Statistical Modelling of Body Composition in Children and their Parents

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Abstract

Several methods of assessing body composition are presented and discussed in this thesis. The assessment of body composition has been a leading area of research for many years. The increasing prevalence of obesity in recent years has done nothing but stress the importance of having accurate and reliable methods which allow us to understand better the composition of the body itself, as well as identify any abnormal conditions of the same.

Data was provided by the Gateshead Millennium Study (GMS). This is a large cohort of over 1000 children, who were born in Gateshead, in the Northeast of England, between 1999 and 2000. The children have so far been followed up until age 7, when the last data collection was completed. Information about their parents (such as anthropometric measurements) was also recorded. This thesis analyzes the data of the children at age 7 as well as their parents.

A number of methods for determining body composition are currently in use. These vary from taking simple measurements of the body, such as weight or height, to more complicated methods for which sophisticated devices are needed. Various relationships and associations between the different characteristics of the human body have been established, drawn from results of numerous studies. Although these relationships may vary from person to person, as there are many other factors which might affect them (such as diet, genetics or lifestyle), they are fairly well established in adults. However, when assessing children, an important factor should be considered in addition, age. This is fundamental for the

correct assessment of body composition in children. This thesis focusses on two more novel methods of determining body composition, bioelectrical impedance analysis (BIA) and bony frame, in addition to anthropometry (body mass index in particular) and skinfolds.

Parental body composition is thought to be influential on their children's body composition. Such influence does not necessarily have to be genetic, but might indirectly come from the eating habits and lifestyle of the family as a whole. Another factor which is believed to have an influential role is social class. Social differences might be reflected in body composition differences, with people from lower social classes being fatter. Both factors are explored in this thesis.

Chapter 1 gives a general introduction on how body composition can be assessed and describes the data set and aims of the project. These include processing anthropometric (height, weight, body mass index, skinfold thicknesses, waist circumference, bony frame) and impedance data for children and their parents, as well as comparing and validating different methods of assessing body composition.

Chapter 2 provides a review of some relevant published literature and methodology concerning assessment of body composition in children and adults. The principles on which bioelectrical impedance analysis is based are described and different approaches suggested in the past for analyzing bony frame data are reviewed.

Chapter 3 presents the anthropometric data collected on children and their mothers in the GMS. The LMS method was used to calculate standard deviation scores for children's anthropometric data. The results reflected an increase in height, weight, waist circumference, BMI and skinfolds (triceps and subscapular) with respect to reference data (UK 1990 children). In particular, classification criteria based on body mass index and skinfold thicknesses are discussed. Children were classified under the UK National and the IOTF body mass index criteria. The resulting classifications differed, especially for boys. Two different equations were applied to predict %fat from skinfolds, but discrepant results were obtained. The relationship between mothers and children's body mass index was explored. Although it was found to be significant, the correlation was weak.

Of particular interest for this project is bioelectrical impedance analysis (BIA), explored in Chapter 4. This approach is presented as a way of studying the fat and lean mass components of the body separately. A novel methodology for deriving lean and fat indices in children, adjusted for height and age, is discussed. These methods were derived on another data set and are applied here to the GMS children. The results are encouraging, although it is a matter of concern that the variance of the fat index was smaller than expected. Both indices are correlated with weight, waist circumference, BMI and skinfolds. Fat index yields considerably higher correlation with skinfolds than lean index. The relationship between fat index and other measures of fatness is stronger for girls, especially for BMI; while for boys the correlation coefficients with BMI are about the same for both indices, for girls the correlation with fat index is clearly higher. The methodology was then adapted to derive similar indices for the children's mothers. The resulting indices, especially the fat index, are highly correlated with the body mass index. Mothers and children's lean and fat indices are positively (but not strongly) correlated.

Chapter 5 explores bony frame data. Faced with the lack of a gold standard method, an alternative way of analyzing these data is proposed, taking the average of the internally standardized measurements. The results from a principal components analysis supported this idea. Average limb and trunk measurements were considered separately but this approach did not seem to be better than taking the overall average. Correlation coefficients between bony frame and height, weight and BMI are all high. Waist circumference and skinfolds, which are measures of fatness, are also correlated with bony frame. In general, correlation coefficients are higher for girls. For boys, the correlation of bony frame with lean index is higher than with fat index, while for girls the opposite occurs.

Finally, Chapter 6 summarizes the results and main findings, pointing out the limitations in the methodology used and suggesting areas of study which should be considered in the future.

Bioelectrical impedance analysis has been reported to be a valid and reliable method for assessing body composition in previous studies. The results presented in this thesis are very encouraging. In general, fat and lean indices seem to perform fairly well for both children and adults; the relationships between these indices and various anthropometric measurements agree in sign and magnitude with the expectations. However, there are limitations one should be aware of. The equations for calculating the lean and fat indices for children were derived on a specific age range (7-11 years) and therefore, might not be suitable for children aged outside that range. Also, when applying this method to the GMS children, the variance of the fat index was found to be smaller than expected. The reason for this is not clear yet, and further investigation should be done. In adults, the equations for calculating these indices were derived using solely women's data. The hydration and resistivity constants underpinning the method might differ for males, and also for different age ranges.

The results obtained from analyzing the bony frame data are unclear. The high correlation with fatness, which, in principle, was not expected, could mean two different things: either an actual relationship between bony frame and fat mass, or simply the fact that bony frame calculation is being confounded with fat, and therefore the results would not be reliable. Further work on this field should be done, so that these questions can be answered and an appropriate and reliable method for adjusting for bony frame can be developed.

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Chapter 1

Introduction

1.1 Assessment of body composition

Several methods of assessing body composition are discussed in this thesis, mainly for children, but also for their parents for comparison. The work presented here was done assuming a two compartment model. This divides the body into fat mass (FM) and fat-free mass or lean mass (LM) components, so that the equation FM + LM = weight holds. More complicated models have also been proposed (3 and 4 compartment models), but data allowing these to be fitted was not collected in the study discussed here.

Historically, being fat was synonymous for being healthy. Nowadays, excess fatness has become one of the major health problems [Ebbeling et al. (2002)]. Although prevention is the first step, being able to diagnose the problem once it has appeared is just as important. Identifying people with excess fat becomes essential so that the problem is recognized and appropriate measures can be taken. Hence, precise and reliable methods of assessing body composition are needed.

The prevalence of obesity is rising rapidly worldwide. It affects all age groups, but is spreading among children at an alarming rate [Ebbeling et al. (2002)]. In 2005, the Obesity Task Force estimated that at least 1.1 billion adults and 10%

of children were overweight or obese [Haslam & James (2005)].

There are two main factors that contribute to the build of the body and, therefore, might lead to nutritional or physical problems: eating habits and lifestyle. Both of them are mainly established during childhood and consolidated towards adulthood. It is important then to identify those subjects who already are or might be 'at risk' at an early stage of life. In order to achieve this, a number of methods for assessing body composition have been developed.

In terms of methodology, the 'ideal' way of assessing body composition would be by means of direct methods, but this is not always possible. Some of them are very sophisticated and difficult to implement and therefore, not suitable when working with large groups of people. The need for easier, quicker and also cheaper methods has led the investigators to search for new alternatives.

Different methods measure different aspects of body composition, and the choice of method would depend on the question addressed. There are two different aspects of the body which tend to be confounded: size and fatness. Despite being closely related to each other, they are not the same, and confusing one with the other can lead to misclassifying subjects. Thus, the body mass index (=weight/height^2), for example, would be a measure of size rather than fatness, since it adjusts weight for height but does not take the amount of fat into account directly. The World Health Organization (WHO) defines obesity as "the disease in which excess body fat has accumulated to such an extent that health may be adversely affected" [WHO (2000)]. Therefore, when assessing obesity, an indicator of fatness would be preferable, so that the misclassification is minimal.

The assessment of nutritional status requires several anthropometric characteristics to be considered. Such characteristics should not be interpreted on their own, for they are intimately related to each other. Hence, a number of indices and tables, such as the body mass index, have been developed in order to combine different anthropometric measurements. Skinfold thicknesses, measured at specific sites of the body, give an idea of the amount of subcutaneous fat of a person, and are then often used to predict %body fat. Different equations to do so are reviewed in Chapter 2 and analyzed in Chapter 3.

An appropriate measure of body size should also be helpful to help distinguish between being big and having actual excess fat. The only objective measure of this, that is available from the GMS, is bony frame, and that is also explored in this thesis (Chapters 2 and 5).

Bioelectrical impedance analysis (BIA) arises here as a potential alternative, for it is simple, quick and inexpensive. Although it is widely used in body composition research, there is ongoing debate about the appropriate prediction equations to use to convert impedance measurements into measures of body fatness. Further details on how the method works and performs are given in Chapters 2 and 4, respectively.

Whenever a new method is developed, it has to be validated so that it is reliable as well as generally applicable. Several methods of assessing body composition are tested here. Data was provided by the Gateshead Millenium Study.

1.2 Principal Data Set: The Gateshead Millenium Study

The Gateshead Millennium Study (GMS) is a prospective study of feeding and growth. The subjects forming this large cohort were recruited in Gateshead, an urban area situated in the Northeast of England. The principal aim of the study was “to examine the joint influence of infant feeding behaviour and maternal psychological characteristics on weight gain” [Parkinson et al. (2007)].

Two main criteria were followed for choosing the families:

- The mother had to be a Gateshead resident at the time of delivery
- The baby had to be born within a specified recruiting week (34 weeks in total) in the recruiting time, set from 1/6/99 to 31/5/00, both inclusive.

There were 1270 births in the specified time, from which 1029 children were recruited, 523 male and 506 female. In total, 1011 families took part in the study. "Ethical approval was obtained from Gateshead Local Research Ethics Committee, and from Newcastle and North Tyneside Health Authority Joint Ethics Committee" [Parkinson et al. (2007)].

Data in early childhood were obtained from a wide range of sources: questionnaires, routine health checks and via the Parent-Health Child Record (PCHR) (a special edition was created for those taking part in the study). Collecting data for such a study involves the participation of professionals from different fields. Good organization and fluent communication are essential for the study to be successful. Although studies of this type are very informative, difficulties are likely to appear during the process, the loss of individuals through time being one of the most common problems. For this reason, keeping the families involved and maintaining up-to-date contact details is essential. A great amount of help and support from health professionals, telephone reminders, media involvement, birthday cards and newsletter made it possible to carry out the study [Parkinson et al. (2007)].

The latest phase of the study has just been completed. This involves both the children (aged 6 to 7 years) and their families. It was possible to take measurements on 599 children (297 boys, 302 girls) and 506 of their mothers. Bioelectrical and anthropometric data have been collected, as well as information relating to body shape, diet, activity and psychosocial factors. "The results from this part of the study will help to identify and develop strategies which will be beneficial to families in achieving and maintaining good health in childhood"[GMS (Webpage)].

The work presented in this thesis has been done in combination with this last phase. Further details on how the measurements were taken are detailed below:

- Height was measured without shoes and socks using a Leicester portable height measure (Chasmors, London) to 0.1cm with the head in the Frankfort plane

- Weight was measured to 0.1kg using a Tanita TBF-300MA, (Chasmors, London)

- Waist circumference was taken to 0.1cm using the minimum waist circumference or the midpoint between the lowest rib and the iliac crest [WHO (1995)]

- Hip circumference was taken to 0.1cm at the widest part of the buttocks [WHO (1995), Callaway et al. (1988)]

- Skinfold thicknesses were measured twice (sequentially) to 0.1mm on the non-dominant side using a Holtain skinfold caliper (Chasmors, London). Biceps was measured at the midline of the anterior aspect of the arm. Triceps was measured at the midline of the posterior aspect of the arm. Subscapular was measured at the inferior part to the inferior angle of the scapula. Suprailiac was measured 1cm above and 2cm medial to the anterior superior iliac spine [WHO (1995), Cameron (1984), Harrison et al. (1988)]

- Bioelectrical impedance was measured in Ohms using a Tanita TBW-300MA (Chasmors, London)

- A single measurement for each of the five bony frame measures was taken to 0.1cm. Shoulders (biacromial) and hips (biiliac) were measured using a Harpenden Anthropometer (Chasmors, London). Knee (bicondylar femur), wrist (across the styloid process) and elbow (across the humeral epicondyles) measurements were obtained using a Harpenden bicondylar vernier caliper (Chasmors, London) [Cameron (1978), Wilmore et al. (1988)]

1.3 Secondary Data Set: The 1000 Family Study

We wanted to validate the equations developed for use with the GMS women. For this, we needed another data set in which impedance measurements had been taken. The 1000 Family Study met this requirement, and data were available.

The 1000 Family Study began in 1947, recruiting 1142 babies born in Newcastle upon Tyne, a city located in the Northeast of England. The original aim was to study the causes for the high rate of infections among babies. These babies have been followed up since then. The last data collection was carried out in 1997, when the subjects were aged 50. Anthropometric and impedance measurements were collected on 406 adults [1000Family (Webpage)].

1.4 Aims

The objectives of this thesis are the following:

1. Process anthropometric data collected about the children (height, weight, body mass index, skinfold thicknesses and waist circumference) using a range of published standards, and compare the distribution of standardized values in this cohort with that expected for the population as a whole (Chapter 3).

