reasonable size of fold must be raised so that subcutaneous tissue is included but muscle is not included. The subject was asked to tense the muscles at the site and the fold was rolled between the fingers to release any underlying muscle included.

2.333 Timing of measurement

A rapid compression of the skinfold occurs when the calliper jaws are applied, with a consequent reduction in calliper reading followed by stabilisation of the fold and the calliper reading. If the calliper is left closed on the site, further compression begins to occur.

The reading was therefore taken just after the point of stabilisation had been achieved. During the measurement, the fold was held with the fingers above the point of measurement, and three readings were taken at each site.

2.334 Verification of the technique

Following initial training in the method, by a trained observer (F. Mackay, Glasgow University), the author 'practised' on a subject whose body weight was relatively constant (± 0.5 kg) until the measurements taken became repeatable. A different subject was then measured by the author and the trained observer, and acceptable agreement was demonstrated. Since this was part of a training program, with both observers having been trained to the same method and with access to the originator of the method, the agreement between observers was originally required to be within 2% calculated fat value. In practice, agreement between trained and trainee observers, without sight of one another, was repeatably within approximately 1% calculated fat value.

Ten volunteers (females aged 17-55 years) were measured on 3 separate occasions within 10 days and the results subsequently examined. Greater agreement of results was achieved with the leaner subjects than with those with a greater fat content. After a period of 2 weeks and further practice, another 10 volunteers were asked if they would participate in a similar exercise and this time a level of repeatability was achieved which was acceptable to the author's supervisor and the original trained observer.

One subject was also assessed densitometrically (Edinburgh University) and the assessment compared with skinfold assessment. The result of a difference of 1.8% between densitometric and skinfold assessment was within the error identified by Durnin and Womersley (1974).

2.4 Recording of results

The intention of the study was to consider the relationships of BMR with BW and BC in a random population of women aged 18 to 30 years. It was therefore important to recruit a wide range of body compositions while avoiding bias in recruitment as far as possible. Subjects who volunteered were assessed regardless of their anthropometric characteristics, their results were then put into folders labelled lean, 'standard' and overweight. These 'collections' of subjects were then allowed to accumulate until the total of 90 was reached.

The results were processed by group and subsequently sorted by body mass index and by % body fat.

Assessment dates give the order of assessment in the total population (See Data 1A and IB, appendix).

Chapter 3

Results

Chapter 3

Results

3.0 Study Population

The sample consisted of 90 female subjects, aged 18 to 30 years, in the same phase of the menstrual cycle but with a wide range of body compositions. In this study, they have been referred to by the collective term 'study population' in order to distinguish the total group from the sub - groups into which they were later divided.

104 subjects in total had been recruited, but 14 had produced results for metabolic rate which were not within the 3% limit set for repeatability (see page 50) and were therefore not included in the study.

Energy expenditure was measured by indirect calorimetry (Douglas bag technique) under standard (basal) laboratory conditions.

Anthropometry included measurement of height, body weight and skinfold thickness, measured at four sites according to the method of Durnin and Womersley (1974).

1) Measured parameters were

basal metabolic rate (BMR) MJ per total body weight per 24 hours,

expressed as GBMR except where the term appears in an equation derived from literature where the unit of measurement (MJ/24hrs) is appended. The term '24 hours' is used rather than 'per day' since it is a period of time calculated from the measurement interval.

body weight (kg) expressed as BW

height (m)

skinfold thickness (mm) at four sites

2) Derived values were

basal metabolic rate (J/kg/min.), expressed as unit BMR - uBMR

body mass index (kg/m^2), expressed as BMI

percentage body fat expressed as %FM

percentage fat free mass (FFM) expressed as %FFM

Data are shown in full in Data 1A and 1B, appendix 1.

3.01 General characteristics of the study population.

The general characteristics of the study population are summarised in Table 1.

Table 1

Characteristics of the study population (n = 90)

	Range	Mean ± SD	S E M
Height (m)	1.50 - 1.75	1.63 ± 0.06	0.01
BW (kg)	40.1- 99.9	59.0 ± 9.6	1.0
% FFM	60.0 - 88.1	73.7 ± 6.1	0.6
% FM	11.9 - 40.0	26.3 ± 6.1	0.6
BMI (kg / m^2)	15.9 - 40.3	22.2 ± 3.6	0.4
BMR (MJ/24 hrs)	3.61 - 6.87	5.44 ± 0.70	0.07
BMR / kg (J / min)	77 - 44	65 ± 6	1.0

BW - body weight, FFM - fat free mass, FM - fat mass, BMI - body mass index, BMR - basal metabolic rate

3.02 Covariance of energy expenditure with anthropometric parameters

Energy expenditure, expressed as basal metabolic rate per total body weight (GBMR), for the total study population, was related to the following independent variables - body weight (BW (kg)), fat free mass (FFM (kg)), fat mass (FM (kg)), % FFM, % FM and body mass index (BMI (kg / m^2)). Results are shown in Table 2

Table 2

Covariance of GBMR with anthropometric parameters

Variable	r	p
BW (kg)	0.71	< 0.0001
FFM (kg)	0.75	< 0.0001
FM (kg)	0.58	< 0.001
%FFM	0.50	< 0.001
% FM	0.50	< 0.001
BMI (kg / m^2)	0.54	< 0.001

r - Pearson product moment correlation coefficient
GBMR - basal metabolic rate / total body weight / 24 hours (MJ)
BW - body weight, FFM - fat free mass (kg), FM - fat mass (kg),
BMI - body mass index (kg / m^2)

Comparison of the Pearson product moment values for GBMR with the above parameters showed fat free mass (FFM) to be most highly correlated representing 57 % of variance. The value for covariance with BW was lower with BW representing 51 % of variance.

GBMR values were plotted against BW and against FFM and scatter plots are shown in Figures 1 and 2 respectively, page 67.

Trendlines of GBMR with BW and FFM are shown in Figures 3 and 4, page 67a

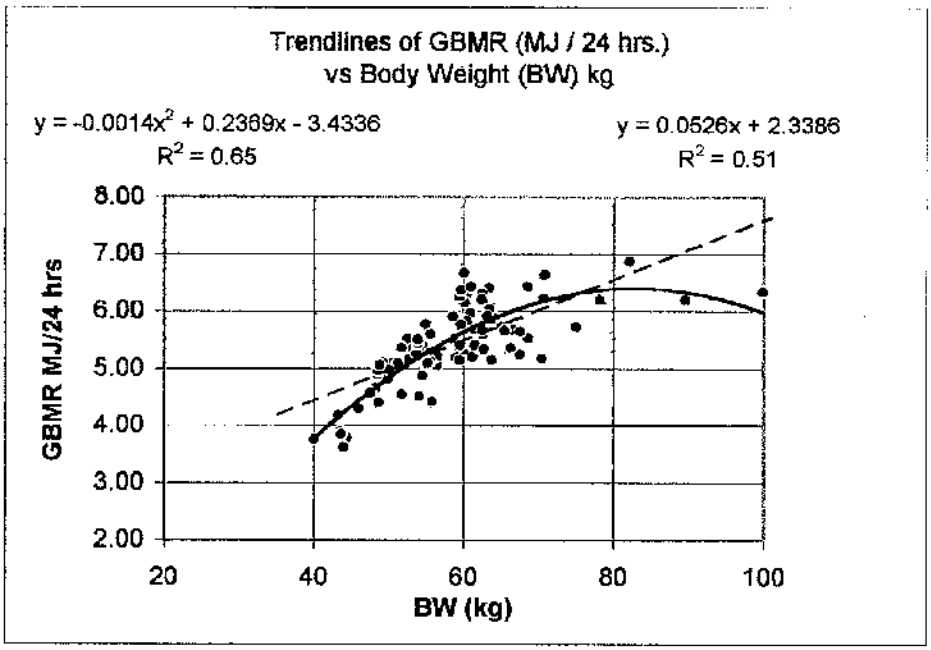


Fig. 3

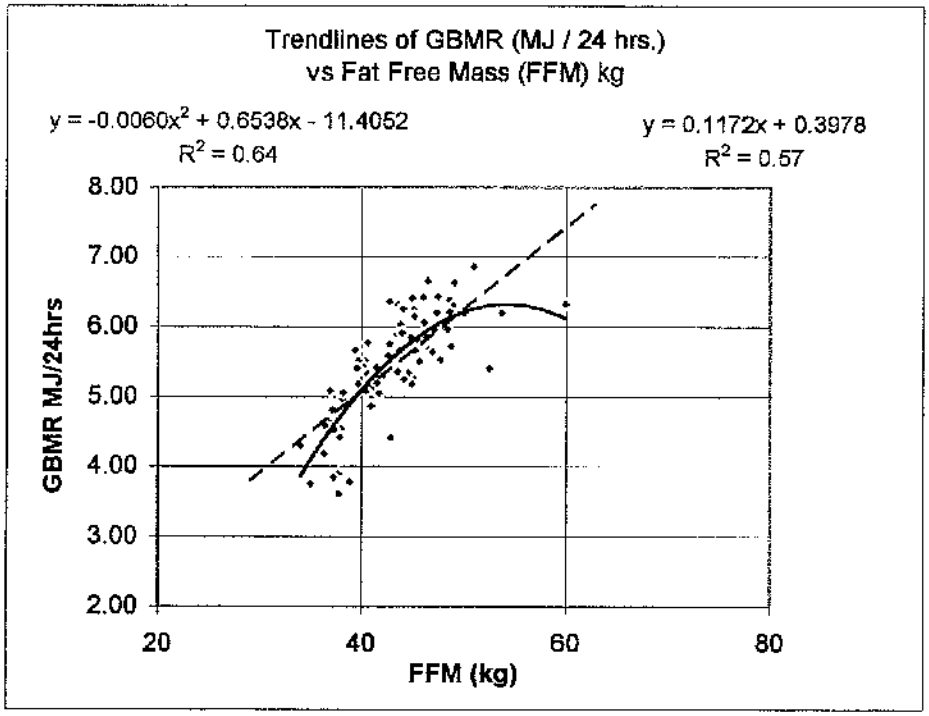


Fig. 4

GBMR - Basal metabolic rate / total body weight / 24 hours. (MJ)
Linear ------- Polynom. --- --- ---

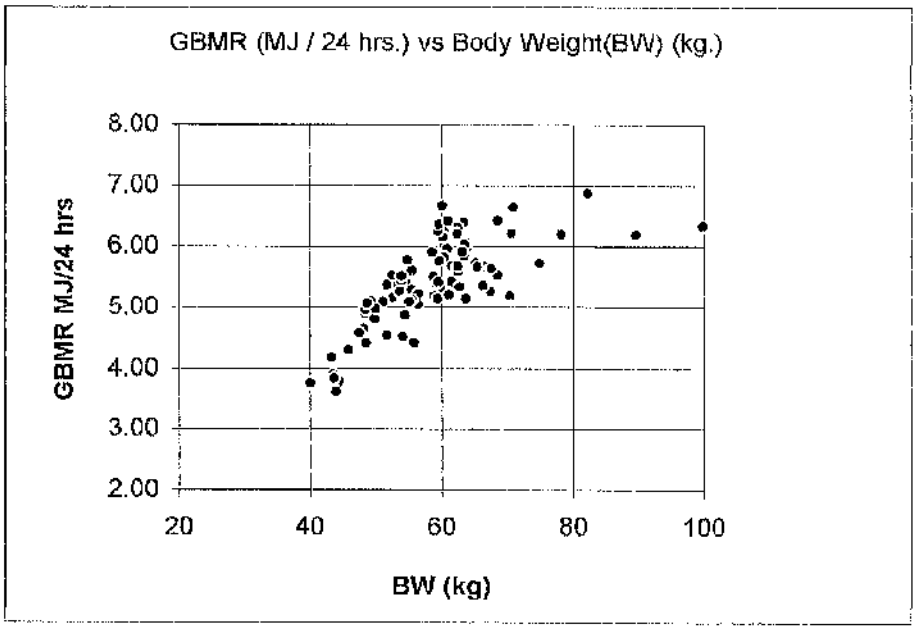


Fig.1

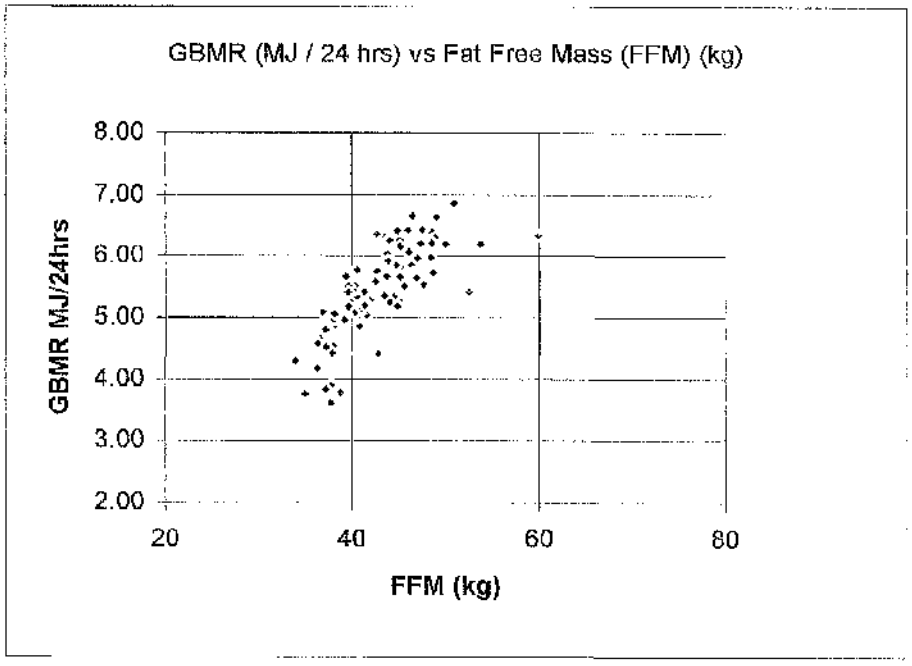


Fig.2

GBMR - Basal metabolic rate / total body weight / 24 hours. (MJ)

3.03 Preliminary examination of the data

Preliminary examination of the data indicated the following -

a) Visual inspection of the scatterplots (Figures 1 and 2) appeared to indicate clustering of data points in the middle ranges of each plot with groups of outliers at low and high body weights and low and high FFM values.

b) Consideration of covariance of GBMR with BW (r = 0.71) and with FFM (r = 0.75) indicated that the relationship, although statistically significant, might be regarded as moderate only.

c) Trendlines plots for GBMR with BW and FFM (Figs. 3 and 4) each showed both linear and polynomial characteristics.
In the case of GBMR with BW, r = 0.71 in the linear relationship but 0.81 at the second polynomial, indicating that the quadratic equation more closely represented the trend of the relationship between GBMR and BW.
In the case of GBMR with FFM, r = 0.75 in the linear relationship, 0.80 at the second polynomial, indicating that the curvilinear relationship was again closer, but that the difference between the two trends was less marked.

These observations suggested that the data may have some non linear characteristics arising from differing relationships of GBMR with either body weight (BW) or body composition (BC) across the range of subjects in the study population.
In order to investigate this possibility, the data were partitioned into two sets of three groups, one set according to a factor which represented body 'build' i.e. body mass index (BMI) and the other by a factor which represented body composition, i.e. percentage body fat, expressed here as %FM.

3.1 Grouping of subjects

In order to examine the characteristics of the study population with reference to body size and body composition, the subjects were grouped as 'overweight', 'standard' and 'lean', according to body mass index (BMI kg / m^2) using the standards suggested by the Royal College of Physicians in 1983, and, more arbitrarily, according to percentage body fat.

These groups are identified in the text as -

a) representing body size

overweight group - G >25BMI - those with BMI greater than 25 kg / m^2 (n = 16)

standard group - G 20 - 25BMI - those with BMI 20 - 25 kg / m^2 (n = 52)

lean group - - G <20BMI - those with BMI less than 20 kg / m^2 (n = 22)

b) representing body composition

overweight group - G >30%FM - those with greater than 30 % FM (n = 26)

standard group - G 20 - 30%FM - those with 20 - 30 % FM (n = 53)

lean group - G <20%FM - those with less than 20 % FM (n = 11)

Because of the inclusion of the height term in BMI, the groups G BMI and G %FM were differently constituted. For example, 22 subjects met the criteria for G <20BMI, but only 11 met the criteria for G <20%FM, although the members of either group might be described as ' lean '. The subjects in the latter group, with one exception, met the criteria for Grades 1,2, and 3 'thinness' (WHO, 1995) - see discussion.

Three subjects in the group described as 'overweight' had BMI of over 30 and therefore should be described as 'obese' using the criteria identified above.(Royal College of Physicians, 1983) When the overweight groups were considered with and without the inclusion of these three subjects, there was no significant difference in mean GBMR or

Table 3

Characteristics of study population, data partitioned according to body mass index, kg/m^2 (BMI)

Parameter	Range	Mean ± SD	SEM	Significance
Full range BMI (kg/m^2)	15.9 to 40.3			
(1) G >25BMI (n = 16)				
Height (m)	1.52 - 1.68	1.61 ± 0.05	0.01	
BW (kg)	59.6 - 99.9	72.1 ± 10.4	2.6	**(1) >(2)** p< 0.001 **(1) >(3)** p< 0.0001
% FFM	60.0 - 69.6	65.4 ± 3.1	0.8	
% FM	30.4 - 40.0	34.6 ± 3.1	0.8	**(1) >(2)** p< 0.001 **(1) >(3)** p< 0.0001
GBMR (MJ/ 24 hrs)	5.18 - 6.87	5.83 ± 0.52	0.13	**(1) cf (2)** n/s **(1) >(3)** p< 0.001
BMR (J/kg/ min) (uBMR)	44 - 65	57 ± 6	1.5	**(1) >(2)** p< 0.001 **(1) >(3)** p< 0.001
(2) G 20 - 25BMI (n = 52)				
Height (m)	1.50 - 1.75	1.63 ± 0.06	0.01	
BW (kg)	45.9 - 70.7	58.7 ± 4.9	0.7	**(2) >(3)** p< 0.001
% FFM	65.6 - 79.9	73.4 ± 3.2	0.4	
% FM	20.1 - 34.4	26.6 ± 3.2	0.4	**(2) >(3)** p< 0.001
GBMR (MJ/ 24 hrs)	4.30 - 6.43	5.60 ± 0.54	0.08	**(2) >(3)** p<< 0.001
BMR (J/kg/ min) (uBMR)	55 - 74	66 ± 5	1.0	**(2) cf (3)** n/s
(3) G <20BMI (n = 22)				
Height (m)	1.53 - 1.80	1.65 ± 0.06	0.01	
BW (kg)	40.1 - 61.6	50.1 ± 5.9	0.1	
% FFM	73.7 - 88.1	80.5 ± 4.8	1.0	
% FM	11.9 - 26.3	19.5 ± 4.8	1.0	
GBMR (MJ/ 24 hrs)	3.61 - 6.66	4.78 ± 0.72	0.15	
BMR (J/kg/ min) (uBMR)	57 - 77	66 ± 5	1.0	

FFM - fat free mass, FM - fat mass, BW - body weight, BMR - basal metabolic rate,
GBMR - basal metabolic rate / whole body/ 24 hours, SEM standard error of mean.

in the means of any of the anthropometric parameters. The three subjects were therefore included under the description 'overweight'.

Data were partitioned for subjects described as 'lean', 'standard' and 'overweight' members of the full study population, classified first according to BMI then according to % FM. Differences between groups within each classification are shown in the following section (para. 3.11 and 3.12), then between the two classifications (para. 3.13)

3.11 Differences within data partitioned according to BMI

Subjects were grouped according to BMI as G >25BMI (overweight), G 20 - 25BMI (standard) and G < 20BMI (lean).

Data are shown in Table 3 on page 70a

Comparison of the data for these groups showed that mean BW was successively lower in G >25BMI, G20 - 25BMI and G <20BMI, with the difference in each case significant at $p < 0.001$. In spite of a difference in mean BW of approximately 15 kg between the overweight G >25BMI and standard G 20 - 25BMI, there was no statistically significant difference in mean GBMR although the mean for the overweight group was higher, 5.83 MJ / 24 hrs compared with 5.60 MJ / 24 hrs.

The mean value for GBMR for the significantly lighter (approximately 6.8 kg difference between means) G < 20BMI group was significantly lower ($p < 0.001$) with approximately 15 % reduction on the G 20 - 25 BMI mean value, a difference amounting to 0.82 MJ.

Consideration of BMR / kg / minute (uBMR) showed the mean values for the standard G 20 - 25BMI and lean G <20BMI to be almost identical.

That for the overweight group G >25BMI was significantly lower ($p < 0.001$), the difference being approximately 17 % (approximately 10 J / kg / min.).

Table 4

Characteristics of study population, data partitioned according to %Fat Mass

Parameter	Range	Mean ± SD	SEM	Significance
Full range %FM	11.9 - 40.0			
(1) G >30%FM (n = 26)				
Height (m)	1.52 - 1.68	1.61 ± 0.05	0.01	
BW (kg)	54.1 - 99.9	68.2 ± 10.0	1.9	**(1) >(2)** p<0.001 **(1) >(3)** p<0.0001
% FFM	60.0 - 70.0	66.6 ± 2.9	0.6	
% FM	30.0 - 40.0	33.4 ± 2.9	0.6	**(1) >(2)** p<0.001 **(1) >(3)** p<0.0001
GBMR (MJ/ 24 hrs)	4.42 - 6.87	5.66 ± 0.58	0.11	**(1) cf (2)** n/s **(1) >(3)** p<0.001
BMR (J/kg/ min) (uBMR)	44 - 66	58 ± 5	1.0	**(1) >(2)** p<0.001 **(1) >(3)** p<0.0001
(2) G 20 - 30%FM (n = 53)				
Height (m)	1.50 - 1.75	1.64 ± 0.06	0.01	
BW (kg)	45.9 - 65.2	56.9 ± 5.0	0.7	**(2) >(3)** p<0.001
% FFM	70.9 - 79.9	75.0 ± 2.1	0.3	
% FM	20.1 - 29.1	25.1 ± 2.1	0.3	**(2) >(3)** p<0.001
GBMR (MJ/ 24 hrs)	4.30 - 6.66	5.55 ± 0.56	0.08	**(2) >(3)** p<<0.001
BMR (J/kg/ min) (uBMR)	59 - 77	68 ± 4	0..6	**(2) >(3)** p<0.01
(3) G <20%FM (n = 11)				
Height (m)	1.53 - 1.80	1.63 ± 0.07	0.02	
BW (kg)	40.1 - 61.6	47.1 ± 5.5	1.7	
% FFM	80.8 - 88.1	84.9 ± 2.4	0.7	
% FM	11.9 - 19.2	15.1 ± 2.4	0.7	
GBMR (MJ/ 24 hrs)	3.61 - 5.41	4.37 ± 0.63	0.19	
BMR (J/kg/ min) (uBMR)	57 - 72	64 ± 5	1.5	

FFM - fat free mass, FM - fat mass, BW - body weight, BMR - basal metabolic rate, GBMR - basal metabolic rate/ whole body / 24 hours, SEM - standard error of mean.

3.12 Differences within data partitioned according to % FM

Subjects were grouped according to % FM into G >30%FM (overweight),
G 20 - 30%FM (standard)and G <20%FM (lean)
Data are shown in Table 4 on page 71a

When these three groups were compared, G >30%FM had significantly higher body weight (BW) than the other two groups ($p < 0.001$, $p < 0.0001$) and G 20 - 30%FM in turn was significantly heavier than G <20FM ($p < 0.001$)

In spite of the significant difference in BW, there was no significant difference in mean total body basal metabolic rate (GBMR) between the overweight group G >30%FM and the standard group G 20 - 30%FM although G >30%FM did have a higher mean value (5.66 compared with 5.55 MJ / 24 hrs.).

Predictably, the lean group G < 20%FM, with a much lower mean BW, had a mean GBMR significantly lower ($p < 0.001$) than the 2 heavier groups.
The difference between mean GBMR in the standard group G 20 - 30%FM and the lean group G<20%FM amounted to approximately 21 % of the G 20 - 30%FM mean, 1.18MJ
The findings were similar to those for data grouped according to BMI, although the magnitude of the difference in mean GBMR between standard and lean groups was larger when the more selective %FM criteria were used.
When BMR / kg BW / min. (uBMR) was considered, it was apparent that the mean for G 20 - 30%FM was significantly higher than that for either the overweight or the lean groups in this classification.
When compared with the overweight group G >30%FM, the difference was significant at $p < 0.001$) and amounted to an increase of 17.2 % on the mean of G >30%FM (10 J/ kg/ min).

The difference between the mean uBMR for G 20 - 30%FM and the lean G <20%FM was less marked, with that for G <20%FM lower by 5.9 %. and significant only at $p < 0.01$.

3.13 Comparison of BMI and %FM groups.

There were no significant differences between the mean values of the BW and BC characteristics of the two overweight groups G >30BMI and G > 30%FM or between the mean values for the two standard groups G 20 - 25BMI and G 20 - 30%FM, although in both cases the ranges in BMI groups were wider.

There were, however, significant differences in the mean BC values of the lean groups G < 20BMI and G < 20%FM

The difference in body composition expressed as % fat free mass (% FFM) and % fat mass (% FM) was significant ($p < 0.001$) with mean % FFM higher and mean % FM lower in G < 20%FM than in G < 20BMI .i.e. G<20%FM was the leaner of the two lean groups.

As far as BW was concerned, mean BW (body weight) was lower in G < 20%FM by approximately 3 kg, however the difference between the means of the groups was significant only at $p < 0.01$.

In the case of GBMR, there were no significant differences in mean values for either overweight or standard groups. Comparison between standard and lean in each grouping, however, showed that while the difference between the two was significant in each grouping,($p << 0.001$) the significance using % FM criteria was an order greater and the value was greater (21% or 1.2 MJ compared with 15 % or 0.8 MJ in the case of BMI). The difference between the two systems of grouping amounted to 0.4MJ, a value likely to be of relevance in practical terms, however, values such as these must be treated with caution in view of the small numbers in the groups, particularly the leanest group, the inherent variability of BMR and the level of experimental error.

When uBMR in standard and lean groups was considered, while the means for the two groups, using BMI criteria, were almost identical, the mean value in the lean G <20%FM was lower than that in the standard G 20 - 30%FM by 5.9 %, although the difference was significant at only $p < 0.01$.

In summary, as far as differences in mean BW, GBMR and uBMR between overweight and standard groups were concerned, there was no significant difference between BMI and % FM grouping except where % FM grouping showed more distinct differences between standard and lean in mean GBMR.

When the effect of the differences in BW throughout the range of the study population was eliminated by the use of BMR / kg (uBMR), there remained a difference in uBMR between standard and lean groups. This reduction in group mean uBMR was apparent only in the leanest group selected by the stricter criteria of % FM, suggesting that the difference may have been due to the difference in body composition.

3.2 Relationships of GBMR with BW, data partitioned according to BMI and %FM

In order to investigate the relationships of GBMR with BW, analysis of covariance was carried out with data partitioned first according to BMI, then according to %FM

3.21 Analysis of covariance of GBMR with BW, data partitioned by BMI

This showed differing coefficient values for the groups, with the highest correlation in the leanest group. The results would appear to indicate differences in the degree of covariance of GBMR with BW over the range of 90 subjects and while the value of r (Pearson coefficient) for the lean group had increased, the differences between overweight standard and full range values were small and may have been partly attributable to the differences in sample size. Results are shown in Table 5 (page 74)

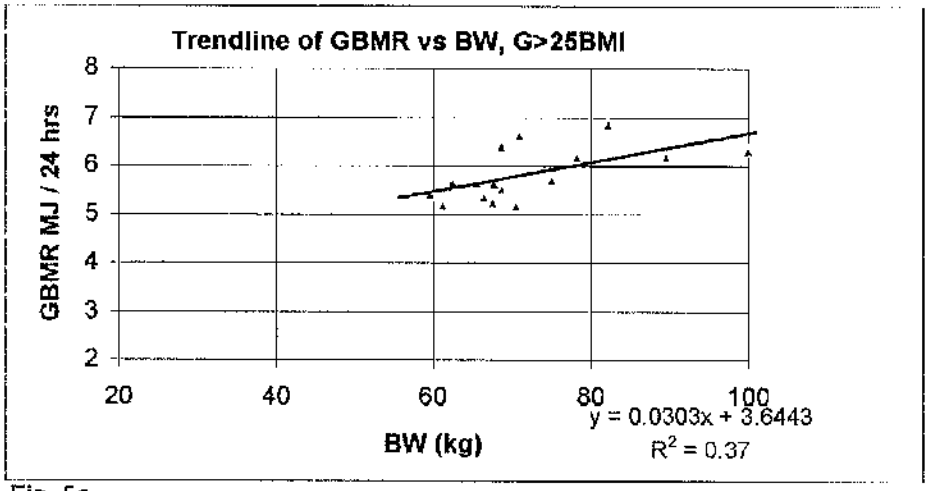


Fig. 5a

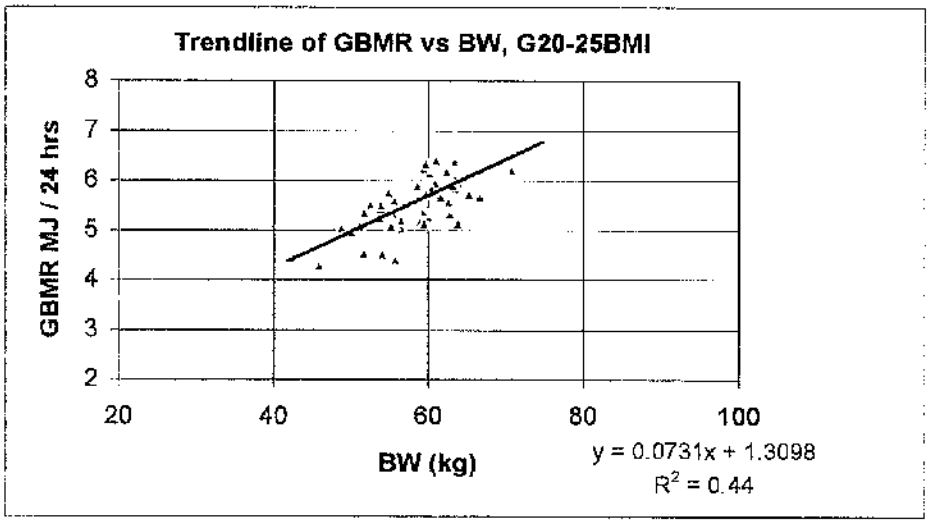


Fig. 5b

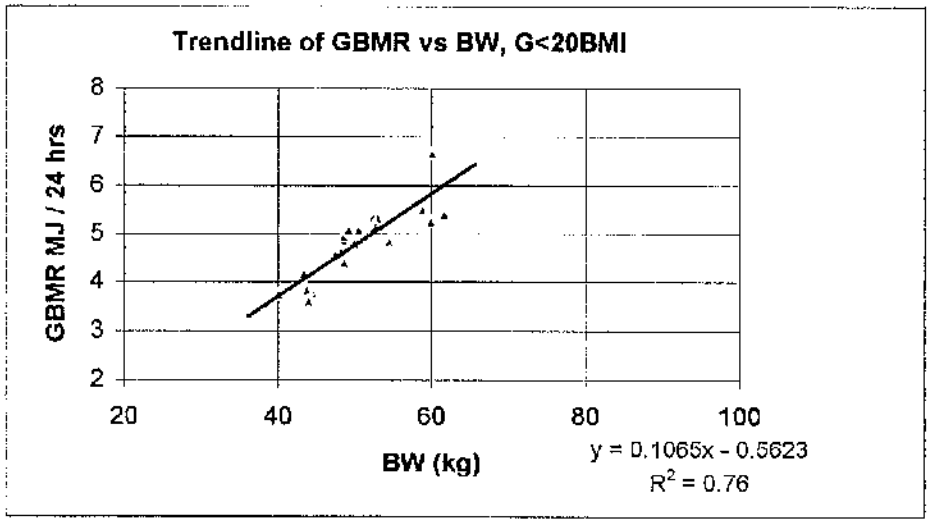


Fig. 5c

Table 5

Covariance of GBMR with body weight (BW) (kg), data partitioned according to BMI

Variable / group	n	r	p
BW G > 25BMI	16	0.61	< 0.01
G 20 - 25BMI	52	0.66	< 0.001
G < 20BMI	22	0.87	< 0.001
Full range	90	0.71	< 0.001

BW - body weight, r - Pearson product moment coefficient,

3.211 Confirmation of difference between groups.

In order to establish whether or not covariance in the groups differed, regression analysis was carried out on the three BMI groups.

The slopes obtained for the covariance of GBMR with BW in groups G >30BMI, G 20-30BMI and G <20BMI are shown in Figures 5a, 5b and 5c respectively (page 74a).

The null hypothesis was proposed that the slopes were the same.

Analysis of variance using Bartlett's tests showed that $F_{2, 88} = 23.11$. The critical value at 2, 90 df = 3.84, $p < 0.0001$.

The null hypothesis that the slopes, i.e. degree of covariance, for these three groups were the same could therefore be rejected.

The results would appear to indicate that there was evidence of departure from a single linear relationship between GBMR and BW over the range of 90 subjects.

3.212 Consideration of covariance in BMI groups

Since the slopes of regression lines in the partitioned data were different from one another, the values of the coefficients were considered in the light of characteristics of the appropriate groups.

The value for r in the lean group G < 20BMI increased to 0.87 compared with 0.71 for the full range i.e. the closest correlation in the lean group.

The decreased level of covariance of GBMR with BW in the standard group G 20 - 25BMI may be due to greater variability in this smaller group of individuals (n = 52) when compared with the total population (n = 90).

This effect was similar in the overweight group where r was reduced to 0.61 (n = 16), a contributory factor may be the influence of the much larger fat mass.

3.22 Analysis of covariance of GBMR with BW - data grouped according to %FM

The analyses carried out with BMI groups were repeated with %FM groups.

When the data were partitioned according to % FM, analysis of covariance showed differences between overweight, standard and lean subjects. As with differences in covariance with subjects grouped by BMI, the differences may have been attributable simply to sample size, however, in this case, standard and lean groups showed higher values of r, while that for the overweight group remained comparable with the full range value. Results are shown in Table 6

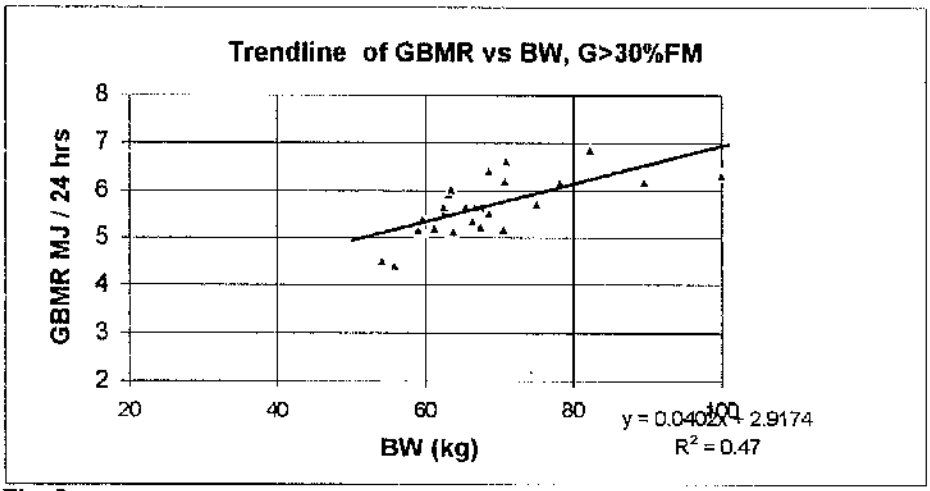


Fig. 6a

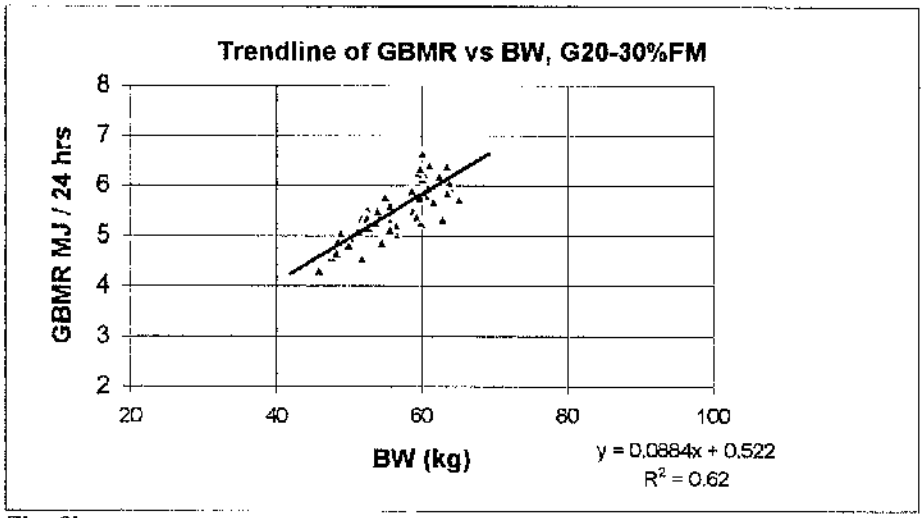


Fig. 6b

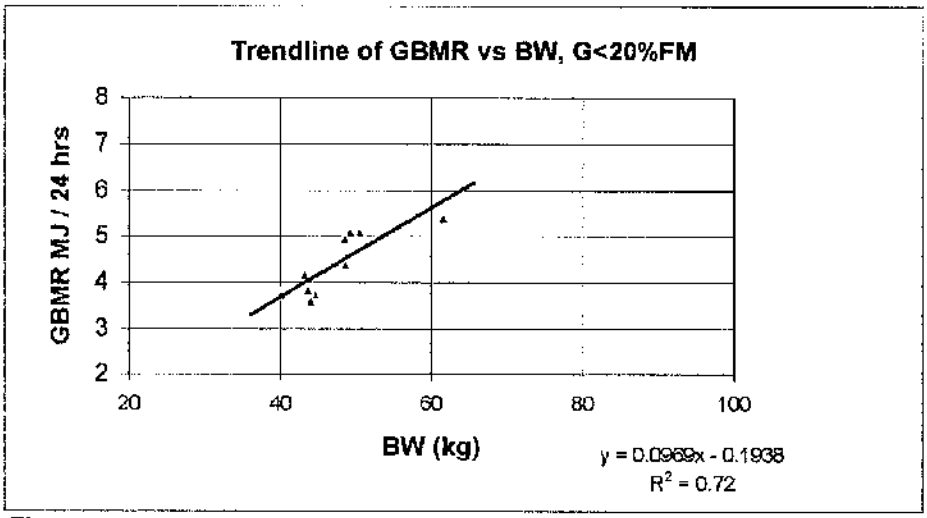


Fig. 6c

Table 6

Covariance of GBMR with body weight (BW) (kg), data partitioned according to % Fat Mass (%FM)

Variable / Group	n	r	p
BW G >30%FM	26	0.69	< 0.001
G 20 -30%FM	53	0.79	< 0.001
G <20%FM	11	0.85	< 0.001
Full range	90	0.71	< 0.001

BW - body weight, r - Pearson product moment coefficient

3.221 Confirmation of the difference between slopes.

The slopes obtained for the covariance of GBMR with BW in groups G >30%FM, G 20-30%FM and G <20%FM are shown in Figures 6a, 6b and 6c respectively (page 76a).

The null hypothesis was proposed that the slopes were the same.

Analysis of variance using Bartlett's tests show that $F_{2, 69} = 31.78$. The critical value at 2, 90 df = 3.84, $p < 0.0001$.

The null hypothesis that the slopes for these three groups were the same could therefore be rejected. The results would appear to suggest that, as with data partitioned according to BMI, data partitioned according to %FM showed some departure from linearity in the relationship between GBMR and BW.

3.222 Consideration of covariance in %FM groups

When the data were partitioned according to % FM, analysis of covariance showed differences between overweight, standard and lean subjects. Covariance of GBMR with BW for the group G > 30%FM when compared the full range was reduced from 0.71 to 0.69 ($p < 0.001$) while the value for G 20 - 30%FM increased from 0.71 to 0.79.

The range of values for both BW and BC, as measured by standard deviation (SD), was wider in the overweight group compared with standard and the group was smaller, both of which have the effect of increasing variance. The relationship between FFM and FM in the overweight group was more variable with a smaller mean component of FFM or conversely a larger mean FM.

In the case of the lean group G <20%FM (n = 11), the value for r was 0.85.
This value represented 72 % of variance and suggested a close association of GBMR with BW in this very lean group.
This group was characterised by high mean % FFM (approximately 85 %). FFM has a higher rate of EE than the FM compartment and, in this group, represented a large component of BW. Its close correlation with GBMR therefore would appear to be a reasonable finding.
Both lean groups had originally appeared to be outliers of the full range regression line, much closer correlation of GBMR with BW could be achieved when these groups were considered separately and a group specific equation used.

3.23 Comparison of covariance in BMI and %FM groups

When covariance was compared in the two groupings, there was no significant difference in the value for r in the 2 **lean** groups (r = 0.85 for G < 20FM and r = 0.87 for G < 20BMI).

In the **standard** groups, the value of r was lower in the BMI group (n = 52) than that for the equivalent group (n = 53) in %FM classification (0.66 compared with 0.79).
Although the mean BW for the 2 groups was very similar, BC in the 2 groups was significantly different. As a group, G 20 - 30%FM was leaner and with a smaller range of % FFM (75.0 ± 2.1) than G 20 - 25BMI (73. 4 ± 3.2). Although there was no

statistically significant difference in the means, the ranges showed a difference significant at $p < 0.003$.

In the **overweight** groups, the values of r were 0.61 for G >25BMI and 0.69 for G >30%FM respectively, in this case, the %FM group was larger (n = 26 of 16) with lower mean BW and with higher mean percentage FFM.

3.3 Preliminary evidence of non-linearity of data

Review of the data thus far showed the following -

- covariance of GBMR with BW and FFM giving values of 0.7 to 0.75 i.e. good correlation but still some way from 1.0

- plots of GBMR with BW and with FFM showing both linear and polynomial trends

- partitioned data for GBMR plotted against BW showing significantly different line slopes for overweight, standard and lean groups in each grouping

- Pearson coefficients for the groups different from one another and from the full range value.

The above observations appeared to indicate that the data may have had some non-linear characteristics and led to the following lines of enquiry -

1. In the study population, what are the values of energy expenditure / unit mass of tissue of different compositions ? Converting EE to a value per unit mass would have the effect of removing one of the variables affecting GBMR i.e. different body weights across the range of subjects.