2. Process bioelectrical impedance data collected about the children to produce lean and fat indices using a novel method.

3. Develop an approach recently taken with pediatric data in order to derive

appropriate formulae for the calculation of adult lean and fat mass from bioelectric impedance measurements, and to produce lean and fat indices standardized for height.

4. Compare the adult measures of body composition that are derived from bioelectric impedance in this way with results automatically obtained from manufacturers equations.

   The work carried out on bioelectrical impedance analysis is presented on Chapter 4.

5. Develop new ways of combining bony frame data (at sites on the wrists, knees, shoulders, hips and elbows) in order to obtain an appropriate overall measure for a child, standardize these measures by internal reference to the cohort, and then validate them by comparison with other measures of body composition (Chapter 5).

6. Explore the relationships between the fat and lean mass of children and their parents.

Chapter 2

Literature and Methods

2.1 LMS Method

Physical measurements that can be used to give information about size and potentially about fatness include weight, body mass index (BMI = weight/height^2) and waist circumference. In studies of children, raw values of these measurements are hard to interpret as they naturally differ systematically with sex and age and are also highly skewed.

The LMS method was proposed by Cole & Green (1992) as a way of standardizing values of a variable y, which depend on a covariate t (age in our case). The method assumes the data to be normally distributed after a suitable power transformation. The conditional distribution of y at each value of the covariate can then be summarized by 3 parameters:

1. Box-Cox power (L)
2. Median (M)
3. coefficient of variation (S)

The three curves L(t), M(t) and S(t) summarize the measurement's distribution over the range of age.

The following formula converts the variable y to its Normal equivalent deviate z (often called a 'Z score' or 'Standard Deviation (SD) Score'):

$$z(t) = \begin{cases} \frac{\{\frac{y}{M(t)}\}^{L(t)}-1}{L(t)\cdot S(t)} & if L(t) \neq 0 \\ \\ \frac{\log\{\frac{y}{M(t)}\}}{S(t)} & if L(t) = 0 \end{cases} \tag{2.1}$$

Therefore, the 100α'th centile of y at t is given by:

$$C_{100\alpha}(t) = \begin{cases} M(t)\cdot\{1 + L(t)\cdot S(t)\cdot z_\alpha\}^{\frac{1}{L(t)}} & if L(t) \neq 0 \\ \\ M(t)\cdot\exp\{S(t)\cdot z_\alpha\} & if L(t) = 0 \end{cases} \tag{2.2}$$

where z_α is the normal equivalent centile for tail area α.

It is usual to have a sample of n independent observations $\{y_i\}$ at corresponding covariates $\{t_i\}$. The three curves L(t), M(t) and S(t) can then be estimated from the data using the method of maximum penalized likelihood [Green (1987)]. The 'penalty' is set by including smoothing parameters in the likelihood function, so that the function is maximized not only in terms of fitting to the data but constrained to smoothness of the curves [Cole & Green (1992)].

Combining data from 11 different studies, Cole et al [Cole et al. (1995), Cole et al. (1998)] developed summary centile curves for height, weight, waist circumference and body mass index (BMI) using the LMS Method and penalized likelihood separately for boys and girls. Their work provided a useful set of reference values for studies on British children.

While the SD scores for weight, waist or BMI are highly informative, they might not be adequate indicators of fatness, for none of them distinguish between lean and fat mass. High BMI values are associated with obesity. However, the body mass index should be merely indicative rather than conclusive about a child's condition. For this reason, other methods of assessing children's body composition (in particular, adiposity) have been developed.

2.2 Measures of Body Composition

The gold standard method for establishing body composition is dissection, which is impossible in live subjects. Apart from this method, hydrodensitometry is usually regarded as the nearest to a gold standard. Hydrodensitometry or underwater weighing is basically a method to measure volume. Based on Archimedes' principle, it consists of weighing the subject in air and under water in a large tank with a correction being made for the residual air in the lungs. Despite being regarded as "the most reliable of available techniques for the estimation of body density" [Brodie et al. (1998)], it appears to be very impractical, especially when working with young children. For this reason, alternative techniques have been developed in order to estimate body density or fatness, but these have not always been vigorously compared with, or calibrated against, dissection or even hydrodensitometry. Data allowing such comparisons to be made was not collected during the Gateshead Millennium Study.

The calculation of percentage body fat from body density in adults is often based on a two-component model, which divides the body into two main components, fat mass (FM) and fat-free mass or lean mass (LM), assuming constant densities of 0.9 g/ml for FM and 1.1 g/ml for LM. The problem with such methods in the context of the GMS is that the constants used to estimate fat in adults are not appropriate for children, for they tend to overestimate body fatness in children [Slaughter et al. (1988)]. This is mainly due to the fact that children are chemically immature, and therefore the chemical composition of the fat free mass is not constant, but it changes as the child passes through puberty. One solution to this might be the use of a multicomponent approach to body composition rather than the traditional two-component model [Slaughter et al. (1988)].

2.3 Skinfold Equations

Skinfold thickness measurements can be used to predict body density and therefore percentage of fat mass. Numerous studies have been carried out in order to determine the best model to relate skinfolds and density and body fatness, under the assumption that the amount of subcutaneous fat is representative of the total amount of body fat [Weststrate & Deurenberg (1989),Brodie et al. (1998)]. Measurements of skinfold thicknesses are taken using a caliper (usually a Harpender caliper) on the same side of the body. The most common sites are biceps, triceps, subscapular and suprailiac.

While this method of determining body fatness "has been shown to be as valid as any other method" in adults [Reilly et al. (1995),Durnin & Womersley (1974),Jebb et al. (1993),Womersley & Durnin (1977)], for children it is not clear what statistical model should be used to predict body fatness from skinfolds, and different studies report different equations. The researchers who derived these equations do not usually discuss the generalisability of their results; for that, we must rely on a small number of comparison studies.

Reilly et al. (1995) tried to validate five equations which were in use at that time. For this, they took a sample of 98 healthy prepubertal children (64 boys, 34 girls) aged 9.1 ± 1.7 years. All the studies reported different equations for boys and girls and most of them included a log transformation (to correct for a skewed distribution) of the sum of either two or four skinfolds. Among the equations Reilly et al. looked at, the following ones were discarded for the present study.

- Durnin & Rahaman (1967) equations:

Predicted density (kg/l) = 1.1553 - 0.0643log(sum of 4 skinfolds) [Boys]

Predicted density (kg/l) = 1.1369 - 0.0598log(sum of 4 skinfolds) [Girls]

- Johnston et al. (1988) equations: (predicted density kg/l)

  Predicted density (kg/l) = 1.166 - 0.070log(sum of 4 skinfolds) [Boys]

  Predicted density (kg/l) = 1.144 - 0.060log(sum of 4 skinfolds) [Girls]

Both pairs of equations had been developed using data from adolescents. Since we are working with children aged 6 to 8 years, these equations are not valid for our data, due to the chemical change in the fat free mass composition through puberty.

- Brook (1971) equations:

  Predicted density (kg/l)= 1.1690 - 0.0788log(sum of 4 skinfolds) [Boys]

  Predicted density (kg/l)= 1.2063 - 0.0999log(sum of 4 skinfolds) [Girls]

Although the age range of this sample was 1-11 years, it is not representative, since it consists of 13 obese children and 10 with short stature.

The ones which seem to apply better to our data are the equations by Slaughter et al. (1988) and Deurenberg et al. (1990):

- Slaughter et al. (1988) suggested the following equations:

  Boys

  $$\%\text{fat} = 1.21(\text{triceps} + \text{subscapular}) - 0.008(\text{triceps} + \text{subscapular})^2 - 1.7$$

  $$\%\text{fat} = 0.783(\text{triceps} + \text{subscapular}) + 1.6 \qquad (\textit{if } T + S > 35mm)$$

  Girls

  $$\%\text{fat} = 1.33(\text{triceps} + \text{subscapular}) - 0.013(\text{triceps} + \text{subscapular})^2 - 2.5$$

  $$\%\text{fat} = 0.546(\text{triceps} + \text{subscapular}) + 9.7 \qquad (\textit{if } T + S > 35mm)$$

Note that the equations presented above have a discontinuity at point 35 which is not mentioned by the authors. Their sample consisted of n = 310, both children and adults aged 8-29 years. The subjects were divided into 4 maturation groups, obtaining a group of 66 prepubescent children (50 boys aged 9.8 ± 1.3 years and 16 girls aged 10.0 ± 1.0 years). To derive these equations, nine skinfolds were taken at first, but, in general, just “two skinfolds (triceps and subscapular) were satisfactory in predicting body fatness”[Slaughter et al. (1988)]. Although the skinfolds are not log transformed, a quadratic term is included in the equations.

Also, Parker et al. (2003) tried to validate the equations by Slaughter. They took a sample of 42 boys aged 10.1 - 14.5 years and they found no significant difference (using the ‘Bland-Altman’ method - see Section 2.6) between the reference method (a three component model) and the skinfold thickness method, neither in FM nor in % body fat.

- Deurenberg et al. (1990) suggested the following equations:

  Boys

  $$\%\text{fat} = -14.61 + 26.51\log(\text{biceps} + \text{triceps})$$

  $$\%\text{fat} = -22.23 + 26.50\log(\text{biceps} + \text{triceps} + \text{suprailiac} + \text{subscapular})$$

  Girls

  $$\%\text{fat} = -16.84 + 29.30\log(\text{biceps} + \text{triceps})$$

  $$\%\text{fat} = -25.87 + 29.85\log(\text{biceps} + \text{triceps} + \text{suprailiac} + \text{subscapular})$$

Again, since the age range of the sample (n=378 aged 7-20 years) was fairly wide, it was divided according to maturation level, getting a prepubertal group of 212 subjects, 114 boys aged 11.3 ± 0.16 years and 98 girls aged 10.5 ± 0.16 years. Four skinfold measurements were taken: triceps, biceps, subscapular and suprailiac and two different combinations were considered, either biceps + triceps or the sum of the four skinfolds, but there was not a significant improvement by including the four measurements in the equation.

They also developed equations for predicted density (kg/l):

- Boys predicted density = 1.1133 - 0.0561log(sum of 4 skinfolds) + 1.7(age[years] x 10^{-3})
- Girls predicted density = 1.1187 - 0.063log(sum of 4 skinfolds) + 1.9(age[years] x 10^{-3})

Although the age term is included, it would mean a very small contribution when substituting age for a particular number, since it appears multiplied by 10^{-3}.

Sarría et al. (1998) developed similar equations just for boys, using a sample of 36 boys aged 7-10.9 years. The equation, to predict body density, is the following:

$$\text{Density} = 1.1417 - 0.0633\log(\text{sum of 4 skinfolds})$$

The values for both the intercept and the slope are not far from Deurenberg's values.

Therefore, of the prediction equations reviewed by Reilly et al. (1995), those of Slaughter and Deurenberg appear to be the most appropriate for use with the children in our sample, and both have been validated by later research. However, the recent work by Parker et al. led them to recommend the Slaughter et al. equations. We will start by using the same approach. Recall that both the Slaughter and Deurenberg equations were derived on children who were on average 3-4 years older than the GMS children (though the age range of their samples overlapped with the age range of the GMS sample).

Both equations will be applied to the GMS data set, and it will be of interest to see how they perform and whether they predict different %fat values for the same individuals. The theoretical equations for the Slaughter and Deurenberg equations are shown in the plots below (Figure 2.1). Notice that the Slaughter equation is not continuous, but it has a discontinuity at x=35, where the function passes from being quadratic to being linear.

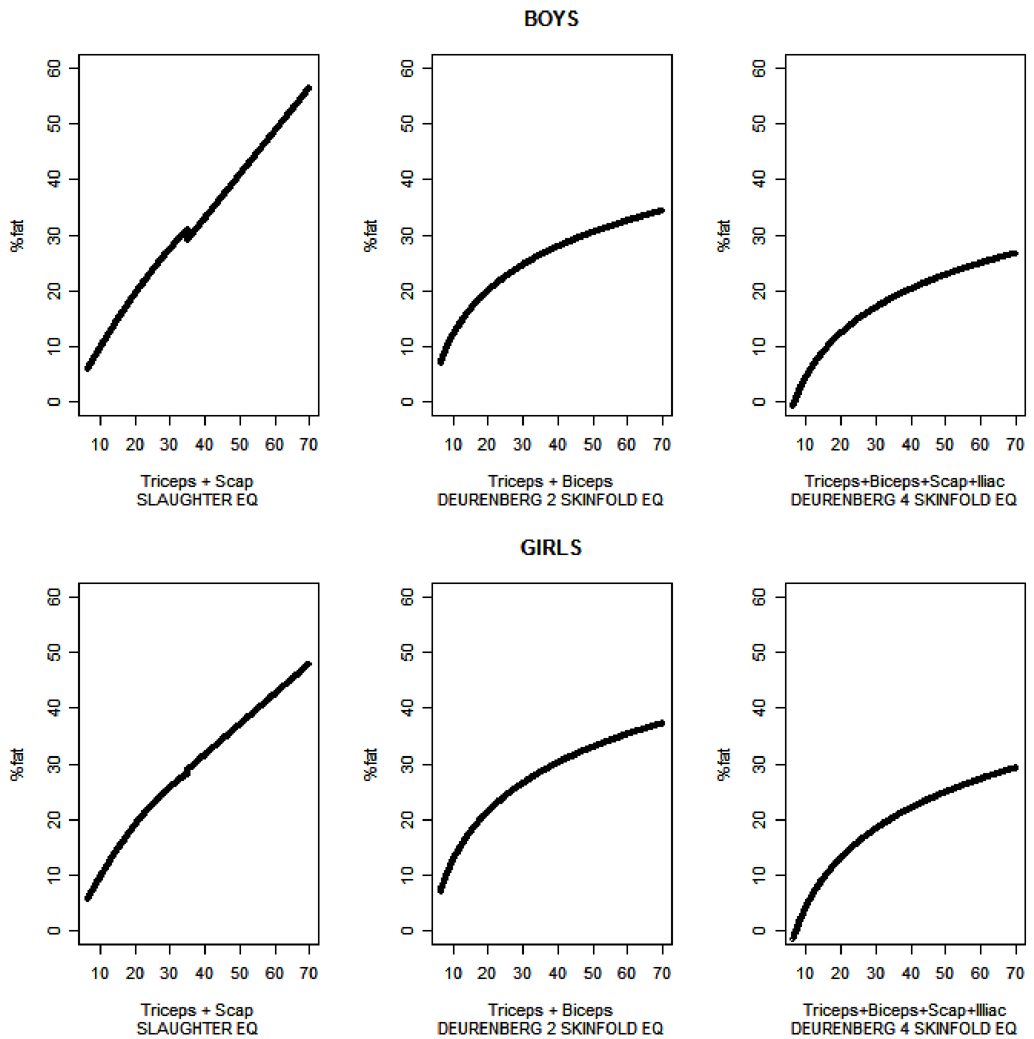

Figure 2.1. Slaughter and Deurenberg theoretical equations

The LMS method described in the previous section is also available for triceps and subscapular skinfolds [Tanner & Whitehouse (1975)]. However, the L(t), M(t) and S(t) curves are based on out-of-date reference values.

2.4 Bioelectrical Impedance Analysis (BIA)

"The bioelectrical impedance analysis (BIA) is a non-invasive body composition assessment approach which (properly used) provides accurate and reliable estimates of fat free mass and total body water (TBW) in healthy populations" [Houtkooper et al. (1996)]. The equipment necessary is safe, portable and relatively inexpensive and the procedure is simple and painless. The results are reproducible and rapidly obtained, making it a suitable method for studying large groups of subjects [Houtkooper et al. (1996), Kyle et al. (2004)].

The method works as follows; a low, safe and imperceptible electrical current is sent through the body (50 kHz alternating current of 800A between electrodes). The impedance value, measured in Ohms, reflects the resistance that the electrical signal encounters when passing through the body. Lean tissue, which is mainly composed of fluids, acts as a conductor, and the current passes freely through them. On the other hand, fat, as it is anhydrous, acts as a resistor to the current [Kyle et al. (2004)].

The measurements are taken by placing 4 surface electrodes at different sites of the human body. Depending on the electrode placement, there are two different ways of measuring impedance:

- Hand-to-leg (e.g. Bodystat): the electrodes are usually placed on the right side of the body on the dorsal surfaces of the wrist and ankle, with the subject in supine position and his legs abducted to 45 $^\circ$.
- Leg-to-leg (e.g. Tanita): the subject is standing erect with bare feet on the analyzer's footpads.

The estimation of TBW is based on the theoretical relation between the volume of a conductor and its electrical impedance, assuming that the conductor has a homogeneous composition, a fixed cross-sectional area and a uniform distribution of current density. Under these assumptions, the resistance (Z) of the conductor is proportional to its length (L) and inversely proportional to its cross-sectional area (A) [Kyle et al. (2004)], so that:

$$\mathrm{Z} = \rho\ (\mathrm{L}\ /\ \mathrm{A}) = \rho\ (\mathrm{L{\cdot}L/A{\cdot}L}) = \rho\ (L^2\ /\ \mathrm{V})\ \text{, where V is volume}$$

And therefore

$$\mathrm{V} = \rho(L^2\ /\ \mathrm{Z})$$

Where ρ is the resistivity constant

Thinking of the human body as a cylinder which satisfies the conditions detailed above, the previous equation can be applied in order to estimate TBW (which would correspond to V in the equation) in terms of the bioelectrical impedance (Z) and length (L), which is taken as the height of the human body:

$$\mathrm{TBW} = \rho(\mathrm{height}^2/\mathrm{Z})$$

Total body water has then to be adjusted for the hydration of the fat free mass to calculate lean mass:

$$\mathrm{LM} = \mathrm{TBW/h}$$

Where h is the hydration constant

Fat mass is finally calculated by subtracting fat free mass from total weight [Wright et al. (2008)].

Although all the above assumptions are not met when the equation is applied to the human body, empirical relationships have been established between impedance and total body water and the previous equations have been widely validated [Houtkooper et al. (1996)].

There are various factors which may affect impedance measurements, such as food intake before the measurement is taken, hydration status, exercise or temperature, as well as the instrumentation used and the position of both the body and the electrodes. Studies on the same subjects report different values for impedance when changes occurred in any of the factors mentioned above [Houtkooper et al. (1996)]. Therefore, it is important to standardize both the instrumentation used and the circumstances under which the measurement is taken in order to obtain reliable impedance measurements.

A large number of validation studies have been carried out to show the usefulness of this approach. Results from cross-validation studies predicting TBW or LM report large R^2 values and relatively small SEE values. Other variables, such as weight, height or sex have been considered, but height^2/Z is generally the best single predictor [Houtkooper et al. (1996)].

However, one should be aware of the limitations of this method, which bases its results on a simplified mathematical model of the human body's shape and composition. Although it has been shown to be a reliable method in population studies, it is said to have limited accuracy in individuals [Houtkooper et al. (1996),Deurenberg et al. (1989)]. In addition, a large number of different equations are currently available. The differences in the regression coefficients are probably due to differences either in the reference methods, the instrumentation used or the particular characteristics of the sample. Therefore, one must be careful when choosing a particular equation, so that it meets best the characteristics of one's own sample.

The impedance values reported in this thesis were obtained with the subjects standing on a machine measuring leg-to-leg impedance (Tanita). The subjects were undressed (wearing underclothes) and had been asked to empty their bladders before the measurement was taken. Different values of the hydration constant and resistivity constant had to be considered for children and adults for reasons we will now explain.

2.4.1 Hydration Constant

The total amount of body water (TBW) in the human body is reported to be strongly correlated to lean mass (LM). This relationship is based on the concept that the water content of the lean body mass is constant and fat is anhydrous.

We will define the hydration constant h as the ratio between total body water and lean mass. Ideally, LM and TBW should be estimated independently from each other in hydration studies. These can be organized into two main categories [Wang et al. (1999)]:

1. In vitro : “based on direct chemical assays of entire animal cadavers or isolated tissues and organs”

2. In vivo : carried out on living humans and animals; “specially used when biological factors that may influence hydration such as age and adiposity are examined”

The principal in vitro method for measuring TBW is by isotope dilution. The most common is deuterium dilution (D_2O). This consists of obtaining either plasma, saliva or urine samples before and after administrating a dose of deuterium diluted into water.

We will assume the hydration constant to be equal to 0.732 in adults and hence the equation relating total body water to fat free mass is:

$$\boxed{\text{LM} = \text{TBW} \ / \ 0.732}$$

Notice that no intercept is included in this equation.

A number of references supporting this assumption are detailed next:

- The "widely quoted" mean h = 0.732 comes from combining available data from different animals. In humans, the value of h = 0.732 was obtained calculating hydration of 16 individual tissues and organs using reference male data [Snyder et al. (1975), as reported in Wang et al. (1999)].
- Lukaski et al. (1985) observed that the correlation coefficient between TBW and LM was r = 0.96. The data (37 healthy men) indicated that the LM contains 74.1 ± 1.3 % water.
- The hydration constant has also been studied by analyzing 9 human cadavers (aged 25-67), obtaining a mean value of h = 0.737±0.036, close to the well recognized value of 0.732. This was calculated combining results from 6 previous studies [Wang et al. (1999)].
- Pace & Rathbun (1945) report a hydration constant of 0.732.

The proportion of water in lean tissue remains controversial. However, there is evidence that this proportion changes considerably during growth, and substantial variation in TBW/LM has been demonstrated across age groups [Hewitt et al. (1993)].

For children, a higher hydration constant than 0.732 has been reported [Lohman (1989)]. Therefore, h has to be adjusted for age (months) and sex. In our particular case, we are going to use the following values: [Sherriff et al. (to appear)]

$$\boxed{\begin{array}{ll} & \text{LM} = \text{TBW/h} \\ \text{where} & \text{Boys: h} = -0.0000833\text{age} + 0.777 \\ & \text{Girls: h} = -0.0001667\text{age} + 0.794 \end{array}}$$

Another age group in which the hydration constant may differ is the elderly [Virgili et al. (1992)]. However, this issue is something we do not have to worry about since the adult data set we will be working just covers the age range 23.58 - 53.08 years (mean 36.56).

As a result, the 'constancy' of lean mass hydration may only be assumed in non elderly adults. Therefore, whoever wants to use the results produced in this thesis must bear in mind that the constants we have assumed may differ for different age groups.

2.4.2 Resistivity constant

Several studies suggest that a constant relationship exists between impedance and total body water (TBW) in adults. Both electrical theory and empirical testing have shown that the volume of a conducting medium, which in our case is TBW, is highly correlated with the square of conductor length divided by impedance. Here, conductor length is taken as being the height of the individual, so that:

$$\mathrm{TBW} = \rho(\mathrm{height}^2/\mathrm{Z})$$

Where Z = impedance

The value ρ is called the resistivity constant. In order to estimate the amount of total body water for the parents' data we will be working with, we searched for literature referring to this constant. It is not very clear what the actual value is, since the results from various papers differ. It is important to highlight that these studies are usually based on small sample sizes and date from a few years ago. Some results from different authors are reported below.

1. Hoffer et al. (1969) studied this relationship by taking a sample of 20 normal volunteers, all males aged 21-38 years old, plus an additional group of

34 patients known to have abnormal levels of hydration. They measured body weight, height, wrist circumference, impedance and total body water on each subject and a regression analysis was conducted in order to determine the correlations between TBW and the rest of the measurements. Although the best relationship found was between TBW and height^2/Z, with a correlation coefficient of r = 0.92, the fitted equation relating these two variables did not appear in the paper.

2. Data from the study of Lukaski et al. (1985), consisting of 37 apparently healthy men, aged 19-42 years old, showed a significant correlation coefficient r = 0.95 between TBW and height^2/Z, and a regression equation:

$$\mathrm{TBW} = 2.03 + 0.63(\mathrm{height}^2/\mathrm{Z})$$

3. Kushner & Schoeller (1986) conducted stepwise multiple-regression analysis on selected variables, as well as ANOVA to test whether the coefficients were significantly different from zero. The following equation was found:

$$\mathrm{TBW} = 0.830 + 0.714(\mathrm{height}^2/\mathrm{Z})$$

   The correlation coefficient between TBW and height^2/Z was r = 0.97 and the standard error of estimate (SEE) = 2.50 litres.

   There are some issues we have to be aware of in this study. First of all, the sample (n = 40) includes 20 obese and 20 non obese subjects. Although there doesn't seem to be a significant difference between obese and non obese males when plotting measured TBW vs. predicted TBW, the equation does not fit so well for females, which makes us think it might be different for obese and non obese females. Therefore, we are not going to rely on the resistivity constant from this paper.

4. The paper by Kushner et al. (1992) reports a study carried out on a bigger sample but covering a wide age range (0.02 - 66 years old). In this

study, linear and stepwise multiple-regression analysis were applied to the data (which included different age groups, from infancy to adulthood) to determine the most significant variables to predict TBW and to yield the lowest SEE. The explanatory variables considered were height, weight, age, height^2/Z, height^2 and $1/Z$. Height^2/Z was found to be the strongest correlated, explaining 99% of the variance in TBW, and giving SEE= 1.47kg. The following equation was produced for the whole group:

$$\text{TBW} = -0.32 + 0.700(\text{height}^2/\text{Z})$$

We do not expect the resistivity constant to be the same for all these different age groups. Therefore, the estimated value of ρ in this study might not be appropriate for any single age group.

In the studies mentioned above, impedance was measured by using arm-to-leg methods. In the following reference, impedance was measured using leg-to-leg techniques.