2. How do these values/ unit mass compare with theoretical EE values per unit mass of composite tissue?

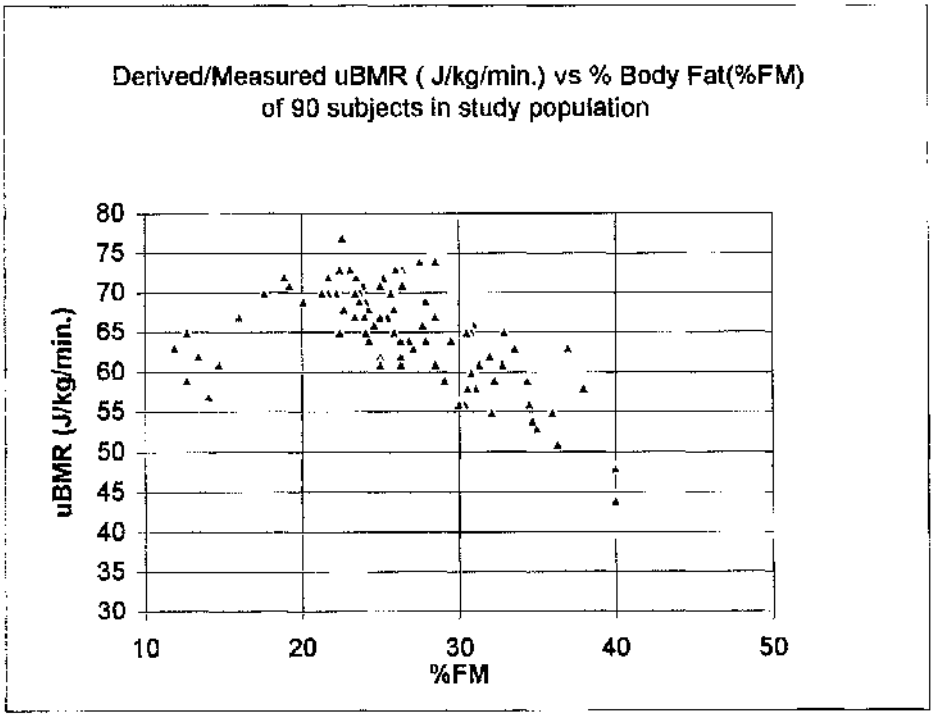

Derived/Measured uBMR (J/kg/min.) vs % Body Fat(%FM)
of 90 subjects in study population
uBMR (J/kg/min.)
80
75
70
65
60
55
50
45
40
35
30
10
20
30
40
50
%FM

Fig.7

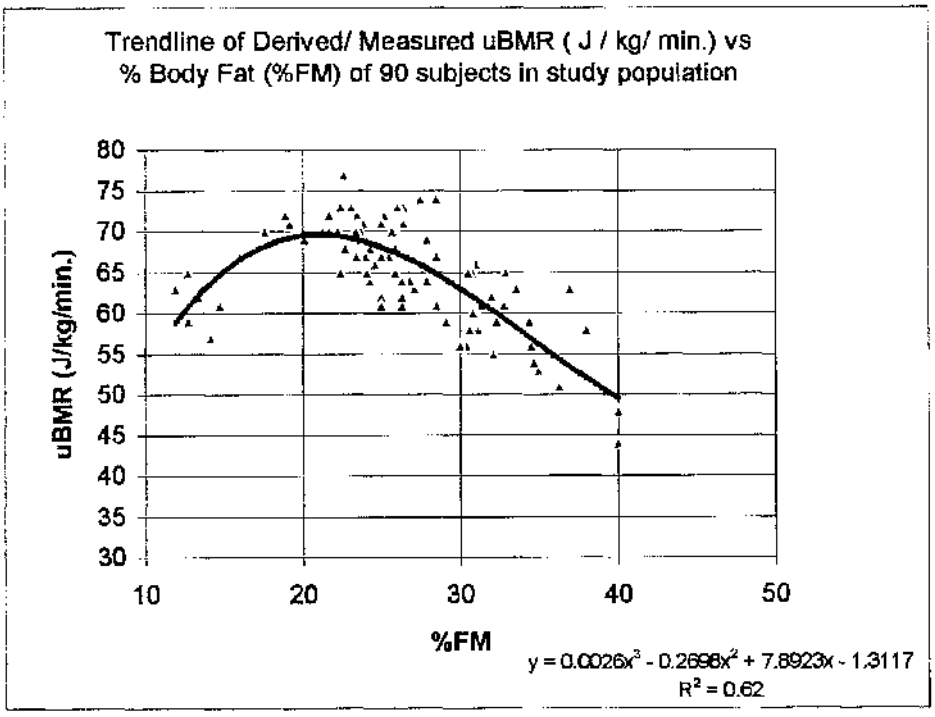

Trendline of Derived/ Measured uBMR (J / kg/ min.) vs
% Body Fat (%FM) of 90 subjects in study population
uBMR (J/kg/min.)
80
75
70
65
60
55
50
45
40
35
30
10
20
30
40
50
%FM
y = 0.0026x³ - 0.2698x² + 7.8923x - 1.3117
R² = 0.62

Fig.8

3. Since linear regression equations are widely used in the prediction of basal metabolic rate of groups, what difference in estimate would be introduced if a full range linear regression equation were to be used rather than a group specific equation ?

4. If any apparent improvement in estimate is obtained by using a group specific equation, is the 'improvement' of any practical or clinical advantage ?

3.31 Basal metabolic rate / unit mass related to individual body composition.

Basal metabolic rate / unit mass (J/ kg/ min.), expressed as uBMR, was related to body composition as defined by %FM.

uBMR values for all 90 subjects were plotted against their %FM values. Results are shown in Figure 7 on page 79a.

The scatter plot showed visual indication of curvilinearity, confirmed by analysis which showed the curvilinear relationship to be significant at the 3°polynomial, see Figure 8 page 79a

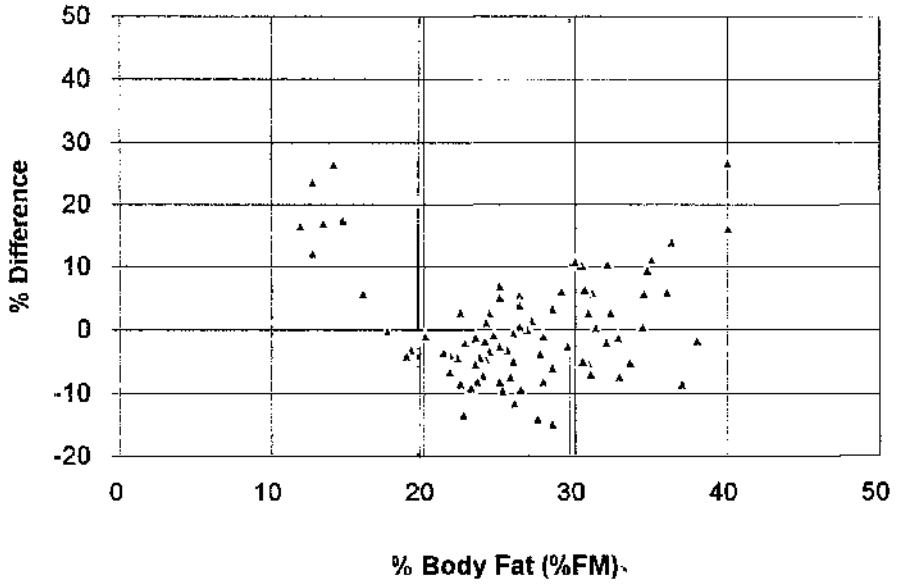
Unit weight of tissue, as derived from total body weight, clearly represents unit weights of widely differing assemblies of FFM and FM.

FFM and FM have been shown by Garby et al (1988) to have very different rates of energy expenditure and it is to be expected that there would be large variation in BMR per unit of composite tissue.

Using the estimates of resting energy expenditure in women of 1.35 and 0.31 J/ kg/ sec suggested by those authors, theoretical expenditure per kg. of body mass was calculated for each individual using FFM and FM percentage of that individual.

These estimates were then compared with figures derived from measurement. (Data 2A and 2B, appendix 1).

Percentage difference between individual measured/ derived uBMR and individual uBMR calculated according to estimates of eneryy expenditure by Garby et al, (1988)



% Diff.	G<20%FM	G20-30%FM	G>30%FM
Mean	11.8	3.6	3.9
S.D.	10.6	5.6	8.4

Fig.10

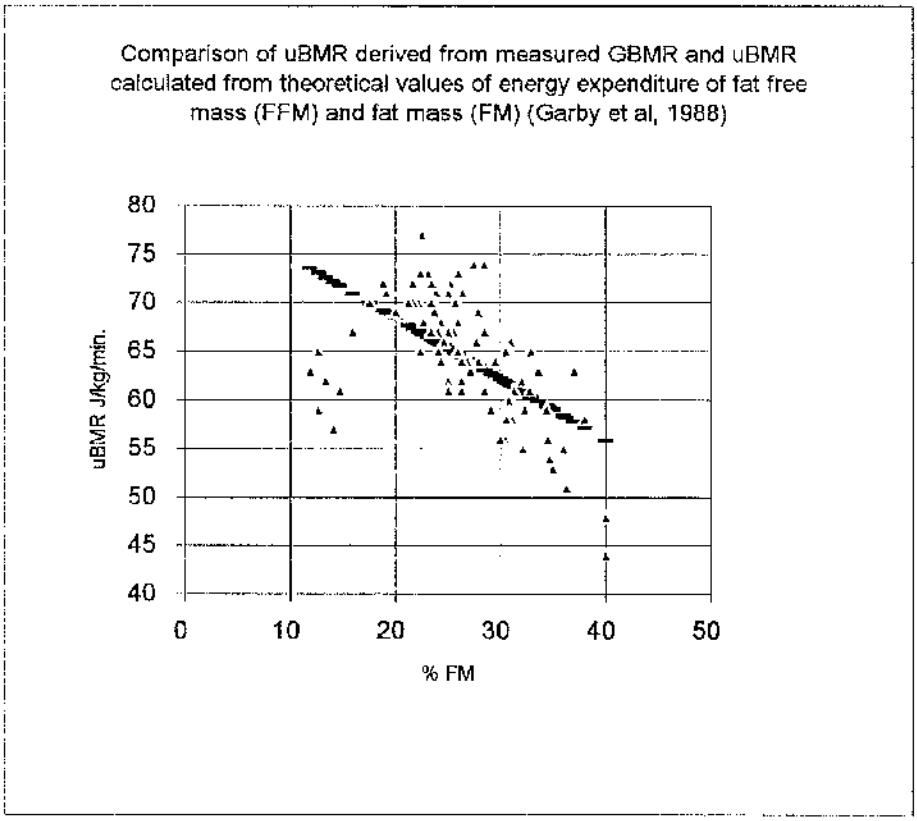


Fig.9 Estimated values are shown by symbol —
derived / measured values are shown by symbol ▲

uBMR - unit BMR - J/kgBW/min,

Distribution of measured and estimated values is shown in Figure 9, page 80a

There was notable contrast between the linear arrangement of the estimated data and the non linear arrangement of the data derived from measured values.

The percentage differences between estimated and derived/ measured uBMR are shown in Figure 10, page 80b.

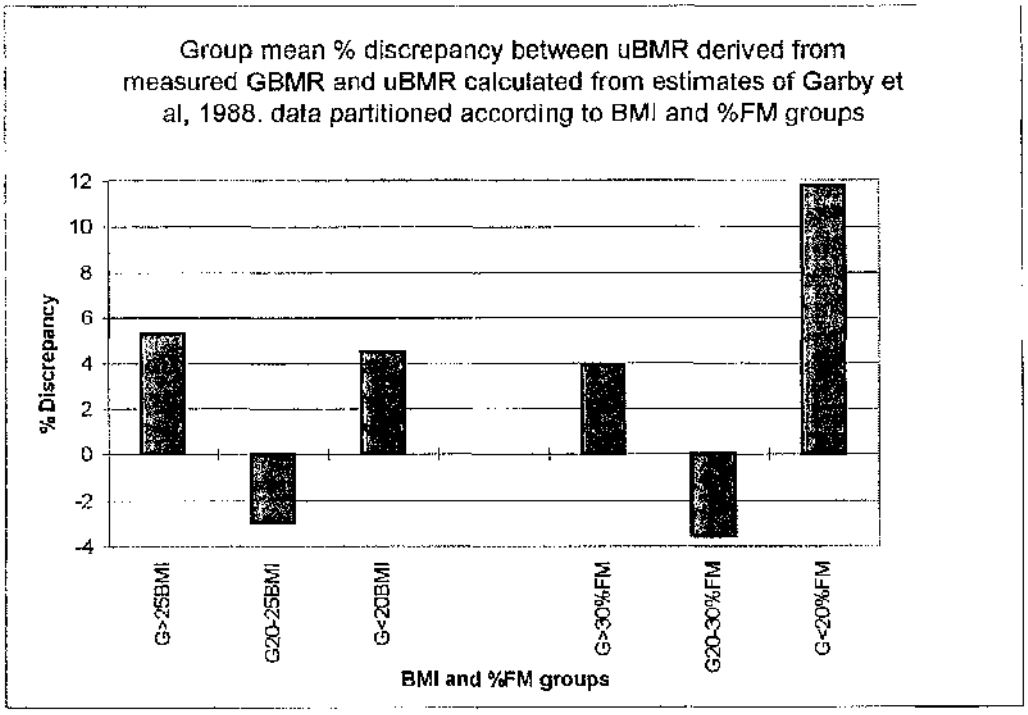


Fig.11, refer to Table 7

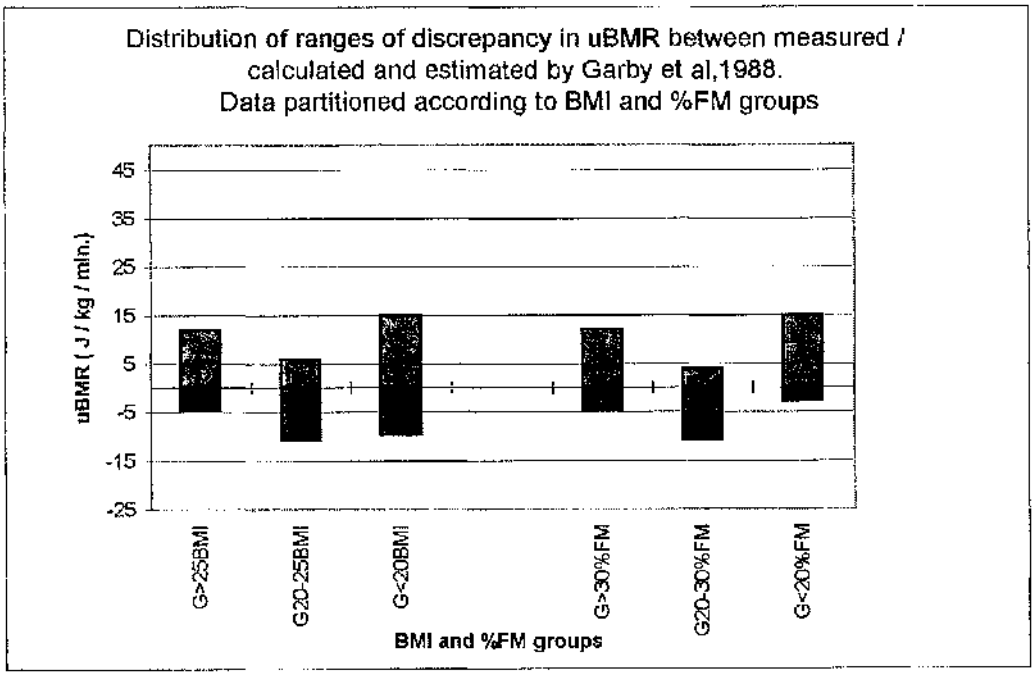


Fig. 12, refer to Table 7

3.32 Differences between group mean measured and estimated values of uBMR, using partitioned data.

In order to examine the differences between measured and estimated values, according to BW and BC, data were grouped as before according to BMI and % FM, and data are shown in Table 7

Table 7

Comparison of group mean uBMR derived from measured GBMR with group mean uBMR calculated from the estimates of Garby et al (1988)

Group	n	est. mean uBMR	Meas. mean uBMR	t	p	Discrep. % See Fig.11	Range J/ min. See Fig.12
G > 25BMI	16	60	57	1.625	< 0.01	+ 5.3	+12 to -5
G 20 - 25BMI	52	64	66	2.934	< 0.0025	- 3.0	+ 6 to -11
G < 20BMI	22	69	66	2.22	< 0.025	+ 4.5	+15 to -10
G > 30%FM	16	60	58	n/s		+ 3.9	+ 12 to -5
G 20 - 30%FM	53	65	69	4.47	< 0.0005	- 3.6	+ 4 to -11
G > 20%FM	11	72	64	4.69	< 0.0005	+ 11.8	+ 15 to -3

uBMR - BMR (J / kg / min.)
(% calculations based on data at first decimal place)

Differences between measured / derived and calculated uBMR are shown in Figures 11 and 12 on page 81a.

3.33 Summary of findings related to group mean uBMR

In each grouping, mean uBMR was over estimated in the lean groups, with the difference greatest and most significant in the leanest G > 20%FM group.

Significant under estimates had occurred in the means for standard groups, however the difference was greater and more significant in %FM group.

The overestimates in the means for overweight groups were significant only at

$p < 0.01$ in the BMI group, and with no significant difference between estimated mean and the mean of values derived from measured values in G>30%FM.

Apart from the last group, the differences were most evident in the groups partitioned by body composition i.e. %FM.

3.4 Effect of degree of non-linearity of data on the accuracy of prediction of GBMR from linear regression equations substituting BW

Basal metabolic rate is often predicted using a linear regression equation in which body weight is entered.

In order to assess the effect of the degree of departure of the data from a linear relationship between GBMR and BW, GBMR data obtained by measurement were compared with data derived by estimate using full range and group specific equations, as detailed below. Discrepancy in practical terms (or difference in residuals in statistical terms) was then calculated. The term 'discrepancy' is used here.

1) Mean body weight for the full range of the study population and for each group was substituted in -

the full range regression equation for the study population

the group specific regression equations

the estimated mean values were then compared with mean measured GBMR

2) Individual BW was substituted in -

the full range regression equation for the study population

the group specific regression equations

comparison was then made between each individual estimate and the individual measured GBMR

3) Mean body weight for each group was substituted in -

the equation proposed by Schofield (1985, 1991)

(there is no equivalent of the group specific equation)

the estimated mean values were then compared with mean measured GBMR

4) Individual BW was substituted in -

the equation proposed by Schofield (1985, 1991)

comparison was then made between each individual estimate and the individual measured GBMR

5). The use of a power factor is said to moderate the distorting effect of low and high body weight on prediction of GBMR related to BW itself (see discussion).

Mean $BW^{0.75}$ for the full range of the study population and for each group was substituted in -

the full range regression equation for the study population

the group specific regression equations

the estimated mean values were then compared with mean measured GBMR

6) Individual $BW^{0.75}$ was substituted in -

the full range regression equation for the study population

the group specific regression equations

comparison was then made between each individual estimate and the individual measured GBMR

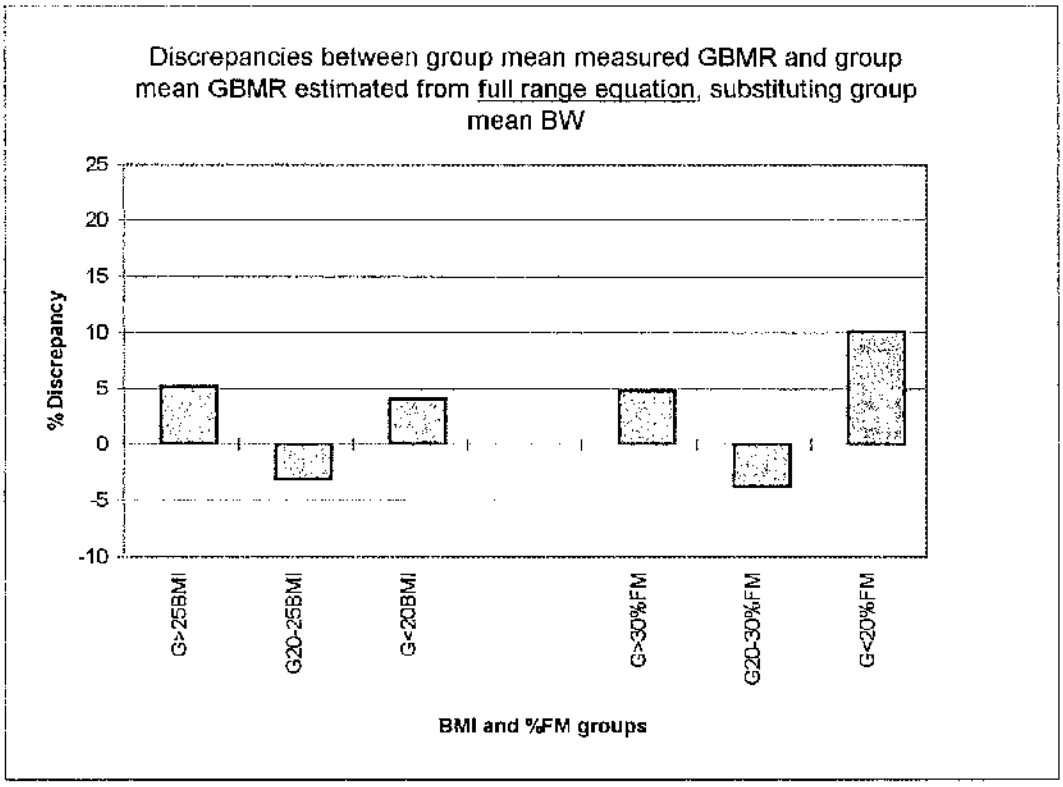


Fig. 13, refer to Table 8

3.41 Comparison of full range and group mean measured GBMR with mean GBMR estimated by substituting mean BW in full range and group specific equations

a) Mean BW for the full range of the study population and of each group was substituted in the full range equation and the group specific equations. The values for the estimated means closely matched the measured means, the equations having been derived from those data.

The greatest discrepancy was found in G <20%FM where there was an overestimate by the group specific equation of 3.3% of the mean measured value, however, this is within the error limit of many methods of assessment.

b) substitution of the group mean values of BW in the full range equation produced a pattern of discrepancy shown in Table 8

Table 8

Comparison of group mean measured GBMR with GBMR estimated by substituting group mean BW (kg) in full range equation GBMR (MJ/24 hrs.) = 0.0526 x BW (kg) + 2.3386

Group	BW (kg)	GBMR est MJ/24hrs	GBMR meas. MJ/24hrs	Discrep. (%)	Discrep (kJ)	Discrep (kcal)
				See Fig.13		
Full range	59.0	5.44	5.44	0.0	3	0
G >25BMI	72.1	6.13	5.83	5.2	303	72
G 20- 25BMI	58.7	5.42	5.60	-3.2	-179	-43
G <20BMI	50.1	4.98	4.78	4.1	196	47
G >30%FM	68.2	5.93	5.66	4.8	272	65
G 20- 30%FM	56.9	5.33	5.55	-3.9	-216	-51
G <20%FM	47.1	4.81	4.37	10.1	441	105

Percentage discrepancies are shown in Figure 13, page 84a.

a) the **overweight** groups showed GBMR to have been overestimated by 5.2 % in G >25 BMI and 4.6 % in G >30%FM

These discrepancies were not significantly different from one another and the overestimates, although statistically significant were, at 303 and 272 kJ (72 and 65 kcal), not considered of practical significance (see discussion).

b) the **standard** groups showed underestimates of 3.2 and 3.9% and these differences of 179 and 216 kJ (43 and 51 kcal) were again considered below practical significance.

c) in the **lean** groups, however, GBMR had been over estimated by the general equation by 4.1 % (196 kJ / 47 kcal) in G< 20BMI and 10.1 % (441 kJ / 105 kcal) in G< 20%FM, the latter reduced to 3.3% by the group specific equation. In this very lean group, the difference in body composition selection criteria highlighted an overestimate of practical significance by the general equation which was obscured in the BMI group where criteria were less selective.

Therefore, although the full range regression equation for GBMR with BW represented the standard and overweight groups, i.e. the majority of the population, mean GBMR of the leanest group was over estimated to an extent likely to have practical importance.

3.42 Comparison of individual differences between measured and estimated GBMR, substituting BW in full range and group specific equations

Although better agreement was achieved between measured and estimated means using group specific regression equations, examination of individual records provided evidence of the wide ranges of discrepancy within each group.

(Data 3A and 3B, appendix 1)

Data are shown in Table 9 page 86 and in Figures 14 and 15, page 86a.

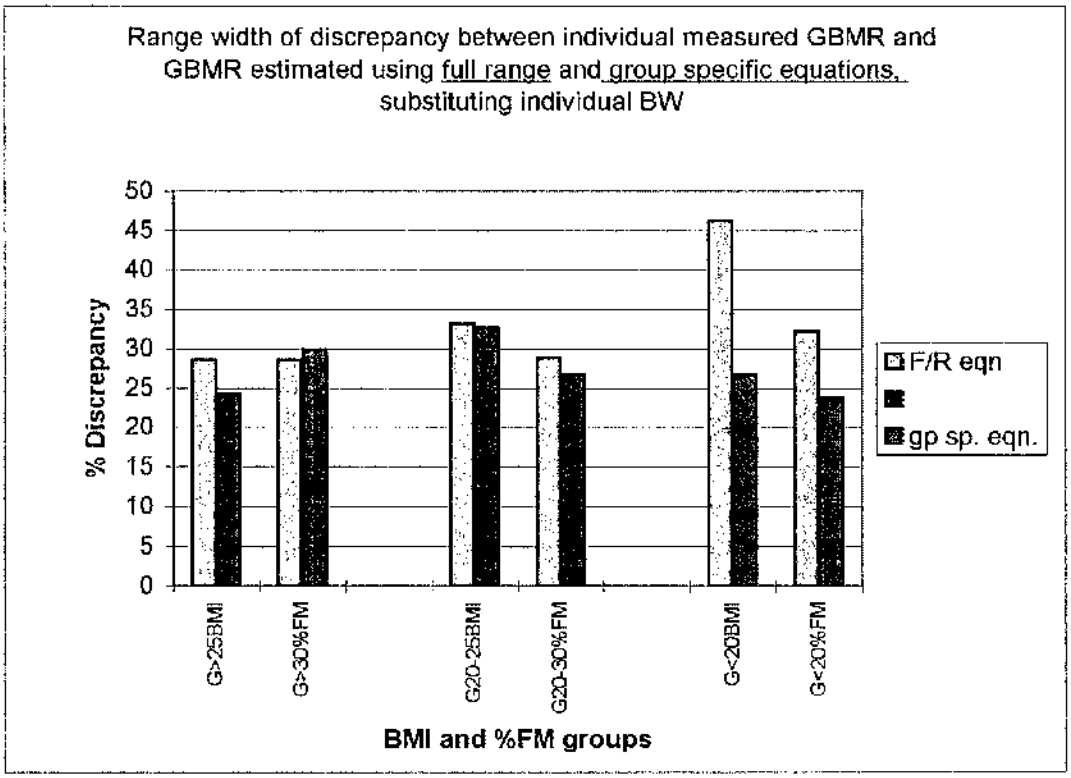


Fig. 14, refer to Table 9

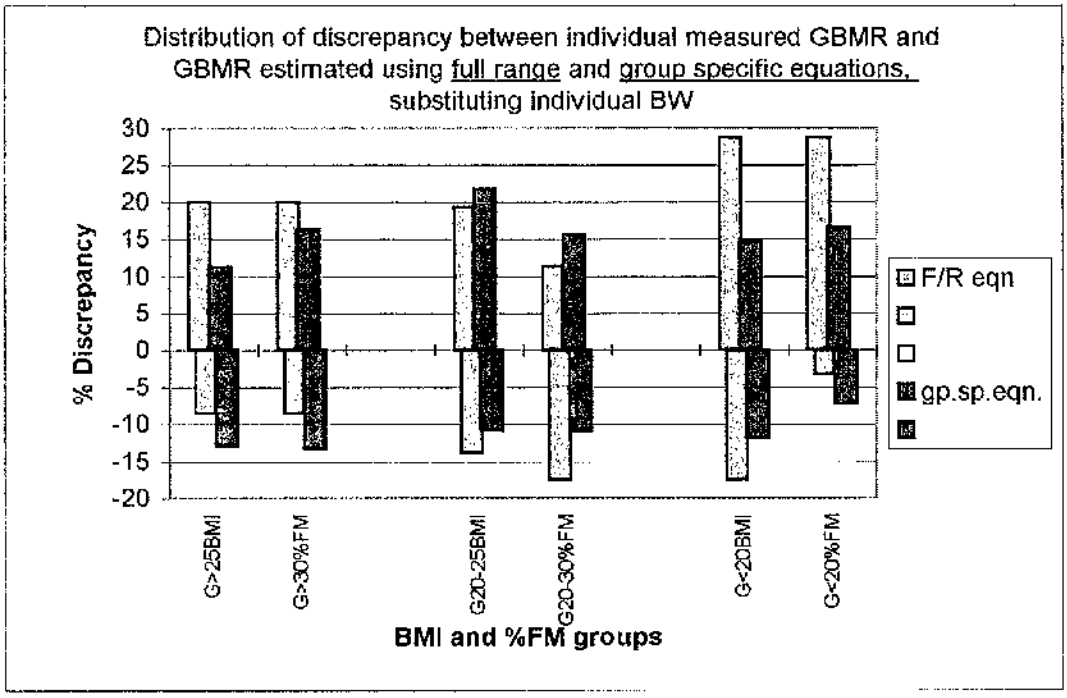


Fig.15, refer to Table 9

Table 9

Range width and distribution of percentage discrepancies between individual measured GBMR and individual GBMR estimated using full range and group specific equations substituting BW (kg)

Group	Full range equation		Group specific equation	
	% Discrepancy Distribution **See Fig 15**	Range width **See Fig. 14**	% Discrepancy Distribution **See Fig 15**	Range width **See Fig.14**
Overweight				
G >25BMI	+20.0 to - 8.6	28.6	+11.3 to -13.0	24.3
G >30%FM	+20.0 to - 8.6	28.6	+16.6 to -13.3	29.9
Standard				
G 20-25BMI	+19.3 to -13.9	33.2	+21.8 to -10.9	32.7
G 20-30%FM	+11.4 to -17.5	28.9	+15.7 to -11.0	26.7
Lean				
G <20BMI	+28.8 to -17.5	46.3	+14.8 to -11.9	26.7
G <20%FM	+28.8 to -3.4	32.2	+16.6 to -7.3	23.9

As examples of largest over and under estimates in the groups -

a) In the **overweight** groups, the subject with the highest %FM showed an overestimate of 1264 kJ or approximately 300 kcal using the full range equation, which was reduced to 586 kJ / 140 kcal by the %FM group specific equation (the discrepancy for this same subject using the BMI group specific equation was 311 kJ / 74 kcal.) The group specific equations increased the underestimate in some subjects e.g. from 568 kJ/ 135 kcal to 880 kJ / 210 kcal.(%FM equation)

b) In the **standard** groups, the largest overestimate was in BMI group at 854 kJ / 203 kcal, not reduced in this case by the group specific equation. The largest underestimate (in %FM group) 1164 kJ / 277 kcal was reduced by the group equation to 735 kJ / 175 kcal.

c) In the **leanest** group where the discrepancy on mean had been an acceptable 3.3 % using the group specific equation, the greatest overestimate was 1041 kJ

or 250 kcal (28.8%) using the full range equation. The was reduced only to 598 kJ / 142 kcal. (16.6%) by the group equation. Each discrepancy would be highly significant in both statistical and practical terms.

The data also showed that although the group equation gave better agreement between estimated and measured mean GBMR, the individual discrepancies indicated that range of discrepancy was not noticeably less, except in the lean groups, particularly G <20BMI.

The apparent improvements had been brought about by the effect of reducing the magnitude of the positive discrepancies and increasing the magnitude of the negative discrepancies in overweight groups with the opposite effect in standard groups

3.43 Summary of findings relating to the use of BW

Comparison of the data found that estimation of mean GBMR for the full study population using the full range equation gave acceptable agreement, the equation having been derived from that data.

However, where the full range equation was used to estimate mean GBMR for any particular BC group, agreement was less good, particularly in the leanest group.

Better agreement between estimated and measured means was achieved by using an equation more appropriate to any discrete body composition group, although the difference is likely to be of any practical significance only in the leanest group in a population.

As with all expressions involving the use of mean values, even where there is apparently good estimation of the mean of a group, the equation is less likely to represent individuals within that group.

(Individual records can be found in data 3A and 3B, appendix 1)

3.5 Comparison of measured GBMR with GBMR estimated from the equation by Schofield (1985, 91).

The linear equations proposed by Schofield (1985) have been widely used to estimate GBMR from BW since their inclusion in the Department of Health document 'Dietary Reference Values for Food Energy and Nutrients' (1991)

In view of the departure from linearity of the study data, the appropriate Schofield equation was used to estimate group and individual GBMR substituting BW, so that discrepancies arising from the use of this equation could be estimated.

3.51 Comparison of mean measured GBMR and mean GBMR for the full range of the study population and for BMI and %FM groups estimated using the Schofield equation appropriate to the study population.

Estimates were made of the discrepancies between the mean measured values for the population and groups and those estimated by substituting mean group BW in the appropriate Schofield equation i.e. that for females 18 - 30 years.

$$BMR\ (MJ/24\ hrs.) = 0.062BW\ (kg) + 2.036$$

Estimated values were compared with measured values of GBMR.

Results are shown in Table 10, page 89, and in Figure 16, page 89a.

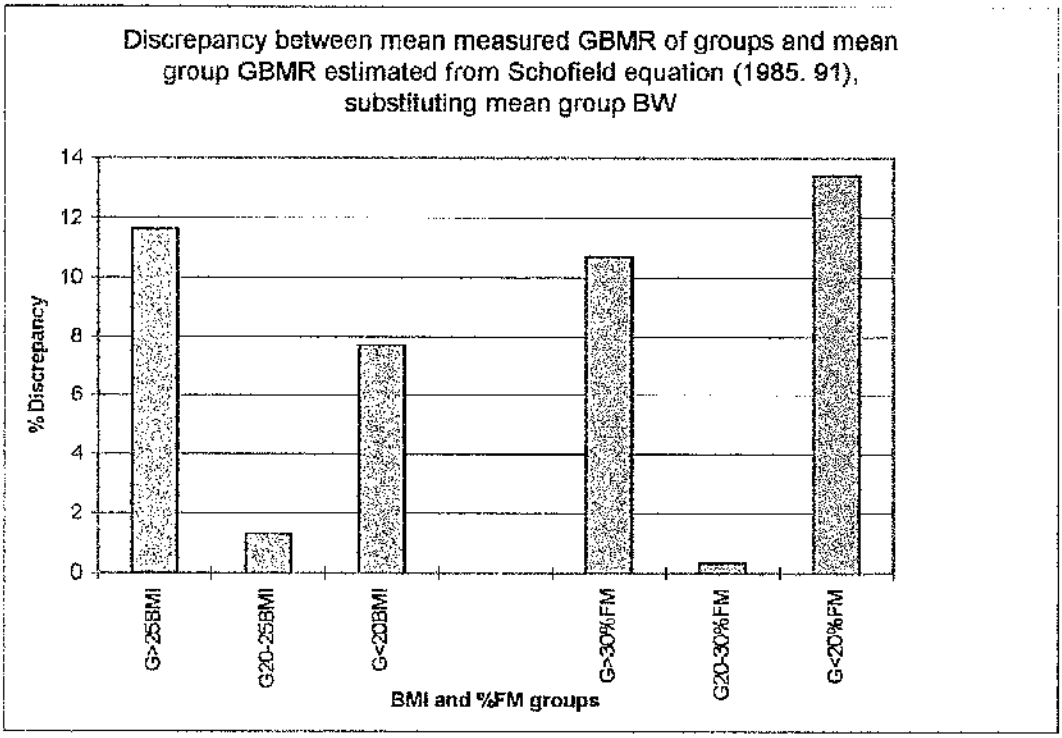


Fig. 16, refer to Table 10

Table 10

Comparison of full range and group mean measured GBMR of study population and groups with mean values estimated using the equation BMR (MJ/24 hrs.) = 0.062BW (kg) + 2.036 (Schofield, 1985, 91), substituting full range and group mean BW (kg)

Group	n	GBMR est. mean MJ / 24hrs	GBMR meas. mean MJ / 24hrs	Discrep. % **See Fig.16**	Discrep. kJ	Discrep. kcal.
Full Range	90	5.69	5.44	+ 4.7	255	61
G > 25BMI	16	6.51	5.83	+ 11.6	682	162
G 20 - 25BMI	52	5.67	5.60	+ 1.3	73	17
G < 20BMI	22	5.15	4.78	+ 7.7	368	88
G > 30%FM	26	6.26	5.66	+ 10.7	599	143
G 20 - 30%FM	53	5.57	5.55	+ 0.2	17	4
G > 20%FM	11	4.95	4.37	+ 13.4	581	138

See also Figure 16, page 89a

1 Comparison of the estimated and measured mean GBMR for the full range showed an over estimate of 4.7 %, although statistically significant, this amounted to only 255 kJ / 61 kcal / 24 hrs and was unlikely to be of practical relevance.

The equation was therefore considered to have given a good estimate of the mean GBMR for the study population.

There is no equivalent of the group specific equations as used in previous sections.

2 Comparison of the partitioned data showed

a) overestimation of the measured means in all BC groups, although this was neither statistically nor practically significant in the **standard** groups.

b) In the **overweight** groups, the discrepancies were over estimates of 11.6 % in G>25BMI and 10.7 % in G>30%FM.

These differences amounted to 682 kJ (162 kcal) and 599kJ (143 kcal) respectively and as such could be considered to be of practical relevance.

c) In the lean groups, group G <20 %FM showed an over estimate of 13.4 % (the greatest discrepancy in this set of results), equivalent to 581 kJ (138 kcal). That for G <20 BMI was 7.7 % equivalent to 368 kJ (88 kcal).
The effect of the discrepancy in the mean of group G < 20%FM is likely to be practically important, however the importance of a difference of 368 kJ or 88 kcal, in G < 20BMI is debatable.

This equation represented the standard population within acceptable limits, but overestimated mean GBMR of the leanest group G <20%FM and, to a lesser extent, over- estimated mean in the overweight groups.

3.52 Comparison of individual measured and estimated GBMR

Estimates of GBMR were made for all individuals by substituting BW in the equation by Schofield. This showed individual discrepancies to be much larger, with a general pattern of overestimate.

Results are shown in Table 11, page 91 and Figures 17a and b, page 91a.

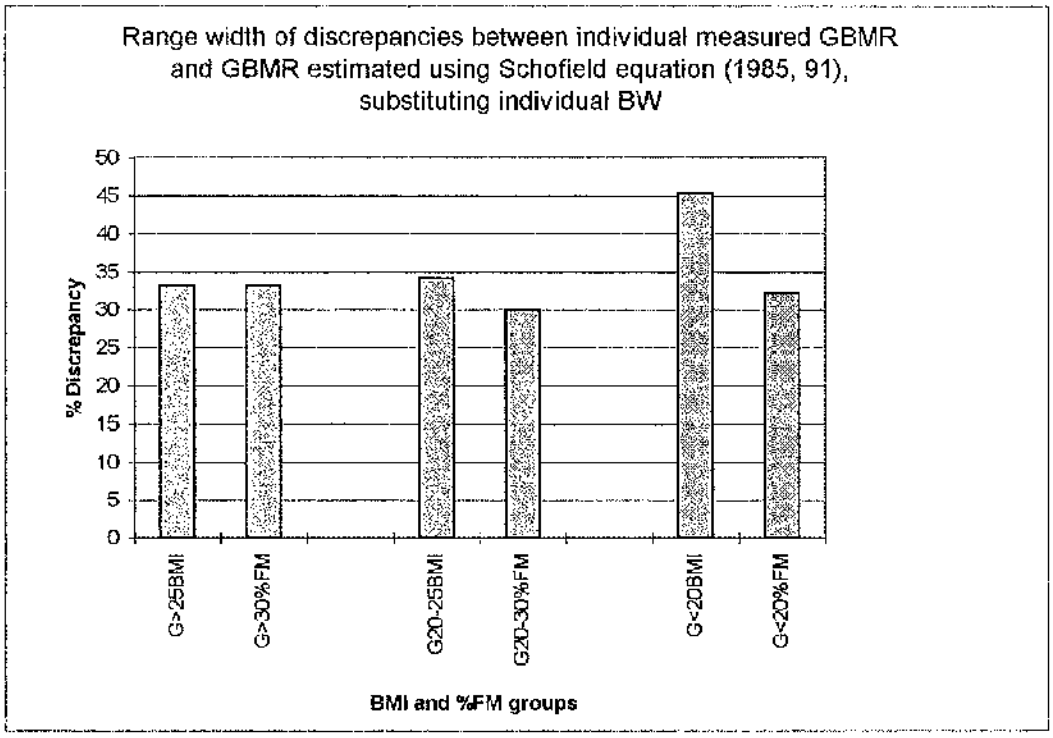


Fig. 17a, refer to Table 11

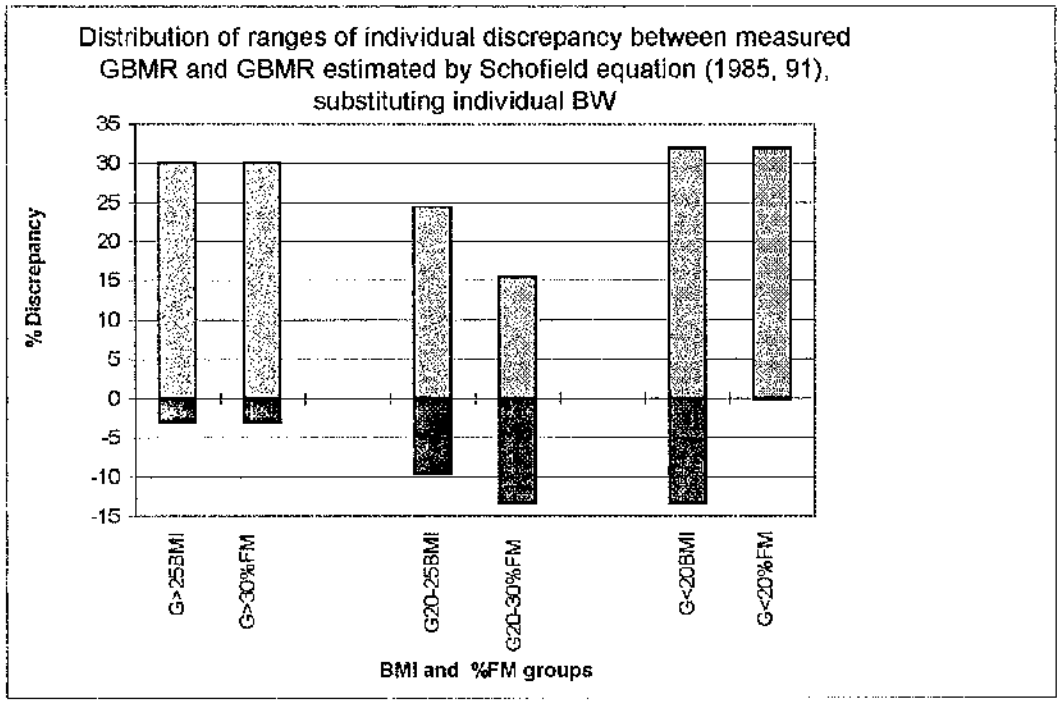


Fig. 17b, refer to table 11

Table 11

Range width and distribution of discrepancies between individual measured GBMR and individual GBMR estimated using the equation BMR (MJ/24 hrs.) = 0.062BW (kg) + 2.036 (Schofield, 1985, 91), substituting individual BW (kg)

Group	% discrepancy range width **See Fig. 17a**	% discrepancy range distrib. **See Fig.17b**
Overweight		
G >25BMI	33.1	+ 30.0 to - 3.1
G >30%FM	33.1	+ 30.0 to - 3.1
Standard		
G 20-25BMI	34.2	+ 24.4 to - 9.8
G 20-30%FM	28.9	+ 15.4 to - 13.5
Lean		
G <20BMI	45.4	+ 31.9 to - 13.5
G <20%FM	32.2	+ 31.9 to - 0.3

See also Figures 17a and 17b, page 91a.