5. Bell et al. (1998) studied the relationship between TBW and impedance in 57 subjects, both males and females, aged 19-56, obtaining the equation:

$$\text{TBW} = 0.65 + 0.66(\text{height}^2/\text{Z})$$

Without having found a specific value for the resistivity constant, we conducted simple linear regression on raw data available in the first of these papers [Hoffer et al. (1969), see Table 2.1]. We would expect to find similar results to those produced by Lukaski et al. (1985), since the type of subject is fairly similar for both studies. We also wanted to check whether it was necessary or not to include an intercept in the equation. The statistical significance of the intercept is an important issue that is not explored in any of the papers mentioned above. Fitting the model with the intercept, we obtained the following fitted line:

$$\text{TBW} = 1.988 + 0.586(\text{height}^2/\text{Z})$$

The intercept in this model is not significantly different from zero (p-value= 0.667). It is, however, one of the largest intercept values in any of the papers discussed so it seems possible that the other studies would also have found the intercept to be non-significant had they checked. We next fitted a model without an intercept, obtaining the following equation:

$$\text{TBW} = 0.611(\text{height}^2/\text{Z})$$

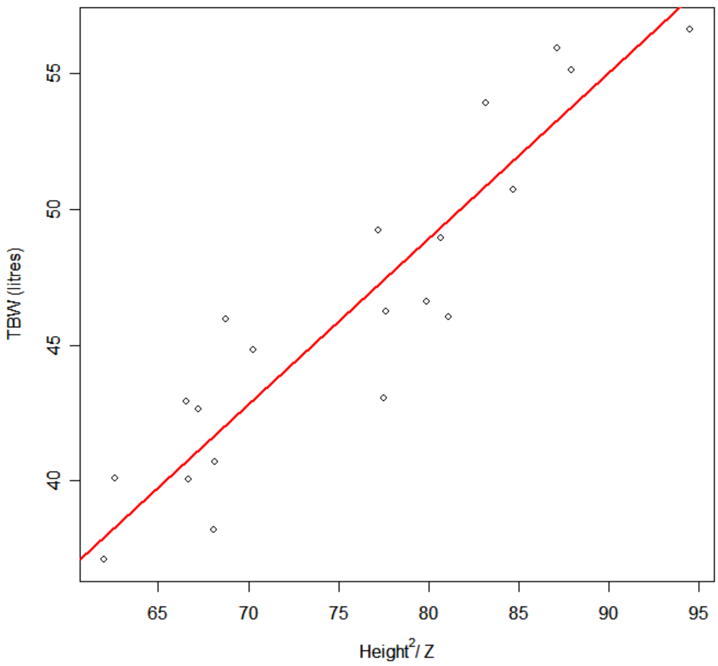

Figure 2.2. Scatterplot of TBW vs. height^2/Z

This last estimate for the resistivity constant is not far from the value produced by Lukaski et al. (1985) (0.63). It is, however, the lowest estimate of ρ from any of these papers. Some of the other studies included both males and females, while these data are only for males, but it is not clear whether ρ should be larger for women.

Also, if we compare our results to those reported by Bell et al. (1998), we can see that the values for the resistivity constant are not exactly the same. This difference might be due to the fact that the methods used to measure TBW are different for the two studies. We have used data from Hoffer et al. (1969) which was obtained by arm-to-leg methods, while Bell et al. (1998) used a leg-to-leg method instead.

AGE(yr)	WEIGHT(kg)	HEIGHT(cm)	TBW(litres)	Z(ohms)
23	79.82	181.6	49.24	427
23	73.98	177.8	40.09	505
23	87.03	176.5	46.05	384
24	115.19	184.2	56.63	359
28	89.00	186.1	50.73	409
29	75.74	177.2	42.65	467
24	91.72	181.0	55.94	376
23	86.45	185.4	55.12	391
22	68.59	182.9	40.71	491
25	89.80	194.3	48.94	468
23	84.81	177.8	42.94	475
21	72.34	180.9	45.94	476
23	61.34	182.3	38.19	488
24	73.58	177.2	44.80	447
24	96.90	193.0	53.89	448
21	58.62	176.2	37.09	501
26	88.89	173.4	43.04	388
38	75.96	182.9	46.23	431
30	66.89	171.5	40.05	441
28	76.45	174.0	46.28	379

Table 2.1. Raw data for 20 male subjects aged 21-38 years, from Hoffer et al. (1969)

We also noticed that TBW is expressed in either kg or litres depending on the paper. This might be due to the general belief that a litre of water is equivalent to a kilogram of water, although this is only true if the temperature of the water is 4C$^\circ$, which is not the case in the human body. We are going to assume that the units for TBW are litres, since we are estimating volume rather than mass.

To start with, we are going to assume the resistivity constant for adults to be:

$$\rho = 0.66, \text{ i.e.}$$
$$\boxed{\text{TBW} = 0.66(\text{height}^2/\text{Z})}$$

This is the value found by Bell et al. (1998), in the only study using leg-to-leg impedance methods. Recall that this value is only valid for non-elderly adults and therefore it might not be appropriate for different age groups. When analyzing the data from Hoffer et al. (1969) the intercept, being one of the largest in any of the papers discussed previously, was found not to be significant. For this reason, the (smaller) intercept reported in Bell et al. (1998) was deleted from the equation we finally used; this implies direct proportionality between adult TBW and height^2/Z which is the relationship that would be naively assumed by almost all researchers in the field.

In children, the regression equation relating leg-to-leg impedance to TBW is reported to be as follows: [Abbott et al. (2003),Sherriff et al. (to appear)]

$$\boxed{\text{TBW} = 0.61(\text{height}^2/\text{Z}) - 0.63}$$

2.4.3 Lean Mass(LM) Index and Fat Mass(FM) Index

Lean and fat mass values are difficult to interpret on their own, as they are expected to differ systematically depending on the subject's height, age and sex [Wells (2001),Fomon et al. (1982)]. Fat mass is usually expressed as %fat (dividing it by total weight) as a means of adjusting for size, while lean mass just remains unadjusted. However, expressing fat mass as a percentage might be inappropriate, specially in children; "individuals will differ in percentage fat either if they have identical lean mass but different fat mass, or if they have identical fat mass but different lean mass"[Wells (2001)]. An alternative approach for adjusting both lean and fat mass for body size was proposed by Wright et al. (2008). Lean mass and fat mass determined using BIA were respectively regressed on height and age using ALSPAC data (9574 children aged 7-11 years), a cohort study of children in the Avon area of South West England. This cohort is considered to be fairly representative of British children [Golding et al. (2001)]. Lean mass was log transformed to achieve normality, while for fat mass a Box-Cox transformation was necessary. The residuals from regression were then standardized (subtracting the mean and dividing by the standard deviation) to get the so called Lean and Fat Indices. Indices for boys and girls were derived separately [Sherriff et al. (to appear)].

The paper providing these indices has not been published yet (but has been submitted and accepted). Height and age were centered before doing the regression. The means for these variables are reported to be as follows:

	Boys	Girls
Height(cm)	139.4	139.7
Age(months)	118.2	118.7

We re-wrote the equations, replacing the centred variables in the original equations with the equivalent raw values, so that they can be applied without having to center the data.

The indices were first derived assuming the same residual standard deviation for all ages (7-11years). However, the authors suggested it might be better to use age specific values depending on the age range the data set covers, and that is the approach that has been adopted in the work presented in this thesis. The resulting indices would be as follows:

<u>LEAN INDEX</u>

$$Boys = (log(LM) - (0.66232 + 0.019Height - 0.0006Age))/0.1 \tag{2.3}$$

$$Girls = (log(LM) - (0.43348 + 0.02Height - 0.0004Age))/0.1 \tag{2.4}$$

FAT INDEX

$$Boys = (FMt - (-3.11176 + 0.038Height + 0.0008Age))/0.589 \tag{2.5}$$

$$Girls = (FMt - (-1.49851 + 0.028Height - 0.0007Age))/0.398 \tag{2.6}$$

Where FMt is a Box-Cox transformation with parameters λ= 0.14 for boys and $\lambda = 0.03$ for girls. Both these values are close to λ=0 (a log transformation) but the authors do not explicitly explore the possibility of using this simpler value.

Note particularly that the residual standard deviations in the previous equations are age specific (7 years old).

2.5 Bony Frame

There is general agreement about the fact that frame size should be considered in the assessment of obesity. Frame size is associated with total mass; larger frame size would imply a greater amount of lean mass, and therefore higher weight [Katch & Freedson (1982)]. As a result, differences in body build will have an impact on the relation between Body Mass Index (BMI) and % body fat [Deurenberg et al. (1999)].

However, it is still unclear how to best deal with this. Different studies report different choices of measurements to estimate bony frame size, and, without a gold standard, it is difficult to decide which method is the most appropriate.

A good measure of frame size should satisfy the following characteristics: [Katch & Freedson (1982), Himes & Bouchard (1985)]

a) High correlation with body mass (weight)

b) High correlation with lean mass

c) Minimal association with fat mass

Apart from these three, which have been generally accepted, it has also been proposed that a good indicator of frame size must have: [Himes & Bouchard (1985)]

a) "Good correlation with lean mass beyond the level produced by height alone"

b) "Little or no association with body fat beyond that which can be accounted for by associations with lean mass".
   It has been shown that lean and fat mass are not independent, especially in obese subjects [Forbes & Welle (1983),Malina et al. (1989)], since larger fat mass is accompanied by relative increases in lean mass also.

In 1959, the Metropolitan Life Insurance Company presented weight-height tables for adults with three different categories for frame size (small, medium, large) [*Metropolitan Life Insurance Company: new weight standards for men and women* (1959), as reported in Himes & Bouchard (1985)]. However, these were unclear; a definition of frame size was not proposed and different levels of body fat were not considered [Himes & Bouchard (1985)]. In 1983, the company revised its previous version and proposed elbow breadth (taken as the greatest breadth across the elbow joint) as the best indicator of frame size [*Metropolitan Life Insurance Company: 1983 Metropolitan height and weight tables* (1983), as reported in Himes & Bouchard (1985)]. The division between the 3 categories was made based on the 25^{th} and 75^{th} percentiles of elbow breadth in their sample. They claimed that their choice was suitable because elbow breadth was not associated with body fat but was strongly related to fat free mass. Despite them being widely used, "the assumptions (underlying these tables) have not been validated with reliable measures of total body composition" [Himes & Bouchard (1985)].

Frisancho & Flegel (1983) also proposed elbow breadth as an appropriate measure of frame size in adults. The cutoff points were set arbitrarily at the 15^{th} and 85^{th} percentiles. Similar cutoffs were used to categorize the subjects in terms of their stature (height). A sample of 16494 (males and females aged 18-74) drawn from the HANES 1 (Health and Nutrition Examination Survey) was then classified according to frame size and stature. The differences in weight between the three frame size categories were greater than the differences in the stature categories. Therefore, frame size would be more effective than stature in the assessment of weight.

Grant et al. (1981) and Lindner (1973) (as reported in Novascone & Smith (1989)) proposed basing the assessment of frame size on the ratio of height to wrist circumference and defined the frame size categories using the 25^{th} and 75^{th} percentiles of this measure.

The elbow breadth and Grant's height to wrist circumference methods were later compared by Nowak & Schulz (1987), who found 69% incidence of agreement. However, Novascone & Smith (1989) applied the methods detailed above and compared them to each other on a sample of 100 young adults (50 males + 50 females, aged 20-29). The kappa statistic (see Section 2.6), which was calculated for each pair of comparisons, was very close to zero in most cases. This means that the level of agreement was likely to occur by chance.

Himes & Bouchard (1985) found that, after accounting for correlation with fat free mass, elbow breadth was still significantly correlated with %fat (estimated from underwater weighing). Their study was carried out on 225 males and 212 females aged 18-59 years. They proposed wrist and ankle breadths as the best measurements of frame size. However, one should be careful when looking at their results, since the sample size was too small and the subjects were leaner than US and Canadian populations (the population as a whole).

Katch & Freedson (1982) proposed what is known as the HAT model. They took several bony frame measurements on a sample of 295 adults (182 females + 113 males) aged 22.0 $\pm$ 0.3 years. These included biacromial, bideltoid, chest, biiliac and bitrochanter diameters, as well as bilateral measurements of elbows, wrist, knees and ankles. %Fat was estimated from underwater weighing. They suggested that "frame size must simultaneously consider both body stature and width", so that "width would account for a portion of the frame size variance unaccounted for by stature". Chest and biiliac measurements were discarded because they are known to be subject to large measurement errors [Katch & Freedson (1982)]. The sum of biacromial (A) and bitrochanter (T) diameters was used to estimate the parameters of the following model:

$$\sum \mathrm{AT} = \alpha + \beta \mathrm{Height}$$

(Where Height, $\sum$AT are in cm)

Different parameter estimates were obtained for males and females.

The different categories of frame size were then defined by drawing perpendicular lines to the fitted models at mean (ht) $\pm$ 1S.D. (Figure 2.3, as described in Katch & Freedson (1982)). However, these limits were set arbitrarily, and they limit the model to persons not further away from the mean stature than 1S.D.

The subjects in their sample were classified into the 3 frame size categories and these categories were compared to each other in terms of height, weight, fat and lean mass and %fat. For males, the differences in weight among categories were not due to differences in fat mass, but in lean mass. For females, the difference for fat mass was only significant between the small and large frame size groups.