Individual overestimates were very large when this equation was used, for example, one of the order of 30 % over estimate for an overweight individual (1900 kJ/ 452 kcal), and an over- estimate of 32 % in the lean G < 20%FM group amounted to 1150 kJ / 274 kcal. This equation produced more and greater discrepancies, mainly over estimates, than those previously discussed.

Individual records of differences between measured and values estimated by this equation are shown in Data 4A and 4B, Appendix 1

3.6 Relationships of GBMR with $BW^{0.75}$

This classical power factor was considered to have the effect of reducing the apparently distorting effect of low body weight on associations of GBMR with BW. Regression equations for the full range of the study population and for BMI and %FM groups were derived from measured GBMR substituting $BW^{0.75}$, estimated values were then derived from the equations as before.

3.61 Covariance of GBMR with $BW^{0.75}$

Analysis of covariance was carried out of GBMR with $BW^{0.75}$ substituting in the equation mean $BW^{0.75}$ for the full range of subjects and for each of the groups. Results are shown in Table 12

Table 12

Covariance of GBMR (MJ/24 hrs.) with BW (kg) $^{0.75}$ over full range of the study population and BMI and %FM groups

Variable / Group	n	r	p
BW (kg) $^{0.75}$ Full range	90	0.73	< 0.0005
G > 25BMI	16	0.61	< 0.01
G 20 -25BMI	52	0.66	< 0.0005
G < 20BMI	22	0.87	< 0.0005
BW (kg) $^{0.75}$ G > 30%FM	26	0.70	< 0.0005
G 20 -30%FM	53	0.79	< 0.0001
G < 20%FM	11	0.85	< 0.0025

r = Pearson product moment coefficient

Covariance of GBMR with $BW^{0.75}$ was highly significant in the lean groups with $BW^{0.75}$ representing 76% and 72% of variance in G<20BMI and G<20%FM respectively.

3.62 Comparison of full range and group mean measured GBMR with mean GBMR estimated by substituting mean $BW^{0.75}$ in full range and group specific equations

In order to examine the effects arising from the altered Pearson coefficients, mean measured GBMR was compared with the estimated GBMR obtained by substituting the mean $BW^{0.75}$ of a group in the full range equation, and with the estimate obtained by substituting mean $BW^{0.75}$ for the group in the group specific equation.

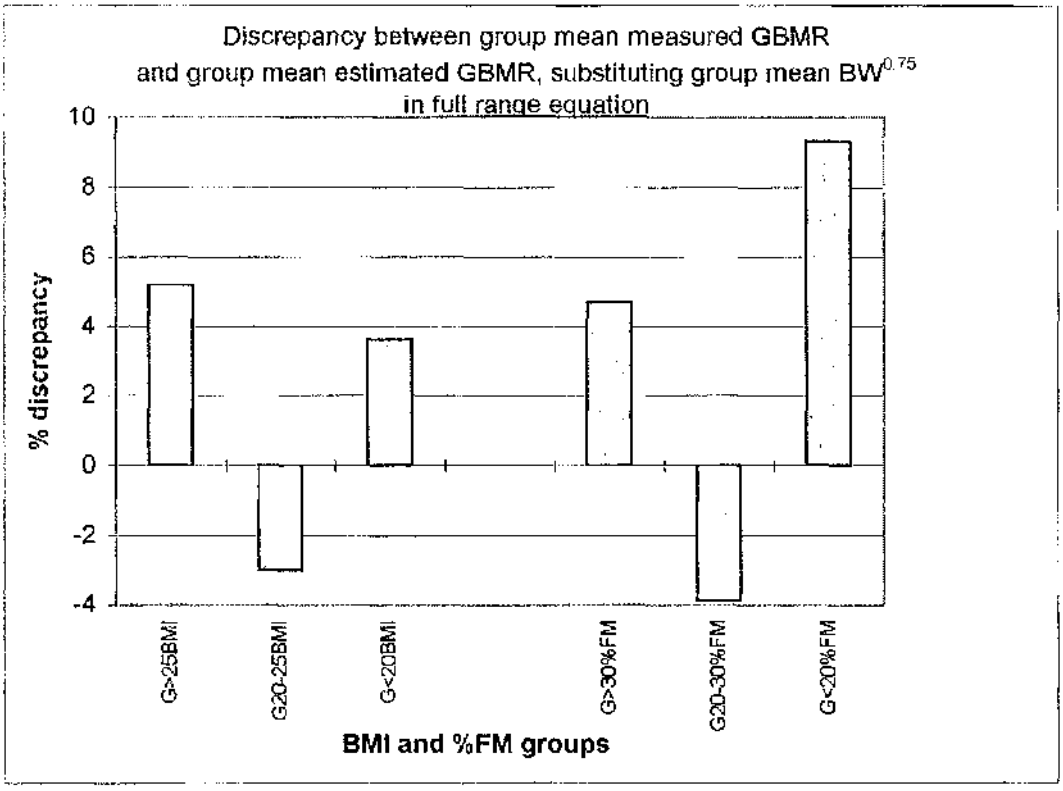


Fig. 18, refer to Table 13

Results showed that

a) the estimated group mean derived from the group equation was very similar to the measured value, the equation having been derived from that data.

b) substitution of the group mean value of BW in the general, full range equation produced a pattern of discrepancies which are shown in Table 13 below.

Table 13

Comparison of group mean measured GBMR with GBMR estimated by substituting group mean $BW^{0.75}$ in full range equation - GBMR (MJ/24 hrs.) = (0.201 x $BW^{0.75}$) + 1.169

Group	$BW^{0.75}$ mean	GBMR MJ/24hrs estimated	GBMR MJ/24hrs measured	Discrep. % **See Fig.18**	Discrep. kJ	Discrep.. kcal
Full range	21.23	5.44	5.44	- 0.1	- 3	-1
G >25BMI	24.70	6.13	5.83	5.2	305	73
G 20 25BMI	21.18	5.43	5.60	-3.0	-167	-40
G <20BMI	18.82	4.95	4.78	3.6	174	41
G >30%FM	23.68	5.93	5.66	4.7	265	63
G 20 30%FM	20.71	5.33	5.55	-3.9	-214	-51
G <20%FM	17.94	4.78	4.37	9.3	405	96

See also Figure 18, page 93a.

a) the discrepancies in the **overweight** groups, an over estimate of 4.7 % in G >30 %FM (265 kJ / 63 kcal) and 5.2 % in G > 25BMI (305 kJ / 73 kcal) were not of practical relevance although both statistically significant.

b) The **standard** groups were similar to one another, showing an under estimate of 3.0 % in G20-25BMI and 3.9% in G20-30%FM, equivalent to 167 and 214 kJ or 40 to 50 kcal.

The mean GBMR of standard groups of the population were therefore well represented by the full range equation using $BW^{0.75}$.

c) The **lean** groups again demonstrated the effect of selection according to BC.

The leanest group, G <20%FM showed over estimation of mean GBMR by 9.3 % (405 kJ/ 96 kcal) while G <20 BMI mean was overestimated by 3.6% , (174 kJ / 41 kcal)

The former discrepancy was considered to be important in a practical context in view of the magnitude of the percentage difference.

The latter discrepancy , in G <20 BMI is not likely to have practical relevance.

3.63 Examination of discrepancies between measured and estimated GBMR in individual records

These showed similar disparity to that found with other correlates (Refer to Data 5A and 5B, appendix 1).

Results are shown in Table 14 page 95 and Figures 19a and 19b, page 95a.

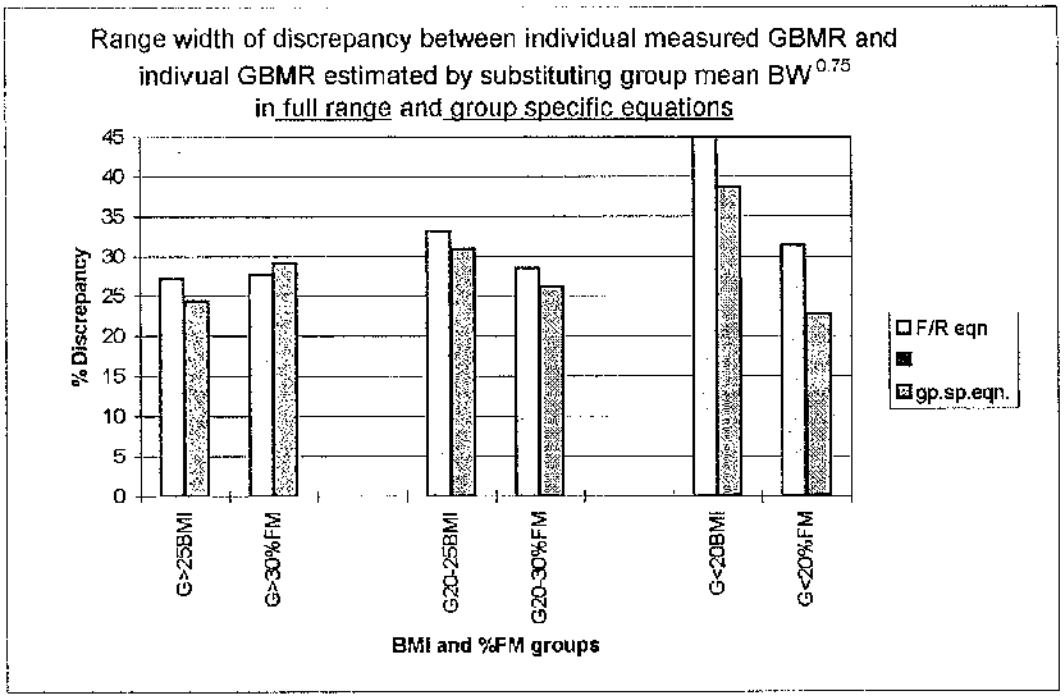


Fig. 19a, refer to Table 14

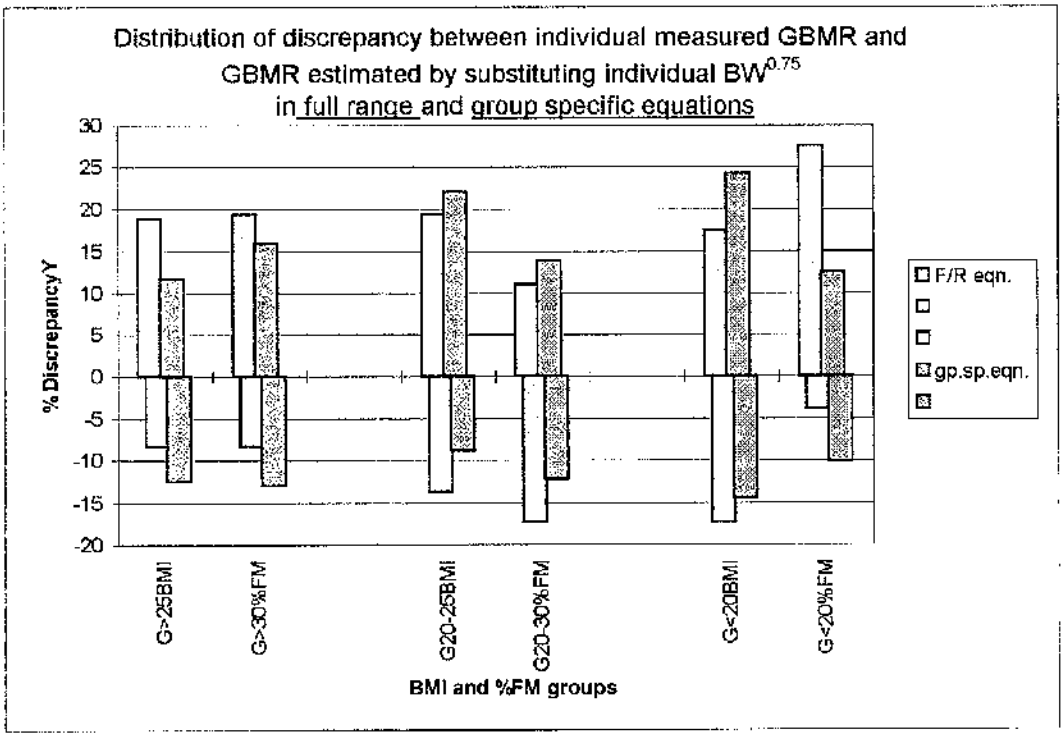


Fig. 19b, refer to Table 14

Table 14

Range width and distribution of discrepancies between individual measured GBMR and individual GBMR estimated using full range and group specific equations substituting individual $BW^{0.75}$

	Full range equation		Group specific equation	
BC group	% Discrepancy distribution **See Fig.19b**	Range width **See Fig 19a**	% Discrepancy distribution **See Fig.19b**	Range width **See Fig 19a**
Overweight				
G >25BMI	+18.8 to -8.4	27.2	+11.7 to -12.6	24.3
G >30%FM	+19.3 to -8.4	27.7	+16.0 to -13.1	29.1
Standard				
G 20-25BMI	+19.3 to -13.8	33.1	+22.0 to - 8.9	30.9
G 20-30%FM	+11.1 to -17.4	28.5	+13.9 to -12.3	26.2
Lean				
G <20BMI	+27.5 to -17.4	44.9	+24.2 to -14.5	38.7
G <20%FM	+27.5 to -3.9	31.4	+12.5 to -10.2	22.7

See Figures 19a and 19b, page 95a.

The values which represent the extreme of the ranges of difference between measured and estimated GBMR for individual subjects in a group were all highly significant statistically and are likely to be highly relevant in practice.

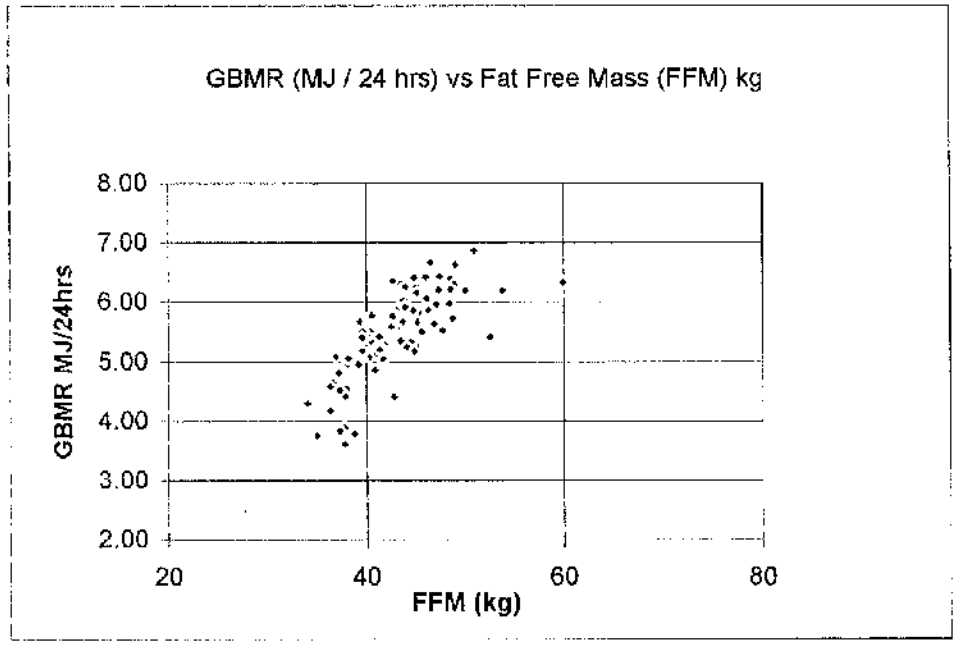
3.64 Summary of findings relating to the use of $BW^{0.75}$

Although the equations relating GBMR to $BW^{0.75}$ acceptably represented the mean of the full range of subjects and the separate groups apart from the leanest, as with all relationships intended for groups, it is likely to incur large errors if used for individuals.

The effect of use of group specific equations was to reduce the range of discrepancy significantly only in G <20%FM. Minor reductions only were achieved in both standard groups and G >25BMI.

The range of discrepancy was increased in G >30%FM .

The general effect of the group equations was to move the range to a more negative position in both overweight groups and the lean %FM group and to a more positive position in both standard groups and the lean BMI group, i.e. to reduce the over and under estimate of the general equation.



Fig, 2

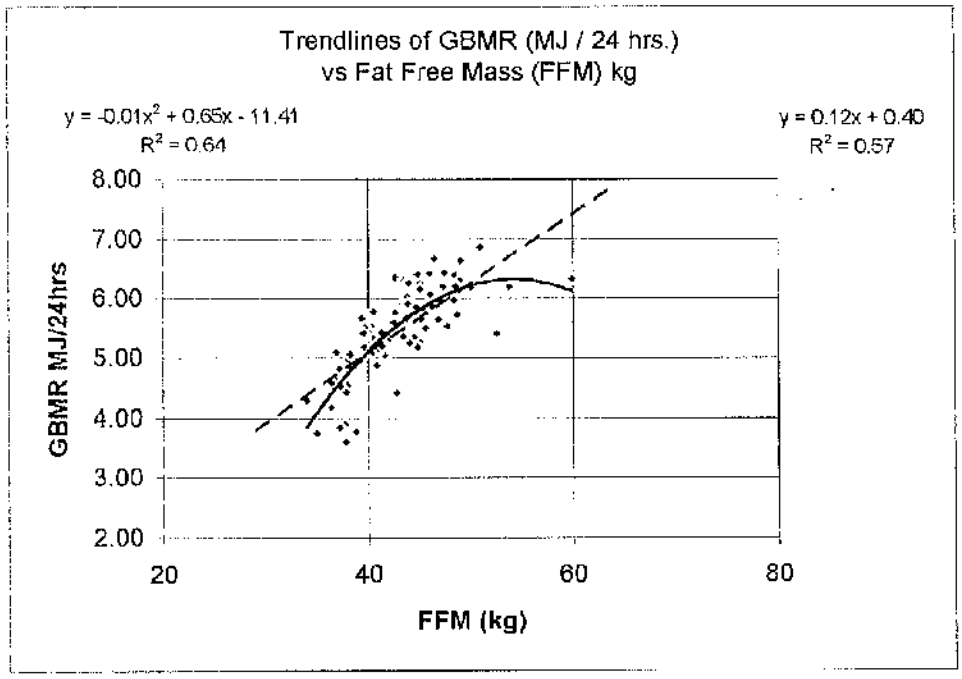


Fig. 4

GBMR - Basal metabolic rate / total body weight / 24 hours. (MJ)
Linear - -- -- -- , polynomial ———

3.7 Relationships of GBMR with Fat Free Mass (FFM)

FFM, as the compartment with higher EE, with a theoretical value of 1.31 J / sec / kg compared with 0.35 J / sec / kg FM (Garby et al, 1988), could be predicted to be more closely related to GBMR than any other single parameter.

Analysis of covariance of GBMR with anthropometric parameters, over the full range of subjects, showed GBMR to be best related with FFM ($p < 0.001$) with Pearson coefficient $r = 0.75$ (Table 2, page 66).Distribution is shown in Figure 2 and trendlines in Figure 4 (page 67a and again at 97a).

The variance represented by the single variable FFM, however, at 57%, still left a considerable margin unaccounted for.

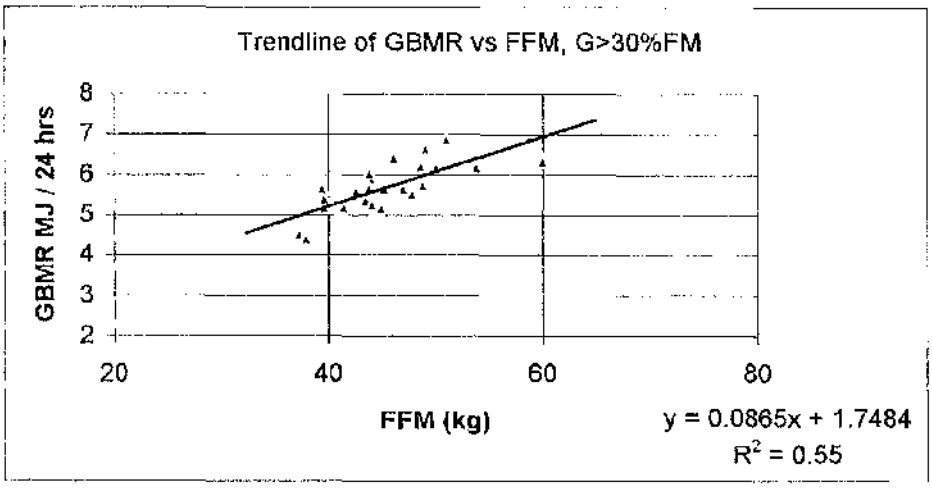
BC in the total group showed a range of approximately 12 to 40 % FM, or 60 to 88 % FFM. With a changing percentage relationship in 2 components with markedly different EE, and assuming that the two compartments inter-relate physiologically, it is not surprising that there is considerable variability in GBMR when correlated with the absolute mass of one of the two parameters.

Trendlines plotted for GBMR with FFM showed both linear and polynomial characteristics with $r = 0.75$ in the linear relationship and 0.80 at the second polynomial, indicating that the curvilinear relationship was closer. The difference between the two trends was less marked than had been with GBMR with BW.

3.71 Linear regression

In order to examine the relationships of FFM with GBMR over the full range of subjects and in the groups as previously, data were partitioned according to BMI and % FM.

Results of linear regression analysis of the full range of subjects are shown in Figure 4.(page 97a) and of the groups in Figures 20 a, b and c (page 98) for data partitioned according to BMI and in Figures 21a, b and c (page 98a) for data partitioned according to %FM.



Fig, 21a

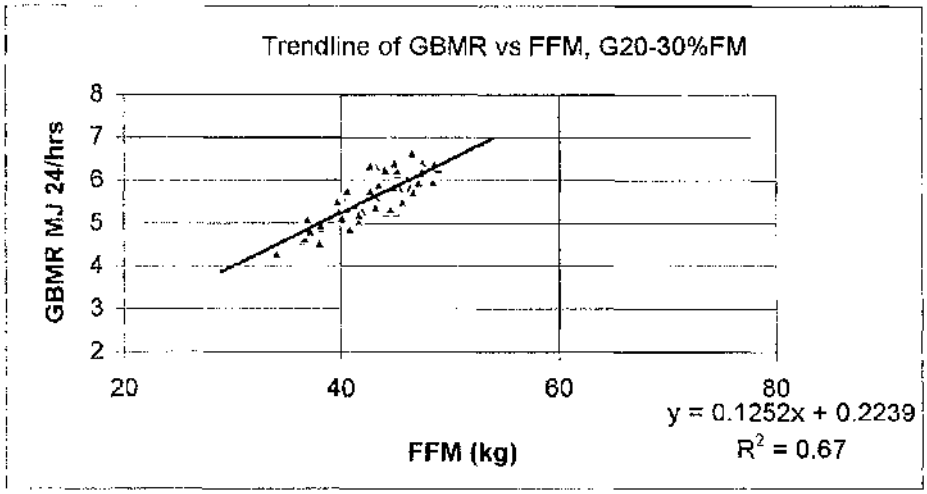


Fig. 21b

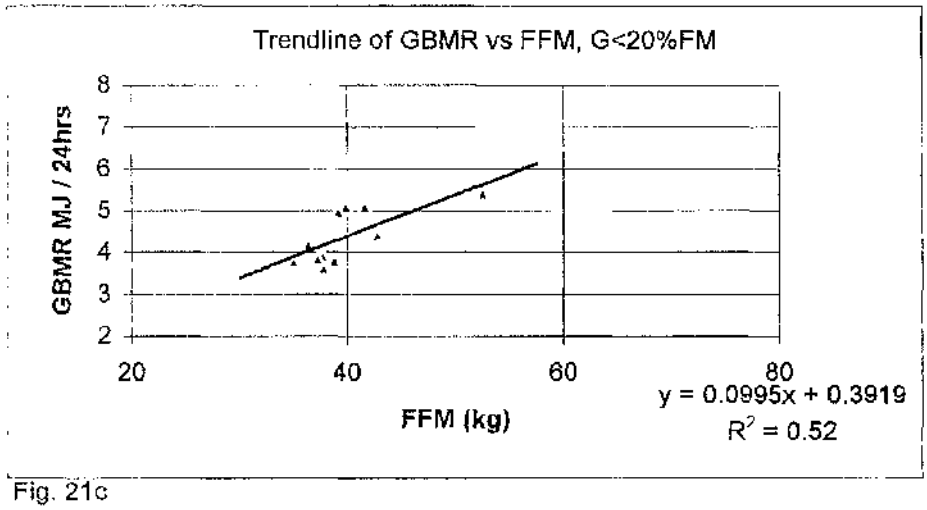


Fig. 21c

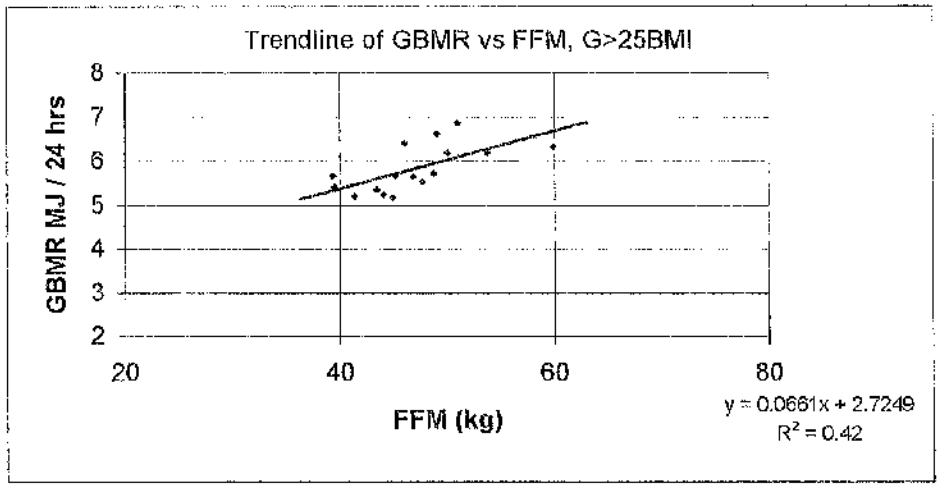


Fig. 20a

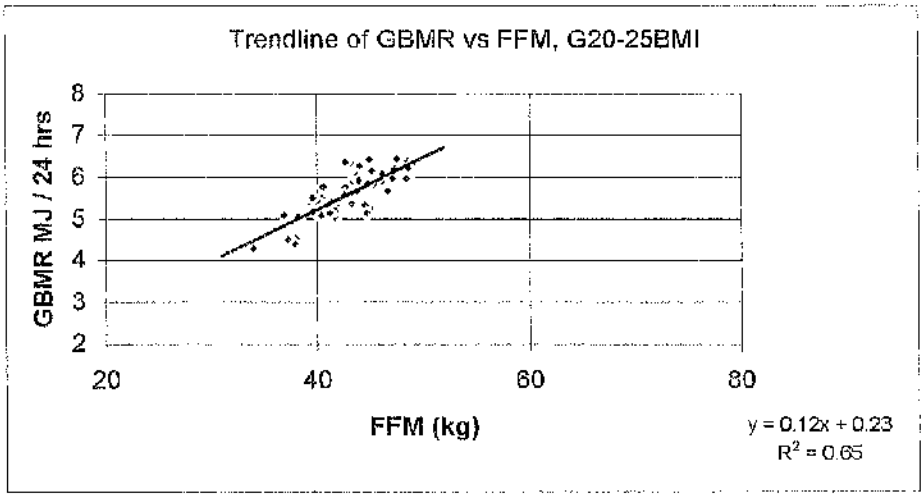


Fig. 20b

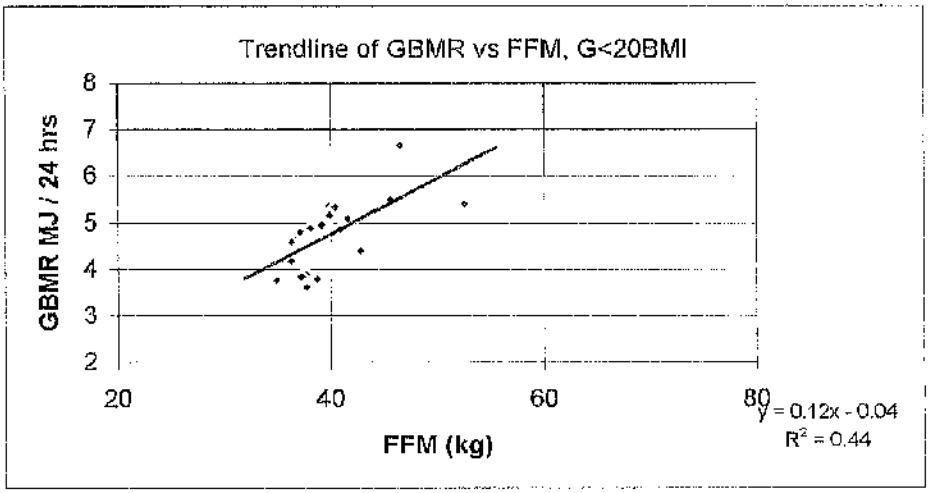


Fig.20c

With respect to BMI grouping, the null hypothesis was proposed that the slopes were the same. Using Bartlett's tests as before, analysis comparing the slopes showed that those for the lean and standard groups were not significantly different from each other, however, that for overweight compared with standard and lean showed overweight to be different.

As for %FM grouping, there was a significant difference between lean and standard, but there were no significant differences in slope in the case of standard compared with overweight.

The results would appear to indicate that there was evidence of departure from a single linear relationship between GBMR and FFM over the range of 90 subjects although the degree of departure was less clear than had been the case with GBMR related to BW. There was also some evidence of the effect of grouping by BMI compared with grouping %FM, in the former a difference between overweight group and the other groups was highlighted and in the latter, the difference between the lean group and the other groups.

3.72 Covariance of GBMR with FFM in full range and in groups, data partitioned according to BMI and %FM

Analysis of covariance was carried out relating GBMR with FFM over the full range of subjects and in groups as before. Results are shown in Table 15 (BMI groups) and Table 16 (%FM groups)

3.721 Data partitioned according to BMI

Analysis of covariance of data partitioned according to BMI are shown in Table 15

Table 15

Covariance of GBMR with fat free mass (FFM) (kg), data partitioned according to BMI

Variable / Group	n	r	p
FFM G > 25BMI	16	0.65	< 0.005
G 20 - 25BMI	52	0.80	< 0.0005
G < 20BMI	22	0.66	< 0.005
Full range	90	0.75	< 0.001

r = Pearson product moment coefficient, FFM = fat free mass (kg)

See also Figures 20a, b and c, page 98.

Pearson product moment coefficient increased to 0.80 in the standard G 20 - 25BMI ($p < 0.000$ (0.0005)) and decreased to 0.65 and 0.67 in the overweight G>25BMI and lean G <20BMI respectively, significant however at $p < 0.005$.

3.722 Data partitioned according to % Fat Mass (%FM)

Analysis of covariance of data partitioned according to %FM are shown in Table 16

Table 16

Covariance of GBMR with fat free mass (FFM) (kg), data partitioned according to % FM

Variable / Group	n	r	p
FFM G > 30%FM	26	0.74	< 0.0005
G 20 -30%FM	53	0.82	< 0.0005
G < 20%FM	11	0.72	< 0.01
Full range	90	0.75	< 0.001

r = Pearson product moment coefficient, FFM = fat free mass (kg)

See also Figures 21a, b and c, page 98a.

The value of the Pearson coefficient of GBMR with FFM in the standard group G 20 - 30%FM increased to 0.82, in the overweight group G > 30%FM there was little change from the value of r for the full range ($r = 0.74$ compared with $r = 0.75$) and in the lean group G <20 %FM, r was reduced to 0.72.
Analysis of covariance indicated that FFM was most closely associated with GBMR in the standard group.

The separation of values when data were partitioned again suggested that covariance was not equally good across the full range of BC. If covariance were poor throughout, it would suggest evidence of scatter, and lower significance in the lean groups does suggest scatter in these groups, however, covariance coefficients for the separate groups support the evidence of the difference in slopes that this would appear not to be a simple straight line relationship, although the evidence was less strong than that for non-linearity in covariance of GBMR with BW..

The highest value, that for the standard G 20 - 30%FM, represents 65 % of variance ($p < 0.0005$) compared with 57 % if correlation is applied throughout the full range. G 20 - 30%FM was a fairly homogeneous group with 53 subjects falling between 70 to 80 % FFM and evidence of reduced variability would be expected.

Covariance was significant at $p < 0.0005$ in the overweight group G > 30 %FM, with $r = 0.74$ similar to that for the full range.
In the lean group G <20%FM, the reduced value of $r = 0.71$ was significant only at $p < 0.01$ and indicated that FFM represented 50 % of variance. It might have been expected that in this leanest of groups with the highest % FFM, correlation might have been closer. This may have been due to the effect of the small number in the group or to a difference in the FFM in the leanest subjects.

Data from both groupings would indicate that FFM best represented GBMR in women who are neither overweight nor lean and who, in this study population, made up the majority.

3.723 Comparison of covariance in BMI and %FM groups.

When coefficients for the two groupings were compared, there was a difference in the degree of change in the value of coefficients in the two groupings and in the continuity of the slopes.

In the % FM grouping, separation of the values was much less marked (r = 0.74, 0.82, 0.72) than in BMI grouping (r = 0.65, 0.80, 0.66)

There were differences in group numbers, differences in range and mean for FFM, % FFM and measured GBMR.

The overweight G >30 %FM included more marginally leaner subjects, i.e. closer to standard BC. The group was also more numerous (n = 26) than G > 25BMI (n = 16) suggesting that the value of r would be higher in the former group. This was reflected in the continuity of the standard and overweight slopes. In BMI grouping, there was continuity of slope between lean and standard and the discontinuity had occurred with the overweight group.

In the lean groups, G < 20%FM although smaller in number (n = 11), was leaner than G <20BMI and in this group, FFM represented a larger percentage compartment. Covariance was closer than was the case with G<20BMI. The slope for G < 20%FM was discontinuous with the slopes for standard and overweight in the same grouping suggesting that the relationship of GBMR with FFM was different from that of the other two %FM groups.

3.73 Effect of degree of nonlinearity on accuracy of prediction of GBMR from linear regression equations substituting FFM

In order to investigate the effect of the differences in covariance across the range of data, full range and group mean measured GBMR were again compared with those found by estimation by regression equations substituting mean FFM appropriate to full range and groups.

3.731 Comparison of full range and group mean measured GBMR with mean GBMR estimated by substituting FFM in full range and group specific equations

The validity of the full range and group equations was verified as follows -

a) When the estimated mean value for GBMR for the full range population, derived by using the full range equation relating GBMR with FFM, was compared with the mean measured GBMR for the full range, there was no statistically significant difference between the two, this full range equation being derived from that population data. Similarly, group mean values estimated from group specific equations gave good agreement with mean measured values, having been derived from those data.

b) Group mean measured GBMR was compared with the group mean derived by substituting the group mean FFM (kg) in the full range equation, results are shown in Table 17, page 104 and Figure 22 page 104a.

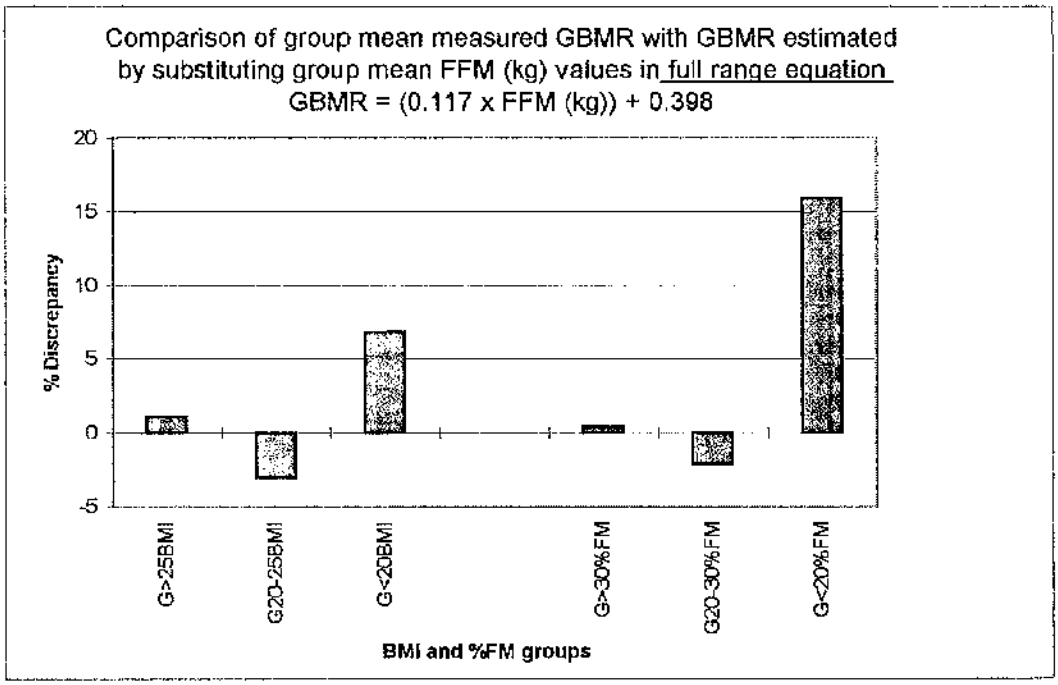


Fig.22, refer to Table 17

Table 17

Comparison of group mean measured GBMR with GBMR estimated by substituting group mean FFM (kg) values in full range equation GBMR = (0.117 x FFM (kg)) + 0.398

Group	FFM mean (kg)	GBMR est. MJ/24hrs	GBMR Meas. MJ/24hrs	Discrep. (%)	Discrep. (kJ)	Discrep. (kcal)
				See Fig.22		
Full range	43.0	5.43	5.44	-0.2	-9	-2
G >25BMI	47.0	5.89	5.83	1.0	58	14
G 20 - 25BMI	43.0	5.43	5.60	-3.0	-16.8	-40
G <20BMI	40.2	5.10	4.78	6.7	320	76
G >30%FM	45.2	5.69	5.66	0.5	28	7
G 20 - 30%FM	42.6	5.38	5.55	-3.1	-172	-41
G <20%FM	39.9	5.07	4.37	16.0	699	166

See also Figure 22, page 104a.

Results indicated that

a) there were no significant differences in the **overweight** and **standard** groups, the largest discrepancy being an underestimate of 172kJ or 41 kcal in the standard G 20 - 30%FM

The general equation therefore represented the overweight and standard groups within acceptable practical limits.

b) Mean GBMR in the **lean** groups had been overestimated by 6.7 % in G <20BMI and 16.0 % in G <20 %FM.

The discrepancy in G <20%FM was equivalent to approximately 700 kJ or 166 kcal, the percentage and absolute differences significant in both practical and statistical terms.

This disparity was once more obscured in G <20BMI, where the difference was 320 kJ / 76 kcal.

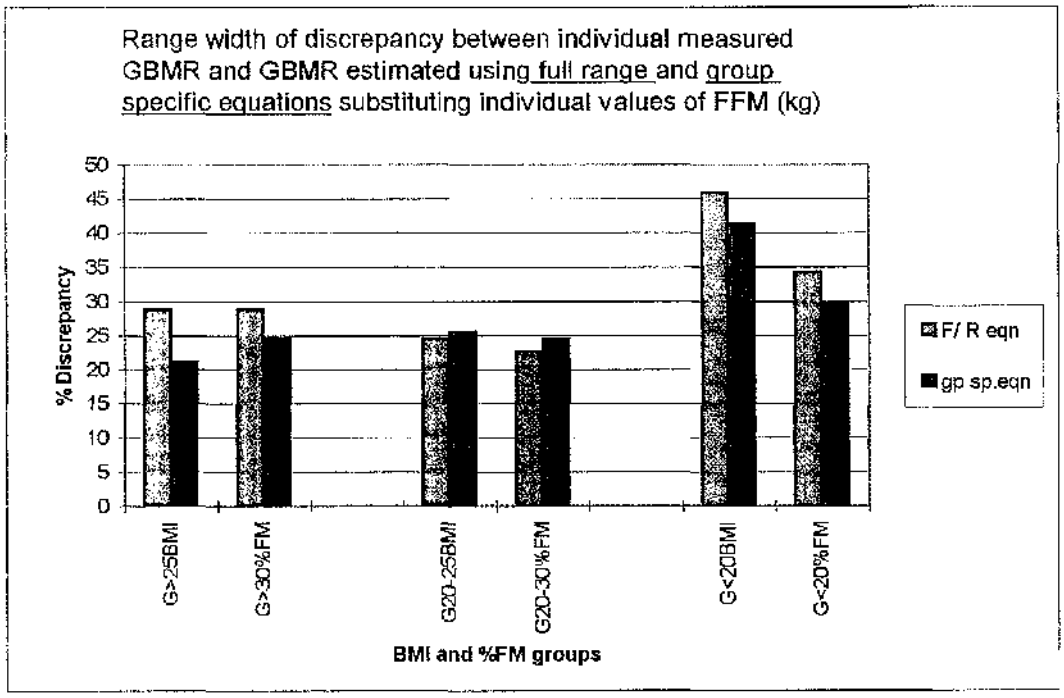


Fig. 23a, refer to Table 18

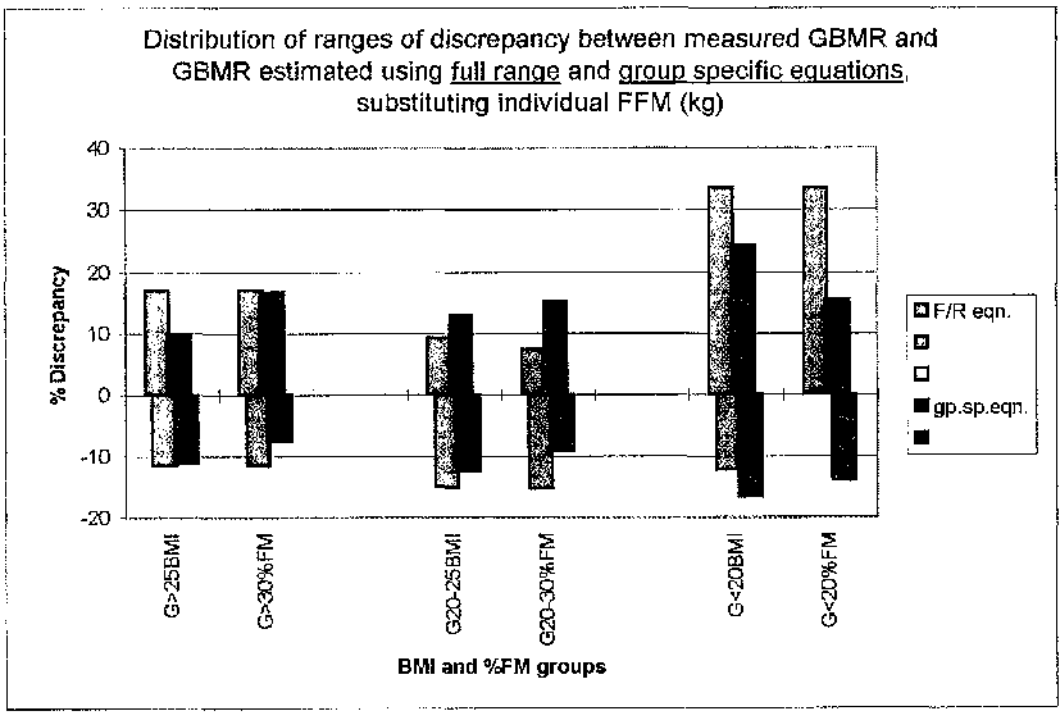


Fig.23b, refer to Table 18

3.732 Comparison of individual measured GBMR and GBMR estimated substituting individual FFM in full range and group specific equations.

As before, individual records were examined in order to assess the range of discrepancies between measured and estimated GBMR.(Data 6A and 6B, Appendix 1) Results are shown in Table 18 and Figures 23a and 23b.

Table 18

Range width and distribution of individual discrepancies between individual measured GBMR and GBMR estimated using full range and group specific equations substituting individual FFM (kg)

Group	Full range equation		Group specific equation	
	% discrepancy distribution **See Fig.23b**	range width **See Fig.23a**	% discrepancy distribution **see Fig.23b**	range width **See Fig.23a**
Overweight				
G >25BMI	+ 17.1 to - 11.7	28.8	+ 9.9 to - 11.3	21.2
G >30%FM	+ 17.1 to - 11.7	28.8	+ 16.8 to - 7.7	24.5
Standard				
G 20-25BMI	+ 9.3 to - 15.2	24.5	+ 13.0 to - 12.5	25.5
G 20-30%FM	+ 7.4 to - 15.2	22.6	+ 15.2 to - 9.3	24.5
Lean				
G <20BMI	+ 33.5 to - 12.4	45.9	+ 24.4 to - 16.8	41.2
G <20%FM	+ 33.5 to - 0.7	34.2	+ 15.5 to - 14.1	29.6

See also Figures 23a and b, page 105a.

The data illustrated the much wider range of discrepancy in subjects in the group G <20BMI. BC in this group was much more varied than in G <20%FM. Both groups have been described as 'lean', but G <20BMI might be better described as 'small and light'.

Use of the group specific equation narrowed the ranges in both groups of overweight subjects and lean %FM subjects.

The ranges for the standard groups widened slightly when the group equation was used, the ranges moving to a more positive distribution.

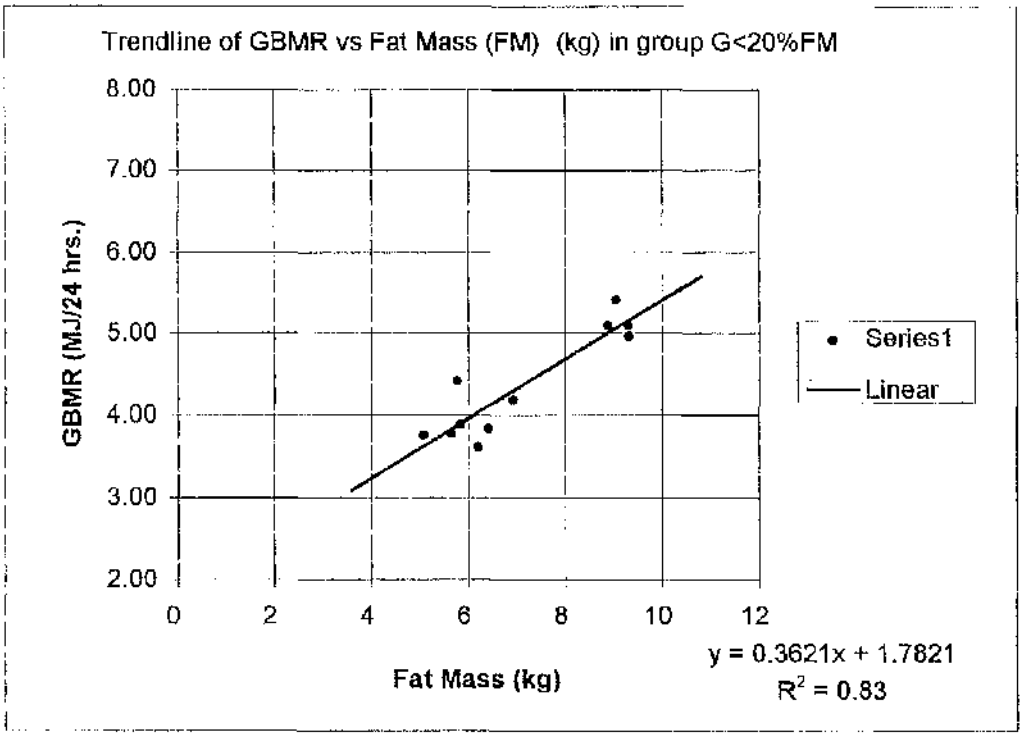

Trendline of GBMR vs Fat Mass (FM) (kg) in group G<20%FM
8.00
7.00
6.00
5.00
4.00
3.00
2.00
GBMR (MJ/24 hrs.)
0
2
4
6
8
10
12
Fat Mass (kg)
Series1
Linear
y = 0.3621x + 1.7821
R2 = 0.83

Fig.24

3.74 Summary of findings relating to the use of FFM

The results indicated that the use of the full range regression equation using FFM in the estimation of mean GBMR for discrete BC groups may result in discrepancies which can be reduced by employing a regression equation derived from data of a group of more appropriate body composition, the difference particularly evident in the leanest %FM group.

Even when good agreement of measured and estimated means was achieved by the use of a more appropriate equation, individual discrepancies may be very large.
In overweight and lean subjects, the range of individual discrepancies was smaller when the group equation was used, however, in all three BC types, the ranges had been redistributed.

3.8 Covariance of GBMR with fat mass (FM)

FM was not highly correlated with GBMR over the full range of subjects (Table 2, page 66), a predictable finding in view of the relatively low contribution of FM to the body's overall energy expenditure. Analysis of covariance, however, produced a surprisingly high Pearson coefficient of r = 0.91 (Figure 24, page 106a) in G<20%FM. The value of r (Pearson coefficient) in G<20BMI was 0.74.
The composition and numbers were very different in those two lean groups, with G<20%FM a small, very lean group (n = 11) compared with G<20BMI (n = 26)

At this body composition, it would be expected that since FFM occupies a large proportion of the total body mass and has higher EE, it would closely represent GBMR. This was not the case. In fact, covariance of GBMR with FFM was lower in those groups (r = 0.72 in G<20%FM and r = 0.66 in G<20BMI)

The close covariance, particularly in the leanest group may simply be a numerical accident, without biological validity, however, it may indicate some other association. The values of uBMR, which might have been expected to be high where the proportion of FFM is high, were in fact lower in the leanest subjects. The covariance may suggest a progressive lowering of metabolic rate as FM is reduced in these very lean individuals.

3.9 Comparison of measured values of GBMR with estimated values derived from the equations substituting BW, BW (Schofield, 1985,91), $BW^{0.75}$ and FFM.

Data derived from equations using BW, BW using the equation by Schofield, $BW^{0.75}$, and FFM were compared by collating the differences identified in the foregoing sections. Comparisons were made between mean measured GBMR and estimated mean GBMR using the equations for the full range of subjects and between mean measured GBMR and mean GBMR derived from group equations in each group in turn.

3.91 Comparison of full range mean measured GBMR with mean GBMR estimated using full range equations substituting full range mean values of previously identified anthropometric parameters.

Results, which can be found in Figure 25 page 108a and Table 19 page 108b, were as follows - (for convenience Table 19 is also shown at 109a) -

1) Where mean measured GBMR for the full range of the study population was compared with the values obtained by using the regression equations for the full range -

a) BW, $BW^{0.75}$ and FFM represented the measured mean most closely. There was no statistically significant difference between measured and estimated GBMR and no statistically significant difference between one estimate and another for this study population.

Table 19

Summary of comparisons of estimates of mean GBMR obtained by substituting full range mean or group mean parameter in **full range equations**

Body Weight GBMR = (0.0526 x BW (kg)) + 2.3386

Group	BW (kg)	est GBMR MJ/24hrs	Meas. GBMR MJ/24hrs	Discrep. (%)	Discrep. (kJ)	Discrep. (kcal)
				See Fig.24		
Full range	59.0	5.44	5.44	0.0	3	1
G >25BMI	72.1	6.13	5.83	5.2	303	72
G 20 25BMI	58.7	5.42	5.60	-3.2	-179	-43
G <20BMI	50.1	4.98	4.78	4.1	196	47
G >30%FM	68.2	5.93	5.66	4.8	272	65
G 20 30%FM	56.9	5.33	5.55	-3.9	-216	-51
G <20%FM	47.1	4.81	4.37	10.1	441	105

Body Weight Schofield (1985) equation, GBMR = (0.062 x BW (kg)) + 2.036

Group	BW (kg)	est GBMR MJ/24hrs	Meas. GBMR MJ/24hrs	Discrep. (%)	Discrep. (kJ)	Discrep. (kcal)
				See Fig. 24		
Full range	59.0	5.69	5.44	4.7	255	61
G >25BMI	72.1	6.51	5.83	11.6	682	162
G 20 25BMI	58.7	5.67	5.60	1.3	73	17
G <20BMI	50.1	5.15	4.78	7.7	368	88
G >30%FM	68.2	6.26	5.66	10.7	599	143
G 20 30%FM	56.9	5.57	5.55	0.2	17	4
G <20%FM	47.1	4.95	4.37	13.4	581	138

BW $^{0.75}$ GBMR = (0.201 x BW$^{0.75}$ (kg)) + 1.169

Group	BW (kg)	est GBMR MJ/24hrs	Meas. GBMR MJ/24hrs	Discrep. (%)	Discrep. (kJ)	Discrep. (kcal)
				See Fig. 24		
Full range	21.2	5.44	5.44	-0.1	-3	-1
G >25BMI	24.7	6.13	5.83	5.2	305	73
G 20 25BMI	21.2	5.43	5.60	-3.0	-167	-40
G <20BMI	18.8	4.95	4.78	3.6	174	41
G >30%FM	23.7	5.93	5.66	4.7	265	63
G 20 30%FM	20.7	5.33	5.55	-3.9	-214	-51
G <20%FM	17.9	4.78	4.37	9.3	405	96

Fat Free Mass GBMR = (0.117 x FFM (kg)) + 0.398

Group	FFM (kg)	est GBMR MJ/24hrs	Meas. GBMR MJ/24hrs	Discrep. (%)	Discrep. (kJ)	Discrep. (kcal)
				See Fig. 24		
Full range	43.0	5.43	5.44	-0.2	-9	-2
G >25BMI	47.0	5.89	5.83	1.0	58	14
G 20 25BMI	43.0	5.43	5.60	-3.0	-168	-40
G <20BMI	40.2	5.10	4.78	6.7	320	76
G >30%FM	45.2	5.69	5.66	0.5	28	7
G 20 30%FM	42.6	5.38	5.55	-3.1	-172	-41
G <20%FM	39.9	5.07	4.37	16.0	699	166

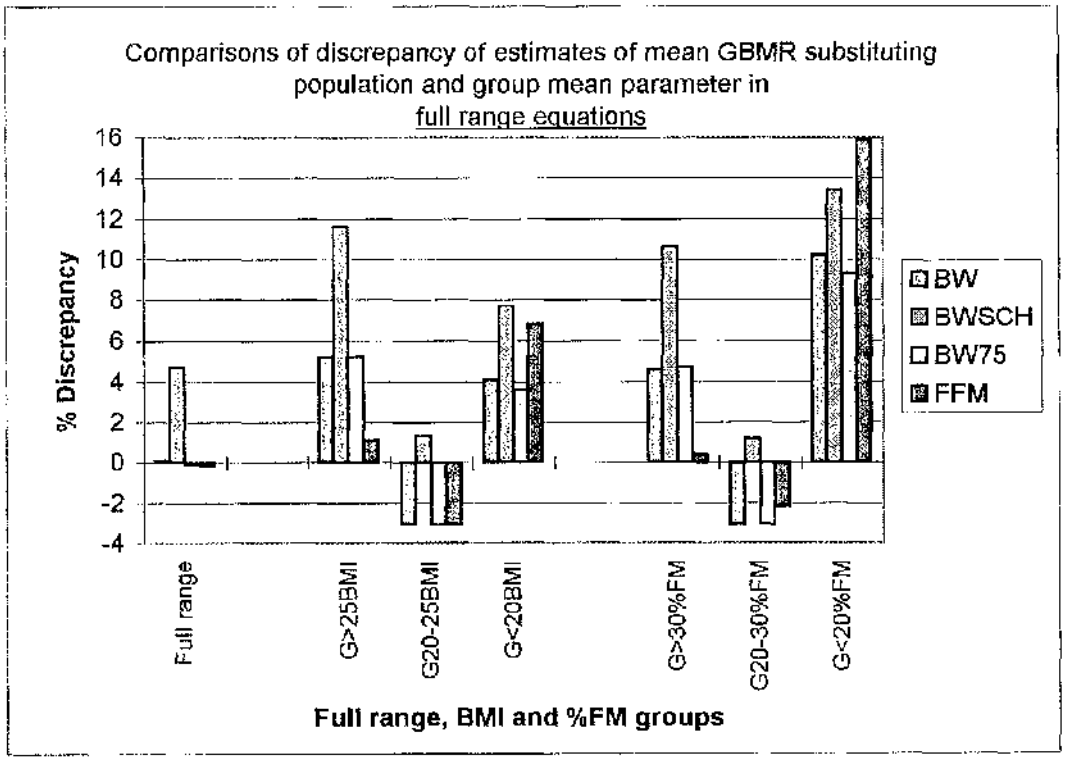


Fig. 25, refer to Table 19

b) The equation suggested by Schofield less closely represented measured mean GBMR, however the over estimate at approximately 5 % (255 kJ or 60 kcal.) not likely to be considered as important in practice (see discussion).

3.92 Comparison of group mean measured GBMR with group mean GBMR estimated by substituting group mean values of previously identified anthropometric parameters in full range equations

For partitioned data, where the estimated mean was calculated by substituting the mean value of the appropriate parameter for that group in the full range equation and compared with measured mean GBMR for that group. Results are shown in Fig. 25 page 108a and in Table 19 on page 108b.

The findings were as follows -

a) In **lean** groups, each regression equation showed the greatest discrepancy, an overestimate , in the **leanest** group G <20%FM. All these differences were considered to be of practical relevance.

Discrepancy in this group was found, in ascending order, in comparisons of estimates based on $BW^{0.75}$, BW, BW (Schofield) and FFM, reaching a maximum of 16.0% in FFM estimates.

In the group G <20BMI, with a less lean BC, the discrepancies were less, all were overestimates, reaching a maximum of 7.7 % using BW (Schofield). This group was best represented by $BW^{0.75}$ or BW itself, with differences between measured and estimated mean GBMR of approximately 170 - 190 kJ. Neither difference was practically significant and they are not significantly different from one another.

Table 19

Summary of comparisons of estimates of mean GBMR obtained by substituting full range mean or group mean parameter in **full range equations**

Body Weight GBMR = (0.0526 x BW (kg)) + 2.3386

Group	BW (kg)	est GBMR MJ/24hrs	Meas. GBMR MJ/24hrs	Discrep. (%)	Discrep. (kJ)	Discrep. (kcal)
				See Fig.24		
Full range	59.0	5.44	5.44	0.0	3	1
G >25BMI	72.1	6.13	5.83	5.2	303	72
G 20 25BMI	58.7	5.42	5.60	-3.2	-179	-43
G <20BMI	50.1	4.98	4.78	4.1	196	47
G >30%FM	68.2	5.93	5.66	4.8	272	65
G 20 30%FM	56.9	5.33	5.55	-3.9	-216	-51
G <20%FM	47.1	4.81	4.37	10.1	441	105

Body Weight Schofield (1985) equation, GBMR = (0.062 x BW (kg)) + 2.036

Group	BW (kg)	est GBMR MJ/24hrs	Meas. GBMR MJ/24hrs	Discrep. (%)	Discrep. (kJ)	Discrep. (kcal)
				See Fig. 24		
Full range	59.0	5.69	5.44	4.7	255	61
G >25BMI	72.1	6.51	5.83	11.6	682	162
G 20 25BMI	58.7	5.67	5.60	1.3	73	17
G <20BMI	50.1	5.15	4.78	7.7	368	88
G >30%FM	68.2	6.26	5.66	10.7	599	143
G 20 30%FM	56.9	5.57	5.55	0.2	17	4
G <20%FM	47.1	4.95	4.37	13.4	581	138

BW $^{0.75}$ GBMR = (0.201 x BW$^{0.75}$ (kg)) + 1.169

Group	BW (kg)	est GBMR MJ/24hrs	Meas. GBMR MJ/24hrs	Discrep. (%)	Discrep. (kJ)	Discrep. (kcal)
				See Fig. 24		
Full range	21.2	5.44	5.44	-0.1	-3	-1
G >25BMI	24.7	6.13	5.83	5.2	305	73
G 20 25BMI	21.2	5.43	5.60	-3.0	-167	-40
G <20BMI	18.8	4.95	4.78	3.6	174	41
G >30%FM	23.7	5.93	5.66	4.7	265	63
G 20 30%FM	20.7	5.33	5.55	-3.9	-214	-51
G <20%FM	17.9	4.78	4.37	9.3	405	96

Fat Free Mass GBMR = (0.117 x FFM (kg)) + 0.398

Group	FFM (kg)	est GBMR MJ/24hrs	Meas. GBMR MJ/24hrs	Discrep. (%)	Discrep. (kJ)	Discrep. (kcal)
				See Fig. 24		
Full range	43.0	5.43	5.44	-0.2	-9	-2
G >25BMI	47.0	5.89	5.83	1.0	58	14
G 20 25BMI	43.0	5.43	5.60	-3.0	-168	-40
G <20BMI	40.2	5.10	4.78	6.7	320	76
G >30%FM	45.2	5.69	5.66	0.5	28	7
G 20 30%FM	42.6	5.38	5.55	-3.1	-172	-41
G <20%FM	39.9	5.07	4.37	16.0	699	166

Estimates derived from FFM and BW (Schofield) over estimated measured mean in this group by approximately 7 %, and 350 kJ.

b) With respect to **standard** groups, each equation except BW (Schofield) underestimated GBMR, although in no case was the difference greater than 3.9 % (214kJ).

The closest approximation was given by BW (Schofield) where, in the two standard groups, the overestimate was only 0.2% in G20-30%FM and 1.3 % in G20-25BMI, the difference amounting to 17 to 75 kJ.

c) The regression equation best representing GBMR in the **overweight** groups was that using FFM, where estimated mean and measured mean GBMR came within 0.5 % of one another in G >30%FM and 1.0 % in G >25BMI.
GBMR in overweight groups was over estimated by approximately 4.5 to 5% by both BW and $BW^{0.75}$, equivalent to approximately 250 - 300 kJ.
A much larger over estimate was found by using BW (Schofield) where the difference amounted to 10.7 % in G > 30%FM and 11.6 % in G >25BMI. This over estimate is likely to introduce a significant error in practice.

3.93 Summary of estimations of mean GBMR derived from equations relating GBMR with anthropometric parameters.

The full range equations, used as described above, showed no equation represented all groups equally well. (Table 19 and Figure 25)

When over and under estimates in the full range and separate groups were considered overall, $BW^{0.75}$ and FFM provided the best fit, although the two parameters showed different areas of discrepancy.

$BW^{0.75}$ gave closer estimates in the lean groups than FFM , with the reverse applying in the overweight groups.

$BW^{0.75}$ was less close at standard BC where the equation of Schofield and that using FFM provided very close agreement with the mean measured GBMR. The equation of Schofield gave very good representation of GBMR at standard BC, but significantly over estimated GBMR in overweight and lean groups, particularly the leanest group where $BW^{0.75}$ provided a better fit.

3.94 Comparison of ranges of discrepancy between measured individual GBMR and individual GBMR estimated using full range and group specific equations.

The ranges of individual discrepancy found in each group with each parameter were compared.

Results of comparison of individual measured GBMR with the estimate achieved by substituting the appropriate parameter in full range equations are shown in Table 20, results of comparison with estimates found by using the appropriate group specific equations are shown in Table 21, both at page 111b.

Comparisons are also shown in Figures 26a and 26b, page 111a.

Table 20

Range width and distribution of discrepancies between individual measured GBMR and individual GBMR estimated using **full range equations** with specified parameters.

Group	BW		BW (Sch.)		$BW^{0.75}$		FFM	
	% Discrep.	Range width	% Discrep.	Range width	% Discrep.	Range width	% Discrep.	Range width
G >25BMI	+20.0 to - 8.6	28.6	+30.0 to - 3.1	33.1	+18.8 to -8.4	27.2	+17.1 to - 11.7	28.8
G 20 25BMI	+19.3 to - 13.9	33.2	+24.4 to - 9.8	34.2	+19.3 to - 13.8	33.1	+9.3 to - 15.2	24.5
G <20BMI	+28.8 to - 17.5	46.3	+31.9 to - 13.5	45.4	+27.5 to - 17.4	44.9	+33.5 to - 12.4	45.9
G >30%FM	+20.0 to - 8.6	28.6	+30.0 to - 3.1	33.1	+19.3 to - 8.4	27.7	+17.1 to - 11.7	28.8
G 20 - 30%FM	+11.4 to - 17.5	28.9	+15.4 to - 13.5	28.9	+11.1 to - 17.4	28.5	+7.4 to - 15.2	22.6
G <20%FM	+28.8 to - 3.4	32.2	+31.9 to - 0.3	32.2	+27.5 to - 3.9	31.4	+33.5 to - 0.7	34.2

Table 21

Ranges of discrepancy between individual measured GBMR and individual GBMR estimated using **group specific equations** with specified parameters.

BC group	BW		BW (Sch.)	$BW^{0.75}$		FFM	
	% Discrep.	Range width	% Discrep.	% Discrep.	Range width	% Discrep.	Range width
			does not apply				
G >25BMI	+11.2 to - 13.0	24.3		+11.7 to - 12.6	24.3	+9.9 to - 11.3	21.2
G 20 25BMI	+21.8 to - 10.9	32.7		+22.0 to - 8.9	30.9	+13.0 to - 12.5	25.5
G <20BMI	+14.8 to - 11.9	26.7		+24.2 to - 14.5	38.7	+24.4 to - 16.8	41.2
G >30%FM	+16.6 to - 13.3	29.9		+16.0 to - 13.1	29.1	+16.8 to - 7.7	24.5
G 20 - 30%FM	+15.7 to - 11.0	26.7		+13.9 to - 12.3	26.2	+15.2 to - 9.3	24.5
G<20%FM	+16.6 to - 7.3	23.9		+12.5 to - 10.2	22.7	+15.5 to - 14.1	29.6

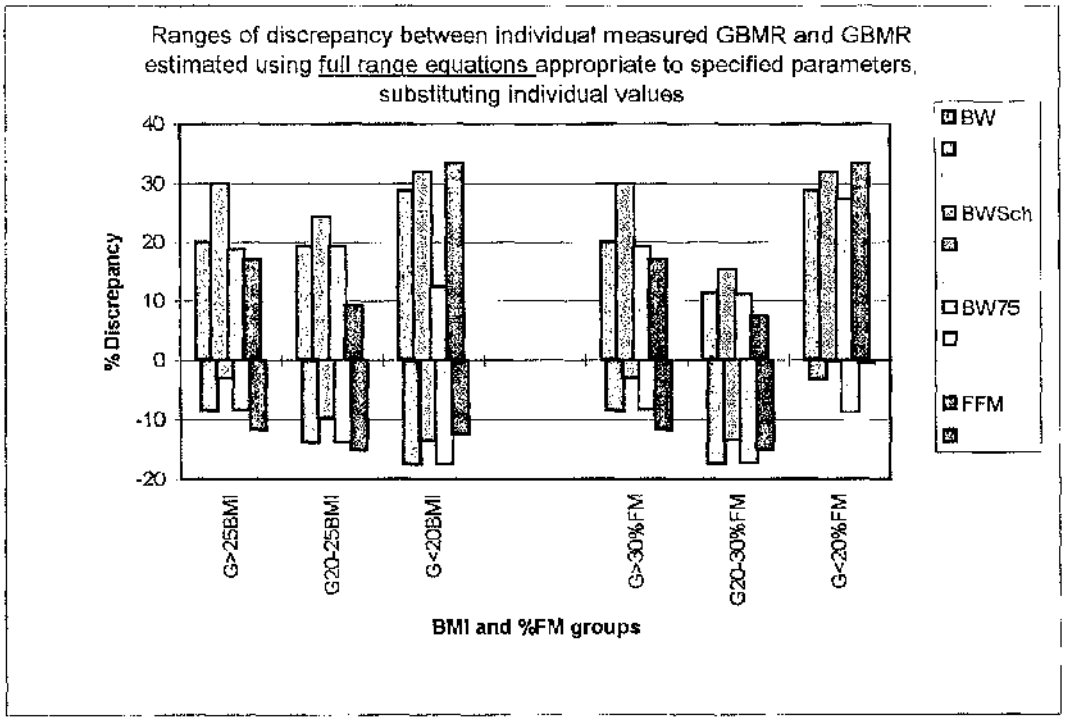


Fig.26a, refer to Table 20

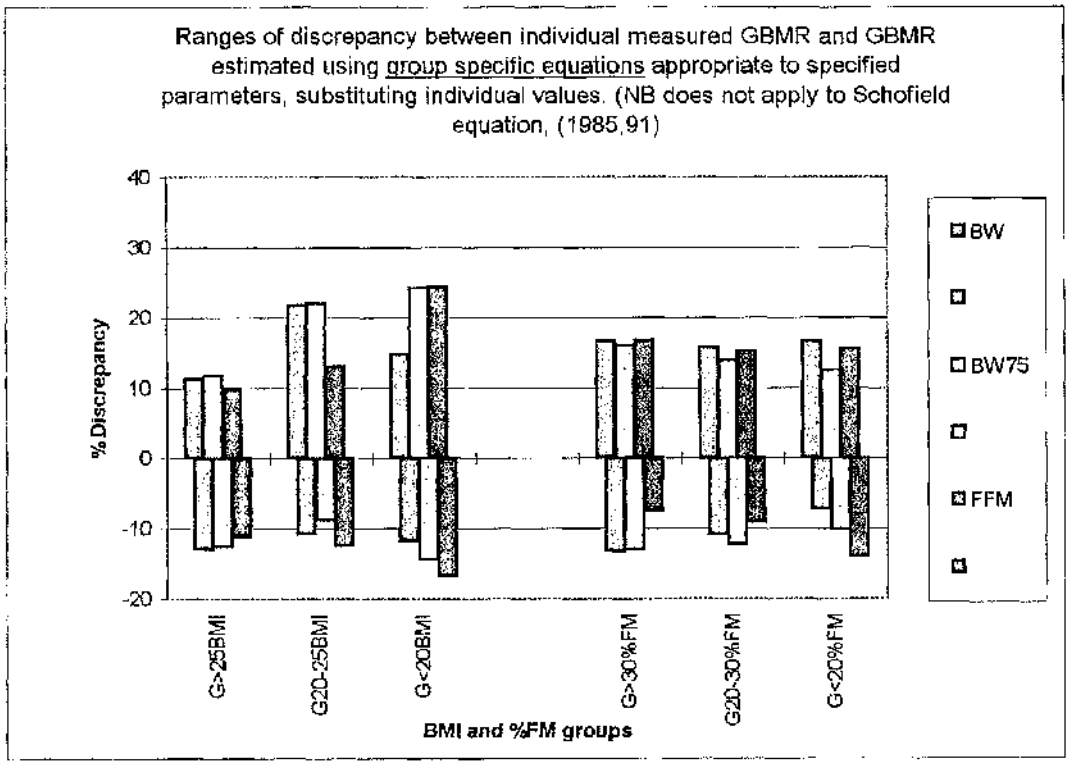


Fig.26b, refer to Table 21

Full range equations

Where a full range equation was used the range of discrepancy was least wide for overweight groups and the lean groups when $BW^{0.75}$ was used as covariant. In the case of standard groups of subjects, FFM was found to have the least wide range, although apart from the equation of Schofield, the differences between the discrepancies were small.

Group specific equations

Where group specific equations were used, the range of discrepancy was less wide for some parameters than others, as had been the case with the full range equations. This time, a smaller range width was found in the lean group G <20%FM with $BW^{0.75}$, i.e. the group specific equation had been better suited to this group. The more diverse G<20BMI were better represented by the use of a group specific equation using BW itself.

The use of BW to a power function was suggested in order to reduce overestimate in very lean or light subjects, this was true of the mean estimate but as far as the range of individual estimates is concerned, it applied in the leanest group although not in the less lean, less selective group G <20BMI.

The application of a group specific equation using FFM in overweight and lean subjects had the effect of reducing the range of individual discrepancy, when compared with the full range equation although the range width was still very large in lean subjects. In standard groups, the groups specific equations had the effect of redistributing and slightly widening the range in the case of FFM. Where BW and $BW^{0.75}$ were used, the group specific equations redistributed and slightly narrowed the ranges.

Chapter 4

Discussion

Chapter 4

Discussion

4.0 Basal metabolic rate, body weight and body composition.

The rate of energy expenditure at basal level, basal metabolic rate (BMR), provides a definable common basis for the estimation of minimum energy requirement in a population, to which can be added estimated energy requirement for activity giving an overall estimate of that population's requirement.

While the relationships of BMR to total energy expenditure and mean energy requirements are now well established (Moe, 1994), there is still a requirement for reliable prediction as patterns of intake and expenditure change. Although there are many areas in the world still in rural economies or making the transition from them, heavy industry and labour intensive occupations have largely disappeared from industrialised societies and patterns of intake must somehow be adjusted to suit.

Prediction of BMR is an inexact science. Predictions are made using equations derived from measured metabolic rates sometimes from more than one source and, while the techniques and instrumentation may have improved, there is still considerable methodological variation in addition to the inherent variability of energy expenditure. The populations and groups of subjects show variability in number, in age and sex of subject, in customary level of activity and nutrition. The methods of assessment and computation are similarly variable. Care and good use of reliable techniques can reduce error in individual measurement and groups of measurements, but one must have reservations about how well these precise results represent the subject whose BMR is, in any case, inherently variable or how the results for one group can be transferred to other groups. None the less, estimates of BMR which can be used with reasonable confidence are of social and economic importance.

Basal metabolic rate may be considered as being determined by the size and composition of the body and modified by the factors and substrates regulating the rate of energy expenditure of its various components.

The term 'basal' is used in this study to describe metabolic rate measured under standard laboratory conditions as described by Benedict (1938), with the subject at rest, fasted and in comfortable quiet surroundings at appropriate ambient temperature.

Body weight is taken as a measure of size in the context of metabolic rate.

Surface area, which might in other circumstances be taken as a measure of the size of an object, has little relevance to the energy expenditure of humans. Although there is undoubtedly long and short term adaptation to ambient temperature, this adaptation is brought about, not by changes in surface area, but by regulatory mechanisms likely to contribute to the variability in the rate of energy expenditure. The standard laboratory conditions in which BMR assessment should be made should at least minimise the short term effects of ambient temperature.

Body weight (BW) and whole body basal metabolic rate calculated over 24 hours (MJ) (GBMR) were measured in each of 90 subjects. Skinfold thickness measurements made according to the method of Durnin and Womersley (1974) were used to assess percentage body fat (%FM) .

The subjects were recruited almost entirely from the student population with no attempt to select or exclude any particular body type, only to ensure that lean, overweight, and the non- lean non-overweight referred to here as 'standard' types were represented.

No medical history could be verified (none was pregnant, diabetic, or replied negatively to 'are you well ?' or 'do you feel well ?'). If the subjects were attending classes and did not have a current acute medical condition (when they would in any case be unlikely to present

themselves for test) they were assumed to be 'normal, healthy' members of the young female population.

4.01 Synopsis and lines of enquiry

Equations of the linear regression type relating BMR to body weight (BW) and / or body composition (BC) are often used to predict BMR and the aim of this study was to investigate the relationships of BMR with BW and BC in a group of 90 women, aged 18 to 30 years, and to assess the effectiveness of the equations produced from these data.

Whole body BMR / 24 hours, expressed as GBMR, was related to -

- body weight (BW)
- BW substituted in a currently used predictive equation (Dept. of Health, 1991)
- BW to a power function, the classical $BW^{0.75}$
- fat free mass (FFM) .

The Pearson values for covariance of these parameters with GBMR were comparable with many from other studies, however distribution of data points and residuals on regression analysis prompted the suggestion that the relationships between GBMR and BW or BC were modest, or that the covariance changed across the range of the study group, or that the data had non-linear characteristics.

The study population was partitioned as described into groups using a parameter representing BW i.e. body mass index (BMI kg/m^2) and a parameter representing body composition (BC) i.e. percentage fat mass (%FM) . Details of the partitioning and the characteristics are given on page 69 and in Tables 3 and 4, pages 70a and 71a.

Pearson coefficients and trendlines of GBMR with BW and with FFM were sufficiently different from one another in different sectors of the full range of the study population to prompt the questions -

1. *Does the EE of unit tissue mass vary across the range of body compositions in the study population?*
2. *What might this be attributed to ?*
3. *With respect to GBMR, what are the discrepancies between mean measured GBMR for the groups within the population and the mean GBMR for these groups estimated from the linear regression equations derived from the data of the full range of the study population (referred to as full range equations) ?*
4. *Is the discrepancy reduced if a group specific equation is used ?*
5. *Which of the relationships of GBMR with BW or BC best represent the study population and its groups ?*
6. *Do the differences produced by use of either full range and group specific equations to predict mean GBMR have any practical or clinical importance?*
7. *What characterises the areas of greatest discrepancy in mean estimates?*
8. *Predictive equations should be used for groups, not for individuals, but what might be the range of discrepancy for the individuals in any group ?*

These questions are re - identified and considered in the sections following.

4.1 Covariance of GBMR with anthropometric parameters.

GBMR values for the full range of the study population were plotted against BW and against FFM and analysis of variance carried out, the Pearson product moment coefficient (r) values were 0.71 and 0.75 respectively, representing 51% and 57% of variance. BW is considered first, FFM in detail at section 4.6 and following.

4.11 Covariance of GBMR with BW.

In this study, covariance of basal metabolic rate per whole body per 24 hours (GBMR) with body weight (BW) over the full range of body compositions in the study population gave a Pearson coefficient value of $r = 0.71$, BW representing 51 % of variance.

This compared with studies of females by Ravussin *et al.* (1982) and Owen *et al.* (1986) who each found correlation coefficients of $r = 0.74$, the latter study found that the correlation coefficient was higher in lean women. de Boer *et al.* (1987) found $r = 0.85$, however her study involved a group almost 40 % of whom were overweight and 60% were lean therefore constituting a different population from this study and those cited above. De Boer did not distinguish between the two very different BC types and gave only the above value for correlation of 'resting energy' with BW. Other studies have shown higher correlations (Dore *et al.* 1982; Mifflin *et al.* 1990), although in each case, the mean age of their study populations was higher. In both cases the authors found BW to be more highly correlated with GBMR than FFM in their female subjects.

Detailed comparison of coefficients from study to study is of limited value since methodological differences introduce 'extrinsic' variability, however the differences between published coefficients were comparable with the differences from group to group in the study population where method was constant throughout.

4.12 Covariance of GBMR with FFM

In this study, FFM was more highly correlated with GBMR than was any other parameter over the full range of subjects with r = 0.75 representing 57% of variance (Table 2 page 66) This was lower than the values found by Webb (1981) r = 0.93, Dore *et al.* (1982) r = 0.9 and Garrow and Webster (1985ii) r = 0.83. These studies all involved women over a range of body compositions, although Webb commented that the high value was due at least in part to the small number in the study (n = 15) and to the fact that none was grossly overweight.

The Pearson coefficient of 0.75 found in the study population was, however, comparable with that found by Ferraro *et al.* (1992) r = 0.80, and with that found by Astrup *et al.* (1992) r = 0.77. The latter study of 50 premenopausal women, in follicular phase and with a wider BW and age range than in the study under discussion, found that 'lean body mass' accounted for 75 % of variance of sleeping EE and 60 % of variance in resting EE. The authors found no difference in correlation in overweight and non overweight women, although the observation applied to 24 hour expenditure and its components rather than BMR.

While preliminary analysis of the data showed that covariance of GBMR with BW and with FFM gave results of the order of those in other studies, direct comparisons must made with care, since as shown by review of the literature, studies are likely to differ in size and composition and methods of assessment. Furthermore, assessment of FFM is as problematic as assessment of BMR. As with covariance with BW, covariance with FFM differed from group to group within the study population with differences similar to those found between the studies cited. The values of Pearson coefficient for BW and FFM in the study population leave large margins for residuals, 49% in the case of BW and 43% for FFM.

Visual inspection of the data points when GBMR was plotted against BW and FFM showed clustering off the linear trend line at the lean, low body weight end of the distribution and to a lesser extent at the overweight end. In each case, the distribution of data (see Figures 3 and 4, page 67a) showed polynomial trends, significant at the second polynomial and in each case with higher values of covariance coefficient than for the linear relationship.

GBMR gave indications of being affected, not simply by increasing BW which would have produced a straight line relationship, but by BC. At the overweight end of the scale GBMR increased less than might have been expected for an increase in weight of the same composition, which might have been predicted since an increase in BW is most commonly achieved by an increase in adipose tissue of lower energy expenditure (EE).

At low body weight end of the scale, GBMR dropped more rapidly than might have been expected from a simple decrease in weight, a less predictable finding, although, clearly, the effect of error or variability in either GBMR or BW would be magnified in low weight individuals. In the case of the relationship of GBMR with FFM, the non linear characteristics were less marked and further evidence of this became apparent when the study population was partitioned.

It would appear, therefore, that covariance of GBMR with BW and with FFM was modest or that the data had some non linear characteristics or that the linear trend changed across the range of the population. Although the effect of variability between and within 90 subjects cannot be discounted, the higher level of covariance within the non-linear relationship than the linear relationship merited investigation. The predictive equations in common use, however, are of linear regression type and, therefore, it was considered appropriate to investigate the effect of this degree of nonlinearity, not by using the curvilinear structure, but by investigating the effect of different slopes applying at different sectors of the study population. These sectors were defined by the pre-existing limits suggested by the Royal

College of Physicians (1983) for BMI or those for % body fat which have been used in clinical practice, rather than by the shape of the hypothetical curve.

4.13 Partitioning of study population

The study population was partitioned into groups according to BMI and %FM. Details of the groups and their characteristics can be found in Tables 3 and 4, pages 70a and 71a.

BMI incorporates BW and representing 'body build' is seen as a useful assessment tool in general (medical) practice (Mclaren, 1988).It is increasingly used by other health care professionals and has become the index of choice since it is more closely correlated with % body fat and is less affected by stature than other indices (Norgan, 1994) The groupings used were those of The Royal College of Physicians (1983)
The term %FM represents BC and grouping was made on an arbitrary, but commonly used clinical basis of less than 20%FM, 20 to 30%FM, and over 30%FM. The subjects within each grouping in this study are referred to as 'lean', 'standard' and 'overweight'. The subjects making up the lean group as defined by %FM, with one exception, fell into the groups defined as Grade 1, 2 and 3 thinness (WHO, 1995)

Within BMI grouping, three subjects were over 30 kg/ m^2 and could be classified therefore as 'obese', however their omission or inclusion in the overweight group made no statistical difference to the mean values of the G>25BMI group and they were therefore included with the 'overweight' group. Two of the three, however, had BMR / kg / min. (uBMR) values most overestimated by theoretical values (Garby *et al.* 1988).(Figure 10, page 80b)

For each BMI and %FM group, Pearson coefficients were calculated (Tables 5, 6, 15 and 16) and regression equations constructed. Bartlett tests on the analyses of variance in the groups in each set showed that covariance and the slopes of the regression lines in the

groups were statistically different from one another for BW (Figures 5a, b and c, page 74a, 6a, b and c, page 76a) and in the case of FFM, the slope for the leanest group G<20%FM was statistically different from the other two %FM groups and that for the heaviest and highest mean fat mass group G>25BMI was statistically different from the other two BMI groups. For FFM, therefore, the difference was significant only at the extreme ends of the BC scale (see Figures 20a, b and c, page 98 and 21a, b and c, page 98a).

The grouping and the effects of the differences in covariance of GBMR with BW and BC are considered in detail in the following sections.

4.2 Energy expenditure of unit tissue mass - uBMR

1. *Does the EE of unit tissue mass vary across the range of body compositions in the study population?*
2. *What might this be attributed to ?*

Since covariance of GBMR with either BW or BC appeared to differ along their range, the effect of one of the variables, BW, was removed in order to consider EE of unit tissue mass across the range of BC in the study population. Energy expenditure / kg BW was calculated, this being expressed as unit basal metabolic rate (uBMR) in J/kg/min.
When the values of uBMR for the full range of the population were plotted against %FM, as a parameter representing BC, the data showed a highly significant curvilinear distribution, significant at the third polynomial with r = 0.79 (Figure 8, page 79a)
Mean uBMR of the subjects whose %FM was below 20% was 64 J/kg/min., for those who were 'standard', 68 J/kg/min and for those who were overweight i.e. above 30%FM, 58 J/kg/min. While recognising the limitations of apparently precise values, it might have been predicted that unit mass which included a high percentage of adipose tissue might have had a lower metabolic rate, unit mass with a high percentage of FFM with a much higher energy expenditure might be expected to have a high uBMR. Examination of Figures 7 and 8 (page 79a) showed that while the values indicated variability, the distribution of the values none the less indicated a group which was different from the adjacent 'standard' group.