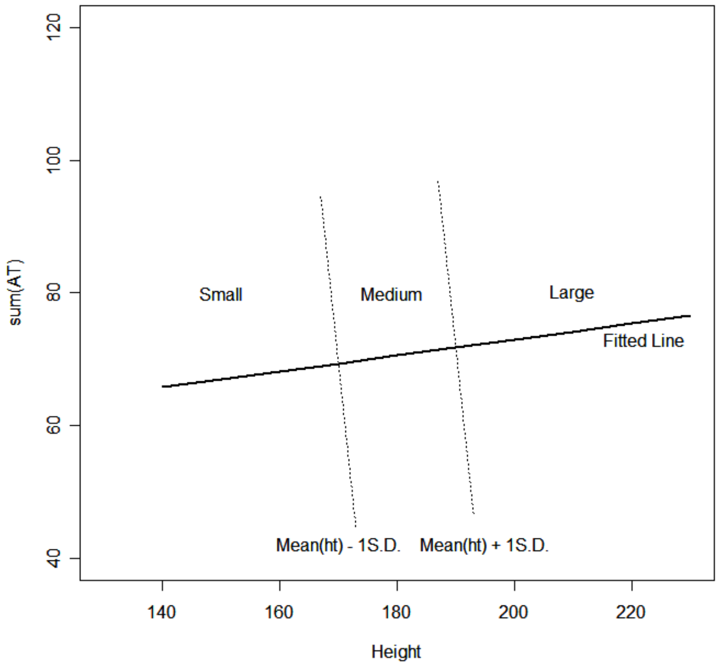

Figure 2.3. HAT model

They calculated as well lean mass/frame size and fat mass/frame size. For males, no significant differences were found for fat mass/frame size, and an increasing trend was identified for lean mass/frame size. For females the results were in the opposite way, so that there were no significant differences for lean mass/frame size but there were significant differences in fat mass/frame size between the small and large and medium and large categories. These last results suggested that "there is some causal relationship between absolute fat storage and frame size in women" that does not happen in males [Katch & Freedson (1982)].

Peters & Eston (1993) applied five already existing methods (elbow breadth from 3 different authors, height to wrist circumference and HAT model) on a sample of 27 young males. The classification of the subjects' frame size according to the 5 different methods showed a general lack of agreement between them.

They proposed as well a measure for the actual frame size (AFS) as the sum of different bony dimensions:

$$\text{AFS} = \sum \text{breadths (cm)} + \sum \text{lengths (cm)} + \sum \text{depths (cm)}$$

This was applied in a sub-sample of 17 subjects. Fat mass and lean mass were estimated from body density (using a predictive equation which includes skinfold thickness and age). Correlation coefficients were calculated between several anthropometric measurements, AFS, fat mass and lean mass, ankle breadth and hand length being the ones with highest correlation with AFS. They also had good correlation with lean mass and no significant correlation with fat mass. On the other hand, AFS was well correlated with weight and lean mass, and not significantly correlated with fat mass, verifying the conditions necessary for a good estimator of frame size.

When comparing the AFS model with the 5 existing methods, the HAT model showed the highest correlation. However, the sample was fairly small and slightly taller and heavier than the general population of the same age.

Baecke et al. (1982) carried out a study on 309 subjects aged 19-21, 24-26 and 29-31 years. Stepwise multiple regression was conducted with total body weight (i.e. not just fat mass) as the dependent variable and height, knee width and wrist width as potential explanatory variables. The best model included both height and knee width, although the accuracy of estimation was only slightly improved with the latter added to the model.

%Fat was calculated from skinfold thickness equations [Durnin & Womersley (1974)] and the correlation with BMI and weight/estimated weight was calculated. The correlation coefficients were the same, showing that the relationship between body fat and BMI was not improved after adjusting for knee width. Also, body fat and knee width were significantly related in females, which is in agreement with the findings of Katch & Freedson (1982).

Fehily et al. (1990) studied several bony frame measurements on a sample of 2512 males aged 45-59 y. Biacromial, bi-iliocristal, wrist and knee diameters were positively correlated with %fat (predicted from skinfolds), wrist being the one with lowest correlation. They derived indices of relative weight adjusting BMI for bony frame and found that the inclusion of frame size did not improve the association between BMI and fatness.

Martínez et al. (1995) carried out a study on 7286 children and adolescents aged 4.5-20.5 years. The subjects were grouped by age and sex specific frame categories, as stated in the Metropolitan Life Insurance Company tables. Height, weight, skinfolds (subscapular, triceps, suprailiac and calf) and elbow breadth were measured on each subject, and descriptive statistics were calculated within each category. It was found that the bigger the frame size was, the greater the amount of subcutaneous fat was, suggesting that frame size and fatness (or, at least, subcutaneous fat) were not independent, even once having adjusted for lean mass.

Contrary to the assumption that elbow breadth is less affected by degree of adiposity than other anthropometric dimensions [Frisancho & Flegel (1983)], they found that elbow breadth was correlated with body fat (estimated from skinfolds). Therefore, frame size should be taken into account, but elbow breadth might not the best predictor according to the characteristics a good measure of bony frame must meet.

On the other side, “it has been suggested that correlations between body breadths and body fat are due to the inclusion of compressed subcutaneous fat thicknesses in the breadth measures” [Tanner (1965), as reported in Himes &

Bouchard (1985)]. While this could happen for shoulders or hips, when measuring elbow breadth "there is little subcutaneous fat over the points measured" [Himes & Bouchard (1985)]. Another possible explanation could be that "bony dimensions would have grown in response to excess weight" [Himes & Bouchard (1985)].

In most of the papers detailed above, the relationship between bony frame and body fat was studied to try and validate their choice, based on the idea that a good measure of bony frame should not be correlated with fat mass. Himes & Bouchard (1985) and Katch & Freedson (1982) predicted %fat from underwater weighing, considered as a gold standard. On the other hand, Peters & Eston (1993), Baecke et al. (1982) and Fehily et al. (1990) used predictive equations based on skinfold thicknesses (a non gold standard mehod). It is important to bear in mind that non gold standard methods may introduce bias, and therefore, the results might not be as reliable.

Martínez et al. (1995) compared elbow breadth with raw skinfold values, and found that they were significantly correlated. This is in agreement with the results reported by Himes & Bouchard (1985). Malina et al. (1989) also suggested that bony frame and fat are not completely independent, since obese children tend to have larger bone widths.

Different methods have been proposed; elbow breadth, the HAT model and the sum of different bony dimensions (resulting in what the authors called 'actual frame size' (AFS)). However, none of them seem particularly effective or applicable to the GMS children. Hence, we will have to propose another way of combining these data.

2.6 Statistical Methods

The standard statistical methods used in this thesis include: Pearson and Spearman correlation coefficients with associated confidence intervals, multiple regression and principal component analysis (PCA).

The Bland-Altman method [Bland & Altman (1986)] is a less common technique that is used for comparing two methods that are intended to measure the same variable. By plotting the paired difference between the two measurements against their mean (which is the best estimate of the individual's true value, given that the true value itself is unknown) for a sample of individuals, we can see how well the methods agree with each other as well as "investigate any possible relationship between the measurement error and the true value"[Bland & Altman (1986)]. Assuming the differences to follow a Normal distribution, we can then calculate limits of agreement as $\overline{d}$±2s.d. ($\overline{d}$ being the mean paired difference). If all the differences lie within these limits and there is no systematic pattern, we can say that any relative bias in the two methods is constant.

Cohen's Kappa statistic [Sheskin (2004),Altman (1991)] was used for assessing the agreement between categorical classification schemes. It is calculated as follows:

$$\kappa = \frac{\sum O_{ij} - \sum E_{ij}}{n - \sum E_{ii}} \quad for \quad i = j \tag{2.7}$$

Where n is the total number of observations, O_{ij} are the observed frequencies and E_{ij} the expected ones (on the assumption that the two classification schemes are independent). A 95% confidence interval can then be calculated as $\kappa \pm 1.96 s.d._{\kappa}$, where

$$s.d._{\kappa} = \sqrt{\frac{\sum O_{ij}(n - \sum O_{ij})}{n(n - \sum E_{ij})^2}} \tag{2.8}$$

Given the nature of the data, it was not sensible to assign weights to disagreements and therefore an unweighted kappa was used.

The analysis was carried out using the software packages R (version 2.2.0), Minitab (version 15) and SPSS (version 15.0) as appropriate.

Chapter 3

Results - Anthropometric Data

As mentioned in Chapter 1, height, weight, waist circumference and skinfold thicknesses (at four sites) were measured on the GMS children. Body Mass Index (BMI) was calculated as weight(kg)/height(m)^2. In total, 599 children (297 boys, 302 girls) were measured. Boys and girls were studied separately.

3.1 Height, Weight, Waist Circumference and BMI

Descriptive statistics for height, weight, waist circumference and body mass index (BMI) are summarized in Tables 3.1 and 3.2.

On average, the boys are slightly taller but not heavier than the girls, who have greater waist circumference and body mass index values. The maximum values for weight (50.3kg for boys and 52.10kg for girls) and waist circumference (81.50cm for boys and 84.65cm for girls) are striking, given that these children are just seven years old.

	Age(yr)	Height(cm)	Weight(kg)	Waist(cm)	BMI(kg/m^2)
Minimum	6.4	107.6	17.5	46.8	12.3
Q1	7.2	121.9	22.8	53.3	15.2
Median	7.4	125.6	25.6	56.2	16.1
Mean	7.5	125.4	26.5	57.1	16.7
Q3	7.8	129.4	28.7	58.7	17.5
Maximum	8.4	138.6	50.3	81.5	27.0
StDev	0.46	5.72	5.45	5.93	2.39
Missing	0	0	1	6	1

Table 3.1. Descriptive statistics for anthropometric measurements (Boys)

	Age(yr)	Height(cm)	Weight(kg)	Waist(cm)	BMI(kg/m^2)
Minimum	6.4	108.1	16.6	43.9	12.5
Q1	7.1	121.1	22.6	52.3	15.2
Median	7.5	124.6	25.5	55.6	16.6
Mean	7.5	124.7	26.7	56.7	17.0
Q3	7.8	128.4	29.6	59.7	18.1
Maximum	8.6	140.1	52.1	84.7	27.0
StDev	0.45	5.82	5.88	6.22	2.56
Missing	0	0	1	2	1

Table 3.2. Descriptive statistics for anthropometric measurements (Girls)

As has already been mentioned, age has to be taken into account when working with children. Therefore, the LMS method (as described in Chapter 2) was applied to the data to produce standard deviation scores (SDS) for height, weight, waist circumference and body mass index (BMI) relative to the 1990 UK Cohort data. Descriptive statistics for these standard deviation scores are presented in Tables 3.3 and 3.4.

	Height	Weight	Waist	BMI
N	297	296	291	296
Minimum	-2.68	-3.07	-2.40	-3.17
Q1	-0.53	-0.41	-0.17	-0.33
Median	0.23	0.35	0.55	0.27
Mean	0.17	0.40	0.61	0.44
Q3	0.89	1.06	1.09	1.10
Maximum	3.10	3.58	3.92	3.68
StDev	1.00	1.16	1.13	1.16
Missing	0	1	6	1

Table 3.3. Standard deviation scores (Boys)

	Height	Weight	Waist	BMI
N	302	301	300	301
Minimum	-3.05	-2.88	-3.33	-2.50
Q1	-0.58	-0.40	-0.21	-0.26
Median	0.09	0.43	0.53	0.37
Mean	0.11	0.37	0.56	0.44
Q3	0.79	1.09	1.31	1.08
Maximum	3.09	3.68	3.79	3.50
StDev	1.05	1.14	1.14	1.09
Missing	0	1	2	1

Table 3.4. Standard deviation scores (Girls)

The histograms of the standard deviation scores for both boys (Figure 3.1) and girls (Figure 3.2) look fairly symmetric.

Both boys and girls are taller (mean 0.17SD for boys and 0.11SD for girls) than the UK 1990 children, and considerably heavier (mean 0.40SD for boys and 0.37SD for girls). The boys' waist and BMI standard deviation scores are slightly right-skewed. The corresponding histograms for both boys and girls are shifted to the right, which means an increase in waist circumference and body mass index with respect to the UK 1990 children.

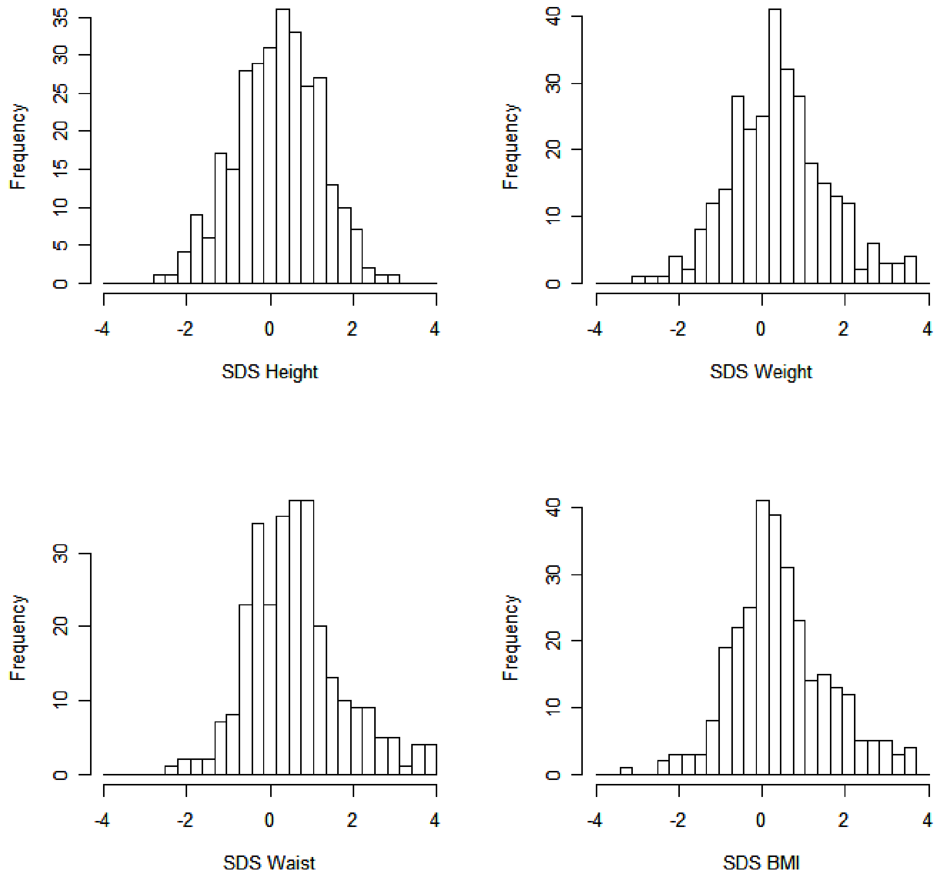

Figure 3.1. Histograms of Standard Deviation Scores for Boys

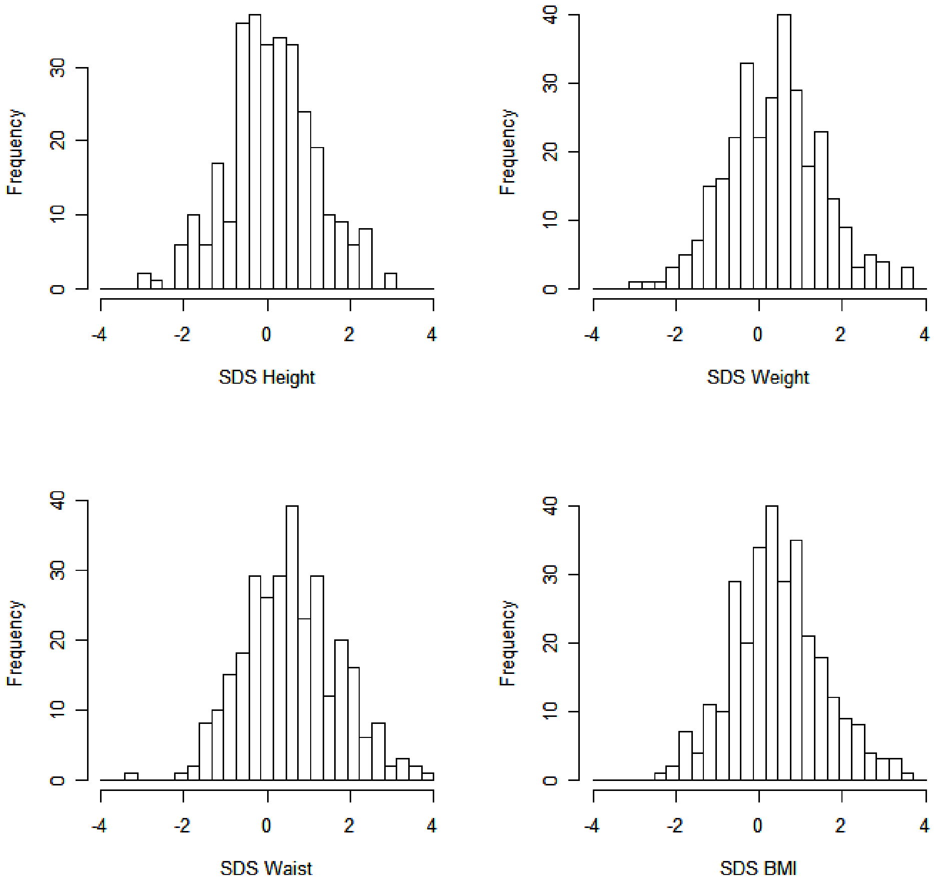

Figure 3.2. Histograms of Standard Deviation Scores for Girls

The interest in the body mass index goes beyond the value itself, for it is used as a classification criterion. This is explored in the next section.

3.1.1 Body mass index(BMI) classification

Children can be classified as underweight, normal, overweight or obese depending on their body mass index. However, different organizations propose different cutoffs values for the classification. The GMS children were classified twice according to two different classification schemes.

1. UK National BMI percentile classification cutoffs [Jotangia et al. (2005)]

These are based on the UK 1990 children. The children are classified in terms of their BMI standard deviation score (calculated using the LMS method) as follows:

- $<5^{th}$ percentile: underweight
- 5^{th} - 85^{th} percentiles: normal
- 85^{th} - 95^{th} percentiles: overweight
- $>95^{th}$ percentile: obese

2. IOTF(International Obesity Task Force) cutoffs
   Age and sex specific cutoffs (different for boys and girls) for ages 2 to 18 were presented in a paper by Cole et al. (2000). These were derived using data collected from six countries (Brazil, Great Britain, Hong Kong, the Netherlands, Singapore and the United States), and correspond to the adults BMI cutoffs for overweight (BMI >25) and obese (BMI >30).
   These cutoffs are based on 6 month intervals. Linear interpolation was used to calculate specific cutoff points at each age [Kremer et al. (2006)].

   The IOTF cutoffs didn't include cut points for underweight. However, Cole et al. (2007) have recently calculated the corresponding adults' underweight cutoff (BMI < 17, underweight grade II) for children aged 2-18 years, using the same methods and data set that had been used for defining the IOTF overweight and obese cut points. Like the IOTF cutoffs, these were based on 6 month intervals and therefore linear interpolation was applied to calculate the exact cut points at each age.

The UK National BMI percentile classification allows direct comparison of a sample with the population of the same country. Using the IOTF criteria, it is intented that the obesity rates can be compared between different countries. The results from both classifications are detailed below.

	UK National		IOTF	
	n	%	n	%
Underweight	9	3.03%	3	1.01%
Normal	211	71.04%	233	78.45%
Overweight	29	9.76%	43	14.48%
Obese	47	15.82%	17	5.72%
Missing	1	0.34%	1	0.34%

Table 3.5. BMI classification (Boys)

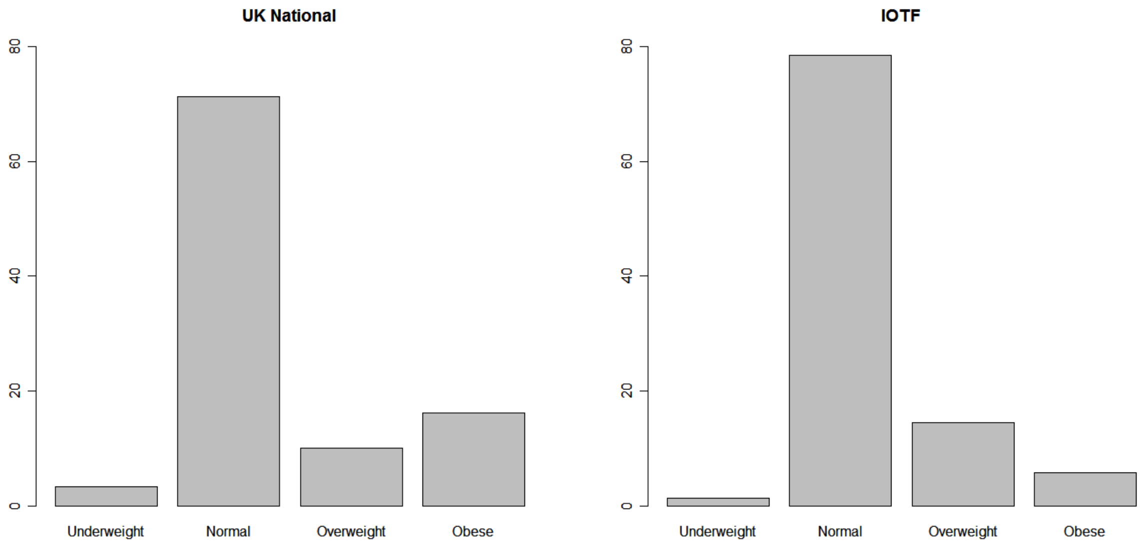

Figure 3.3. BMI classification for Boys: % in each category

	UK National		IOTF	
	n	%	n	%
Underweight	10	3.31%	3	0.99%
Normal	212	70.20%	221	73.18%
Overweight	39	12.91%	57	18.87%
Obese	40	13.25%	20	6.62%
Missing	1	0.33%	1	0.33%

Table 3.6. BMI classification (Girls)

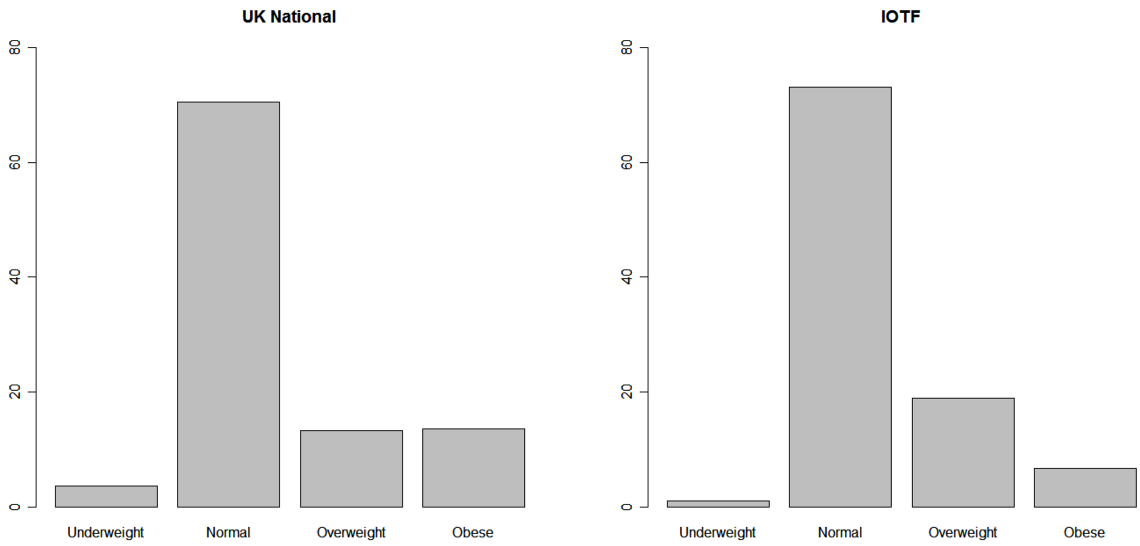

Figure 3.4. BMI classification for Girls: % in each category

There is a substantial difference between the two sets of results. The difference is bigger for boys. For girls, the number of overweight and obese in total is roughly similar (26.16% UK vs. 25.49% IOTF), but for boys there is a considerable difference (25.58% UK vs. 20.20% IOTF).

		IOTF				
		Underweight	Normal	Overweight	Obese	All
UK	Underweight	3	6	0	0	9
	Normal	0	211	0	0	211
	Overweight	0	16	13	0	29
	Obese	0	0	30	17	47
	All	3	233	43	17	296

Table 3.7. UK vs IOTF classification (Boys)

		IOTF				
		Underweight	Normal	Overweight	Obese	All
UK	Underweight	3	7	0	0	10
	Normal	0	212	0	0	212
	Overweight	0	2	37	0	39
	Obese	0	0	20	20	40
	All	3	221	57	20	301

Table 3.8. UK vs IOTF classification (Girls)

Tables 3.7 and 3.8 show a cross-tabulation comparing the two classification criteria for boys and girls, respectively. The pattern of swapping is the same in both cases, the biggest disagreement taking place between the categories of overweight and obese, where the IOTF generally classifies children into a lower category (ie, under the UK scheme they would be classified as obese, while under the IOTF scheme they are classified as overweight). As it has already been mentioned, the difference is bigger for boys.

According to the UK National BMI percentile classification, 25.58% of the GMS boys and 26.16% of the girls suffer from being either overweight or obese. However, as discussed in Chapter 2, BMI might not be the best way of determining whether a child has excess fat, since it is not exactly a measure of fatness. On the contrary, skinfold thickness allows a direct assessment of subcutaneous fat. It will be of interest then to study how these two concepts (body mass index and skinfold thickness) relate to each other.

3.2 Skinfold thickness

Skinfold thickness was measured at four different sites: subscapular, suprailiac, biceps and triceps. The measurements are all in millimeters (mm). The descriptive statistics for the four measurements are shown in Tables 3.9 and 3.10. Note that there is a considerable number of missing values. This is possibly due to the fact that measuring skinfold thickness is not as simple as measuring weight or height and therefore some children might object to being measured. In general, girls have bigger skinfold thicknesses than boys, as expected.