EE values of 1.35 and 0.31 J/kg/second for FFM and FM respectively have been proposed (Garby *et al.* 1988; Garby and Lammert, 1994). These values were used to produce theoretical estimates of EE/kg of composite tissue, the composition calculated using each subject's percentage FFM/ FM.

These estimated values were then compared with those derived from measurement. Relationships between the two sets of results are shown in Figure 9, page 80a and the percentage differences in Figure 10, page 80b.

It was clear that the uBMR values derived from measurement differed considerably from the theoretical estimates and that the discrepancies were greatest at the extreme ends of the BC scale.

Estimated uBMR for subjects who might be described as 'standard' BC, i.e. those between 20 to 30%FM (n = 56), came fairly close to those derived from measurement, apart from 4 subjects, all were within ± 10%.

Of the subjects over 30%FM (n = 26), 5 had been overestimated by more than 10% and one subject by more than 20%.

A greater percentage of lean subjects (n = 11) showed greater overestimates, 6 with greater than 10%, 2 of those over 20%.

The standard group were also more consistent as defined by standard deviation (mean % difference = -3.6, S.D = 5.5), this compared with the lean group with the largest scatter (mean % difference 11.8, S.D = 10.6)

In the context of whole body EE, Garby *et al.* in their paper on FFM and FM in vivo (1988) described as a nonsensical observation that 'EE can be approximated by a linear equation with a positive intercept since as body weight increases, percentage body fat increases'. While the most obvious reason for the lower uBMR at the upper end of the %FM scale is the presence of a large proportion of a tissue with a lower EE, it contradicts the finding of lower uBMR in the leanest members of the study population, where FFM with its higher EE is the predominant tissue. It is difficult to separate the effects of possible greater variability in low and high fat value sections of the curve from possible real differences, however, as before, the evidence of a significant curvilinear distribution merited investigation.

The BC factors which may contribute to the differences in uBMR across the range of the population may be

- differences in the relative size of the compartments
- differences in the components making up a compartment
- differences within a component, for example, its fuel selection and rate of fuel usage

4.21 Body composition and the study population

BC was very variable in this group of 90 women. The subjects were self selecting, no attempt had been made to recruit any particular type, only to ensure that the main body types were represented.

% FFM ranged from 60 to 88%, BMI from 15.9 to 40.3 kg/m^2 (this last subject was considerably outside the main overweight range, the subject below this being 32.9 kg/m^2)

Details of BC can be found in Table 1, page 65 and tables 3 and 4, pages 70a and 71a.

Body composition in this study was considered as two major compartments, FFM and FM, each with very different properties and each with very different energy expenditure.

Body composition was assessed by skinfold thickness according to the method of Durnin and Womersley (1974) giving %FM from which %FFM could be derived, given BW.

The assessment of BC is likely to be more problematic than the assessment of BW.

Garrow (1982) said that the ideal method of assessment of BC should be relatively inexpensive, cause little inconvenience for the subject, be capable of operation by unskilled technicians and produce results which are accurate and highly reproducible.

While all of these apply to methods of assessment of BW, the same cannot be said of assessment of BC.

This study employed the technique of skinfold thickness measurement, which, although apparently less technically demanding than many of the methods now available, still demands manual skill and much practice before reproducible results can be produced. (Walker and Kindlen, 1988) .

Of studies comparing methods of BC assessment Pullicino *et al.* (1990) found that skinfold thickness measurement emerged as one of the two best predictors of BC assessed by deuterium dilution, and skinfold thickness assessment was found to be the best predictor when compared with densitometry as reference method (Fuller and Elia, 1989). A well trained anthropometrist should be able to achieve results within 5% of that obtained by densitometry with the error increasing where the skinfold was either very large or small (Cameron, 1978, cited by Lukaski, 1992). Unfortunately, during this study, it was possible to assess only one subject by densitometry (Edinburgh University, Physiology department) with results within approximately 2% of those produced by skinfold thickness measurement.

All the skinfolds in this study were measured by one observer, after an extensive training and practice programme which ensured repeatable results and which met the criteria of the supervisor (Durnin) whose method it was. It was clear however that, in very overweight subjects particularly, there was a degree of subjectivity in the selection of the fold thickness. Discretion must be used when considering any BC assessment results and where results from separate studies are being compared or have been used cumulatively in a synthetic review, even greater caution must be exercised.

4.211 Variability in the relative proportions of FFM and FM

BC is likely to be variable in any group. The range of %FFM over 90 subjects was from 60 to 88.1%. Even within the discrete BMI and %FM groups there was a considerable range of

percentage composition, for example, in the standard groups, the range of 70.9 to 79.9 % FFM was found in G 20 - 30%FM and 65.6 to 79.9 % in G 20 - 25BMI.

4.212 Variability in EE of BC within study population.

Individuals with the same or very similar % BC were found to have values of uBMR more than 10 % different, for example, two subjects with 69.4 % and 69.5 % FFM whose uBMR were 58 and 65 J/minute.

Examples of such variability were found in all three of the lean, standard and overweight body types.

While the differences were small in the context of BMR, such variability cannot be considered as solely related to relative masses of FFM and FM.

4.213 Components of FFM

FFM itself is made up of a variety of tissues with a range of energy demands.

Skeletal muscle, with a normally moderate resting rate and constituting an EE component roughly equivalent to that of the brain, has a large mass and is capable of increasing EE by 100 fold in exercise. Even at rest skeletal muscle exhibits tone which may be increased by sympathetic stimulation to achieve a higher energy demand without any visible movement. Liver and brain on the other hand are of relatively low mass but constitute a steady high energy demand. Organ mass has been estimated (Passmore and Draper, 1965) to use about 40 % of oxygen consumption at rest while muscle mass may use less than 20 %.

The components of FFM do not have a constant mass relationship.

Organ mass is preserved for some time in chronic negative energy balance at the expense of muscle mass (Barac - Nieto *et al.* 1978). Earlier studies showed a progressive loss of 40 % muscle over a period of 6 months. The reduction in BMR however did not match the loss of FFM, indicating some preservation of organ mass (Grande, 1980)

Much later work was also able to show that in subjects who were semi- starved, organ mass was spared at the expense of muscle mass (Soares *et al.* 1992) and that as muscle decreases, the contribution to EE of organ mass increases proportionately (Garby and Lammert, 1994)

Organ mass, however, cannot remain unaffected. Organs of concentration camp prisoners and famine victims estimated to have lost 25 to 45% of their original weight weighed between 52% (spleen) and 80% (heart) of normal (Keys *et al.* 1950). Evidence from the 1944 - 45 Dutch famine, quoted by Elia (1994), showed gut mucosal thickness to be reduced, poorly perfused and contributing to reduced gut weight.

The more acute of these effects are familiar to trauma units which are well accustomed to the phenomenon of loss of muscle, as evidenced by creatinine output in severely injured patients, while organ proteins are spared for some time. The effects of trauma accelerate the loss of body protein and its diversion to energy substrate.

Since FFM is not of uniform or constant composition, while its EE is likely to more closely represent that of the whole body, its expenditure is likely to be variable on compositional grounds alone. The effects on energy expenditure of changes in FFM are seen most clearly where the changes have been gross, however smaller changes in relative mass and activity of the components are likely to act as contributors to the variability of the whole FFM compartment. In addition to this source of variability, each of the components may show evidence of variability.

4.214 Variability of energy expenditure within FFM.

GBMR for each individual subject was assessed on one occasion only, scrupulous care was taken over the procedure and no assessment was accepted that did not comply with the limit of 3% variation between two of the three measurements. There is no guarantee however that any result of the measurement of GBMR will give completely typical results for any individual and this caveat must apply to all 90 subjects and all subjects in any study. Some of the individual differences in GBMR may be evidence of variability in composition or regulation of tissue mass. The study population included examples of subjects with the same or very similar FFM : FM whose uBMR differed markedly, for example, two individuals with very similar % BC, but different BW, had uBMR values separated by more than 16 %.

Conversely, there were subjects with the same value for uBMR with very different BC. This variation may be due to compositional differences in FFM, although it is unlikely that healthy individuals in the same BC group would have gross differences in the ratio of organ mass to muscle mass, and it is more likely that regulatory factors and / or differences in fuel usage also contribute to variability.

4.2141 Regulatory factors and FFM

Each of the components of FFM is sensitive to chemical stimuli such as the catecholamines, thyroid hormones, insulin, growth hormone and the corticosteroids, each of which has multiple interactions with the others. Production of the factors and sensitivity to them is controlled within homeostatic ranges therefore, by definition, biologically unlikely to be fixed at a constant value.

Activity of tissues is increased in response to noradrenaline and / or adrenaline (for a review of studies, see Young and MacDonald, 1992). When the sympathetic thermogenic response to cold was blocked using the non -selective blocker propranalol, daily EE was

reduced and weight gained (Astrup *et al.* 1990). A study on obese and lean women indicated that an effect of exercise was to increase the density of α_2 adrenoceptors but to reduce their affinity, the reduced affinity correlated with a rise in plasma noradrenaline. In the obese women the smaller increase in noradrenaline was not related to a change in α_2 receptors. In the same study, a period of energy restriction increased β_1 sensitivity in both lean and obese women (Berlin *et al.* 1990) While the effect of exercise on affinity of receptors is not relevant to the basal state, the effects of a change in the number of receptors may be retained for long enough to affect the basal state.

MR in skeletal muscle was shown to be reduced by adrenoceptor blockade, although the studies involved the use of biopsied skeletal muscle rather than in vivo (Fagher *et al.* 1993; Christin *et al.* 1993). Recent studies of noradrenaline turnover have shown that, in relation to RMR, much of the variability in RMR not attributable to body size and composition can be associated with variability in sympathetic activity (Poehlman *et al.* 1995; Toth and Poehlman, 1994 cited by Ravussin and Tataranni, 1996). These studies, taken in conjunction with that of Spraul *et al.* (1993) on muscle activity, were considered by the authors to indicate that RMR was modulated by sympathomedullary activity.

Thyroid hormones

Thyroid hormones have a profound effect on MR, for example, in thyrotoxicosis, MR can be doubled or more and, at one time, estimation of BMR was used in the diagnosis of thyroid dysfunction. An investigation into suppression of thyroid axis activity found that thyroxine (T_4) increased sleeping energy expenditure (SEE) by 4.1% on 180μg / day over 3 weeks and 8.5% when the dose was doubled over a further 3 week period. All subjects showed a normal thyroid stimulating hormone (TSH) suppression (Braco *et al.* 1993)

Although T_3 (triiodothyronine) and T_4 effects on energy expenditure can be seen clearly at clinically abnormal levels, at normal levels, the position is less clear and although

catecholamine levels were found to be reduced in some obese subjects, Ravussin *et al.* (1982) found there was no difference in thyroid hormone levels in obese and control subjects.

Astrup *et al.* (1996) examined fat oxidation in skeletal muscle in non -obese, obese and post -obese subjects. They have suggested that, although some studies have proposed that the proportion of type I and II muscle fibres may differ in obese subjects and that this may be associated with obesity (citing Wade *et al.* 1990) other better controlled and larger studies (citing Simoneau and Bouchard, 1995) had shown no significant relationship between muscle fibre type and body fatness.

The authors, however, quoting unpublished results from Raben *et al.* found evidence of varying enzymic activity in the muscle of post obese subjects compared with controls and suggest that 'some neuro hormonal influence may be responsible' such as lower hormone status (citing Astrup *et al.* 1996). The authors cited studies showing that a low free T_3 and low sympathetic activity could both be responsible for lower fat oxidation capacity in skeletal muscle and that both are risk factors for weight gain (citing unpublished results of Toubro *et al.*).

Regulatory mediators themselves are likely to be affected by body composition. Distribution, therefore storage and subsequent release of, for example, steroid hormones is affected by their sequestration into fat mass. It might be speculated where there are individuals in the same population with very large fat mass or with very lean body composition, mediators such as steroid hormones would have very different effects. The glucocorticoid cortisol interacts with both catecholamines and thyroid hormones with the possibility of widespread influence in addition to its own metabolic effects. While this would be compensated for by changes in output and down or up regulation at the target tissue, the possibility for differences across a wide body composition range is large.

The relationship between the two major compartments may be organised to some extent by their own relative mass and the consequent distribution of regulatory factors i.e. the activity of FFM may be affected by the mass and activity of FM.

4.2142 Regulatory factors and fat mass

Estimates have been made of the EE /kg of FFM and FM of 1.35 J/sec for FFM and 0.31 J/sec for FM, (Garby *et al.* 1988; Garby and Lammert, 1994)

Fat mass, although the lower EE component of the two compartment model, makes a significant contribution. It is not the inert tissue once imagined, it has a good blood supply and is capable of numerous metabolic reactions. Its role in energy exchange and management operating through triacylglycerol (TAG) has been extensively studied (Frayn *et al.* 1995). It is sensitive to many mediators and the effects of insulin, insulin - like growth factors and other hormones have been reviewed by Abate and Garg (1995) among others. Neither is it a homogeneous mass. The roles and characteristics of the 'minor fat depots' which are associated with lymph nodes, while histologically alike, differ from the large depots and from one another (Pond, 1996). Fat depots close to lymph nodes are likely to be paracrinely affected by them and differences in TAG - FA composition as large as many induced by many weeks of controlled diet and measured in a large depot can be found from simultaneously collected samples within a small depot.

Pond made the reasonable contention that it would be biologically sensible to separate fat depots which serve to maintain the energy availability from whole body lipid supplies (Frayn *et al.* 1995) from small depots whose functions may be entirely different, e.g. the responses of the immune system and the reservoir of particular rare but essential nutrients. The fat depots which lack lymph nodes, e.g. the paunch in humans, are capable of large expansion in over-intake, whereas those that associated with lymph nodes are not

(Bjorntorp, 1987, cited by Pond 1996) and in very lean wild animals, the lipid in the adipose tissue surrounding the nodes is the last to be reclaimed.(Pond, 1996).

In many individuals FM constitutes a very large mass. The highest %FM value in this study 40%, considerably lower than subjects studied by Garrow and Webster (1985i) whose range of FM extended to 60%.

The magnitude of the FM compartment in this study population ranged from 11.9 to 40 % and was significantly different from one group to another whether partitioned by BMI or %FM. ($p < 0.001$).

GBMR and uBMR in this study population showed distinct relationships with parameters representing BC.

- Covariance of GBMR with BW and with FFM differed from one BC group to the next.
- Covariance of GBMR with FM (kg), not close in the other BC groups, was very close ($r = 0.9$) in the leanest group of subjects G<20%FM, although this may have been a numerical artefact.
- When uBMR for the population was plotted against %FM, the curvilinear distribution was highly significant, the lower values of uBMR being found at the lower and upper ends of the %FM scale.

FM plays an important role in the energy economy acting as a large energy reserve. Since its rate of energy expenditure is very different to that of FFM, its mass relative to that of FFM significantly affects BMR and its range of metabolic activities is likely to contribute to the overall variability in BMR.

There was evidence in the study population of individual low uBMR when data were plotted against %FM (Figure 7, page 79a) and when the magnitude of discrepancy between estimated and measured values was examined (Figure 10, page 80b). When mean

discrepancy was considered, standard deviation had been found to be very large in the lean group (mean 11.8% discrepancy, S.D. 10.6)

The lean group (less than 20% fat mass) included individuals of very low BW, low % FM and low absolute FM.

There was no evidence that these subjects were in other than normal health, although one at least had admitted to having been intermittently amenorrhaeic.

Shetty (1993) has observed that elevated post absorptive RQ indicates a predominant dependence on carbohydrate, which may be related to the habitual diet of undernourished subjects as well as their depleted fat stores. Shetty has also observed the BMR of undernourished subjects was not lower when corrected for BW and that BMR / kg FFM is not altered.

In the present study, this was true of uBMR of lean subjects above 15 to 18%FM but not true of the subjects below this.

A sharp decline had been found to have occurred in resting EE of women who were severely anorexic, but who had retained a normal thermogenic response to food (Scalfi *et al.* 1993). Lean healthy women in the same study had higher resting EE but reduced thermogenic response to food. The very lean women had retained greater body fat than the anorexic women, with about 5 % difference in the means This finding may indicate that the reduced EE may only be found at very low %FM.

Maughan (1994) in a study of energy intake, expenditure and activity has found that in sports where women require a low body weight, particularly a low fat content, for example, gymnastics and distance running, many of these women have a very low fat mass, less than 10% is not uncommon in female long distance runners. He also found that these women consistently show a lower than expected intake to maintain their weight.

Reduced BMR values had been found by Keys *et al.* (1950) in their experimental and highly controlled Minnesota study both during starvation of human subjects and during restricted refeeding. Data from this study has been re-examined by Dulloo (1997) as part of work on energy mobilisation from body compartments during starvation. The author described a conceptual model in which the size of the compartments affects the mobilisation systems, the scheme being highly dependent on fat mass. In this proposed model, when refeeding occurs, thermogenesis is suppressed until FM is replaced. Many studies have found FM to be replaced before FFM on refeeding (MacLean and Graham, 1980; Jackson, 1984; Waterlow, 1992) or a delay in replacing total body nitrogen (Jeejeebhoy *et al.* 1982). In essence, the model might work as follows - in energy deprivation, rates of mobilisation of lean and fat reserves are determined by energy partitioning, the P ratio, (proposed by Payne and Dugdale, 1977, and defined by Dulloo as the proportion of body energy mobilised as protein during weight loss) which appears to be highly individual. Adaptive reduction in thermogenesis reduces the overall fuel use and spares both lean and fat compartments. On weight recovery during the restoration of tissue in the proportions determined by the P ratio, the reduction in metabolic rate allows fat replacement over and above that determined by the P ratio, resulting in the repletion of FM before FFM. None of the subjects in the study could be described as being starved or refed, however very low intake concomitant with low %FM and low BW might induce some of the characteristics of 'partial refeeding'. No biochemical / physiological mechanisms for this model have as yet been identified although its author has suggested that the mechanism may be in any one of several fields.

The possible close relationship of EE with %FM or FM (kg) identified in G<20%FM may be evidence of metabolic adaptation in the very lean, with EE closely associated with the mass of the fat reservoir.

Since fuel substrates are provided from exogenous and endogenous sources in the fed state and from endogenous in the fasted state, the mass and composition of endogenous stores must have a profound an effect on metabolism as will the customary pattern of intake which established them.

In the review by Randle (1995) it has been estimated that in a Western diet, the fuel mix is approximately 50% carbohydrate, 33% fat and 17% protein in the fed state, shifting to 12% carbohydrate, 70% fat and 18% protein after an overnight fast and 0% carbohydrate, 95% fat and 5% protein after 40 days starvation. In prolonged starvation, glucose oxidation is replaced by lipid oxidation in tissue other than brain and in the brain by ketone bodies to about 90% of total.

Flatt (1996) has proposed a model operating through the relative sizes of glycogen and fat reserves with the two fuels interdependent and related by the glucose fatty acid cycle (considered further at section 4.22).

The mechanism of glucose or FFA selection is highly dependent on insulin. Glucoreceptors on pancreatic cells operating through glucose transporter (GLUT 4) and glucokinase (GK) produce changes in the mitochondrial pyruvate dehydrogenase complex (PDH complex). A rise in extracellular glucose causes activity in GLUT 4 and GK i.e. activity in the glucoreceptor mechanism with subsequent increased flow through the mitochondrial shuttle causing an increase in ATP:ADP in both mitochondria and cytosol. The end result is both the release of insulin and the maintenance of releases through further PDH activity (the biphasic response to glucose).

Randle speculated that the mechanism of glucoreceptors may be similar in the brain and therefore that long term effects of lipid fuel on PDH kinase and PDH complex might be central to the control of catecholamines, growth hormone and the hormones of the HPA axis. It might be that the speculation of Randle regarding the effects of fuel supplies on endocrine central regulation might be apposite to the model of Dulloo. If the model can be

applied to the subjects in the two lean groups, there was evidence of both low values and considerable variability in uBMR. There may also be influence from a mediator such as leptin, closely associated with FM and affecting both BC and EE (Trayhurn, 1996).

The evidence from the present study suggested that low % FM was associated with reduced EE in some lean individuals, supporting the proposition that % BC is a significant determinant of BMR in lean subjects. The small numbers of very lean subjects in this study do not allow conclusions to be drawn about the role of low absolute fat mass, however covariance of GBMR with FM (kg) was found to be very close in the leanest group G<20%FM with r = 0.91, although this may have been a numerical artefact. (Covariance of GBMR with FM is discussed at section 4.7)

The presence of FM whether small or large would appear to influence BMR. Where FM is large, BW includes a large compartment of low EE, thus affecting BMR of the whole and affecting the fuel substrates available. Where FM is small it is possible that this may have the effect of suppressing thermogenesis to preserve the fuel compartments (Dulloo, 1997) and there may be adaptive changes in tissues to reduce EE, the compartments themselves influencing the adaptive changes (Flatt, 1996). This would suggest however that tissue was capable of becoming more energy efficient. Since regulatory systems are capable of changes in the short term, their effects are likely to add to the already existing variability. At the very least, the mix of fuel substrates available must be affected.

4.22 Fuel usage

Tissues have fuels of choice. The energy equivalent of the fuel substrates is variable and therefore fuel availability or selection will affect the energy economy. The heat of combustion of glucose (2.8 MJ/mol) is about 50% more than that of ketone bodies (1.78 /mol acetoacetate, 2.01 MJ/mol 3 OH butyrate) and 4 times less than that of NEFA (10.9 MJ/mol)) (Elia and Livesey, 1992, cited by Elia, 1995)

Skeletal muscle at rest uses predominantly non esterified fatty acids (NEFA), corresponding to about 80% of oxygen uptake (Havel *et al.* 1967, in Henrikkson, 1995) Only a small proportion of the total is derived from carbohydrate mainly from plasma glucose (Wahren *et al.* 1971 in Henrikkson, 1995) As activity levels rise, the dependence on carbohydrate increases.

Complex arrays of abilities to metabolise substrates with localised concentrations on particular fuels have been demonstrated by smaller units such as the kidney. In rat proximal nephron (in vivo), glutamine and citrate were readily oxidised while glucose and lactate were not significantly used. (Baverel *et al.* 1995). Glucose and lactate were found to be oxidised at high rates in the thick ascending limb of the loop of Henle but not in the proximal convoluted tubule and when glucose and lactate were presented together, lactate was the preferred fuel. (Le Bouffant *et al.* 1984).

Fuel usage varies. In order to survive, tissues must be capable of using alternative substrates and one of the determining factors in fuel use must be the circulating level available. If dietary intake is acutely restricted, BMR is increased in the first few days prior to the reduction which is likely to follow. (Webber and Macdonald ,1994)

The restriction of intake, particularly carbohydrate, prompts a reduction in insulin output and an increase in activity in the hypothalamo-pituitary-adrenal axis resulting in an increase in the output of a number of mediating factors including cortisol. The resulting increase in gluconeogenesis, ketogenesis and triacylglycerol (TAG) recycling may amount to 5% of resting EE and indicates a shift in fuel usage from an intake likely to contain carbohydrate towards greater use of endogenous protein and fat.

The availability and subsequent use of fuels illustrates the dependence of components on one another. To paraphrase Ella (1995), the brain's use of ketone bodies in starvation

probably depends mainly on their circulating concentration, the liver acts as a source of ketone bodies, but the liver requires a source of NEFA, which is, of course, adipose tissue. It must therefore be borne in mind that data from studies on isolated tissue may not reflect that tissue's function in vivo.

Levels of nutrient or fuel substrate in plasma may be highly variable, but they cannot be chaotic, such a state is not compatible with health and may not be compatible with life. Plasma glucose, for example, is tightly controlled in normal health, even at its outside limits it is rarely beyond 3 - 8 mmol/l. In the short term hypoglycaemia is damaging to central nervous function and if severe and uncorrected, may be fatal. Hyperglycaemia, although survivable in the short term, is damaging in the long term, its effects e.g. excess glycation, producing some of the complications associated with diabetes mellitus.

Other fuel substrates are less tightly controlled, FFA levels can vary by about 15 fold between fasting and feeding with a high fat intake.(Randle, 1995)

Flatt (1996) has described the total energy reserve as a two compartment model, with the smaller glycogen and the larger, fat. The glycogen and fat reserves are inter-dependent. Glucose and fatty acid are related by the glucose fatty acid cycle and changes in either one will affect the other. Food intake makes changes to both compartments, large changes to the smaller compartment and relatively insignificant changes to the larger fat compartment. Flatt considered that modulation of food intake in a way that helps maintain stable glycogen reserves has now been recognised in animals and human subjects and that this in turn will affect the size of the fat compartment. When habitual glycogen levels are raised as a result of frequent intake, the content of the fat reservoir must increase to match fat oxidation to fat intake. Glycogen stores, therefore could be said to influence both food intake and reservoir capacity.

If, as according to Flatt, an increase in glycogen reserve level is likely to promote a secondary increase in the size of the fat compartment, one might speculate that a

prolonged reduction in fat store might conversely affect glycogen store, therefore availability of glucose to the brain. Recurrent shifts to fuel other than glucose e.g. ketone bodies may subsequently affect the central mechanisms regulating the hormonal axes, suggesting that FM may be a major regulatory influence and that a marked increase or reduction may have an influence on EE of a range of tissues.
The lowering of EE in composite mass of very low %FM may be, not a primary effect stemming from adaptation in FFM, but a response in FFM, secondary to centrally mediated changes brought about by FM or %FM via glycogen reserve.

The mechanism of glucose or FFA selection is highly dependent on insulin. Glucoreceptors on pancreatic cells operating through glucose transporter GLUT 4 and glucokinase produce changes in the mitochondrial PDH complex. If the mechanism is the same in the brain, it may be that long term effects of lipid fuel on PDH kinase might be central to the control of the catecholamines, growth hormone and the hormones of the HPA axis (Randle, 1995) and to the regulation or mobilisation of the energy compartments (Dulloo, 1997).

4.23 Summary of EE and unit tissue mass

The complexity of regulatory systems and the heterogeneous nature of the fuels used suggests that in addition to variability due to the relative mass of FFM and FM and their components, there is also likely to be variability in EE due to short term changes within the component tissues. The acquisition of evidence related to differences in levels and activity of regulatory agents and possible differences in the fuel usage (although all subjects were fasted) was beyond the scope of this investigation and these factors can be regarded only as probable contributors to the differences found in the EE of unit mass of tissue (uBMR) within groups of similar BC and the level of variance found generally between GBMR and either BW or FFM. Therefore, although FFM represented GBMR to a greater degree than BW in the majority of subjects, neither could not be expected to represent more than a

large fraction of the variance. The curvilinear distribution of uBMR vs %FM may however suggest that the relationship is not simply random and that there may have been adaptation of FFM : FM to low intake in the very lean or to the presence of a large fat reservoir or customary high intake in the overweight.

In summary, the values of uBMR from 77 to 44 J/kg/min. illustrated a number of points - (NB - with respect to uBMR, only %FM groups are considered)

1. the relatively large number of standard BC subjects within 55 to 74 J/kg/min with mean of 68 with SD of 4 indicated fairly consistent EE.

2. the marked difference between the values for the standard BC and those for the lean on the one hand and the overweight on the other, both sets of values lower than those for standard BC subjects, giving a curvilinear distribution of uBMR with %FM.

3. the increased variability of uBMR values within the overweight group and even more so in the lean group as defined by mean and SD from group mean. The numbers in those groups were, unfortunately, small.

4. in the case of the subjects with high %FM, that the size of FM in itself would contribute to the overall lowering of uBMR, but variability may be due to regulatory influences having become adapted to high intake or to the customary fuel mix available or altered by their distribution in the body compartments.

5. in lean subjects, there was also a reduction in uBMR most marked in the leanest subjects. Since this was not due to the presence of a large FM of relatively low EE, the reduction must be due to factors which either alter the composition and /or EE within FFM or which depress EE in FM even more. In the leanest, the reduction may be due

to adaptation to prolonged insufficient intake or to the fuel available, either by the regulatory mechanisms or by the tissue at receptor or post receptor level.

6. The variability in the lean groups may support the hypothesis of Dulloo (1997) concerning the individuality of the P ratio and its effect on mobilisation of substrates.

4.3 Relationships between GBMR and BW / BC in the study population

As it became apparent that the values of GBMR when plotted against either BW or FFM showed polynomial as well as linear trends and later that distribution of uBMR with %FM was curvilinear, the study population was partitioned into groups according to BMI, an expression representing body size and %FM representing body composition. Details of the groups and their characteristics can be found in Tables 3 and 4, pages 70a and 71a.

BMI incorporates BW and represents 'body build'. M^{c} Laren (1988) has commented that the visual assessment of body build is still one of the most useful tools of general practice.
The groupings used were those of The Royal College of Physicians (1983)
The term %FM represents BC and grouping was made on an arbitrary, but commonly used clinical basis of less than 20%FM, 20 to 30%FM, and over 30%FM. The subjects within each grouping are referred to as 'lean', 'standard' and 'overweight'. The leanest group apart from one subject could all be described as Grade 1, 2 or 3 thin (WHO, 1995)
The term %FM was chosen rather than %FFM since, as far as method was concerned, %FM was derived directly from skinfold thickness, %FFM derived in turn from BW and %FM. In practical terms, 'overweight' and 'lean' subjects are conventionally thought of in terms of their body fat rather than their lean body mass.
Within BMI grouping, three subjects were over 30 kg/ m^2 and could therefore be described as 'obese', however their omission or inclusion in the overweight group made no statistical difference to the mean values of the G>25BMI group and were therefore included with the

'overweight' group. Two of the three, however, had uBMR values most overestimated by Garby *et al.* (1988) theoretical values (Figure 10, page 80b)

For each BMI and %FM group, analysis of covariance was carried out and regression equations constructed. Bartlett tests on the analyses of variance in the groups in each set showed that covariance and the slopes of the regression lines of GBMR with BW in the groups were statistically different from one another.(Figures 5a, b and c, page 74a , 6a, b and c at page 76a). In the case of FFM (Figures 20a, b and c, page 98, 21a, b and c at page 98a) there was discontinuity of slope for the leanest group G<20%FM and the most overweight group G>25BMI. Comparison of covariance in the groups is discussed at sections 4.13, 4.4 and 4.6.

Of the questions identified earlier, those below are considered in the following sections.

3. *With respect to GBMR, what were the discrepancies between mean measured GBMR for the groups within the population and the mean GBMR for these groups estimated from the linear regression equations derived from the data of the full range of the study population (referred to as full range equations) ?*

4. *Was the discrepancy reduced if a group specific equation is used ?*

5. *Which of the relationships of GBMR with BW or BC best represented the study population and its groups ?*

6. *Did the differences produced by use of either full range and group specific equations to predict mean GBMR have any practical or clinical importance?*

7. *What characterised the areas of greatest discrepancy in mean estimates?*

8. *Predictive equations should be used for groups, not for individuals, but what was the range of discrepancy for the individuals in any group ?*

BW, although usually thought to be less well correlated with BMR than FFM and by no means constant from day to day, has the prime advantage of being easily and accurately measured with methods which are familiar and non-invasive for the subject. FFM assessment has the disadvantages of being more invasive and the result requires to be derived from skinfold thickness, density, impedance or other assessment, all of which require skill and / or equipment of a very different order from that required for the assessment of BW. A report of a workshop on energy measurement (Gibney and Leahy, 1996), indicated that Stock had queried whether BMR should be expressed in relation to FFM to avoid the confusing effect of secular changes in body composition if BMR is related to BW, however it was observed by the report that 'measuring FFM created even further problems'.

The relationships of GBMR with BW are discussed below, those with FFM at section 4.6.

As suggested earlier, covariance of GBMR with BW over the full range of subjects with a Pearson coefficient of 0.71 was comparable with other studies in women. Even when the greatest care is taken with the conditions of measurement, the inherent short-term variability of BMR, due in the main to the effect of regulatory factors such as the catecholamines and thyroid hormones, require that the level of covariance must be limited. When the factors which affect variability of unit mass of tissue are considered, it is not surprising that BW represents only 50 % of variance, however, by reducing the range of body compositions, i.e. by grouping the individuals according to body 'type', it was considered that it might be possible to increase the level of correlation within any group.

4.4 Covariance of GBMR with BW in partitioned groups

When the subjects were grouped according to either BMI or %FM, the value of the Pearson coefficient r increased in both lean groups, decreased in both overweight groups and differentiated between the two standard groups.

'Standard' groups

- Covariance increased in the standard group G20-30%FM from 0.71 for full range to 0.79 but not in G20-25BMI (0.71 to 0.66) . Although the numbers were similar in the two groups and mean BC was not significantly different, G20-30%FM had the narrower range of %FFM (70.9 - 79.7 c.f. 65.6 - 79.9), suggesting that increased covariance was associated with a smaller range of variation in BC produced by the exclusion of data outlying the linear trend by selection for G20-30%FM.

'Lean' groups

- GBMR was best represented by BW in the two lean groups. The value of the Pearson coefficient increased from r = 0.71 for the full range to r = 0.87 in G<20BMI and 0.85 in G<20%FM. A similar observation in lean subjects was made by Owen *et al.* (1986) who found BMR more highly correlated with BW in ' athletic ' subjects. Closer examination of the details of these athletes found them to be women (n = 6) whose mean %FM was 18.8 % (SD 1.85) In this study, group means were 19.5 %FM (G <20BMI) and 15.1 %FM (G<20%FM) .

  The number was very small in Owen's study, smaller than in G <20%FM, a factor likely to affect covariance, however, in these lean women, where FFM approaches BW , since FFM is the greater contributor to total EE, mathematically at least it might be expected that correlation with BW should be high. The group size was larger in G <20BMI (n = 22) and the value of r was marginally higher (0.87) .

Covariance of GBMR with BW was close in the lean groups and the slope and intercept in the leanest G<20%FM were significantly different from standard and overweight groups. It should be remembered however, that when uBMR was compared with theoretical estimated uBMR, the greatest discrepancies were found in the leanest individuals. There may be a contradiction in that, at very lean BC, GBMR was closely associated with BW, but unit BW varied considerably in its EE and in its departure from estimated EE which was large and varied (mean of 11.8% discrepancy from theoretical estimate, SD = 10.6). This level of variability may be partly due to the effect of the small number in the group and partly due to the magnification of any error or variability in the data for subjects of low BW and low GBMR. The close covariance may indicate that differences from predicted unit values when translated into resultant body weights assume a more orderly distribution and may be characteristic of very lean body compositions.

'Overweight' groups

- Variability was more evident in the overweight groups and the association of GBMR with BW less. The Pearson coefficient was reduced from 0.71 for the full range to 0.61 for G>25BMI and 0.69 for G>30%FM. The reduced degree of covariance may again be due to the smaller group numbers and the greater effect of outliers within the smaller number.

  Many investigators (James *et al.* 1978; Garrow, 1981; Garrow and Webster, 1985ii; Astrup *et al.* 1992), have shown increased EE in overweight subjects although these studies in the main refer to 24 hour EE which included light activity. The highest value for % FM was considerably lower in this study than in some published studies, for example that by Garrow and Webster (1985ii) of obese subjects where the range extended to 60 % FM.

It is conceivable that EE at other than basal, as in the studies above, might be significantly higher. Some of this increase may be due to the increase demanded by moving a large bulk around (de Boer *et al.* 1987) or to increased cost of protein turnover (Owen *et al.* 1986), which is considerable, estimated to be at least 30 % of EE in normal health (Jackson, 1984).

In this study, however, GBMR was raised only marginally and when converted to EE per kg, the mean expenditure of the overweight groups was significantly lower than that in either standard or lean groups.

It has been observed that (in women) as BW increases, EE /kg BW decreases (James *et al.* 1978; Felig *et al.* 1983) This was found to be true of the groups of overweight subjects in this study where mean uBMR of 57 and 58J / minute was found to be significantly lower than the value of 66 and 68J / minute for mean GBMR in the two standard groups and 66 and 64 J/ min. in the 2 lean groups (Tables 3 and 4, pages 70a and 71a)

In the overweight groups, the value of the coefficient was reduced, particularly in G>25BMI.The difference in the Pearson coefficients (BMI group : r = 0.61 and %FM group : r = 0.69) could not be related to BC since there was no significant difference in mean or ranges of the % components of BC, although the number contributing to the ranges differed (16 for BMI, 26 for %FM), likely to be a contributory effect.

This reduction in covariance in the overweight groups was contrary to the finding of de Boer (1987) who found BW to represent 82 % of variance in a group 40 % of whom were overweight, the others lean. Covariance in de Boer's study may apply less to a characteristic of the overweight subjects in her group than to the particular lean and overweight distribution in that study.

4.5 Generation and application of regression equations from study population data

Garby *et al.* (1988) observed that EE cannot usefully be related to a linear regression equation and, more recently, Butte *et al.* (1995) have proposed that from their study of infants, girls and adults, human energy requirements appear to be related to a power function rather than a linear function of BW and BC.

None the less, many equations predicting resting or basal energy requirements are of the linear type, for example those proposed by Schofield (1985) and subsequently included in Dietary Reference Values for Food Energy and Nutrients for the UK (Dept. of Health, 1991). These equations continue to be widely used in practical and clinical fields.

On consideration of the differing degrees of covariance of GBMR with BW and BC in the separate groups across the full range of the population, it was appropriate to examine the effects of imposing a linear equation on data which show evidence of departure from linearity.

The questions had been -

a) If a linear regression equation derived from a large population (referred to as a 'full range equation') was used to predict mean GBMR for a smaller, less widely ranging group, was there a discrepancy between estimated mean and mean measured GBMR and was the magnitude of the discrepancy ?

b) If there was a discrepancy, can the discrepancy be reduced by the use of an equation relating more specifically to that group (referred to as a 'group specific equation') ?

c) Where was the area of greatest discrepancy ?

d) Did the difference achieved by the use of a group specific equation have any practical or clinical relevance ?

The term 'estimation' is used here to denote a value obtained by calculation from an equation obtained either from the population data or from another source such as the equation by Schofield. The term 'assessment' is used to denote a value obtained by measurement or derived directly from measurement.

The most usual purpose of assessment or estimate of energy expenditure is to use the evaluation as a means of estimating energy requirement and what is regarded as an 'important' or 'significant' as an energy discrepancy must be somewhat subjective. Just as energy expenditure is variable, energy intakes vary from day to day, the combined effects still allowing weight to be maintained.

The study of Taggart (1962) showed that her energy intake was reduced during weekdays and increased during weekends by about 4000 kJ, she lost a small amount of weight, about 500g on weekdays, regained the weight during weekend days and maintained BW over the 11 week period of the study.

Regulation of food intake appears to be associated primarily with the maintenance of carbohydrate balance (Flatt, 1993,1996). The work on mice was also demonstrated in humans (Stubbs, 1996) where changes in food intake appear to be regulated over a period of days and with the aim of maintaining glycogen stores. EE is likely to be similarly variable in a normal healthy human. Variability within an individual appears to be of the order of 300 to 400 kJ/24 hours (Soares and Shetty, 1986). At about 90 kcal. this would be approximately 4.5% of an intake amounting to 8.4 MJ or 2000 kcal, 5.1% of 7.4 MJ or 1750 kcal, 6.0% of 6.3 MJ or 1500 kcal. The repeatability limit of 3% set in this study is approximately. 250 kJ or 60 kcal as a percentage of 8.4 MJ / 2000 kcal energy intake. Where intake is larger, the percentage would be less, however where customary intake

might be low, perhaps in the leanest subjects, the relevance of any discrepancy would be a matter for experienced judgement.

Any discrepancy between measured value and estimate must be regarded with caution since the theoretical estimate is based on the assumption that the equation applies equally to all in the group and although measurement may be done with all possible care, it remains the measurement of a variable entity. A version of the 'uncertainty principle' may apply here, since the mere act of measuring EE is likely to cause it to change. With that caveat, throughout the study, the same conditions were used, the same equations were applied uniformly and the results were compared with one another.

The relationships of GBMR with BW are discussed below, those with FFM at section 4.6.

4.51 Relationships of GBMR with BW

The relationships of GBMR with BW were investigated using BW itself, BW substituted in the equation proposed by Schofield (1985) and recommended in Dietary Reference Values for Food Energy and Nutrients (Dept. of Health, 1991), and BW to the power function $BW^{0.75}$.

In addition to consideration of the mean values for the study population and the groups within it, individual values were also examined. Predictive equations should not be used to predict GBMR for individuals, however all groups are made up of individuals and it is appropriate to consider the range and distribution of discrepancy for individuals within that group. An apparently close fit of estimated mean GBMR with the mean of measured values may hide substantial lack of fit for an individual.

The pattern of investigation shown below is that used in 'Results' (page 82)

1. The full range and group specific equations were tested by substituting full range and group specific means of the appropriate parameter and, except where identified, the equations gave estimated values in close agreement with measured means.

2. GBMR data obtained by measurement were compared with data derived by estimate using full range and group specific equations, as detailed below. Discrepancy (in practical terms) or difference in residuals (in statistical terms) was then calculated. The term 'discrepancy' is used here.

    a i) Mean BW for full range and each group was substituted in -

    the full range regression equation for the study population

    the group specific regression equations

    estimated values were then compared with the mean measured GBMR

    a ii) Individual BW was substituted in -

    the full range regression equation for the study population

    the group specific regression equations

    each estimated value was then compared with each individual measured GBMR

    b i) Mean BW for full range and for each group was substituted in -

    the equation proposed by Schofield (1985, 1991)

    (there is no equivalent of the group specific equation)

    estimated values were then compared with mean measured GBMR

b ii) Individual BW was substituted in -

the equation proposed by Schofield (1985, 1991)

each estimated value was then compared with each individual measured GBMR

c i) Mean BW for full range and for each group was substituted in -

GBMR related to $BW^{0.75}$

This relationship makes some allowance for the distorting effect of low and high body weight and may compensate the non linear effect in the population data to some extent. Equations were derived for the full range of subjects and for each group.

Results were obtained using

the full range regression equation for the study population

the group specific regression equations

estimated values were compared with mean measured GBMR

c ii)Individual BW was substituted in the equation relating GBMR to $BW^{0.75}$

Results were obtained using

the full range regression equation for the study population

the group specific regression equations

each estimated value was then compared with each individual measured GBMR

4.511 Mean GBMR estimated using full range and group specific equations substituting BW.

In order to quantify the effects of use of full range and group specific equations in the estimation of mean GBMR of the groups within the population -

Mean body weight for each group was substituted in -

the full range regression equation for the study population

the group specific regression equations

estimated values were then compared with mean measured GBMR and the differences quantified (kJ / kcal)

Full range equation

Standard groups

- In the standard groups, the full range equation underestimated mean GBMR by 3.9%.(BMI) and 3.2% (%FM), this is near the error limit of many methods of assessment and at approximately 180 to 220 kJ or 40 to 50 kcal. was an acceptable approximation.

Overweight groups

- In the overweight groups, the full range equation overestimated mean GBMR by 5.2 % in G>25BMI and 4.8% in G >30%FM.

  A finding of overestimation in overweight subjects was also described by Schofield (1985) who cited the 1973 WHO / FAO standards which had overestimated GBMR by 10 % in subjects of 50 kg and almost 18 % by the end of the scale (85 kg)

  Although, in this study, the discrepancy between estimated mean GBMR based on

mean BW in the overweight groups and the measured mean GBMR was much smaller than that quoted by Schofield, there were examples of large individual overestimates, for example, one of 20 % (1260 kJ).

This overestimate was obtained by substituting BW in the full range equation, as would be the case if the WHO / FAO regression equations were used as described by Schofield.

Lean groups

- In lean subjects, however, there was a greater degree of over-estimation of group mean GBMR by the full range equation, particularly in the leanest group, G < 20%FM amounting to 10.1 % or approximately 450 kJ.

  Mean GBMR in the less lean group G <20BMI was also over-estimated but the discrepancy was of much less practical significance amounting to 4.1 % (approximately 200 kJ) .

  The pattern of over and under-estimate is a reflection of the trend shown by uBMR values, the effect being modified by the magnitude of BW.

It would appear from the data that, while the full range equation gave good representation of mean GBMR for the standard groups and acceptable representation in practical terms of the mean of overweight groups, it would be preferable in the case of the leanest group G<20%FM to use an equation derived from data for lean subjects.

The group equation derived from this group data in the study produced a value which while it did not match measured mean for the group, gave an over-estimate which was within 3.5 % of the measured mean GBMR compared with the 10% given by the full range equation.

4.512 Estimation of individual GBMR by full range and group specific equations substituting individual BW

Estimates of individual GBMR were made first using the full range equation, then using the group specific equation. Each estimate was then compared with individual measured GBMR.

The magnitude of the range width and distribution of discrepancy are shown in Table 9, page 86 and in Figures 14 and 15, page 86a.

Prediction made on the basis of regression analysis can give only an approximation of a biological parameter and furthermore, recommendation or prediction which is intended to apply to a group must incur large discrepancies if individuals are considered, however groups are made up of individuals and it was appropriate to consider the magnitude of the discrepancy possible.

There were examples of wide ranges of discrepancy when individual measured GBMR values were compared with those estimated from the full range equation. The range width was reduced only marginally by the group specific equation with the exception of that in the lean groups. The ranges had been redistributed, more negatively in the overweight groups and more positively in the standard groups i.e. by moving the range up or down, the group specific equation had come closer to the measured mean.

Lean groups

- In the case of the lean groups, the range of discrepancy was very wide, 46.3 and 32.2% reduced to 26.7 and 23.9% in G<20BMI and G<20%FM respectively. The magnitude of difference using the full range equation reached 29 %, an over-estimate of 1040 kJ or 250 kilocalories / 24 hours in a lean individual, important for that individual. This was

reduced to 16 % by the group specific equation. An under-estimate of 17.5% (1164 kJ) was reduced to 11.9% by the group equation.

Overweight groups

- In one overweight individual the over-estimate of 20% amounted to 1264 kJ or approximately 300 kilocalories / 24 hours

  The finding of very large overestimates in overweight subjects bears out the observation of Schofield (1985), the overestimate of 20 % was found in the heaviest subject in the study population. This was reduced to 9.3% using a group specific equation (G>30%FM), still a large discrepancy. This group highlighted the changes in predicted values which could be achieved by modifications in selection criteria. The prediction for this heaviest individual could be 'improved' to an overestimate of 4.9% by using the group specific G>25BMI equation, a group to which she also belonged. The discrepancies in quantified terms were approximately 1300, 600 and 300 kJ. Although this was a very striking example, this principle could be applied throughout.

Standard groups

- The standard groups, where estimated group mean GBMR had been approximately 3 to 4% of measured mean obtained by the full range equation, also showed wide discrepancies, from an over-estimate of 19.3% equivalent to 853 kJ (204 kcal) to an under-estimate of 17.5% equivalent to 1164 kJ (277 kcal). Using a group specific equation, the range was slightly narrowed and redistributed more positively, thereby reducing the under-estimates. Each of these large discrepancies would be highly relevant to that individual.

While it is recognised that group estimates of EE have very limited application to individuals in the group, any equation which may reduce the magnitude of the discrepancy is worthy of consideration. The range of discrepancy was, however, reduced by the use of a group specific equation only in lean groups. In overweight subjects the range of discrepancy produced by the group equation was, in fact slightly larger, but the range was distributed more evenly about zero, thus having the effect of reducing the degree of overestimation apparent in the mean. Considerable differences in discrepancy in predicted values could be produced by changes in the constituency of the groups from which data are generated, even where the groups belong to the same general 'body type'.

4.513 Summary of relationship of GBMR with BW.

In summary, equations substituting BW acceptably represented mean GBMR in large groups and in smaller groups of standard BC, however there was evidence of considerable variation in degree of covariance.

The full range equation using BW in standard and overweight groups in this study population represented mean GBMR with estimated values not markedly different in practical terms from the measured mean GBMR of the groups, although these differences were statistically significant and may be practically important in circumstances where there is a small margin for error.

Mean GBMR was not well represented by mean BW in the leanest group by the full range equation and a smaller discrepancy could be achieved by using a group specific equation derived for lean subjects. The use of the full range equation resulted in large discrepancies between estimated and measured values for some individuals in all BC groups. These discrepancies could be reduced for a number of these individuals by the use of a group specific equation, but mainly at the expense of increasing discrepancies in other individuals in that group.

4.52 Estimation of GBMR substituting BW in the equation of Schofield (1985, 91)

The equation by Schofield, recommended for use in women of this age group (Dietary Reference Values for Food Energy and Nutrients for the UK, 1991), provided useful comparison with the BW and later with $BW^{0.75}$ equations which were both derived from data of the study population itself. It could only be used, however, as a 'full range' equation, therefore there is no equivalent, in this section, of the group specific equation.

4.521 Estimation of full range and group mean GBMR substituting mean BW of full range, BMI and %FM groups in the equation of Schofield (1985, 91)

Full range equations

Where full range equations derived from the study population data were used to estimate the means of the full range, estimates were predictably very close to measured. This can be compared with the equation of Schofield which overestimated the full range mean by 4.7% (approximately 250 kJ / 60 kcal.), which as observed earlier, when considered as a number of kilojoules or kilocalories, would be likely to be acceptable in practical terms. Not all areas of the full range, however, were equally well represented by the equation of Schofield.

Standard groups

- Unlike the other equations, Schofield's equation did not underestimate GBMR in the standard groups and gave the best estimate (see comparative Table 19, page 108b and 109a and Figure 25, page 108a) of group mean GBMR for this body composition, within approximately 1% of the measured mean. (Table 10, page 89)

Overweight groups

- In the overweight groups there were, however, significant over-estimates.

  Mean GBMR was overestimated in G >25BMI by 11.6 % and in G >30%FM by 10.7 %.

  These discrepancies in mean GBMR in the overweight groups at 600 to 700 kJ were considered to be large enough to be relevant in practice.

Lean groups

- The largest overestimate was found in the mean GBMR of the leanest group, this amounted to 13.4 % compared with 7.7 % in the less lean G <20BMI group.

  The discrepancies found were predictable in view of the uBMR values found in lean subjects. Particularly in the leanest group they would be likely to be important in practice, and they provide further evidence for the requirement for a more specific predictive equation when this BC type is considered.

4.522 Estimation of individual GBMR substituting individual BW in the equation of Schofield (1985, 91)

Individual discrepancies found by using this equation were larger than any found using any of the equations considered, for example 30 % (1900 kJ) in an overweight subject and 32 % (1150 kJ) in a very lean subject. (Table 11, page 91, Figure 17a and b, page 91a)

Even within the standard groups where the mean GBMR had been within approximately 1% of measured mean, the range of discrepancy was between +24.4% (in BMI) to - 13.5% (in %FM)

While equations which are intended to be applicable only to the estimation of group means should not be used in the context of an individual, the magnitude of difference which might be incurred should be considered.

This tendency to produce very large discrepancies at the extreme ends of the population range is always likely when a linear relationship is imposed on non-linear data. The comment of Garby and Lammert (1994) about the nonsensical application of linear equations when BW is increased by an increase in the proportion of FM, applies here to the overweight end of the study population but the same argument cannot be used for subjects at the lean end of the range.

One can only speculate as to which factor or factors affecting the tissue mass might underlie the overestimates here, but it can be taken as yet more evidence for the requirement for a separate equation more appropriate to this very lean group of the population.

4.53 Estimation of GBMR using $BW^{0.75}$

Where subjects of similar height but different BW are compared, BMR per unit tissue appears higher in the lighter individual. Where an individual assessment is made, the distortion is likely to be due to the difference in BC, where BMR is estimated from a linear equation, the positive intercept of the slope has a distorting effect. Any error of estimation will be magnified in a low body weight subject and, in the absence of any means of assessing BC, one measure suggested was the use of a power factor.

It has been shown by this study that BW itself considerably overestimates GBMR in lean groups. The classic expression where BMR was related to $BW^{0.75}$ was used in this study to assess the effect of use of a power factor.

4.531 Estimation of mean GBMR substituting mean $BW^{0.75}$ for full range, BMI and %FM groups in full range and group specific equations.

The regression equations constructed from the study data relating GBMR to $BW^{0.75}$ provided an estimate of mean GBMR which, in the case of the leanest group, came closer to measured mean GBMR , although, of course, the values of the Pearson coefficients were very similar to those for BW itself.

The discrepancy between estimated and measured group means was still significant, but was reduced in the area of greatest discrepancy, G<20%FM from 10.1 % with BW to 9.3 %. with $BW^{0.75}$ (Table 8, page 84 and Table 13, page 93). The difference between the two, however, amounted to approximately 40 kJ (see summary at Table 19, page 108b), unlikely to be relevant in practical terms.

Both $BW^{0.75}$ and BW gave closer estimated mean GBMR values for lean groups of subjects than did the equation using BW by Schofield (1985) which had produced discrepancies of 13.3 % for G<20%FM and 7.7%. for G<20BMI.

4.532 Estimation of individual GBMR substituting individual $BW^{0.75}$ in full range and group specific equations

Full range equations

Large discrepancies were again found in all groups using the full range equation, the range width in most groups being of the order of 30%, apart from G<20BMI where the range width was approximately 45%. The range in the less diverse G<20%FM was 31.4%

Group specific equations

In overweight and standard groups the effect of a group specific equation was a reduction in range width of about 3 to 4 %

In lean groups the reduction in range width in G<20BMI was approximately 6% and 9% in G<20%FM. The group specific equation also had the effect of redistributing the range in the lean groups more evenly about zero (Table 14, page 95, Figures 19a and 19b, page 95a) The use of the power function of $BW^{0.75}$ did marginally reduce the error of estimate of the mean GBMR in lean groups compared with BW, this was further reduced by the use of a group specific equation substituting $BW^{0.75}$

The ranges of individual discrepancies were large, but could be reduced particularly in the leanest group by the use of a group specific equation.

4.54 Preliminary summary of comparison of regression equations relating GBMR with BW

The expressions used substituted BW itself, BW in the equation of Schofield (1985, 91) and $BW^{0.75}$

4.541 Mean GBMR of study population and groups within the population

(See Table 19, page 108b and Figure 25, page 108a and 109a)

It would appear that-

1. **full range** mean GBMR was overestimated by the equation by Schofield although providing a value likely to be within acceptable practical limits. (BW and $BW^{0.75}$ equations were constructed from the study population data)

2. **standard groups** mean values of GBMR were well represented by the equation of Schofield (BW and $BW^{0.75}$ equations were constructed from the study population data)

3. **overweight groups** mean values of GBMR were more closely represented by equations using either $BW^{0.75}$ or BW itself. The Schofield equation most over-estimated

mean GBMR in overweight groups by margins which would have been of practical relevance, indicating a full range population different from that used to construct the predictive equation..

4. **lean groups** were best represented by $BW^{0.75}$ or BW but with equations appropriate to their specific body composition. The leanest group G<20%FM was greatly over-estimated by all equations, even the group specific equation using $BW^{0.75}$ gave discrepancies in mean GBMR which would be considered relevant in practical terms.

4.542 Individual GBMR and BW

The Individual records show subjects with the same BW with a difference of approximately 17 % in GBMR and conversely, individuals with less than 1 % difference in GBMR with W difference of 16 kg. Clearly, BW or $BW^{0.75}$, while providing acceptable correlation with GBMR in large groups, represent only a proportion of the variance in GBMR.

The range of individual discrepancies in all groups, using all equations, was large. (see Tables 21 and 22)

1. Overweight and lean subjects showed the greatest discrepancies particularly where the equation of Schofield was used

2. where BW itself was concerned, the range could be reduced in the lean groups by the use of a group specific equation.

3. In the case of $BW^{0.75}$, the range could be reduced by a group specific equation in G <20%FM but not in the more variable group G <20BMI.

4. From the evidence of the individual records, the effect of use of a group specific equation was to achieve a better mean by redistributing the range of discrepancy

5. Marked differences in discrepancy of estimate could be produced by selection of different group specific equations even within the same general body type.

4.6 Fat Free Mass

As discussed under uBMR, FFM is not a single uniform compartment in spite of the overall EE conventionally assigned to it, but is a multicomponent assembly of tissues each with complex regulatory systems and fuel usage. It has been proposed by many authors that FFM as the higher contributor to EE, might be more closely related to GBMR than BW. FFM in this study did represent a higher proportion of variance than BW, in the population as a whole (57%), increased in the two groups of 'standard' BC to 64 - 67%.

Where FM constituted a large part of BW, covariance of GBMR with FFM was lower, the simplest reason perhaps being that as the proportion of FFM decreases, the effect of a large mass of tissue with a markedly lower EE would reduce the degree of covariance with FFM. On that basis, where FFM was the predominant tissue covariance with FFM would increase. This was not the case in this study where the value of the Pearson coefficient was reduced in lean groups.(r = 0.75 for full range to r = 0.66 and 0.72, see Tables 15 and 16, page 100)

It was true however that where BW was predominantly FFM i.e. in the lean groups G<20BMI and G<20%FM, BW rather than FFM was more closely related to GBMR (r = 0.66 and 0.72 for FFM compared with r = 0.87 and 0.85 for BW, see Tables 15 and 16, page 100, and Tables 5 and 6, pages 74 and 76)

When the slopes of GBMR with FFM in the BMI and %FM groups were compared with those given for GBMR with BW, it became apparent that the pattern of covariance differed. In the case of GBMR with BW in either grouping, the slopes for the three groups were distinct from one another. In the case of FFM, however, there was discontinuity between the slopes only in the leanest group G<20%FM with the other two %FM groups and in the heaviest, highest fat mass group G>25BMI whose higher mean FM and BW had produced a slope statistically different from the standard and lean BMI groups. It would appear that for FFM, departure from linearity became significant only at the extreme ends of the range and that predictions using FFM were less affected by BC differences i.e. a linear expression using FFM would theoretically have fewer areas of discrepancy when used to predict BMR in a population of varied BC. This proved to be the case in the estimated means for overweight and standard groups in the study population.

The discrepancies among lean subjects however were very marked.
The characteristics of individual subjects in the lean groups merit examination.
The leanest group numbered 11, some of whom could be described as 'lean and fit', some were 'thin and light' and 3 were extremely thin. As identified earlier, no attempt had been made to recruit or exclude any particular body type and no medical history could be verified (none was pregnant, diabetic, or replied negatively to 'are you well ?' or 'do you feel well ?') The subjects were almost all students and if they were attending classes and did not have a current acute medical condition (when they would in any case be unlikely to present themselves for test) they were assumed to be 'normal, healthy' members of the young female population. They had been recruited throughout the study as and when they presented themselves, although the data pertaining to them have been shown as a group in the appendix (see Method section, page 63)

It was clear from the mean and SD of the differences between estimated uBMR and uBMR derived from measurement that although all the subjects with less than 20%FM had all been described as 'lean', they were very different and it is worth noting that in any random sample of lean women, there may be the athletic 'low fat mass' lean individuals and the 'possibly anorexic' lean.

Reference has already been made to the work of Maughan (1994) who found that young women long distance runners not infrequently had less than 10%FM. He found that these women consistently show a lower than expected intake to maintain their weight. Maughan said that there was no obvious physiological explanation for this and that it may be due to methodological error in the calculation energy intake and expenditure, but observed that it is odd that it should apply specifically to this group of athletes. It must be presumed that these athletes, in order to be able keep performing at a level acceptable to them, must be approximately in energy balance, since a progressive loss of weight would affect performance.

The lowest %FM in the study population was 11.9% but it was clear from the results of uBMR calculation that there were some unexpectedly low values of EE. the lowest being 57J/kg/min. with the mean for the leanest group of 64 J/kg/min, a finding which would support the findings of Maughan (1994) of low energy expenditure. The low energy expenditure with marked variability would be in agreement with the model of Dulloo (1997)

It is possible that low energy intake and consequent adaptation may be characteristic of some of the very lean subjects in G <20%FM, resulting in variability in the contribution of FFM to total energy expenditure at low %FM. Covariance of GBMR with FM (kg) showed a Pearson value of 0.91. This high value may be due simply to a mathematical effect, but it might be speculated that in the very lean, GBMR may be related to absolute FM.

Considering the full range of this study population, if judged only by covariance coefficients, GBMR in overweight and standard BC women was better represented by FFM than BW. GBMR in lean women was better represented by $BW^{0.75}$ or BW, but not where BW was used in the equation of Schofield.

As before, analysis of variance was used to derive regression equations then used to estimate GBMR. The same pattern of full; range and group specific equations was used to estimate group mean and individual GBMR values which were compared with the measured values.

4.61 Estimation of mean GBMR in full range, BMI and %FM groups comparing full range and group specific equations substituting FFM

When mean GBMR was estimated using full range and group specific equations, full range mean was represented very closely by the full range equation. The group means were well represented by the group equations with only groups G>30%FM and G20-30%FM differing by 2.7 and 1.6 % respectively.

When group means were estimated using full range equations, discrepancies were produced which could be reduced in all groups by using the group specific equations.

Lean groups

- The difference between full range and group specific estimation was most noticeable in the lean G<20BMI (6.7%) and G<20%FM (16.0%), see Table 17, page 104 and Figure 22, page 104a. These discrepancies amounted to overestimates of approximately 320 and 700 kJ respectively, the latter likely to be highly relevant for the leanest members of the group. In these two groups FFM made up a large percentage of total mass and the discrepancy produced by the full range equation subsequently reduced by an equation derived from this particular group, may reflect differences discussed

previously in EE of FFM or some component of FFM in these very lean individuals and certainly reflects a difference between EE in the very lean and the full range mean. Where the selection of lean subjects was made by BMI, this large overestimation of mean GBMR was obscured, only becoming apparent when the stricter criterion of a limit of 20%FM was applied.

Standard and overweight groups

- The results indicated that FFM represented GBMR well in standard and overweight groups, the largest discrepancy (in standard groups) amounted to an underestimate of only 170 kJ / 40 kcal.

4.62 Estimation of individual GBMR using full range and group specific equations substituting FFM

When individual GBMR estimates were made substituting individual FFM (kg) in the full range equation then in the group specific equations, the largest discrepancies were again found in the leanest groups. The range width of 45.9% in G<20BMI narrowed to 41.2% using the appropriate group specific equation and in G<20%FM, the range width narrowed from 34.2% to 29.6% The distribution of discrepancy was more negative therefore more evenly about zero, reflecting the improvement in estimate of the mean found earlier (see Table 18, page 105 and Figs 23a and 23b, page 105a).

Redistribution of the range of discrepancy had occurred in all the groups.

The wide range of discrepancy found in the lean groups reflected the wide range found in uBMR values, as suggested earlier, the lean groups, particularly G<20%FM, included individuals whose %BC was not greatly different, but whose unit BW (or unit FFM) appeared to have very different characteristics.

4.70 Fat mass

FM plays an important role in the energy economy acting as a large energy reserve and covariance of GBMR with either BW or FFM was clearly affected by its magnitude.
FM compartment in this study population varied from 11.9 to 40 % and was significantly different from one group to another whether partitioned by BMI or %FM ($p < 0.001$) .
Since %FM appeared to have a strong influence on uBMR, particularly in the leanest subjects where its relative absence appeared to affect EE of the composite tissue which was largely FFM, it appeared to be appropriate to consider covariance of GBMR with FM (kg) .

It is less usual for GBMR to be correlated with FM, however, Cunningham (1991), in his review of the potential effect of FM, has cited studies by Bernstein *et al.* (1983) and Garrow and Webster (1985ii) where FM was considered to be a significant factor. Webb (1981), Ravussin *et al.* (1982) and Ferraro *et al.* (1992) have all found FM to be a significant determinant of BMR in overweight subjects. In those studies where FM was a significant factor, all the subjects were women and most were overweight.
Cunningham observed that it may be that, in women, the contribution of FM becomes appreciable as BW increases above normal and that this factor is sex specific and masked in mixed sex data sets.

4.71 Covariance of GBMR with FM in study population

Unlike the studies cited by Cunningham, data from this study found covariance with FM in the overweight groups was significant only at $p < 0.05$ in G >25BMI ($r = 0.52$) and at $p < 0.001$ in G >30 %FM ($r = 0.58$) .
The means and ranges were very similar in the two groups, G >30 %FM being the larger of the two groups numerically.
Covariance with FM in standard groups was less significant with $r = 0.47$.

Analysis of covariance however produced a Pearson coefficient of 0.91 for GBMR with FM (kg) in the leanest group G<20%FM (see Figure 24, page 106a).

The high value for covariance in the leanest group, r = 0.91, was not matched in the more variable and less lean group G<20BMI, again indicating a difference disclosed by selection for the leanest subjects.

The values of uBMR, which might have been expected to be high where FFM is high were in fact lower in the leanest subjects, and, echoing the speculation of Maughan (1994), it might be that the covariance may suggest a progressive lowering of EE as FM is reduced in these very lean women.

4.8 Comparison of estimates of GBMR and practical relevance of discrepancies between estimated and measured values.

The equations used were those substituting BW, BW in the equation of Schofield (1985,91), $BW^{0.75}$ and FFM, estimates were made of -

1. full range mean GBMR
2. group mean GBMR
3. individual GBMR

4.81 Full range equations used to estimate mean GBMR for the full range of the study population

As would be expected, where a full range equation was derived from the population's own data, there was no significant difference between mean measured GBMR and mean GBMR estimated using that equation. This applied to equations substituting BW, $BW^{0.75}$ and FFM. where the discrepancies were all less than 0.5% (see Table 19, page 108b and Figure 25, pages 108a and 109a)

The discrepancy produced by substitution of mean BW of 90 subjects in the equation of Schofield was 4.7% This discrepancy in fact amounted to 255 kJ or 61 kcal. a discrepancy of little or no relevance in practical or clinical terms.

The equation by Schofield, recommended for use in women of this age group (Dietary Reference Values for Food Energy and Nutrients for the UK, 1991), while over-estimating the mean, provided representation of the mean GBMR of the group as a whole with a difference from the measured mean which was not likely to be of practical or clinical relevance. Good representation of the means of the full range and standard groups however obscured considerable overestimates in overweight and lean groups.

4.82 Comparison of estimates of group mean GBMR using full range and group specific equations

The discrepancies produced by each of the full range equations were compared with those produced by group specific equations for each parameter, group mean parameter values being substituted.

Comparison showed the following - (the figures used below can be found in Table 19, page 108b and 109a and Figure 25, page 108a)

Standard groups

- **both BMI and %FM were best represented by BW substituted in the equation of Schofield.** The over-estimates were 1.3% and 0.2% respectively amounting to 73 and 17 kJ (17 and 4 kcal) - a very close estimate in each group.

  Full range equations using the other parameters, BW, $BW^{0.75}$, FFM all underestimated mean GBMR in standard groups by approximately 3 to 4% but at approximately 170 to 200 kJ/ 40 to 50 kcal , representation of mean GBMR of standard groups by a full range equation using those parameters could be considered as good.

Overweight groups

- **mean GBMR was best represented by FFM**, with an overestimate of 1.0% and 0.5% in G>25BMI and G>30%FM respectively, and least well by the equation of Schofield, 11.6% (approximately 700 kJ) and 10.7% (approximately 600 kJ) . Both of latter discrepancies would be considered as relevant in practical terms.
  Both BW and $BW^{0.75}$ over-estimated mean GBMR in overweight groups by about 5% (approximately 270 - 300 kJ) . Where it is not possible or desirable to measure FFM, either BW or $BW^{0.75}$ in an equation reflecting the group would give a better estimate of mean GBMR in the overweight than Schofield's equation.

Lean groups

- **were best represented by $BW^{0.75}$**, supporting the original proposition of the use of a power function of BW for lean and low weight subjects.
  The full range equation substituting $BW^{0.75}$ produced discrepancies of 3.6% (174 kJ/ 41 kcal) for G<20BMI but 9.3% (405 kJ/ 96 kcal) for G<20%FM, the latter a large over- estimate in this leanest of groups. This finding supported the finding reported by Maughan (1994) of apparently low energy requirements in very lean women and the very evident need to consider them separately.

When compared with one another, the groups showed the effects of the number and composition of the groups. G<20BMI was more numerous, more varied and had higher mean %FM (Tables 3 and 4, pages 70a and 71a) and was better represented by all equations than was G<20%FM.

While all equations over-estimated mean GBMR in each lean group, in G<20BMI the largest over-estimate was by the equation of Schofield at 7.7% (c.f. FFM at 6.7%) and in G<20% FM, the largest over-estimate was by FFM at 16.0%.

4.83 Comparison of individual estimates of GBMR using full range and group specific equations

When individual GBMR was estimated for the 90 subjects using full range and group specific equations, each equation gave a wide range of discrepancy. The equations are not intended to be used to estimate individual GBMR, but it is appropriate to consider how an equation being used to estimate population or group mean might represent the individuals making up the population or group.

The figures given below for range width can be found in Table 20, page 111b and Figure 26a, page 111a, and for range distribution in Table 21 and Figure 26b on the same pages.

Standard individuals

- **In standard groups, range width of individual discrepancy was least when FFM was used, this was not reduced when a group specific equation was used** (there is no equivalent of a group specific equation of Schofield), although the distribution was more evenly about zero, indicating that the magnitude of the larger discrepancies would be reduced.

  The range width produced by BW, BW substituted in Schofield equation, and $BW^{0.75}$ was approximately 33% in G20-25BMI and 29% in G20-30%FM.

  The largest over-estimate of 24.4% was produced by the equation of Schofield in the BMI group

  BW and $BW^{0.75}$ each produced larger under-estimates at approximately 14% in the BMI group and 17% in G20-30%FM, these were not usefully altered by the use of a group specific equation.

Overweight individuals

- **BW, $BW^{0.75}$ and FFM produced ranges of 27 to 29%, with those from FFM most evenly distributed about zero. The ranges were reduced by the use of group specific equations.**

  The results for BMI and %FM groups were very similar.

  The largest range width of discrepancy occurred with the equation by Schofield, approximately 33%, the equation of Schofield also gave the largest over-estimate of 30%. There is no equivalent of a group specific equation for the equation of Schofield, however the other group specific equations each reduced the range width by about 3 -4%, with the exception of FFM in G>25BMI where there was a reduction in range width of about 7%.

Lean individuals

- **The greatest range width of discrepancy occurred in G<20BMI, estimates using BW, BW using the equation of Schofield, and FFM in full range equations all showing a range of discrepancy of approximately 45%. The use of a group specific equation narrowed the range width most with BW,** from 46.3 to 26.7% in G<20BMI (approximately 20%) and 32.2 to 23.9% in G<20%FM, (approximately 8%). There was a reduction of 6 to 8% with a group specific equation using $BW^{0,75}$ and 4 to 5% with FFM.

  The magnitude of this range of discrepancy in G<20BMI reflected the more diverse BC in these subjects when compared G<20%FM where, again using full range equations, narrower ranges of discrepancy were found, approximately 31 to 34%

  The distribution of discrepancy also pointed to the difference between the two groups, in the case of G<20BMI the range was more evenly distributed about zero, while the discrepancy in G<20%FM consisted mainly of over-estimate.

The most striking difference produced by the use of the group equation was the redistribution of what had been almost entirely over-estimate in G<20%FM to a much more even pattern of over and under-estimate, thereby reducing the largest over-estimates. This change in distribution along with a reduction in range width underlies the improvement in estimate of mean GBMR when the group specific equation was substituted for the full range equation.

It would appear from the results that the use of a group specific equation most improved estimates for the lean groups and reinforces the argument for a special case to be made when considering EE in very lean women.

4.9 Summary of conclusions

This study was designed to investigate the relationships of GBMR with BW and BC in a group of 90 women aged 18 to 30 years, the nature of the data when produced guided the lines of enquiry.

Analysis of covariance of GBMR with BW and with FFM showed in each case values sufficiently different from one another in different sectors of the full range of the study population to prompt the questions -

1. Did the EE of unit tissue mass vary across the range of body compositions in the study population ?
2. What might this be attributed to ?
3. With respect to GBMR, what were the discrepancies between measured mean GBMR for the groups within the population and the mean GBMR for these groups estimated from linear regression equations derived from the data of the full range of the study population (full range equations) ?

4. Was the discrepancy reduced by a group specific equation ?

5. Which of the relationships of GBMR with BW or BC best represented the study population and its groups ?

6. Did the differences produced by use of either full range and group specific equations to predict mean GBMR have any practical or clinical importance?

7. What characterised the areas of greatest discrepancy in mean estimates?

8. Predictive equations should be used for groups, not for individuals, but what might be the range of discrepancy for the individuals in any group ?

The results of the study summarised as responses to the questions were as follows -

1. *Did the EE of unit tissue mass vary across the range of body compositions in the study population ?*

When BMR values / kg composite tissue mass - uBMR- were plotted against %FM, the distribution was significantly curvilinear, with lower values not only where %FM was high as might be expected, but also where %FM was low.
This curvilinear distribution was clearly a factor underlying the polynomial or at least, less than strictly linear distribution of GBMR with either BW or FFM.

2. *What might this be attributed to ?*

The reasons for the uBMR distribution can only be a matter for speculation, in the absence of relevant biochemical data, however the distribution of uBMR values was clearly associated with BC.
It was not the case that the higher EE compartment, FFM, when present at its maximum in the range, produced the highest unit EE. This could only be said of subjects above approximately 15 to 18 %FM. Below this percentage fat mass, values of uBMR were

progressively reduced, suggesting that at low %FM, fat mass itself in percentage or absolute terms may become an important factor in the rate of EE of the composite mass. It might be speculated that a quantitative relationship between the two major compartments may be organised at the level of fuel use or fuel supply perhaps by a centrally regulated response to for example, frequently recurring shifts from glucose to an alternative fuel in the brain which in turn may act as a stimulus to the hormones of both the hypothalamic - pituitary axis and the axes of glucose regulation.

The lowering of EE in composite mass of very low %FM may be, not a primary effect stemming from adaptation in FFM, but a response in FFM, secondary to centrally mediated changes brought about by FM or %FM via glycogen reserve or by a mediator or mediators from FM itself.

3. *With respect to GBMR, what were the discrepancies between measured mean GBMR for the groups within the population and the mean GBMR for these groups estimated from the linear regression derived from the data of the full range of the study population (full range equations) ?*

4. *Was the discrepancy reduced if a group specific equation is used ?*

5. *Which of the relationships of GBMR with BW or BC best represented the study population and its groups ?*

6. *Did the differences produced by use of either full range and group specific equations to predict mean GBMR have any practical or clinical importance?*

Whatever the reasons for the curved distribution of uBMR, the effect was to move the distribution of GBMR away from linear, to lessen the effectiveness of predictive equations of the linear regression type and to add to the unavoidable effects of the inherent variability of energy expenditure.

Nevertheless, when the accuracy of prediction of mean GBMR was considered, the discrepancies produced by the non-linearity were of little practical consequence at least for the mean of the full range of the study group. Even where the equation was used which produced the largest discrepancy i.e. that of Schofield (1985, 91), the difference between measured and estimated means was less than would be likely to be considered relevant in practice.

Where standard groups were concerned, again all the full range equations produced estimates which were very close to measured, the equation of Schofield coming closest to measured mean for this group. This obscured the less good representation of mean values for groups who were other than standard.

When using a full range equation, overweight groups were best represented by FFM and least closely by Schofield's equation. In their case, where FFM cannot be assessed, the study population full range equation using BW itself gave an estimate of mean GBMR which would have been acceptable in practice.

Apart from lean groups, however, the effects of the non-linearity were minimal in practical terms and only a marginal improvement was gained when a group specific equation was used.

7. *What characterised the areas of greatest discrepancy in mean or individual estimates?*

The most noticeable effect of non-linearity was found where lean subjects were considered. The effect tended to be masked when subjects were grouped by BMI as 'lean', but when the very lean G<20%FM were treated as a separate group, it became obvious that all the full range equations greatly over-estimated mean GBMR. The largest discrepancies were produced by FFM in G<20%FM and the equation by Schofield in G<20BMI, the least discrepancy in both lean groups was given by $BW^{0.75}$.

It was in the leanest group that the largest improvement was achieved by the use of a group specific equation, this applied to each equation used. In each case, the discrepancy produced by the full range equation and the improvement achieved would have been relevant in practice. The magnitude of the discrepancies in this group were evidence of the need for very lean subjects to be considered separately.

8. *Predictive equations should be used for groups, not for individuals, but what might be the range of discrepancy for the individuals in any group ?*

The range of discrepancy was large in all groups using each full range equation. The group specific equations, while improving estimate of the mean, in many cases achieved this by redistributing the range of discrepancy. In some cases individual GBMR was better estimated by one group specific equation than the other in the equations representing the same parameter in the same general body type.

Standard subjects as individuals were best represented by FFM and least well by the equation of Schofield, indicating that good representation of the mean does not mean good representation of the range.

Overweight individuals showed the largest range width with Schofield's equation, the use of à group specific version of the other equations only marginally narrowed their range.

In the case of lean individuals, the difference between the two groups became evident, G<20BMI showed a wide range of discrepancy with all equations, while in G<20%FM the discrepancies were mostly over-estimates. This again indicated the need for this lean group to be considered as a separate group.

The original aim of the study was to examine the mathematical relationships of GBMR, BW and BC and the effects of scatter or lack of linearity in the distribution of data evident from published sources and subsequently from the study data. Because of the inherent variability

and the numerous sources of experimental error and lack of precision, apparently precise numerical relationships, comparisons and conclusions could be viewed in practice only as 'best estimates'. The experimental protocol could, with hindsight, have been modified to eliminate some of the lack of precision, but the apparently large differences in predicted energy requirement based on relationships between GBMR and BW or BC remained largely irrelevant when reduced to numbers of kilojoules or kilocalories and thought in terms of food intake.

Although at an individual level the error of prediction may have been large, a finding typical of prediction of energy requirement, the GBMR estimates given by the full range equations including that of Schofield were shown, on the whole, to be close enough for practical purposes. In any randomly selected population, however, there will be those who are lean or overweight or whose data are for some reason 'non standard'. In this study, because of their small numbers, their presence had little or no practical effect on predictions of energy requirements for the majority, although, for them, the error of prediction was greatest. This pointed to the need for further investigation with a larger population, also normally distributed, to evaluate the characteristics of the minority groups, particularly that group whose members are leanest, and to reduce the error of prediction of their energy expenditure.

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Addenda

Desai, I.D. (1989) Nutritional status and physical work performance of agricultural migrants in southern Brazil. *Proceedings of the XIV International Congress of Nutrition, Seoul, Korea.*, 297-301

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List of abbreviations

BMR basal metabolic rate
- GBMR gross basal metabolic rate / total body weight / 24 hours (megajoules)
- uBMR unit basal metabolic rate / kilogram body weight / minute (joules)
- RMR resting metabolic rate
- SMR sleeping metabolic rate

BC body composition
- %BC percentage body composition

BSA body surface area

BW body weight (kilograms)

DEXA/DXA
dual energy X-ray absorption

EE energy expenditure
- REE resting energy expenditure
- SEE sleeping energy expenditure
- 24EE energy expenditure over 24 hours

FAO Food and Agriculture Organisation

FFM fat free mass
- %FFM percentage fat free mass

FM fat mass
- %FM percentage fat mass

Groups within study population
- G >25BMI - those with BMI greater than 25 kg / m^2
- G 20 - 25BMI - those with BMI 20 - 25 kg / m^2
- G <20BMI - those with BMI less than 20 kg / m^2

- G >30%FM - those with greater than 30 % FM
- G 20 - 30%FM - those with 20 - 30 % FM
- G <20%FM - those with less than 20 % FM

J joule(s)
- kJ kilojoule(s)
- MJ megajoule(s)

kcal kilocalorie(s)

kg kilogram(s)

LBM lean body mass

m metre

min. minute

MRI magnetic resonance imaging

NMR nuclear magnetic resonance

p probability

r Pearson product moment coefficient

SD standard deviation

SEM standard error of mean

TBK total body potassium

TBW total body water

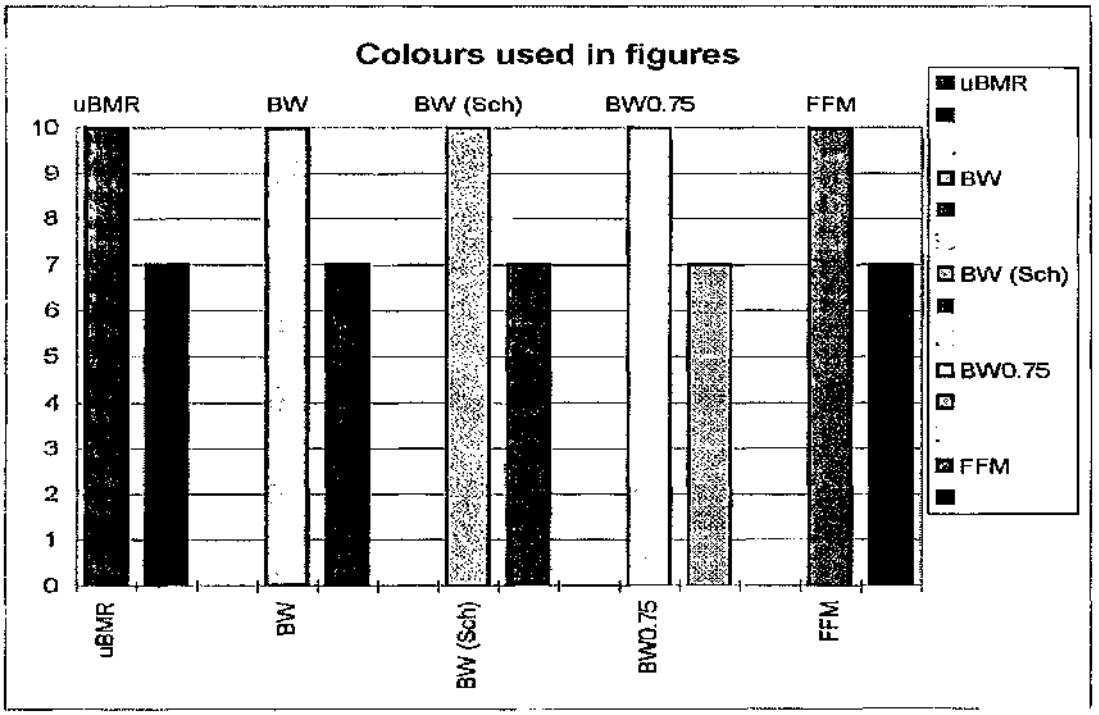
WHO World Health Organisation

List of abbreviations

Fold out 

Figure colour key

Fold out 



uBMR - unit basal metabolic rate (J/kg/min)
BW - body weight (kg)
BW (Sch) - body weight (kg) in equation of Schofield (1985, 91)
BW 0.75 - body weight$^{0.75}$ (kg)
FFM - fat free mass (kg)

Appendix contents.