	Subscapular(mm)	suprailiac(mm)	Biceps(mm)	Triceps(mm)
N	272	269	288	281
Minimum	2.750	2.650	2.650	3.100
Q1	5.000	5.075	4.413	7.325
Median	5.925	6.700	5.675	9.050
Mean	7.635	8.439	6.517	10.293
Q3	8.337	9.700	7.237	11.700
Maximum	40.000	38.800	30.100	31.950
StDev	5.046	5.584	3.502	4.639
Missing	25	28	9	16

Table 3.9. Descriptive statistics of skinfolds (Boys)

	Subscapular(mm)	suprailiac(mm)	Biceps(mm)	Triceps(mm)
N	284	273	291	291
Minimum	3.700	3.400	2.800	4.800
Q1	5.913	6.200	5.500	9.700
Median	8.000	9.700	7.100	11.650
Mean	9.614	11.442	7.921	12.774
Q3	10.975	14.000	8.950	14.850
Maximum	36.500	37.250	28.300	33.200
StDev	5.807	6.850	3.960	4.925
Missing	18	29	11	11

Table 3.10. Descriptive statistics of skinfolds (Girls)

After examining scatter plots of these data, Pearson correlation coefficients were calculated for each pair of skinfolds (Table 3.11). The correlation coefficients are all quite high.

Boys

	Subscapular	suprailiac	Biceps	Triceps
Subscapular	1.00	0.84	0.88	0.85
suprailiac	0.84	1.00	0.82	0.87
Biceps	0.88	0.82	1.00	0.86
Triceps	0.85	0.87	0.86	1.00

Girls

	Subscapular	suprailiac	Biceps	Triceps
Subscapular	1.00	0.87	0.83	0.83
suprailiac	0.87	1.00	0.79	0.83
Biceps	0.83	0.79	1.00	0.84
Triceps	0.83	0.83	0.84	1.00

Table 3.11. Correlation coefficients of skinfolds

In order to analyze the skinfolds data, z-scores were produced applying the LMS method. The method is only available for subscapular and triceps. The standard deviation scores are summarized in Table 3.12.

	Boys		**Girls**	
	Subscapular	Triceps	Subscapular	Triceps
N	297	297	302	302
Minimum	-3.18	-3.94	-2.00	-2.52
Q1	-0.12	-0.32	-0.10	-0.09
Median	0.44	0.36	0.67	0.52
Mean	0.61	0.44	0.58	0.53
Q3	1.36	1.13	1.31	1.19
Maximum	3.20	3.70	2.53	3.06
StDev	1.05	1.20	0.95	1.00
Missing	25	16	18	11

Table 3.12. Standard deviation scores for skinfolds

As we can see in the plots below (Figure 3.5), all the histograms appear to be shifted to the right. We also detected a few outliers on the left hand side of the histogram. These were taken away and the LMS method was re-applied. However, we did not achieve a great improvement.

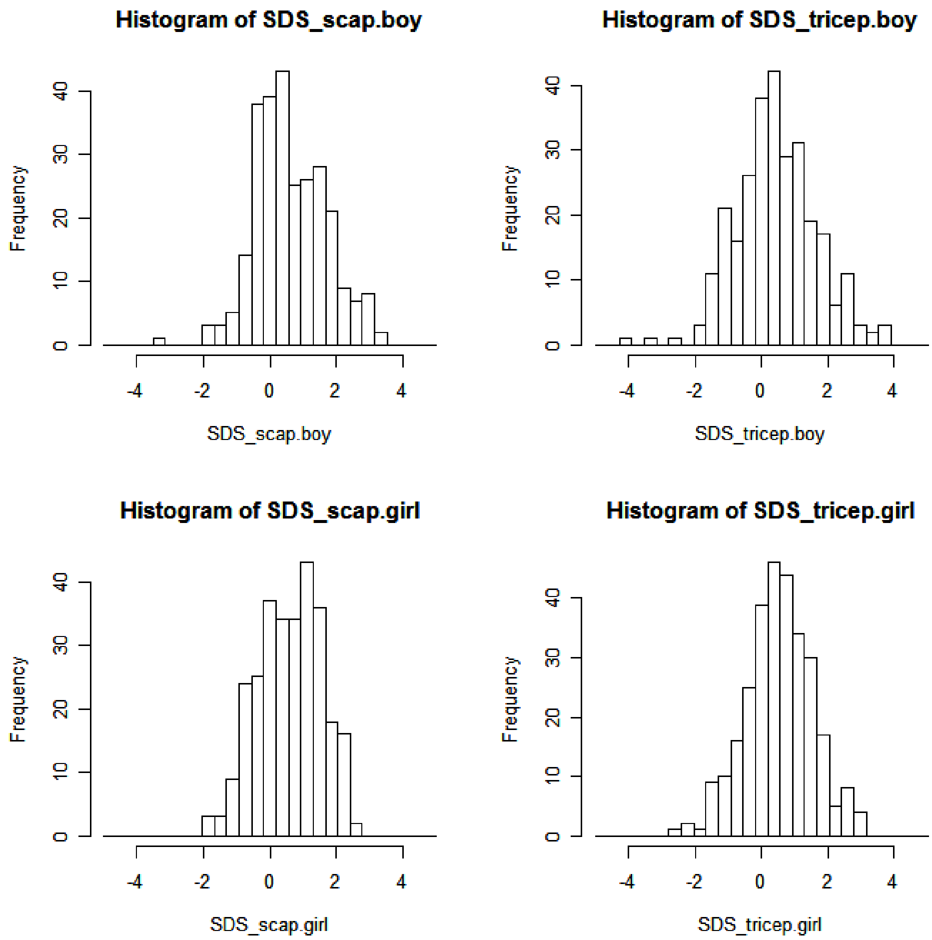

Figure 3.5. Histograms of Skinfold thickness SD Scores

The Tanner-Whitehouse reference values used to convert the raw measurements into standard deviation scores date from 1975 (and were derived using data collected in 1966-1967). The histograms look fairly symmetric but instead of being centred at zero, they are shifted to the right, which means that the values we obtained are, in general, greater than expected. This might show no more than the fact that there has been an increase in body fat since 1975.

Another way of dealing with this data is using skinfold thicknesses to predict %fat values. Several equations to do so are available in the literature, as discussed in Chapter 2. Among these, both the Slaughter and the Deurenberg equations were applied to the data. These two were chosen for being the most suitable for children of 7 years old (see chapter 2 for details).

We first present the results for boys.

	Min	Q1	Median	Mean	Q3	Max	StDev
Slaughter	5.8	12.1	14.9	16.8	19.4	51.9	7.4
Deurenberg, 2 skinfolds	9.8	13.9	16.4	17.0	19.2	32.9	4.3
Deurenberg, 4 skinfolds	9.0	13.4	15.8	16.7	19.3	32.5	4.7

Table 3.13. Descriptive statistics of predicted %fat (Boys)

As we can see in Table 3.13, there does not seem to be a big difference between using either the 2 or the 4 Deurenberg skinfold equation. Although the median is slightly bigger for both Deurenberg equations, the Slaughter equation produces much higher values, with very extreme values for those subjects whose sum of skinfolds is big.

Next, we wanted to compare whether there is a significant difference between the Slaughter and Deurenberg equations.

The following plots (Figure 3.6) show the values produced by the three equations compared to each other, as well as an equality line. The 2 and 4 skinfolds Deurenberg equations produce values that are fairly similar. However, we would like to remark that for high values of %fat (> 22 % aprox.) all the points lie above the equality line, which means that the 4 skinfold equation generally predicts higher amounts of fat than the 2 skinfold equation. When comparing the Slaughter equation to both Deurenberg equations, it is clear that there is a big difference. Most of the points in both scatterplots lie over the line for small values and under the line for bigger values. Moreover, a few points are far away from the equality line.

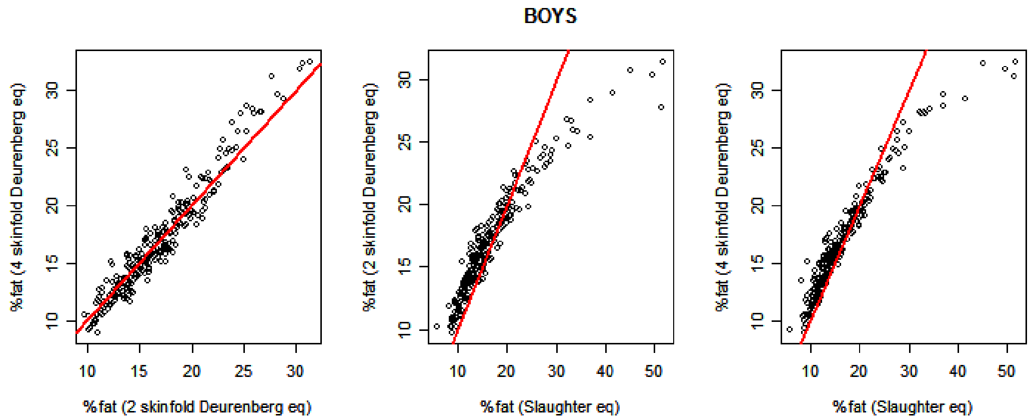

Figure 3.6. Predicted %fat values compared to each other (Boys)

In order to see if the difference between the two methods was significant, two different approaches were used. First, we carried out Wilcoxon signed rank tests. The results suggested that there is a significant difference on average between the Slaughter and Deurenberg equations (p-value < 0.00001 in both cases, 95%C.I. for median difference (-1.094, -0.617) Slaughter vs 2 skinfold Deurenberg and (-0.760, -0.398) Slaughter vs 4 skinfold Deurenberg), but not between the 2 and 4 skinfold Deurenberg equations (p-value=0.1207, 95%C.I.: (-0.031, 0.268)).

We also wanted to test how well the methods agree. For this, the Bland-Altman Method was applied to the data. The limits of agreement on Figure 3.7 are rather narrow (just about ± 2 percentage points) and there does not seem to be any relationship between the average and the difference, except that the differences are all negative when the mean is above 23%, which means that the 2 skinfold equation gives relatively low values of %fat when skinfolds are large.

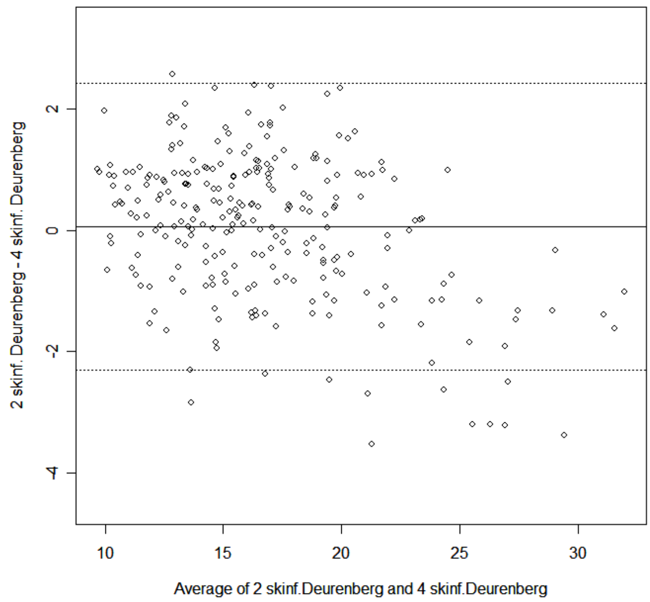

Figure 3.7. 2 skinf. Deurenberg vs. 4 skinf. Deurenberg (Boys)

On the other hand, as we can see in the plots below (Figures 3.8 and 3.9), limits of agreement between other pairs of methods are wide, indicating poor agreement between predictions. There also seems to be a relationship between the means and the differences; the greater the values, the more negative the difference between the two methods. Notice that there are some points completely out of the limits of agreement. These points correspond to high %fat values. Since all these points are under the lower limit of agreement, it means that the Slaughter equation produces bigger values of %fat than the Deurenberg equations.

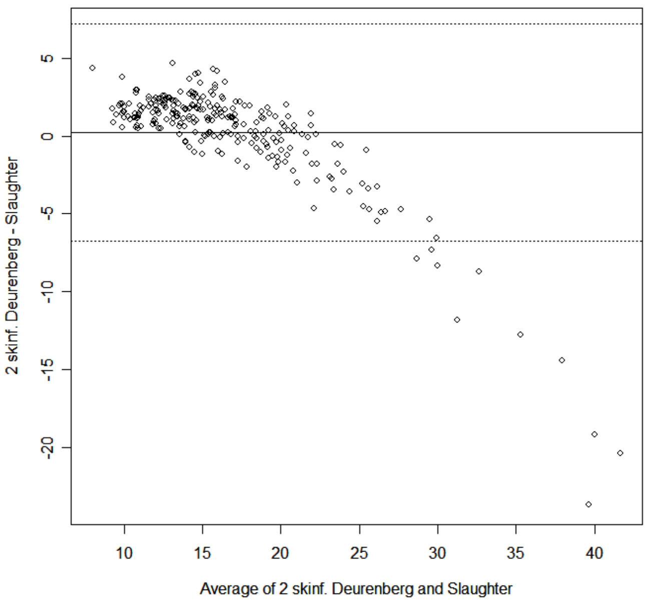

Figure 3.8. 2 skinf. Deurenberg vs. Slaughter (Boys)

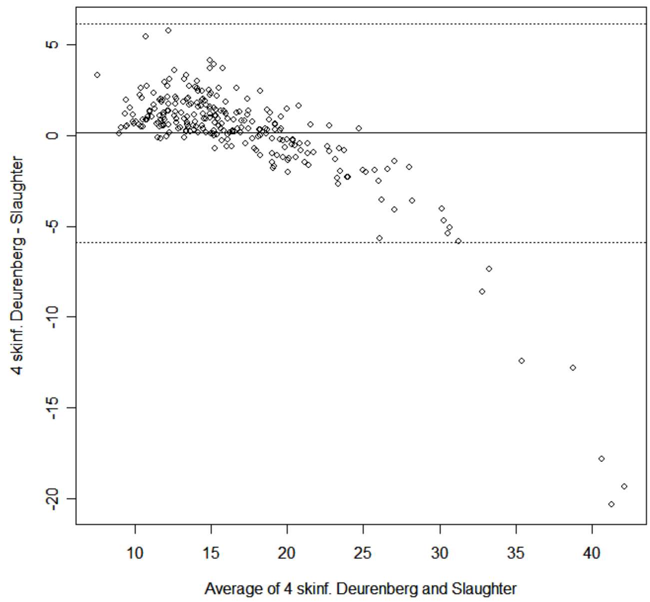

Figure 3.9. 4 skinf. Deurenberg vs. Slaughter (Boys)

Similar analyses were carried out using the girls' data.