List of regression equations

Data lists

Differences between individual measured/derived and estimated values of energy expenditure

Full range and group specific regression equations

Group	Equation
GBMR with BW (kg)	
Full range	0.0526 * BW +2.3386
G >25BMI	0.03 * BW + 3.644
G 20 - 25BMI	0.073 * BW + 1.310
G <20BMI	0.107 * BW - 0.562
G > 30%FM	0.04 * BW + 2.920
G 20 - 30%FM	0.09 * BW + 0.52
G < 20%FM	0.10 * BW - 0.19

Full range 2 ^{0} polynomial

$$y = -0.00x^2 + 0.24x - 3.43$$

GBMR with BW (kg) (Schofield)	
Full range	0.062 * BW + 2.036

GBMR with $BW^{0.75}$ (kg))	
Full range	0.201 * $BW^{0.75}$ + 1.169
G >25BMI	0.121 * $BW^{0.75}$ + 2.841
G 20 - 25BMI	0.381 * $BW^{0.75}$ - 2.386
G <20BMI	0.269 * $BW^{0.75}$ - 0.109
G > 30%FM	0.159 * $BW^{0.75}$ + 1.881
G 20 - 30%FM	0.323 * $BW^{0.75}$ - 1.129
G < 20%FM	0.346 * $BW^{0.75}$ - 1.849

GBMR with FFM (kg))	
Full range	0.117 * FFM + 0.398
G >25BMI	0.066 * FFM + 2.725
G 20 - 25BMI	0.125 * FFM + 0.229
G <20BMI	0.120 * FFM - 0.041
G > 30%FM	0.09 * FFM + 1.75
G 20 - 30%FM	0.13 * FFM + 0.22
G < 20%FM	0.10 * FFM + 0.39

Full range 2 ^{0} polynomial

$$y = -0.01x^2 + 0.65x - 11.41$$

Data 1A

FILE : DATA 1A BMI order

INDIVIDUAL CHARACTERISTICS OF THE STUDY POPULATION, ARRANGED IN ORDER OF BODY MASS INDEX (BMI) kg/m²

BC GROUP	Date	Height H (m)	Body Weight BW(kg)	$BW^{0.73}$ (kg)	B (mm)	T (mm)	SS (mm)	SI (mm)	B+T+SS+SI (mm)	% Fat	%Lean	Fat free mass (kg)	Fat mass (kg)	GBMR (MJ/24hrs)	uBMR (J/kg/min)	BMI BW(kg) / H(m²)
	25.12.84	1.575	99.8	31.60	17.5	36.5	15	43	112	40	60	59.8	40.0	6.330	44	40.27
	12.11.85	1.551	69.6	29.12	20	40	40	40	140	40	60	53.6	35.8	6.193	46	32.67
	8.1.85	1.561	75.2	28.30	15	30	20	29	94	36	64	50.0	28.2	6.193	55	32.69
	19.12.84	1.677	82.2	27.30	13	32	22	40	107	38	62	51.0	31.2	6.665	56	29.23
	22.5.84	1.526	62.6	22.23	10	34	36	20	100	37	63	39.4	23.1	5.670	63	26.87
	29.5.85	1.572	75	25.49	16	26	24	30	96	35	65	48.8	26.3	5.724	53	26.83
	12.6.84	1.626	70.5	24.33	12	28	30	35	105	36.3	63.7	44.9	25.6	5.178	51	26.67
	26.1.84	1.6	66.4	23.26	7	15	32	24	81	34.5	65.5	43.5	22.9	5.354	56	25.94
	22.5.85	1.524	59.6	21.45	10	15	25	27	80	33.6	66.4	39.6	20.0	5.407	63	25.66
	10.12.85	1.624	67.5	23.58	10	15	20	22	70	30.6	69.4	46.9	20.7	5.846	56	25.63
	23.2.84	1.55	61.2	21.88	8.5	15	23	29.5	76	32.3	67.7	41.4	19.8	5.200	59	25.47
	16.5.84	1.61	65.8	23.02	9	20	18	25	72	31	69	45.2	20.3	5.659	60	25.27
	21.2.84	1.535	67.5	23.55	10	25	26	22	85	34.7	65.3	44.1	23.4	5.249	54	25.25
	10.10.85	1.676	70.9	24.43	7.5	24	15	19.5	66	30.8	69.2	49.1	21.8	5.636	65	25.24
	17.6.84	1.651	68.6	23.84	10	20	14.5	20	64.5	30.4	69.6	47.7	20.9	5.532	56	25.17
G>25BMI	14.11.85	1.652	68.6	23.84	12	22	18	24	76	32.9	67.1	46.0	22.6	5.421	65	25.14
	24.1.84	1.682	70.7	24.38	8.5	21	19	20	68.5	31.3	68.7	48.6	22.1	6.210	61	24.99
	13.12.84	1.651	66.7	23.34	12	24	18	30	84	34.4	65.6	43.8	22.9	5.667	59	24.47
	23.5.84	1.62	63.2	22.41	7	17	18	22	64	30.5	69.5	43.9	19.3	5.916	65	24.08
	10.1.85	1.575	59.5	21.42	7.5	22.5	15	20	65	30.8	69.2	41.2	18.3	5.141	60	23.99
	22.3.84	1.575	59	21.29	8.5	18	24.5	31	82	32.8	67.2	39.6	19.4	5.183	61	23.78
	7.5.85	1.628	62.6	22.26	7.5	20	27	22.5	77	32	68	42.6	20.0	5.569	62	23.68
	19.1.84	1.64	63.5	22.49	6	17	19.5	26	70.5	31	69	43.8	19.7	5.335	56	23.61
	4.12.84	1.646	63.8	22.57	9	20	14	20	63	30	70	44.7	19.1	5.145	56	23.55
	9.6.85	1.612	61	21.63	8.5	16	9	17.5	49	26.4	73.6	44.9	16.1	5.412	73	23.47
	15.10.85	1.62	61.6	21.99	6	14	7	15	44	24.3	75.7	46.6	15.0	5.577	64	23.47
	18.5.85	1.52	54.1	19.95	11	20	18	23	72	31.1	68.9	37.3	16.8	4.516	56	23.42
	24.4.84	1.5	59.7	21.46	6	17	12.5	21	56.5	28.5	71.5	42.7	17.0	5.362	74	23.32
	15.1.85	1.596	59.3	21.37	6	15	15	15	53	27.1	72.9	43.2	16.1	5.360	63	23.28
	25.3.84	1.549	55.8	20.42	9	16	21	24	72	32.1	67.9	37.9	17.9	4.419	66	23.25
	15.5.85	1.593	58.6	21.15	7	16	10	14	47	25.9	74.1	43.4	15.2	5.007	70	23.09
	16.10.85	1.548	55.2	20.25	7	23	13	10	53	26.8	73.2	40.4	14.8	5.067	64	23.04
	20.11.84	1.616	59.5	21.42	5	15	7.5	17	47.5	25	74	44.0	15.5	5.255	73	22.78
	24.5.84	1.656	62.5	22.31	7.5	20.5	15	17.5	60.5	29.1	70.9	44.5	18.3	5.335	59	22.63
	28.11.84	1.626	59.7	21.46	9.5	14	14.5	18	56	28.5	71.5	42.7	17.0	5.760	67	22.58
	30.11.83	1.702	65.2	22.94	6	15	13	20	66	28.6	71.5	46.6	18.6	5.727	61	22.51
	17.1.85	1.645	53.9	19.69	6.5	22	12	10	50.5	25.7	74.3	40.0	13.9	5.433	70	22.49
	27.3.85	1.548	53.9	19.69	6.5	22	12	10	50.5	26.4	73.6	39.7	14.2	5.511	71	22.49
	26.4.84	1.575	55.8	20.36	4.5	17.5	12.5	20	54.5	27.9	72.1	40.1	15.5	5.124	64	22.41
	15.11.84	1.636	59.8	21.45	5	16	14	20	55	27.5	72.5	43.2	16.4	5.351	74	22.27
	23.1.85	1.648	60.2	21.61	6	15	10	15	46	25	75	45.2	15.1	5.155	71	22.22
	8.10.85	1.677	62.4	22.20	8	12	9	14	43	24.1	75.9	47.4	15.0	6.200	69	22.19
	22.11.84	1.692	63.5	22.49	9	26	10.5	15	60.5	29.5	70.5	44.8	18.7	5.852	64	22.18
	21.6.85	1.682	62.5	22.23	5	9	10	12	36	21.7	78.3	48.9	13.6	6.300	70	22.09
	29.1.85	1.696	63.5	22.49	6.5	17.5	14	16	54	27	73	46.4	17.1	5.852	54	22.08
	15.2.84	1.661	54.9	20.17	8	15	15	12	50	26.1	73.9	40.6	14.3	5.771	73	21.96
	31.1.85	1.658	60.3	21.84	7.5	15	8	14	44.5	25.2	74.8	45.1	15.2	6.252	72	21.94
	20.3.85	1.711	63.8	22.57	8	17	14	14	53	27.7	72.3	46.1	17.7	6.064	66	21.79
	14.8.84	1.601	55.6	20.36	6	15	7	8	36	22.2	77.8	43.3	12.3	5.804	70	21.69
	13.11.84	1.676	60.4	21.67	5	19	7.5	15	46.5	25	75	45.3	15.1	5.827	67	21.50
	9.2.84	1.727	63.4	22.47	6	14	8	11	41	23.4	76.6	48.5	14.8	6.391	70	21.26
	8.11.84	1.661	60	21.56	6	16	8	14	44	25	75	45.0	15.0	5.270	61	21.23
	13.3.85	1.702	61.2	21.88	7	12	10	9	38	22.4	77.6	47.5	13.7	6.433	73	21.13
	21.3.84	1.702	60.9	21.80	6	13	6	14	39	22.7	77.3	47.1	13.8	6.863	68	21.02
	18.10.84	1.669	61.7	19.28	4.5	15	9.5	10.5	39.5	23.5	76.5	59.6	12.1	5.360	72	21.00
	7.12.83	1.745	63.8	22.57	6	14	12	11	43	24.1	75.9	48.4	15.4	5.972	66	20.93
	10.5.84	1.662	56.5	20.61	9.5	13	12	14	48.5	26.3	73.7	41.6	14.9	5.207	64	20.70
	16.10.84	1.594	52.5	19.60	4.5	14	9.5	12	40	23.1	76.9	40.4	12.1	5.519	73	20.66
	13.3.84	1.646	55.8	20.36	7	12	12	14	45	24.6	75.4	41.9	13.7	5.284	66	20.52
	24.10.84	1.502	46.9	17.63	7	17	13.5	9.5	47	25.9	74.1	34.0	11.9	4.296	65	20.35
	8.2.84	1.949	48.8	18.46	4	6	10	15	35	21.7	78.3	38.2	10.6	5.060	72	20.34
	13.5.85	1.525	53.7	19.84	5.5	11.5	13	17	47	25.9	74.1	39.8	13.9	5.256	65	20.34
	27.2.85	1.595	51.7	19.26	10	15	10	18	53	28.5	73.5	38.0	13.7	4.841	61	20.32
	16.1.84	1.67	56.5	20.61	9.5	13	12	14	48.5	26.3	73.7	41.6	14.9	5.044	62	20.26
	23.10.84	1.575	50	18.80	5	11	11	15	42	23.7	76.3	38.2	11.9	4.968	69	20.16
	8.5.84	1.645	54.5	20.06	6	12	10	15	43	24.1	75.9	41.4	13.1	5.415	69	20.14
	10.10.84	1.596	51.2	19.14	6.5	17.4	14	16.2	54.1	27.9	72.1	36.9	14.3	5.087	69	20.10
G20-25BMI	15.3.84	1.739	60.5	21.69	3.5	13.5	5.5	5.5	31	20.1	79.9	48.3	12.2	6.011	69	20.01
	12.12.84	1.628	62.7	19.56	5	9	10	20	44	24.3	75.7	39.9	12.8	5.160	68	19.93
	12.1.84	1.564	48.9	18.77	4.5	15.5	14.2	11.2	45.6	25.5	74.5	37.2	12.7	4.514	67	19.89
	7.2.85,	1.72	58.5	21.23	7.5	12.5	7	11	38	22.4	77.6	45.6	13.2	5.504	66	19.88
	28.2.84	1.739	60.1	21.59	4	16	6	11	37	22.6	77.4	46.5	13.6	5.664	77	19.87
	12.6.85	1.666	54.5	20.06	6.5	16.5	9	13	45	25	75	40.9	13.6	4.556	62	19.64
	5.6.84	1.75	59.9	21.53	6.2	17	8.2	17.2	48.6	26.3	73.7	44.1	15.8	5.252	61	19.56
	13.2.85	1.655	53	19.64	6	14	9	13	42	23.7	76.3	40.4	12.6	5.342	70	19.28
	18.1.84	1.651	52.4	19.48	7.2	15.2	7.6	11.2	41.2	23.9	76.1	39.9	12.5	5.357	71	19.22
	5.2.85	1.6	61.6	21.99	2.5	6	5	7.5	21	14.7	85.3	52.5	9.1	5.411	61	19.01
	10.1.84	1.525	44	17.06	2.5	5.5	5.5	6.5	20	14.1	85.9	37.8	6.2	3.612	57	18.92
	9.10.84	1.592	47.5	18.09	5.5	14.2	11	11.5	42.2	23.4	76.6	36.4	11.1	4.553	67	18.74
	11.12.84	1.625	49.2	18.58	4	10	7	8	29	18.9	81.1	39.9	9.3	5.103	72	18.63
	7.3.84	1.615	48.2	18.29	6	15.6	9	10.4	41.2	24	76	38.6	11.6	4.850	67	18.41
	4.6.85	1.628	46.6	18.41	3	4	4	6	17	11.9	88.1	42.8	5.8	4.409	63	18.38
	31.1.84	1.665	50.5	18.94	3.5	9	7	7	26.5	17.6	82.4	41.6	8.9	5.090	70	18.22
	14.2.85	1.657	48.5	18.38	4.5	11	7	7	29.5	19.2	80.8	39.2	9.3	4.959	71	17.66
	22.2.84	1.575	43.7	17.00	3	5	5	8	21	14.7	85.3	37.3	6.4	3.839	61	17.62
	26.2.85	1.577	48.5	18.38	4.5	12.5	7	11	35	21.3	78.7	38.2	10.3	4.659	70	17.25
	5.12.84	1.569	43.3	16.82	3	6	6	6	23	16	84	36.4	6.9	4.115	67	17.15
	6.4.84	1.6	43.6	16.97	3	6	5	5	19	13.4	86.6	37.8	5.8	3.983	62	17.03
	25.12.84	1.645	44.5	17.23	2	4	6	6	18	12.7	87.3	38.8	5.7	3.751	59	16.36
G<20BMI	7.11.84	1.569	40.1	15.94	2.5	5	5.5	4.5	17.5	12.7	87.3	35.0	5.1	3.753	66	16.56

Key - B - biceps skinfold thickness
T - triceps skinfold thickness
SS- subscapular skinfold thickness

BC - body composition
BW - body weight
H - height
BMI - body mass index : BW (kg)/H(m)²

GBMR - 'gross' BMR - BMR per whole body /24 hours (MJ/24 hrs)
uBMR - 'unit' BMR - BMR / kgBW (J/kg/min.)

Data 1B

FILE : DATA 1B %FM order

INDIVIDUAL CHARACTERISTICS OF THE STUDY POPULATION, ARRANGED IN ORDER OF %BODY FAT (%FM)

BC GROUP	Date	Height H (m)	Body Weight BW(kg)	$BW^{0.75}$ (kg)	B (mm)	T (mm)	SS (mm)	SI (mm)	B+T+SS+SI (mm)	% FAT	%LEAN	Fat Free Mass(kg)	Fat mass (kg)	GBMR (MJ/24 hrs)	uBMR (J/kg/min)	BMI BW(kg)/ H(m²)
	25.12.84	1.575	88.9	31.60	17.5	36.5	19	43	112	40	60	59.9	40.0	6 330	44	40.27
	12.11.85	1.861	89.6	29.12	20	40	40	40	140	40	60	53.8	35.8	6 193	48	32.87
	19.12.84	1.677	82.2	27.30	13	32	22	40	107	36	64	51.0	31.2	5 865	56	29.23
	22.5.84	1.525	82.5	27.23	10	34	35	20	100	37	63	39.4	23.1	5 670	63	35.47
	12.6.84	1.625	70.5	24.33	12	26	30	35	103	36.3	63.7	44.9	25.6	5 178	61	26.67
	9.1.85	1.561	78.2	26.30	15	20	20	29	84	35	64	50.0	28.2	6 193	55	32.09
	29.5.85	1.672	75	25.49	15	26	24	30	95	35	65	48.8	26.3	5 724	53	26.83
	21.2.84	1.635	67.5	23.55	10	26	26	22	86	34.7	65.3	44.1	23.4	5 249	54	25.25
	26.1.84	1.6	66.4	23.26	7	18	32	24	81	34.5	65.5	43.5	22.9	5 354	56	25.94
	13.12.84	1.651	66.7	23.34	12	24	18	30	84	34.4	65.6	43.8	22.9	5 667	59	24.47
	22.5.85	1.524	59.6	21.46	10	18	25	27	80	33.6	66.4	39.6	20.0	5 407	63	25.66
	14.11.85	1.652	65.6	23.04	12	22	18	24	76	32.9	67.1	44.0	22.6	6 423	65	25.14
	22.3.84	1.575	59	21.29	8.5	13	24.5	31	82	32.6	67.2	39.6	19.4	5 183	61	23.75
	23.2.84	1.55	61.2	21.85	8.5	16	23	29.5	79	32.3	67.7	41.4	19.8	5 200	59	25.47
	28.3.84	1.649	55.8	20.42	9	15	21	24	72	32.1	67.9	37.9	17.9	4 419	55	23.26
	7.9.85	1.626	62.6	22.26	7.5	20	27	22.5	77	32	68	42.6	20.0	5 569	62	23.68
	24.1.84	1.682	70.7	24.36	8.5	21	19	20	68.5	31.3	68.7	48.6	22.1	6 210	61	24.99
	18.5.85	1.62	54.1	19.96	11	20	15	23	73	31.1	68.9	37.3	16.8	4 918	56	23.42
	16.5.84	1.61	65.5	23.02	9	20	18	25	72	31	69	45.2	20.3	5 669	60	25.27
	19.1.84	1.64	63.5	22.49	6	17	19.5	28	70.5	31	69	43.8	19.7	6 036	65	23.61
	10.10.85	1.676	70.9	24.43	7.5	24	15	19.5	66	30.8	69.2	49.1	21.8	6 636	65	25.24
	10.1.85	1.575	59.5	21.42	7.5	22.5	16	20	66	30.5	69.2	41.2	18.3	5 141	60	23.99
	10.12.85	1.624	67.6	23.56	10	18	20	22	70	30.6	69.4	46.9	20.7	5 646	56	25.63
	23.5.84	1.62	63.2	22.41	7	17	18	22	64	30.5	69.5	43.9	19.3	5 916	65	24.05
	17.5.84	1.651	66.6	23.84	10	20	14.5	20	64.5	30.4	69.6	46.2	20.9	5 532	56	25.17
G>30%FM	4.12.84	1.646	63.8	22.87	9	20	14	20	63	30	70	44.7	19.1	5 145	58	23.55
	22.11.84	1.692	63.5	22.49	9	20	10.5	15	60.5	29.5	70.5	44.8	18.7	5 852	64	22.18
	24.5.84	1.666	62.5	22.31	7.5	20.5	12	17.5	60.5	29.1	70.9	44.5	18.3	5 935	59	22.53
	24.4.84	1.6	59.7	21.48	6	17	12.5	21	56.5	28.5	71.5	42.7	17.0	5 362	74	23.32
	28.11.84	1.626	59.7	21.45	9.5	14	14.5	18	56	28.5	71.5	42.7	17.0	5 760	67	22.56
	30.11.83	1.702	66.2	22.94	5	15	13	20	53	28.5	71.5	46.6	18.6	5 727	61	22.51
	26.4.84	1.575	55.6	20.36	4.5	17.5	12.5	20	54.5	27.9	72.1	40.1	15.5	5 124	64	22.41
	10.10.84	1.595	51.2	19.14	6.5	17.4	14	16.2	54.1	27.8	72.1	36.9	14.3	5 087	69	20.10
	20.3.85	1.711	63.8	22.57	8	17	14	14	53	27.7	72.3	46.1	17.7	6 064	65	21.79
	15.11.84	1.636	59.6	21.46	6	16	14	20	56	27.5	72.5	43.2	16.4	6 361	74	22.27
	15.1.85	1.596	59.3	21.37	8	15	15	15	53	27.1	72.9	43.2	16.1	5 380	63	23.28
	29.1.85	1.696	63.5	22.49	8.5	17.5	14	16	54	27	73	46.4	17.1	5 852	64	22.08
	16.10.85	1.648	55.2	20.25	7	23	13	10	53	26.8	73.2	40.4	14.8	5 087	64	23.04
	27.2.85	1.695	51.7	19.26	10	15	10	18	53	26.5	73.5	38.0	13.7	4 541	61	20.32
	9.5.85	1.612	61	21.83	6.5	16	9	17.5	49	26.4	73.6	44.9	16.1	6 412	73	23.47
	27.3.85	1.648	53.9	19.88	6.5	22	12	10	50.5	26.4	73.6	39.7	14.2	5 511	71	22.48
	10.5.84	1.662	56.5	20.61	9.5	13	12	14	48.5	26.3	73.7	41.6	14.9	5,207	64	20.70
	18.1.84	1.67	56.5	20.61	9.5	13	12	14	48.5	26.3	73.7	41.6	14.9	5,044	62	20.26
	5.6.84	1.76	58.9	21.53	8.2	17	8.2	17.2	48.6	26.3	73.7	44.1	15.8	5,262	61	19.56
	19.2.84	1.581	54.9	20.17	8	15	15	12	50	26.1	73.9	40.6	14.3	5,771	73	21.96
	20.11.84	1.616	59.5	21.42	6	15	7.5	17	45.5	26	74	44.0	15.5	6,255	73	22.78
	15.5.85	1.593	55.6	21.16	7	16	10	14	47	25.9	74.1	43.4	15.2	5,807	70	23.09
	24.10.84	1.502	45.9	17.63	7	17	13.5	9.5	47	25.9	74.1	34.0	11.9	4,296	65	20.35
	13.5.85	1.625	53.7	19.84	5.5	11.5	13	17	47	25.9	74.1	39.8	13.9	5,258	68	20.34
	17.1.85	1.548	53.9	19.89	6.5	22	12	10	50.5	25.7	74.3	40.0	13.9	5,433	70	22.49
	12.1.84	1.564	49.9	18.77	4.6	16.8	14.2	11.2	45.8	25.5	74.5	37.2	12.7	4,814	67	19.89
	31.1.85	1.665	60.3	21.64	7.6	15	8	14	44.6	25.2	74.8	45.1	15.2	5,252	72	21.94
	23.1.85	1.646	60.2	21.61	6	15	10	15	46	25	75	45.2	15.1	6,159	71	22.22
	13.11.84	1.676	60.4	21.67	5	19	7.5	15	46.5	25	75	45.3	15.1	5,827	67	21.50
	6.11.84	1.681	60	21.55	6	15	8	14	44	25	75	45.0	15.0	5,270	61	21.23
	12.6.85	1.668	54.5	20.06	6.5	16.5	9	13	45	25	75	40.9	13.6	4,866	62	19.54
	13.3.84	1.646	55.6	20.36	7	12	12	14	45	24.8	75.4	41.9	13.7	5,284	66	20.52
	15.10.85	1.62	51.6	21.99	6	14	7	15	44	24.3	75.7	45.6	15.0	5,677	64	23.47
	12.12.84	1.626	52.7	19.56	5	9	10	20	44	24.3	75.7	39.9	12.8	5,160	66	19.93
	8.10.85	1.677	62.4	22.20	8	12	9	14	43	24.1	75.9	47.4	15.0	6,200	69	22.19
	7.12.83	1.746	63.8	22.87	6	14	12	11	43	24.1	75.9	48.4	15.4	5,972	65	20.93
	5.5.84	1.645	54.5	20.06	6	12	10	15	43	24.1	75.9	41.4	13.1	5,415	69	20.14
	7.3.84	1.618	48.2	18.29	6	15.8	9	13.4	44.2	24	76	36.6	11.6	4,650	67	18.41
	18.1.84	1.651	52.4	19.48	7.2	15.2	7.6	11.2	41.2	23.9	76.1	39.9	12.5	5,357	71	19.22
	23.10.84	1.578	50	18.80	5	11	11	15	42	23.7	76.3	38.2	11.9	4,968	69	20.16
	13.2.85	1.658	53	19.84	6	14	9	13	42	23.7	76.3	40.4	12.6	5,342	70	19.28
	18.10.84	1.569	51.7	19.28	4.5	15	9.5	10.5	39.5	23.6	76.5	39.6	12.1	5,360	72	21.00
	9.2.84	1.727	63.4	22.47	8	14	8	11	41	23.4	76.6	48.6	14.8	5,391	70	21.26
	9.10.84	1.582	47.5	18.08	5.5	14.2	11	11.5	42.2	23.4	76.6	36.4	11.1	4,583	67	18.74
	15.10.84	1.594	52.5	19.50	4.5	14	9.5	12	40	23.1	76.9	40.4	12.1	5,619	73	20.66
	21.3.84	1.702	60.9	21.80	6	13	6	14	39	22.7	77.3	47.1	13.8	5,963	68	21.02
	28.2.84	1.739	60.1	21.59	4	16	6	11	37	22.6	77.4	46.5	13.6	6,664	77	19.87
	13.3.85	1.702	61.2	21.88	7	12	10	9	38	22.4	77.6	47.5	13.7	6,433	73	21.13
	7.2.85.	1.72	58.8	21.23	7.5	12.5	7	11	38	22.4	77.6	45.6	13.2	5,504	65	19.86
	14.8.84	1.601	55.8	20.36	5	15	7	8	35	22.2	77.8	43.3	12.3	5,604	70	21.89
	21.5.85	1.662	62.5	22.23	5	9	10	12	36	21.7	78.3	48.9	13.6	6,300	70	22.09
	8.2.84	1.549	48.8	18.46	4	6	10	16	36	21.7	78.3	38.2	10.6	5,060	72	20.34
	26.2.85	1.677	48.5	18.38	4.5	12.5	7	11	35	21.3	78.7	38.2	10.3	4,889	70	17.25
G20-30%FM	15.3.84	1.739	60.5	21.99	3.5	13.5	5.5	8.5	31	20.1	79.9	48.3	12.2	6,011	69	20.01
	14.2.85	1.657	48.5	18.38	4.5	11	7	7	29.5	19.2	80.8	39.2	9.3	4,959	71	17.66
	11.12.84	1.625	49.2	18.58	4	10	7	8	29	18.9	81.1	39.9	9.3	5,101	72	18.63
	31.1.84	1.566	50.6	18.94	3.5	9	7	7	26.5	17.6	82.4	41.6	8.9	5,090	70	18.22
	5.12.84	1.569	43.3	16.86	3	6	6	6	23	16	84	36.4	6.9	4,176	67	17.15
	5.2.85	1.8	51.6	21.99	2.5	6	5	7.5	21	14.7	85.3	52.5	9.1	5,411	61	19.01
	22.2.84	1.575	43.7	17.00	3	5	5	8	21	14.7	85.3	37.3	6.4	3,839	61	17.62
	10.1.84	1.525	44	17.08	2.5	5.5	5.5	6.5	20	14.1	85.9	37.8	6.2	3,612	57	18.92
	6.4.84	1.5	43.6	16.97	3	6	6	5	19	13.4	86.6	37.8	5.8	3,893	62	17.03
	25.12.84	1.845	44.5	17.23	2	4	6	6	18	12.7	87.3	38.8	5.7	3,761	59	16.35
	7.11.84	1.669	40.1	15.94	2.5	5	5.5	4.5	17.5	12.7	87.3	35.0	5.1	3,753	65	15.65
B<20%FM	4.5.85	1.525	48.5	18.41	3	4	4	6	17	11.9	88.1	42.8	5.8	4,409	63	18.38

Key - B - biceps skinfold thickness

T - triceps skinfold thickness

SS- subscapular skinfold thickness

BC - body composition

BW - body weight

H - height

BMI - body mass index : BW (kg)/H(m)^2

GBMR - 'gross' BMR - BMR per whole body /24 hours (MJ/24 hrs)

uBMR - 'unit' BMR - BMR / kgBW (J/kg/min.)

Data 2A **uBMR (BMR - J /kg/min.)** **BMI order**

Differences between measured / derived (M/D) values and values calculated according to Garby et al, 1988

	BMI (kg/m^2)	M/D uBMR J/kg/min	est.uBMR J/kg/min	Diff. %	Diff. J/min.
G>25BMI	40.3	44	56	27.4	12
	32.9	48	56	16.8	8
	32.1	55	59	6.4	4
	29.2	58	57	-1.2	-1
	26.9	63	58	-8.1	-5
	26.8	53	59	11.6	6
	26.7	51	58	14.4	7
	25.9	56	59	6.2	3
	25.7	63	60	-4.7	-3
	25.6	58	62	6.7	4
	25.5	59	61	3.1	2
	25.3	60	62	2.8	2
	25.3	54	59	9.9	5
	25.2	65	62	-5.0	-3
	25.2	56	62	10.8	6
	25.1	65	60	-7.0	-5
G20-25BMI	25.0	61	61	0.8	0
	24.5	59	60	0.9	1
	24.1	65	62	-4.7	-3
	24.0	60	62	3.0	2
	23.8	61	61	-0.8	0
	23.7	62	61	-1.6	-1
	23.6	66	62	-6.6	-4
	23.5	56	62	11.2	6
	23.5	73	65	-11.6	-8
	23.5	64	66	2.9	2
	23.4	58	62	6.2	4
	23.3	74	63	-14.6	-11
	23.3	63	64	1.7	1
	23.3	55	61	10.9	6
	23.1	70	65	-7.4	-5
	23.0	64	64	0.4	0
	22.8	73	65	-11.3	-8
	22.6	59	63	6.5	4
	22.6	67	63	-5.6	-4
	22.5	61	63	3.6	2
	22.5	70	65	-7.2	-5
	22.5	71	65	-9.1	-6
	22.4	64	64	-0.6	0
	22.3	74	64	-13.7	-10
	22.2	71	65	-7.9	-6
	22.2	69	66	-4.4	-3

data ↓ **over**

	BMI/ (kg/m^2)	meas/der. J/kg/min	est. uBMR J/kg/min	Diff. %	Diff. J/min
	22.2	64	63	-2.2	-1
	22.1	70	67	-3.6	-3
	22.1	64	64	0.2	0
	22.0	73	65	-11.4	-8
	21.9	72	65	-9.3	-7
	21.8	66	64	-3.5	-2
	21.7	70	67	-4.1	-3
	21.5	67	65	-2.4	-2
	21.3	70	66	-5.1	-4
	21.2	61	65	7.2	4
	21.1	73	67	-8.2	-6
	21.0	68	67	-1.7	-1
	21.0	72	66	-7.9	-6
	20.9	65	66	1.5	1
	20.7	64	65	0.9	1
	20.7	73	67	-8.8	-6
	20.5	66	66	-0.5	0
	20.3	65	65	-0.2	0
	20.3	72	67	-6.3	-5
	20.3	68	65	-4.6	-3
	20.3	61	64	5.7	3
	20.3	62	65	4.2	3
	20.2	69	66	-4.0	-3
	20.1	69	66	-4.4	-3
	20.1	69	64	-7.8	-5
	20.0	69	68	-0.8	-1
G<20BMI	19.9	68	66	-3.2	-2
	19.9	67	65	-2.9	-2
	19.9	65	67	3.1	2
	19.9	77	67	-13.1	-10
	19.6	62	65	5.5	3
	19.6	61	65	5.9	4
	19.3	70	66	-5.4	-4
	19.2	71	66	-6.9	-5
	19.0	61	72	17.7	11
	18.9	57	72	26.7	15
	18.7	67	66	-0.9	-1
	18.6	72	69	-3.9	-3
	18.4	67	66	-1.5	-1
	18.4	63	74	16.8	11
	18.2	70	70	0.0	0
	17.7	71	69	-2.8	-2
	17.6	61	72	17.7	11
	17.2	70	68	-3.3	-2
	17.1	67	71	6.0	4
	17.0	62	73	17.2	11
	16.4	59	73	23.7	14
	15.9	65	73	12.3	8

Data 2B **uBMR (BMR - J/kg/min) %FM order**

Differences between measured/derived (M/D) values and values estimated according to Garby et al, 1988

	%FM	M/D uBMR J/kg/min	est.uBMR J/kg/min	Diff. %	Diff. J/min.
G>30%FM	40	48	56	16.3	8
	40	44	56	26.8	12
	38	58	57	-1.6	-1
	37	63	58	-8.4	-5
	36.3	51	58	14.0	7
	36	55	58	6.0	3
	35	53	59	11.2	6
	34.7	54	59	9.5	5
	34.5	56	59	5.8	3
	34.4	59	59	0.6	0
	33.6	63	60	-5.0	-3
	32.9	65	60	-7.3	-5
	32.8	61	60	-1.1	-1
	32.3	59	61	2.8	2
	32.1	55	61	10.5	6
	32	62	61	-1.9	-1
	31.3	61	61	0.5	0
	31.1	58	61	5.9	3
	31	60	61	2.5	1
	31	66	61	-6.9	-5
	30.8	60	62	2.7	2
	30.8	65	62	-5.2	-3
	30.6	58	62	6.4	4
	30.5	65	62	-4.9	-3
	30.4	56	62	10.4	6
	30	56	62	10.9	6
G20-30%F	29.5	64	62	-2.5	-2
	29.1	59	63	6.2	4
	28.5	67	63	-5.9	-4
	28.5	74	63	-14.8	-11
	28.5	61	63	3.4	2
	27.9	64	63	-0.9	-1
	27.9	69	63	-8.1	-6
	27.7	66	64	-3.7	-2
	27.5	74	64	-14.0	-10
	27.1	63	64	1.5	1
	27	64	64	0.0	0
	26.8	64	64	0.2	0
	26.5	61	64	5.4	3
	26.4	71	64	-9.3	-7
	26.4	73	64	-11.8	-9
	26.3	61	64	5.6	3
	26.3	62	64	3.9	2
	26.3	64	64	0.7	0
	26.1	73	65	-11.6	-8
	26	73	65	-11.5	-8

data ↓ over

Data 2B **%FM order** page2

	BMI/ (kg/m²)	meas/der. J/kg/min	est. uBMR J/kg/min	Diff. %	Diff. J/min
	25.9	68	65	-4.9	-3
	25.9	65	65	-0.5	0
	25.9	70	65	-7.6	-5
	25.7	70	65	-7.4	-5
	25.5	67	65	-3.1	-2
	25.2	72	65	-9.5	-7
	25	62	65	5.2	3
	25	71	65	-8.1	-6
	25	67	65	-2.6	-2
	25	61	65	7.0	4
	24.6	66	66	-0.8	0
	24.3	68	66	-3.4	-2
	24.3	64	66	2.6	2
	24.1	65	66	1.3	1
	24.1	69	66	-4.6	-3
	24.1	69	66	-4.6	-3
	24	67	66	-1.7	-1
	23.9	71	66	-7.1	-5
	23.7	70	66	-5.6	-4
	23.7	69	66	-4.2	-3
	23.5	72	66	-8.1	-6
	23.4	67	66	-1.1	-1
	23.4	70	66	-5.3	-4
	23.1	73	66	-9.0	-7
	22.7	68	67	-1.9	-1
	22.6	77	67	-13.3	-10
	22.4	65	67	2.9	2
	22.4	73	67	-8.4	-6
	22.2	70	67	-4.3	-3
	21.7	72	67	-6.5	-5
	21.7	70	67	-3.8	-3
	21.3	70	68	-3.5	-2
	20.1	69	68	-1.0	-1
G<20%FM	19.2	71	69	-3.0	-2
	18.9	72	69	-4.0	-3
	17.6	70	70	-0.1	0
	16	67	71	5.9	4
	14.7	61	72	17.6	11
	14.7	61	72	17.6	11
	14.1	57	72	26.5	15
	13.4	62	73	17.0	11
	12.7	65	73	12.3	8
	12.7	59	73	23.7	14
	11.9	63	74	16.7	11

Data 3A BMI order

Comparison of measured GBMR and GBMR estimated using full range (FR) and group specific (GS) regression equations substituting BW

GBMR Meas. MJ/24 hrs.	GBMR F.R eqn. MJ/24 hrs.	diff. %	diff. kJ	diff. kcal.	GBMR G.S. eqn MJ/24 hrs.	diff. %	diff. kJ	diff. kcal.
6.330	7.593	20.0	1264	301	6.641	4.9	311	74
6.193	7.052	13.9	858	204	6.332	2.2	139	33
6.193	6.452	4.2	258	62	5.990	-3.3	-203	-48
6.865	6.662	-3.0	-203	-48	6.110	-11.0	-755	-180
5.670	5.626	-0.8	-44	-10	5.519	-2.7	-151	-36
5.724	6.284	9.8	560	133	5.894	3.0	170	40
5.178	6.047	16.8	869	207	5.759	11.2	581	138
5.354	5.831	8.9	477	114	5.636	5.3	282	67
5.407	5.474	1.2	67	16	5.432	0.5	25	6
5.646	5.894	4.4	248	59	5.672	0.5	26	6
5.200	5.558	6.9	358	85	5.480	5.4	280	67
5.659	5.784	2.2	125	30	5.609	-0.9	-50	-12
5.249	5.889	12.2	640	152	5.669	8.0	420	100
6.636	6.068	-8.6	-568	-135	5.771	-13.0	-865	-206
5.532	5.947	7.5	415	99	5.702	3.1	170	40
6.421	5.947	-7.4	-474	-113	5.702	-11.2	-719	-171
6.210	6.057	-2.5	-153	-36	6.471	4.2	261	62
5.667	5.847	3.2	180	43	6.179	9.0	512	122
5.916	5.663	-4.3	-253	-60	5.924	0.1	8	2
5.141	5.468	6.4	328	78	5.654	10.0	513	122
5.183	5.442	5.0	259	62	5.617	8.4	434	103
5.589	5.631	0.8	42	10	5.880	5.2	291	69
6.035	5.679	-5.9	-356	-85	5.946	-1.5	-90	-21
5.145	5.694	10.7	550	131	5.967	16.0	823	196
6.412	5.547	-13.5	-865	-206	5.763	-10.1	-649	-155
5.677	5.579	-1.7	-98	-23	5.807	2.3	130	31
4.518	5.184	14.7	666	159	5.259	16.4	741	176
6.362	5.479	-13.9	-883	-210	5.668	-10.9	-694	-165
5.380	5.458	1.5	78	19	5.639	4.8	259	62
4.419	5.274	19.3	854	203	5.383	21.8	964	230
5.907	5.421	-8.2	-486	-116	5.588	-5.4	-319	-76
5.087	5.242	3.0	155	37	5.340	5.0	252	60
6.255	5.468	-12.6	-786	-187	5.654	-9.6	-601	-143
5.335	5.642	5.7	306	73	5.894	10.5	559	133
5.760	5.479	-4.9	-281	-67	5.668	-1.6	-92	-22
5.727	5.768	0.7	41	10	6.070	6.0	342	82
5.433	5.174	-4.8	-259	-62	5.245	-3.5	-188	-45
5.511	5.174	-6.1	-337	-80	5.245	-4.8	-266	-63
5.124	5.263	2.7	139	33	5.369	4.8	245	58
6.351	5.474	-13.8	-877	-209	5.661	-10.9	-690	-164
6.155	5.505	-10.6	-650	-155	5.705	-7.3	-450	-107

data ↓ over

Data 3A **BMI order** page2

MJ/24 hrs.	MJ/24 hrs.	%	kJ	kcal.	MJ/24 hrs.	%	kJ	kcal.
6.200	5.621	-9.3	-579	-138	5.865	-5.4	-335	-80
5.852	5.679	-3.0	-173	-41	5.946	1.6	93	22
6.300	5.626	-10.7	-674	-160	5.873	-6.8	-428	-102
5.852	5.679	-3.0	-173	-41	5.946	1.6	93	22
5.771	5.226	-9.4	-545	-130	5.318	-7.9	-453	-108
6.252	5.510	-11.9	-742	-177	5.712	-8.6	-540	-129
6.064	5.694	-6.1	-369	-88	5.967	-1.6	-96	-23
5.604	5.263	-6.1	-341	-81	5.369	-4.2	-236	-56
5.827	5.516	-5.3	-312	-74	5.719	-1.9	-108	-26
6.391	5.673	-11.2	-717	-171	5.938	-7.1	-453	-108
5.270	5.495	4.3	224	53	5.690	8.0	420	100
6.433	5.558	-13.6	-876	-208	5.778	-10.2	-656	-156
5.963	5.542	-7.1	-421	-100	5.756	-3.5	-208	-49
5.360	5.058	-5.6	-302	-72	5.084	-5.2	-276	-66
5.972	5.694	-4.6	-277	-66	5.967	-0.1	-4	-1
5.207	5.311	2.0	103	25	5.435	4.4	227	54
5.519	5.100	-7.6	-419	-100	5.143	-6.8	-376	-90
5.284	5.263	-0.4	-21	-5	5.369	1.6	85	20
4.296	4.753	10.6	457	109	4.661	8.5	364	87
5.060	4.905	-3.0	-154	-37	4.872	-3.7	-187	-45
5.258	5.163	-1.8	-95	-23	5.230	-0.5	-28	-7
4.541	5.058	11.4	517	123	5.084	12.0	543	129
5.044	5.311	5.3	266	63	5.435	7.7	390	93
4.968	4.969	0.0	1	0	4.960	-0.2	-8	-2
5.415	5.205	-3.9	-210	-50	5.289	-2.3	-127	-30
5.087	5.032	-1.1	-56	-13	5.048	-0.8	-40	-9
6.011	5.521	-8.2	-490	-117	5.727	-4.7	-285	-68
5.160	5.111	-1.0	-50	-12	5.077	-1.6	-83	-20
4.814	4.963	3.1	149	35	4.777	-0.8	-37	-9
5.504	5.431	-1.3	-72	-17	5.730	4.1	226	54
6.664	5.500	-17.5	-1164	-277	5.869	-11.9	-795	-189
4.866	5.205	7.0	340	81	5.270	8.3	404	96
5.262	5.489	4.3	228	54	5.847	11.1	586	139
5.342	5.126	-4.0	-216	-51	5.109	-4.4	-233	-56
5.357	5.095	-4.9	-263	-63	5.045	-5.8	-313	-74
5.411	5.579	3.1	168	40	6.029	11.4	618	147
3.612	4.653	28.8	1041	248	4.146	14.8	534	127
4.583	4.837	5.5	254	61	4.521	-1.4	-62	-15
5.101	4.927	-3.4	-175	-42	4.702	-7.8	-399	-95
4.650	4.874	4.8	224	53	4.595	-1.2	-55	-13
4.409	4.895	11.0	486	116	4.638	5.2	229	55
5.090	4.995	-1.9	-95	-23	4.842	-4.9	-249	-59
4.959	4.890	-1.4	-69	-16	4.628	-6.7	-331	-79
3.839	4.637	20.8	799	190	4.114	7.2	275	66
4.889	4.890	0.0	1	0	4.628	-5.3	-261	-62
4.178	4.616	10.5	439	104	4.071	-2.5	-106	-25
3.893	4.632	19.0	739	176	4.103	5.4	211	50
3.781	4.679	23.8	899	214	4.200	11.1	419	100
3.753	4.448	18.5	695	165	3.729	-0.7	-25	-6

Data 3B %FM order

Comparison of measured GBMR and GBMR estimated using full range (FR) and group specific (GS) regression equations substituting BW

GBMR Meas.	GBMR F.R. eqn. MJ/24 hrs	diff. %	diff. kJ	diff. kcal.	GBMR G.S. eqn. MJ/24 hrs	diff. %	diff. kJ	diff. kcal.
6.330	7.593	20.0	1264	301	6.916	9.3	586	140
6.193	7.052	13.9	858	204	6.504	5.0	311	74
6.865	6.662	-3.0	-203	-48	6.208	-9.6	-657	-157
5.670	5.626	-0.8	-44	-10	5.42	-4.4	-250	-60
5.178	6.047	16.8	869	207	5.74	10.9	562	134
6.193	6.452	4.2	258	62	6.048	-2.3	-145	-35
5.724	6.284	9.8	560	133	5.92	3.4	196	47
5.249	5.889	12.2	640	152	5.62	7.1	371	88
5.354	5.831	8.9	477	114	5.576	4.1	222	53
5.667	5.847	3.2	180	43	5.588	-1.4	-79	-19
5.407	5.474	1.2	67	16	5.304	-1.9	-103	-25
6.421	5.947	-7.4	-474	-113	5.664	-11.8	-757	-180
5.183	5.442	5.0	259	62	5.28	1.9	97	23
5.200	5.558	6.9	358	85	5.368	3.2	168	40
4.419	5.274	19.3	854	203	5.152	16.6	733	174
5.589	5.631	0.8	42	10	5.424	-3.0	-165	-39
6.210	6.057	-2.5	-153	-36	5.748	-7.4	-462	-110
4.518	5.184	14.7	666	159	5.084	12.5	566	135
6.035	5.679	-5.9	-356	-85	5.46	-9.5	-575	-137
5.659	5.784	2.2	125	30	5.54	-2.1	-119	-28
5.141	5.468	6.4	328	78	5.3	3.1	159	38
6.636	6.068	-8.6	-568	-135	5.756	-13.3	-880	-210
5.646	5.894	4.4	248	59	5.624	-0.4	-22	-5
5.916	5.663	-4.3	-253	-60	5.448	-7.9	-468	-111
5.532	5.947	7.5	415	99	5.664	2.4	132	31
5.145	5.694	10.7	550	131	5.472	6.4	327	78
5.852	5.679	-3.0	-173	-41	6.235	6.5	383	91
5.335	5.642	5.7	306	73	6.172	15.7	837	199
6.362	5.479	-13.9	-883	-210	5.893	-7.4	-469	-112
5.760	5.479	-4.9	-281	-67	5.893	2.3	133	32
5.727	5.768	0.7	41	10	6.388	11.5	661	157
5.087	5.032	-1.1	-56	-13	5.128	0.8	41	10
5.124	5.263	2.7	139	33	5.524	7.8	400	95
6.064	5.694	-6.1	-369	-88	6.262	3.3	198	47
6.351	5.474	-13.8	-877	-209	5.884	-7.4	-467	-111
5.380	5.458	1.5	78	19	5.857	8.9	477	114
5.852	5.679	-3.0	-173	-41	6.235	6.5	383	91
5.087	5.242	3.0	155	37	5.488	7.9	401	95
4.541	5.058	11.4	517	123	5.173	13.9	632	150
5.511	5.174	-6.1	-337	-80	5.371	-2.5	-140	-33
6.412	5.547	-13.5	-865	-206	6.01	-6.3	-402	-96

data over

MJ/24 hrs.	MJ/24 hrs.	%	kJ	kcal.	MJ/24 hrs.	%	kJ	kcal.
5.044	5.311	5.3	266	63	5.605	11.1	561	133
5.207	5.311	2.0	103	25	5.605	7.6	398	95
5.262	5.489	4.3	228	54	5.911	12.3	649	155
5.771	5.226	-9.4	-545	-130	5.461	-5.4	-310	-74
6.255	5.468	-12.6	-786	-187	5.875	-6.1	-380	-90
5.907	5.421	-8.2	-486	-116	5.794	-1.9	-113	-27
4.296	4.753	10.6	457	109	4.651	8.3	355	84
5.258	5.163	-1.8	-95	-23	5.353	1.8	95	23
5.433	5.174	-4.8	-259	-62	5.371	-1.1	-62	-15
4.814	4.963	3.1	149	35	5.011	4.1	197	47
6.252	5.510	-11.9	-742	-177	5.947	-4.9	-305	-73
4.866	5.205	7.0	340	81	5.425	11.5	559	133
5.827	5.516	-5.3	-312	-74	5.956	2.2	129	31
6.155	5.505	-10.6	-650	-155	5.938	-3.5	-217	-52
5.270	5.495	4.3	224	53	5.92	12.3	650	155
5.284	5.263	-0.4	-21	-5	5.524	4.5	240	57
5.677	5.579	-1.7	-98	-23	6.064	6.8	387	92
5.160	5.111	-1.0	-50	-12	5.263	2.0	103	24
5.415	5.205	-3.9	-210	-50	5.425	0.2	10	2
5.972	5.694	-4.6	-277	-66	6.262	4.9	290	69
6.200	5.621	-9.3	-579	-138	6.136	-1.0	-64	-15
4.650	4.874	4.8	224	53	4.858	4.5	208	49
5.357	5.095	-4.9	-263	-63	5.236	-2.3	-121	-29
4.968	4.969	0.0	1	0	5.02	1.0	52	12
5.342	5.126	-4.0	-216	-51	5.29	-1.0	-52	-12
5.360	5.058	-5.6	-302	-72	5.173	-3.5	-187	-45
4.583	4.837	5.5	254	61	4.795	4.6	212	51
6.391	5.673	-11.2	-717	-171	6.226	-2.6	-165	-39
5.519	5.100	-7.6	-419	-100	5.245	-5.0	-274	-65
5.963	5.542	-7.1	-421	-100	6.001	0.6	38	9
6.664	5.500	-17.5	-1164	-277	5.929	-11.0	-735	-175
6.433	5.558	-13.6	-876	-208	6.028	-6.3	-405	-97
5.504	5.431	-1.3	-72	-17	5.812	5.6	308	73
5.604	5.263	-6.1	-341	-81	5.524	-1.4	-80	-19
6.300	5.626	-10.7	-674	-160	6.145	-2.5	-155	-37
5.060	4.905	-3.0	-154	-37	4.912	-2.9	-148	-35
4.889	4.890	0.0	1	0	4.885	-0.1	-4	-1
6.011	5.521	-8.2	-490	-117	5.965	-0.8	-46	-11
4.959	4.890	-1.4	-69	-16	4.885	-1.5	-74	-18
5.101	4.927	-3.4	-175	-42	4.73	-7.3	-371	-88
5.090	4.995	-1.9	-95	-23	4.86	-4.5	-230	-55
4.178	4.616	10.5	439	104	4.14	-0.9	-38	-9
3.839	4.637	20.8	799	190	4.18	8.9	341	81
5.411	5.579	3.1	168	40	5.97	10.3	559	133
3.612	4.653	28.8	1041	248	4.21	16.6	598	142
3.893	4.632	19.0	739	176	4.17	7.1	277	66
3.753	4.448	18.5	695	165	3.82	1.8	67	16
3.781	4.679	23.8	899	214	4.26	12.7	479	114
4.409	4.895	11.0	486	116	4.67	5.9	261	62

Data 4A **BMI order**

Comparison of measured GBMR and GBMR estimated using the equation of Schofield (1985.91) substituting BW. There is no equivalent of the group specific equation.

	GBMR Meas. MJ/24 hrs.	GBMR Scho. eqn. MJ/24 hrs.	diff. %	diff. kJ	diff. kcal
G>25BMI	6.330	8.230	30.0	1900	452
	6.193	7.591	22.6	1398	333
	6.193	6.884	11.2	691	165
	6.865	7.132	3.9	267	64
	5.670	5.911	4.3	241	57
	5.724	6.686	16.8	962	229
	5.178	6.407	23.7	1229	293
	5.354	6.153	14.9	798	190
	5.407	5.731	6.0	324	77
	5.646	6.227	10.3	581	138
	5.200	5.830	12.1	631	150
	5.659	6.097	7.7	438	104
	5.249	6.221	18.5	972	231
	6.636	6.432	-3.1	-204	-49
	5.532	6.289	13.7	757	180
	6.421	6.289	-2.1	-132	-31
G20-25BMI	6.210	6.419	3.4	209	50
	5.667	6.171	8.9	505	120
	5.916	5.954	0.7	39	9
	5.141	5.725	11.4	584	139
	5.183	5.694	9.9	511	122
	5.589	5.917	5.9	328	78
	6.035	5.973	-1.0	-62	-15
	5.145	5.992	16.5	847	202
	6.412	5.818	-9.3	-594	-142
	5.677	5.855	3.1	178	42
	4.518	5.390	19.3	872	208
	6.362	5.737	-9.8	-624	-149
	5.380	5.713	6.2	333	79
	4.419	5.496	24.4	1076	256
	5.907	5.669	-4.0	-238	-57
	5.087	5.458	7.3	371	88
	6.255	5.725	-8.5	-530	-126
	5.335	5.930	11.1	594	141
	5.760	5.737	-0.4	-22	-5
	5.727	6.078	6.1	351	84
	5.433	5.378	-1.0	-55	-13
	5.511	5.378	-2.4	-133	-32
	5.124	5.483	7.0	359	86
	6.351	5.731	-9.8	-620	-148
	6.155	5.768	-6.3	-386	-92

data ↓ over

	GBMR MJ/24 hrs	Schof. est MJ/24 hrs	Diff. %	Diff. kJ	Diff. kcal
	6.200	5.905	-4.8	-295	-70
	5.852	5.973	2.1	121	29
	6.300	5.911	-6.2	-389	-93
	5.852	5.973	2.1	121	29
	5.771	5.440	-5.7	-331	-79
	6.252	5.775	-7.6	-477	-114
	6.064	5.992	-1.2	-72	-17
	5.604	5.483	-2.2	-121	-29
	5.827	5.781	-0.8	-47	-11
	6.391	5.967	-6.6	-424	-101
	5.270	5.756	9.2	486	116
	6.433	5.830	-9.4	-603	-144
	5.963	5.812	-2.5	-152	-36
	5.360	5.241	-2.2	-119	-28
	5.972	5.992	0.3	20	5
	5.207	5.539	6.4	332	79
	5.519	5.291	-4.1	-228	-54
	5.284	5.483	3.8	199	47
	4.296	4.882	13.6	586	139
	5.060	5.062	0.0	2	0
	5.258	5.365	2.0	107	25
	4.541	5.241	15.4	700	167
	5.044	5.539	9.8	495	118
	4.968	5.136	3.4	168	40
	5.415	5.415	0.0	0	0
	5.087	5.210	2.4	123	29
	6.011	5.787	-3.7	-224	-53
G<20BMI	5.160	5.303	2.8	143	34
	4.814	5.130	6.6	315	75
	5.504	5.682	3.2	178	42
	6.664	5.762	-13.5	-902	-215
	4.866	5.415	11.3	549	131
	5.262	5.750	9.3	488	116
	5.342	5.322	-0.4	-20	-5
	5.357	5.285	-1.4	-73	-17
	5.411	5.855	8.2	444	106
	3.612	4.764	31.9	1152	274
	4.583	4.981	8.7	398	95
	5.101	5.086	-0.3	-15	-3
	4.650	5.024	8.0	374	89
	4.409	5.049	14.5	640	152
	5.090	5.167	1.5	77	18
	4.959	5.043	1.7	84	20
	3.839	4.745	23.6	907	216
	4.889	5.043	3.2	154	37
	4.178	4.721	13.0	543	129
	3.893	4.739	21.7	847	202
	3.781	4.795	26.8	1014	241
	3.753	4.522	20.5	769	183

Data 4B %FM order

Comparison of measured GBMR and GBMR estimated using the equation of Schofield (1985,91), substituting BW. There is no equivalent of the group specific equation.

	GBMR Meas. MJ/24 hrs.	GBMR Schof eqn. MJ/24 hrs.	diff. %	diff. kJ	diff. kcal
G>30%FM	6.330	8.230	30.0	1900	452
	6.193	7.591	22.6	1398	333
	6.865	7.132	3.9	267	64
	5.670	5.911	4.3	241	57
	5.178	6.407	23.7	1229	293
	6.193	6.884	11.2	691	165
	5.724	6.686	16.8	962	229
	5.249	6.221	18.5	972	231
	5.354	6.153	14.9	798	190
	5.667	6.171	8.9	505	120
	5.407	5.731	6.0	324	77
	6.421	6.289	-2.1	-132	-31
	5.183	5.694	9.9	511	122
	5.200	5.830	12.1	631	150
	4.419	5.496	24.4	1076	256
	5.589	5.917	5.9	328	78
	6.210	6.419	3.4	209	50
	4.516	5.390	19.3	872	208
	6.035	5.973	-1.0	-62	-15
	5.659	6.097	7.7	438	104
	5.141	5.725	11.4	584	139
	6.636	6.432	-3.1	-204	-49
	5.646	6.227	10.3	581	138
	5.916	5.954	0.7	39	9
	5.532	6.289	13.7	757	180
	5.145	5.992	16.5	847	202
G20-30%FI	5.852	5.973	2.1	121	29
	5.335	5.930	11.1	594	141
	6.362	5.737	-9.8	-624	-149
	5.760	5.737	-0.4	-22	-5
	5.727	6.078	6.1	351	84
	5.087	5.210	2.4	123	29
	5.124	5.483	7.0	359	86
	6.064	5.992	-1.2	-72	-17
	6.351	5.731	-9.8	-620	-148
	5.380	5.713	6.2	333	79
	5.852	5.973	2.1	121	29
	5.087	5.458	7.3	371	88
	4.541	5.241	15.4	700	167
	5.511	5.378	-2.4	-133	-32
	6.412	5.818	-9.3	-594	-142

data over

	GBMR MJ/24 hrs	Schof. est MJ/24 hrs	Diff. %	Diff. kJ	Diff. kcal
	5.044	5.539	9.8	495	118
	5.207	5.539	6.4	332	79
	5.262	5.750	9.3	488	116
	5.771	5.440	-5.7	-331	-79
	6.255	5.725	-8.5	-530	-126
	5.907	5.669	-4.0	-238	-57
	4.296	4.882	13.6	586	139
	5.258	5.365	2.0	107	25
	5.433	5.378	-1.0	-55	-13
	4.814	5.130	6.6	315	75
	6.252	5.775	-7.6	-477	-114
	4.866	5.415	11.3	549	131
	5.827	5.781	-0.8	-47	-11
	6.155	5.768	-6.3	-386	-92
	5.270	5.756	9.2	486	116
	5.284	5.483	3.8	199	47
	5.677	5.855	3.1	178	42
	5.160	5.303	2.8	143	34
	5.415	5.415	0.0	0	0
	5.972	5.992	0.3	20	5
	6.200	5.905	-4.8	-295	-70
	4.650	5.024	8.0	374	89
	5.357	5.285	-1.4	-73	-17
	4.968	5.136	3.4	168	40
	5.342	5.322	-0.4	-20	-5
	5.360	5.241	-2.2	-119	-28
	4.583	4.981	8.7	398	95
	6.391	5.967	-6.6	-424	-101
	5.519	5.291	-4.1	-228	-54
	5.963	5.812	-2.5	-152	-36
	6.664	5.762	-13.5	-902	-215
	6.433	5.830	-9.4	-603	-144
	5.504	5.682	3.2	178	42
	5.604	5.483	-2.2	-121	-29
	6.300	5.911	-6.2	-389	-93
	5.060	5.062	0.0	2	0
	4.889	5.043	3.2	154	37
	6.011	5.787	-3.7	-224	-53
G<20%FM	4.959	5.043	1.7	84	20
	5.101	5.086	-0.3	-15	-3
	5.090	5.167	1.5	77	18
	4.178	4.721	13.0	543	129
	3.839	4.745	23.6	907	216
	5.411	5.855	8.2	444	106
	3.612	4.764	31.9	1152	274
	3.893	4.739	21.7	847	202
	3.753	4.522	20.5	769	183
	3.781	4.795	26.8	1014	241
	4.409	5.049	14.5	640	152

Data 6A BMI order

Comparison of measured GBMR with GBMR estimated using full range (F.R.) and group specific (G.S.) equations substituting $BW^{0.75}$

GBMR Meas. MJ/24 hrs	GBMR F.R. eqn. MJ/24 hrs	diff. %	diff. kJ	diff kcal	GBMR G.S. eqn. MJ/24 hrs	diff. %	diff. kJ	diff kcal
6.330	7.520	18.8	1191	284	6.664	5.3	335	80
6.193	7.023	13.4	830	198	6.365	2.8	172	41
6.193	6.455	4.2	261	62	6.023	-2.8	-171	-41
6.865	6.656	-3.0	-209	-50	6.144	-10.5	-721	-172
5.670	5.637	-0.6	-33	-8	5.531	-2.5	-139	-33
5.724	6.292	9.9	568	135	5.925	3.5	201	48
5.178	6.059	17.0	882	210	5.785	11.7	607	145
5.354	5.844	9.2	490	117	5.656	5.6	301	72
5.407	5.481	1.4	74	18	5.436	0.5	30	7
5.646	5.908	4.6	262	62	5.694	0.8	48	11
5.200	5.567	7.1	367	87	5.489	5.6	289	69
5.659	5.797	2.4	138	33	5.627	-0.6	-32	-8
5.249	5.902	12.5	654	156	5.690	8.4	442	105
6.636	6.080	-8.4	-556	-132	5.797	-12.6	-839	-200
5.532	5.960	7.7	428	102	5.725	3.5	193	46
6.421	5.960	-7.2	-461	-110	5.725	-10.8	-696	-166
6.210	6.070	-2.3	-141	-33	6.903	11.2	693	165
5.667	5.860	3.4	193	46	6.506	14.8	840	200
5.916	5.674	-4.1	-241	-57	6.154	4.0	239	57
5.141	5.475	6.5	334	80	5.776	12.4	636	151
5.183	5.448	5.1	265	63	5.725	10.5	542	129
5.589	5.642	1.0	53	13	6.093	9.0	504	120
6.035	5.690	-5.7	-345	-82	6.184	2.5	149	36
5.145	5.706	10.9	562	134	6.215	20.8	1070	255
6.412	5.556	-13.4	-856	-204	5.930	-7.5	-482	-115
5.677	5.589	-1.6	-88	-21	5.991	5.5	314	75
4.518	5.179	14.6	660	157	5.214	15.4	696	166
6.362	5.486	-13.8	-876	-208	5.797	-8.9	-565	-134
5.380	5.464	1.6	85	20	5.756	7.0	376	90
4.419	5.273	19.3	853	203	5.393	22.0	973	232
5.907	5.426	-8.1	-481	-114	5.684	-3.8	-223	-53
5.087	5.240	3.0	152	36	5.330	4.8	243	58
6.255	5.475	-12.5	-780	-186	5.776	-7.6	-478	-114
5.335	5.653	6.0	318	76	6.114	14.6	778	185
5.760	5.486	-4.8	-274	-65	5.797	0.6	37	9
5.727	5.781	0.9	54	13	6.356	11.0	629	150
5.433	5.167	-4.9	-266	-63	5.193	-4.4	-240	-57
5.511	5.167	-6.2	-343	-82	5.193	-5.8	-318	-76
5.124	5.262	2.7	138	33	5.372	4.8	248	59
6.351	5.481	-13.7	-870	-207	5.787	-8.9	-564	-134

data ↓ over

Data 5A **BMI order** page2

MJ/24 hrs.	MJ/24 hrs.	%	kJ	kcal.	MJ/24 hrs.	%	kJ	kcal.
6.155	5.513	-10.4	-642	-153	5.848	-5.0	-307	-73
6.200	5.632	-9.2	-568	-135	6.073	-2.1	-127	-30
5.852	5.690	-2.8	-162	-39	6.184	5.7	332	79
6.300	5.637	-10.5	-663	-158	6.083	-3.4	-217	-52
5.852	5.690	-2.8	-162	-39	6.184	5.7	332	79
5.771	5.223	-9.5	-548	-131	5.298	-8.2	-473	-113
6.252	5.518	-11.7	-733	-175	5.858	-6.3	-393	-94
6.064	5.706	-5.9	-357	-85	6.215	2.5	151	36
5.604	5.262	-6.1	-343	-82	5.372	-4.2	-233	-55
5.827	5.524	-5.2	-304	-72	5.869	0.7	41	10
6.391	5.685	-11.0	-706	-168	6.174	-3.4	-216	-52
5.270	5.502	4.4	232	55	5.828	10.6	557	133
6.433	5.567	-13.5	-866	-206	5.951	-7.5	-483	-115
5.963	5.551	-6.9	-412	-98	5.920	-0.7	-43	-10
5.360	5.044	-5.9	-316	-75	4.960	-7.5	-400	-95
5.972	5.706	-4.4	-265	-63	6.215	4.1	243	58
5.207	5.311	2.0	104	25	5.466	5.0	259	62
5.519	5.089	-7.8	-430	-102	5.045	-8.6	-474	-113
5.284	5.262	-0.4	-23	-5	5.372	1.7	87	21
4.296	4.714	9.7	417	99	4.333	0.8	36	9
5.060	4.880	-3.5	-179	-43	4.649	-8.1	-411	-98
5.258	5.156	-1.9	-102	-24	5.172	-1.6	-86	-21
4.541	5.044	11.1	503	120	4.960	9.2	419	100
5.044	5.311	5.3	267	64	5.466	8.4	421	100
4.968	4.948	-0.4	-20	-5	4.778	-3.8	-190	-45
5.415	5.201	-4.0	-214	-51	5.256	-2.9	-159	-38
5.087	5.016	-1.4	-71	-17	4.907	-3.6	-181	-43
6.011	5.529	-8.0	-482	-115	5.879	-2.2	-132	-32
5.160	5.100	-1.2	-60	-14	5.153	-0.2	-8	-2
4.814	4.943	2.7	128	31	4.941	2.6	127	30
5.504	5.437	-1.2	-67	-16	5.603	1.8	99	24
6.664	5.508	-17.4	-1156	-275	5.697	-14.5	-966	-230
4.866	5.201	6.9	335	80	5.287	8.7	421	100
5.262	5.497	4.5	235	56	5.683	8.0	421	100
5.342	5.117	-4.2	-225	-54	5.175	-3.1	-167	-40
5.357	5.084	-5.1	-274	-65	5.130	-4.2	-227	-54
5.411	5.589	3.3	178	42	5.806	7.3	395	94
3.612	4.603	27.5	991	236	4.487	24.2	875	208
4.583	4.806	4.9	223	53	4.758	3.8	175	42
5.101	4.903	-3.9	-198	-47	4.888	-4.2	-213	-51
4.650	4.846	4.2	196	47	4.812	3.5	161	38
4.409	4.869	10.4	460	109	4.842	9.8	433	103
5.090	4.977	-2.2	-114	-27	4.987	-2.0	-104	-25
4.959	4.863	-1.9	-96	-23	4.835	-2.5	-124	-29
3.839	4.585	19.5	747	178	4.463	16.3	624	149
4.889	4.863	-0.5	-26	-6	4.835	-1.1	-54	-13
4.178	4.562	9.2	384	91	4.432	6.1	254	60
3.893	4.579	17.6	687	164	4.455	14.5	563	134
3.781	4.632	22.5	851	203	4.526	19.7	745	177
3.753	4.372	16.5	619	147	4.178	11.3	424	101

Data 5B %FM order

Comparison of measured GBMR with GBMR estimated using full range (F.R.) and group specific (G.S.) equations substituting $BW^{0.75}$.

GBMR Meas. MJ/24 hrs	GBMR F.R. eqn. MJ/24 hrs	diff %	diff kJ	diff kcal.	GBMR G.S. eqn. MJ/24 hrs	diff %	diff kJ	diff kcal.
6.330	7.520	18.8	1191	284	6.905	9.1	576	137
6.193	7.023	13.4	830	198	6.512	5.1	318	76
6.865	6.656	-3.0	-209	-50	6.222	-9.4	-644	-153
5.670	5.637	-0.6	-33	-8	5.415	-4.5	-255	-61
5.178	6.059	17.0	882	210	5.749	11.0	572	136
6.193	6.455	4.2	261	62	6.062	-2.1	-131	-31
5.724	6.292	9.9	568	135	5.933	3.7	209	50
5.249	5.902	12.5	654	156	5.625	7.2	377	90
5.354	5.844	9.2	490	117	5.579	4.2	225	54
5.667	5.860	3.4	193	46	5.592	-1.3	-75	-18
5.407	5.481	1.4	74	18	5.292	-2.1	-115	-27
6.421	5.960	-7.2	-461	-110	5.671	-11.7	-750	-179
5.183	5.448	5.1	265	63	5.266	1.6	83	20
5.200	5.567	7.1	367	87	5.360	3.1	160	38
4.419	5.273	19.3	853	203	5.127	16.0	708	169
5.589	5.642	1.0	53	13	5.420	-3.0	-169	-40
6.210	6.070	-2.3	-141	-33	5.758	-7.3	-453	-108
4.518	5.179	14.6	660	157	5.053	11.8	534	127
6.035	5.690	-5.7	-345	-82	5.458	-9.6	-577	-137
5.659	5.797	2.4	138	33	5.542	-2.1	-117	-28
5.141	5.475	6.5	334	80	5.287	2.9	147	35
6.636	6.080	-8.4	-556	-132	5.766	-13.1	-870	-207
5.646	5.908	4.6	262	62	5.629	-0.3	-16	-4
5.916	5.674	-4.1	-241	-57	5.445	-8.0	-471	-112
5.532	5.960	7.7	428	102	5.671	2.5	139	33
5.145	5.706	10.9	562	134	5.470	6.3	325	77
5.852	5.690	-2.8	-162	-39	6.137	4.9	285	68
5.335	5.653	6.0	318	76	6.077	13.9	741	176
6.362	5.486	-13.8	-876	-208	5.808	-8.7	-553	-132
5.760	5.486	-4.8	-274	-65	5.808	0.8	48	12
5.727	5.781	0.9	54	13	6.282	9.7	555	132
5.087	5.016	-1.4	-71	-17	5.053	-0.7	-34	-8
5.124	5.262	2.7	138	33	5.448	6.3	324	77
6.064	5.706	-5.9	-357	-85	6.163	1.6	99	24
6.351	5.481	-13.7	-870	-207	5.799	-8.7	-552	-131
5.380	5.464	1.6	85	20	5.773	7.3	394	94
5.852	5.690	-2.8	-162	-39	6.137	4.9	285	68
5.087	5.240	3.0	152	36	5.412	6.4	325	77
4.541	5.044	11.1	503	120	5.099	12.3	557	133
5.511	5.167	-6.2	-343	-82	5.296	-3.9	-214	-51
6.412	5.556	-13.4	-856	-204	5.921	-7.7	-491	-117

data ↓ over

Data 5B **%FM order** page2

MJ/24 hrs.	MJ/24 hrs.	%	kJ	kcal.	MJ/24 hrs.	%	kJ	kcal.
5.044	5.311	5.3	267	64	5.527	9.6	483	115
5.207	5.311	2.0	104	25	5.527	6.2	320	76
5.262	5.497	4.5	235	56	5.826	10.7	564	134
5.771	5.223	-9.5	-548	-131	5.386	-6.7	-386	-92
6.255	5.475	-12.5	-780	-186	5.791	-7.4	-464	-110
5.907	5.426	-8.1	-481	-114	5.712	-3.3	-195	-46
4.296	4.714	9.7	417	99	4.567	6.3	271	64
5.258	5.156	-1.9	-102	-24	5.278	0.4	20	5
5.433	5.167	-4.9	-266	-63	5.296	-2.5	-137	-33
4.814	4.943	2.7	128	31	4.935	2.5	121	29
6.252	5.518	-11.7	-733	-175	5.860	-6.3	-391	-93
4.866	5.201	6.9	335	80	5.350	9.9	484	115
5.827	5.524	-5.2	-304	-72	5.869	0.7	42	10
6.155	5.513	-10.4	-642	-153	5.852	-4.9	-303	-72
5.270	5.502	4.4	232	55	5.834	10.7	564	134
5.284	5.262	-0.4	-23	-5	5.448	3.1	163	39
5.677	5.589	-1.6	-88	-21	5.973	5.2	296	70
5.160	5.100	-1.2	-60	-14	5.189	0.5	28	7
5.415	5.201	-4.0	-214	-51	5.350	-1.2	-65	-16
5.972	5.706	-4.4	-265	-63	6.163	3.2	191	45
6.200	5.632	-9.2	-568	-135	6.042	-2.5	-158	-38
4.650	4.846	4.2	196	47	4.780	2.8	129	31
5.357	5.084	-5.1	-274	-65	5.162	-3.7	-196	-47
4.968	4.948	-0.4	-20	-5	4.944	-0.5	-24	-6
5.342	5.117	-4.2	-225	-54	5.216	-2.4	-127	-30
5.360	5.044	-5.9	-316	-75	5.099	-4.9	-262	-62
4.583	4.806	4.9	223	53	4.715	2.9	132	32
6.391	5.685	-11.0	-706	-168	6.128	-4.1	-263	-63
5.519	5.089	-7.8	-430	-102	5.171	-6.3	-348	-83
5.963	5.551	-6.9	-412	-98	5.913	-0.9	-51	-12
6.664	5.508	-17.4	-1156	-275	5.843	-12.3	-821	-195
6.433	5.567	-13.5	-866	-206	5.939	-7.7	-495	-118
5.504	5.437	-1.2	-67	-16	5.730	4.1	226	54
5.604	5.262	-6.1	-343	-82	5.448	-2.8	-157	-37
6.300	5.637	-10.5	-663	-158	6.051	-4.0	-249	-59
5.060	4.880	-3.5	-179	-43	4.835	-4.4	-225	-54
4.889	4.863	-0.5	-26	-6	4.807	-1.7	-82	-19
6.011	5.529	-8.0	-482	-115	5.878	-2.2	-133	-32
4.959	4.863	-1.9	-96	-23	4.510	-9.0	-449	-107
5.101	4.903	-3.9	-198	-47	4.579	-10.2	-522	-124
5.090	4.977	-2.2	-114	-27	4.706	-7.6	-385	-92
4.178	4.562	9.2	384	91	3.991	-4.5	-186	-44
3.839	4.585	19.5	747	178	4.032	5.0	193	46
5.411	5.589	3.3	178	42	5.759	6.4	348	83
3.612	4.603	27.5	991	236	4.062	12.5	451	107
3.893	4.579	17.6	687	164	4.022	3.3	129	31
3.753	4.372	16.5	619	147	3.665	-2.4	-89	-21
3.781	4.632	22.5	851	203	4.112	8.8	332	79
4.409	4.869	10.4	460	109	4.520	2.5	111	26

Data 6A BMI order

Comparison of measured GBMR with GBMR estimated using full range (F.R.) and group specific (G.S.) equations substituting FFM (kg)

GBMR Meas. MJ/24 hrs	GBMR F.R. eqn. MJ/24 hrs	diff. %	diff. kJ	diff kcal	GBMR G.S. eqn. MJ/24 hrs	diff. %	diff. kJ	diff kcal
6.330	7.411	17.1	1081	257	6.681	5.6	351	84
6.193	6.688	8.0	495	118	6.273	1.3	80	19
6.193	6.254	1.0	60	14	6.028	-2.7	-165	-39
6.865	6.361	-7.3	-505	-120	6.089	-11.3	-777	-185
5.670	5.005	-11.7	-665	-158	5.324	-6.1	-346	-82
5.724	6.102	6.6	378	90	5.943	3.8	219	52
5.178	5.652	9.2	475	113	5.689	9.9	511	122
5.354	5.487	2.5	132	31	5.595	4.5	241	57
5.407	5.028	-7.0	-379	-90	5.337	-1.3	-70	-17
5.646	5.887	4.3	241	57	5.821	3.1	175	42
5.200	5.246	0.9	46	11	5.460	5.0	260	62
5.659	5.686	0.5	27	6	5.708	0.9	49	12
5.249	5.555	5.8	306	73	5.634	7.3	385	92
6.636	6.138	-7.5	-498	-119	5.963	-10.1	-673	-160
5.532	5.984	8.2	452	108	5.876	6.2	344	82
6.421	5.784	-9.9	-637	-152	5.763	-10.2	-658	-157
6.210	6.081	-2.1	-129	-31	6.300	1.5	90	21
5.667	5.517	-2.6	-149	-36	5.698	0.6	32	8
5.916	5.537	-6.4	-378	-90	5.720	-3.3	-196	-47
5.141	5.215	1.5	75	18	5.376	4.6	235	56
5.183	5.037	-2.8	-146	-35	5.185	0.0	2	1
5.589	5.378	-3.8	-210	-50	5.550	-0.7	-39	-9
6.035	5.524	-8.5	-511	-122	5.706	-5.5	-329	-78
5.145	5.623	9.3	478	114	5.812	13.0	667	159
6.412	5.651	-11.9	-761	-181	5.841	-8.9	-571	-136
5.677	5.854	3.1	177	42	6.058	6.7	381	91
4.518	4.759	5.3	241	57	4.888	8.2	370	88
6.362	5.392	-15.2	-969	-231	5.565	-12.5	-797	-190
5.380	5.456	1.4	76	18	5.633	4.7	253	60
4.419	4.831	9.3	412	98	4.965	12.3	546	130
5.907	5.478	-7.3	-428	-102	5.657	-4.2	-250	-60
5.087	5.126	0.8	38	9	5.280	3.8	193	46
6.255	5.550	-11.3	-705	-168	5.733	-8.3	-522	-124
5.335	5.607	5.1	272	65	5.795	8.6	459	109
5.760	5.392	-6.4	-368	-88	5.565	-3.4	-195	-46
5.727	5.852	2.2	125	30	6.056	5.7	329	78
5.433	5.084	-6.4	-350	-83	5.235	-3.6	-198	-47
5.511	5.039	-8.6	-471	-112	5.188	-5.9	-323	-77
5.124	5.088	-0.7	-36	-9	5.240	2.3	116	28
6.351	5.454	-14.1	-897	-214	5.630	-11.3	-721	-172

data ↓ over

Data 6A **BMI order** page2

MJ/24 hrs.	MJ/24 hrs.	%	kJ	kcal.	MJ/24 hrs.	%	kJ	kcal.
6.155	5.681	-7.7	-474	-113	5.873	-4.6	-282	-67
6.200	5.939	-4.2	-261	-62	6.149	-0.8	-51	-12
5.852	5.636	-3.7	-216	-52	5.825	-0.5	-27	-6
6.300	6.124	-2.8	-176	-42	6.346	0.7	46	11
5.852	5.822	-0.5	-31	-7	6.023	2.9	171	41
5.771	5.145	-10.9	-626	-149	5.300	-8.2	-471	-112
6.252	5.675	-9.2	-577	-137	5.867	-6.2	-385	-92
6.064	5.795	-4.4	-269	-64	5.995	-1.1	-69	-16
5.604	5.459	-2.6	-145	-35	5.636	0.6	32	8
5.827	5.698	-2.2	-129	-31	5.892	1.1	64	15
6.391	6.080	-4.9	-311	-74	6.300	-1.4	-91	-22
5.270	5.663	7.4	393	93	5.854	11.1	584	139
6.433	5.954	-7.4	-479	-114	6.165	-4.2	-268	-64
5.963	5.906	-1.0	-57	-14	6.113	2.5	150	36
5.360	5.025	-6.2	-335	-80	5.173	-3.5	-187	-45
5.972	6.064	1.5	92	22	6.282	5.2	310	74
5.207	5.270	1.2	63	15	5.434	4.4	227	54
5.519	5.122	-7.2	-397	-95	5.276	-4.4	-243	-58
5.284	5.303	0.4	19	4	5.469	3.5	185	44
4.296	4.377	1.9	81	19	4.480	4.3	184	44
5.060	4.869	-3.8	-191	-45	5.005	-1.1	-54	-13
5.258	5.054	-3.9	-205	-49	5.203	-1.1	-55	-13
4.541	4.844	6.7	303	72	4.979	9.6	438	104
5.044	5.270	4.5	226	54	5.434	7.7	390	93
4.968	4.862	-2.1	-106	-25	4.998	0.6	30	7
5.415	5.238	-3.3	-177	-42	5.400	-0.3	-15	-4
5.087	4.717	-7.3	-370	-88	4.843	-4.8	-244	-58
6.011	6.054	0.7	42	10	6.271	4.3	260	62
5.160	5.066	-1.8	-95	-23	4.746	-8.0	-414	-99
4.814	4.748	-1.4	-67	-16	4.420	-8.2	-394	-94
5.504	5.737	4.2	233	55	5.434	-1.3	-69	-16
6.664	5.841	-12.4	-823	-196	5.541	-16.8	-1123	-267
4.866	5.180	6.5	315	75	4.864	0.0	-2	0
5.262	5.563	5.7	302	72	5.257	-0.1	-5	-1
5.342	5.129	-4.0	-213	-51	4.812	-9.9	-531	-126
5.357	5.064	-5.5	-294	-70	4.744	-11.4	-613	-146
5.411	6.546	21.0	1135	270	6.264	15.8	853	203
3.612	4.820	33.5	1209	288	4.495	24.4	883	210
4.583	4.655	1.6	72	17	4.325	-5.6	-258	-61
5.101	5.066	-0.7	-35	-8	4.747	-6.9	-354	-84
4.650	4.684	0.7	34	8	4.355	-6.4	-295	-70
4.409	5.408	22.6	999	238	5.097	15.6	688	164
5.090	5.267	3.5	176	42	4.952	-2.7	-138	-33
4.959	4.983	0.5	24	6	4.662	-6.0	-297	-71
3.839	4.759	24.0	921	219	4.432	15.5	594	141
4.889	4.864	-0.5	-25	-6	4.539	-7.1	-349	-83
4.178	4.654	11.4	476	113	4.324	3.5	146	35
3.893	4.816	23.7	923	220	4.490	15.3	597	142
3.781	4.943	30.7	1163	277	4.621	22.2	840	200
3.753	4.494	19.7	740	176	4.160	10.8	407	97

Data 6B %FM order

Comparison of measured GBMR and GBMR estimated using full range (F.R.) and group specific (G.S.) equations. substituting FFM (kg)

GBMR Meas. MJ/24 hrs	GBMR F.R. eqn. MJ/24 hrs	diff. %	diff. kJ	diff. kcal.	GBMR G.S. eqn. MJ/24 hrs	diff. %	diff. kJ	diff. kcal.
6.330	7.411	17.1	1081	257	7.145	12.9	815	194
6.193	6.688	8.0	495	118	6.588	6.4	395	94
6.865	6.361	-7.3	-505	-120	6.337	-7.7	-529	-126
5.670	5.005	-11.7	-665	-158	5.294	-6.6	-376	-90
5.178	5.652	9.2	475	113	5.792	11.9	614	146
6.193	6.254	1.0	60	14	6.254	1.0	61	14
5.724	6.102	6.6	378	90	6.138	7.2	414	98
5.249	5.555	5.8	306	73	5.717	8.9	468	111
5.354	5.487	2.5	132	31	5.664	5.8	310	74
5.667	5.517	-2.6	-149	-36	5.688	0.4	21	5
5.407	5.028	-7.0	-379	-90	5.312	-1.8	-95	-23
6.421	5.784	-9.9	-637	-152	5.893	-8.2	-528	-126
5.183	5.037	-2.8	-146	-35	5.318	2.6	136	32
5.200	5.246	0.9	46	11	5.479	5.4	279	67
4.419	4.831	9.3	412	98	5.160	16.8	741	176
5.589	5.378	-3.8	-210	-50	5.581	-0.1	-8	-2
6.210	6.081	-2.1	-129	-31	6.121	-1.4	-89	-21
4.518	4.759	5.3	241	57	5.105	13.0	586	140
6.035	5.524	-8.5	-511	-122	5.693	-5.7	-342	-81
5.659	5.686	0.5	27	6	5.818	2.8	158	38
5.141	5.215	1.5	75	18	5.456	6.1	315	75
6.636	6.138	-7.5	-498	-119	6.166	-7.1	-471	-112
5.646	5.887	4.3	241	57	5.972	5.8	326	78
5.916	5.537	-6.4	-378	-90	5.703	-3.6	-212	-51
5.532	5.984	8.2	452	108	6.047	9.3	515	123
5.145	5.623	9.3	478	114	5.769	12.1	625	149
5.852	5.636	-3.7	-216	-52	6.040	3.2	188	45
5.335	5.607	5.1	272	65	6.008	12.6	673	160
6.362	5.392	-15.2	-969	-231	5.769	-9.3	-593	-141
5.760	5.392	-6.4	-368	-88	5.769	0.2	9	2
5.727	5.852	2.2	125	30	6.280	9.7	553	132
5.087	4.717	-7.3	-370	-88	5.019	-1.3	-68	-16
5.124	5.088	-0.7	-36	-9	5.431	6.0	307	73
6.064	5.795	-4.4	-269	-64	6.217	2.5	153	36
6.351	5.454	-14.1	-897	-214	5.837	-8.1	-514	-122
5.380	5.456	1.4	76	18	5.840	8.6	460	110
5.852	5.822	-0.5	-31	-7	6.246	6.7	394	94
5.087	5.126	0.8	38	9	5.473	7.6	386	92
4.541	4.844	6.7	303	72	5.160	13.6	619	147
5.511	5.039	-8.6	-471	-112	5.377	-2.4	-134	-32
6.412	5.651	-11.9	-761	-181	6.056	-5.5	-356	-85

data ↓ over

Data 6B **%FM order** page2

MJ/24 hrs.	MJ/24 hrs.	%	kJ	kcal.	MJ/24 hrs.	%	kJ	kcal.
5.044	5.270	4.5	226	54	5.633	11.7	589	140
5.207	5.270	1.2	63	15	5.633	8.2	426	101
5.262	5.563	5.7	302	72	5.959	13.3	697	166
5.771	5.145	-10.9	-626	-149	5.494	-4.8	-277	-66
6.255	5.550	-11.3	-705	-168	5.944	-5.0	-311	-74
5.907	5.478	-7.3	-428	-102	5.865	-0.7	-42	-10
4.296	4.377	1.9	81	19	4.642	8.0	345	82
5.258	5.054	-3.9	-205	-49	5.393	2.6	135	32
5.433	5.084	-6.4	-350	-83	5.426	-0.1	-7	-2
4.814	4.748	-1.4	-67	-16	5.053	5.0	238	57
6.252	5.675	-9.2	-577	-137	6.084	-2.7	-168	-40
4.866	5.180	6.5	315	75	5.534	13.7	668	159
5.827	5.698	-2.2	-129	-31	6.109	4.8	282	67
6.155	5.681	-7.7	-474	-113	6.090	-1.1	-65	-16
5.270	5.663	7.4	393	93	6.070	15.2	800	190
5.284	5.303	0.4	19	4	5.670	7.3	386	92
5.677	5.854	3.1	177	42	6.282	10.7	605	144
5.160	5.066	-1.8	-95	-23	5.406	4.8	246	59
5.415	5.238	-3.3	-177	-42	5.598	3.4	182	43
5.972	6.064	1.5	92	22	6.515	9.1	543	129
6.200	5.939	-4.2	-261	-62	6.377	2.9	177	42
4.650	4.684	0.7	34	8	4.982	7.1	332	79
5.357	5.064	-5.5	-294	-70	5.404	0.9	47	11
4.968	4.862	-2.1	-106	-25	5.180	4.3	212	50
5.342	5.129	-4.0	-213	-51	5.477	2.5	135	32
5.360	5.025	-6.2	-335	-80	5.362	0.0	1	0
4.583	4.655	1.6	72	17	4.950	8.0	367	87
6.391	6.080	-4.9	-311	-74	6.533	2.2	143	34
5.519	5.122	-7.2	-397	-95	5.468	-0.9	-50	-12
5.963	5.906	-1.0	-57	-14	6.340	6.3	377	90
6.664	5.841	-12.4	-823	-196	6.267	-6.0	-397	-94
6.433	5.954	-7.4	-479	-114	6.394	-0.6	-39	-9
5.504	5.737	4.2	233	55	6.152	11.8	648	154
5.604	5.459	-2.6	-145	-35	5.843	4.3	239	57
6.300	6.124	-2.8	-176	-42	6.582	4.5	282	67
5.060	4.869	-3.8	-191	-45	5.187	2.5	128	30
4.889	4.864	-0.5	-25	-6	5.182	6.0	293	70
6.011	6.054	0.7	42	10	6.504	8.2	493	117
4.959	4.983	0.5	24	6	4.309	-13.1	-650	-155
5.101	5.066	-0.7	-35	-8	4.380	-14.1	-721	-172
5.090	5.267	3.5	176	42	4.551	-10.6	-539	-128
4.178	4.654	11.4	476	113	4.027	-3.6	-150	-36
3.839	4.759	24.0	921	219	4.118	7.3	279	66
5.411	6.546	21.0	1135	270	5.644	4.3	234	56
3.612	4.820	33.5	1209	288	4.170	15.5	558	133
3.893	4.816	23.7	923	220	4.166	7.0	273	65
3.753	4.494	19.7	740	176	3.891	3.7	137	33
3.781	4.943	30.7	1163	277	4.275	13.1	494	118
4.409	5.408	22.6	999	238	4.672	6.0	263	63