	Min	Q1	Median	Mean	Q3	Max	StDev
Slaughter	7.9	15.0	19.0	19.9	22.6	46.8	6.7
Deurenberg, 2 skinfolds	10.5	17.6	20.6	20.8	23.1	35.6	4.5
Deurenberg, 4 skinfolds	11.7	17.0	20.7	21.2	24.1	37.0	5.3

Table 3.14. Descriptive statistics of predicted %fat (Girls)

As we can see in Table 3.14, there does not seem to be a big difference on average between using either the 2 or the 4 Deurenberg skinfold equation. Although the median and mean are bigger for both Deurenberg equations, the Slaughter equation produces higher values in general, with very extreme values for those subjects whose sum of skinfolds is big.

The following plots show the values produced by the three equations compared to each other, as well as an equality line. While for boys the 2 and 4 skinfolds

Deurenberg equations produced values that were fairly similar, for girls the difference between the two equations is bigger. A great number of points lie above the equality line, which means that the 4 skinfold equation generally predicts higher amounts of fat than the 2 skinfold equation. However, this discrepancy is for estimated values above 20-25% just as for the boys; more girls than boys have %fat values in this range. When comparing the Slaughter equation with both Deurenberg equations, it is clear that there is a big difference. Most of the points in both scatterplots lie over the equality line, and the points lying below the line are far away from it.

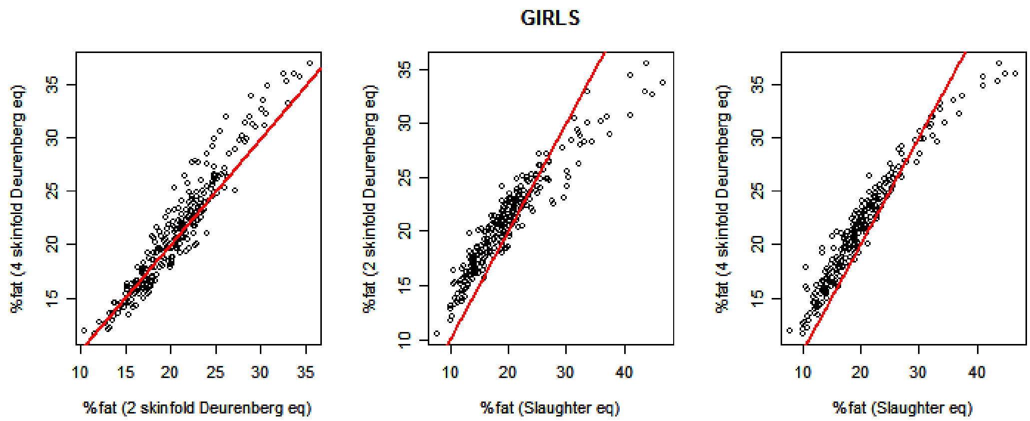

Figure 3.10. Predicted %fat values compared to each other (Girls)

The results of Wilcoxon signed ranked tests suggested that there is a significant difference on average between the Slaughter and Deurenberg equations (p-value < 0.00001 in both cases, 95%C.I. (-1.094, -0.617) Slaughter vs 2 skinfold Deurenberg and (-0.760, -0.398) Slaughter vs 4 skinfold Deurenberg), but also between the 2 and 4 skinfold Deurenberg equations (p-value=0.0001984, 95%C.I.: (-0.5498, -0.1701)).

To see how well the methods agree, we used the Bland-Altman method.

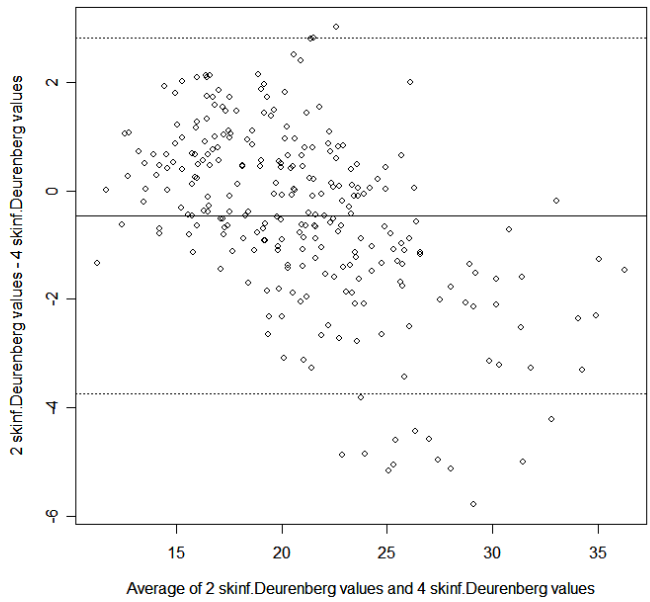

Figure 3.11. 2 skinf. Deurenberg vs. 4 skinf. Deurenberg (Girls)

As we can see on the first plot (Figure 3.11), limits of agreement when comparing both Deurenberg equations are wider for girls than they were for boys. Also, because the values are bigger, the relationship between average and difference is now more evident than it was for boys.

When comparing the Slaughter equation to each of the Deurenberg equations (Figures 3.12 and 3.13), limits of agreement between the two methods are wide, indicating poor agreement between predictions. In particular, the limits for the 2 skinfold Deurenberg vs. Slaughter equation are wider than those for the 4 skinfold Deurenberg vs. Slaughter. There is a strong relationship between the means and the differences. Notice that there are some points completely out of the limits of agreement. These points correspond to high %fat values. Since all these points are under the lower limit of agreement, it means that the Slaughter equation produces bigger values of %fat than the Deurenberg equations when the sum of skinfolds is big.

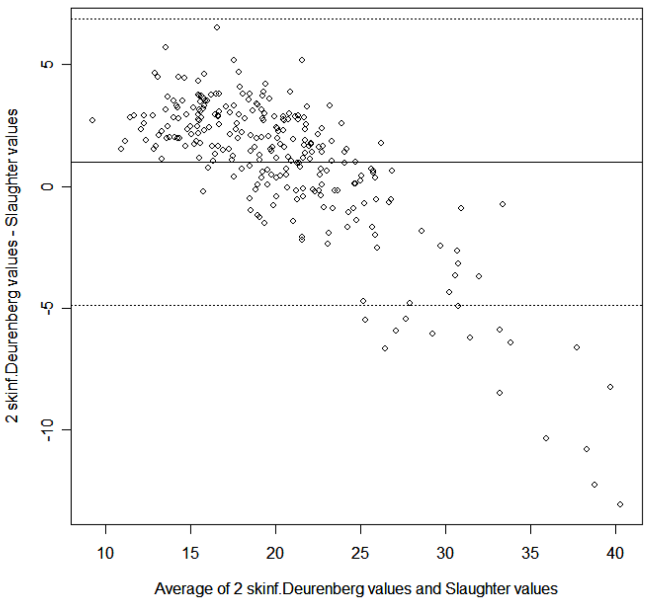

Figure 3.12. 2 skinf. Deurenberg vs. Slaughter (Girls)

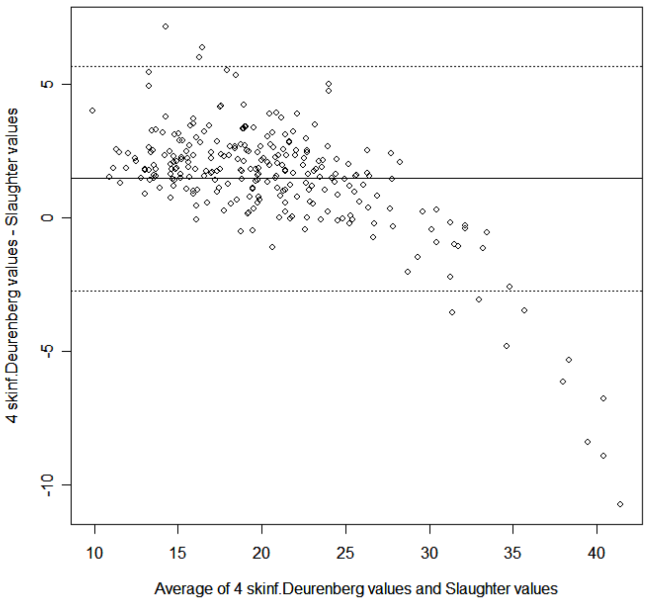

Figure 3.13. 4 skinf. Deurenberg vs. Slaughter (Girls)

In light of these results, at most one of the methods is correct.

3.2.1 An alternative approach to handling skinfolds data

The equations which try to predict %fat from skinfolds give conflicting results on these data, but the LMS Method can only be applied to subscapular and triceps skinfolds. As a way of working with all four skinfold measurements (subscapular, suprailiac, biceps and triceps) the average of the ranked values was calculated. For this, each of the four skinfold variables was ranked individually. Then, the average of the four ranks was taken for each individual. This approach is justified to some extent by the high correlations between skinfolds. It avoids all the difficulties of external standardization of the data, but gives a measure that is only useful for comparisons within the GMS data set. As an alternative to this a principal components analysis was performed, the first principal component being just an average of the five skinfolds. This approach was not explored further in this thesis.

The following plots (Figures 3.14 and 3.15) illustrate how this measurement relates to the standard deviation scores for height, weight, waist and body mass index calculated in Section 3.1. There does not seem to be any significant relationship with the standard deviation scores for height, which is what one would expect. The relationship with weight, waist and BMI shows some kind of 'S' shape. There is a very mild positive relationship, which becomes clearly pronounced towards the ends.

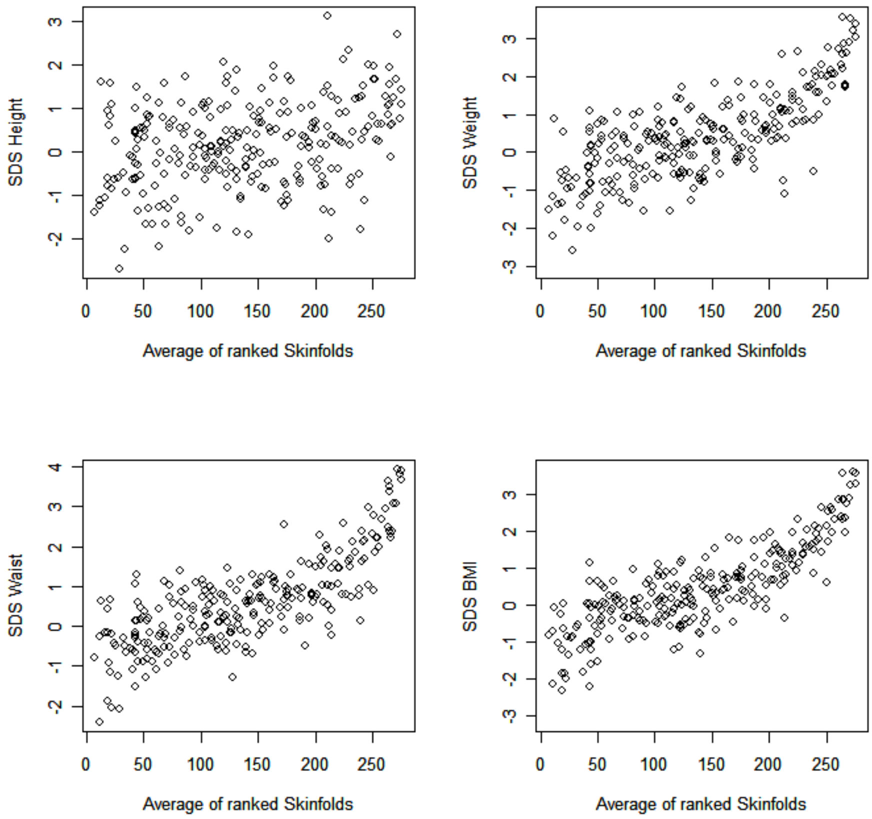

Figure 3.14. Average of ranked skinfolds vs. standard deviation scores (Boys)

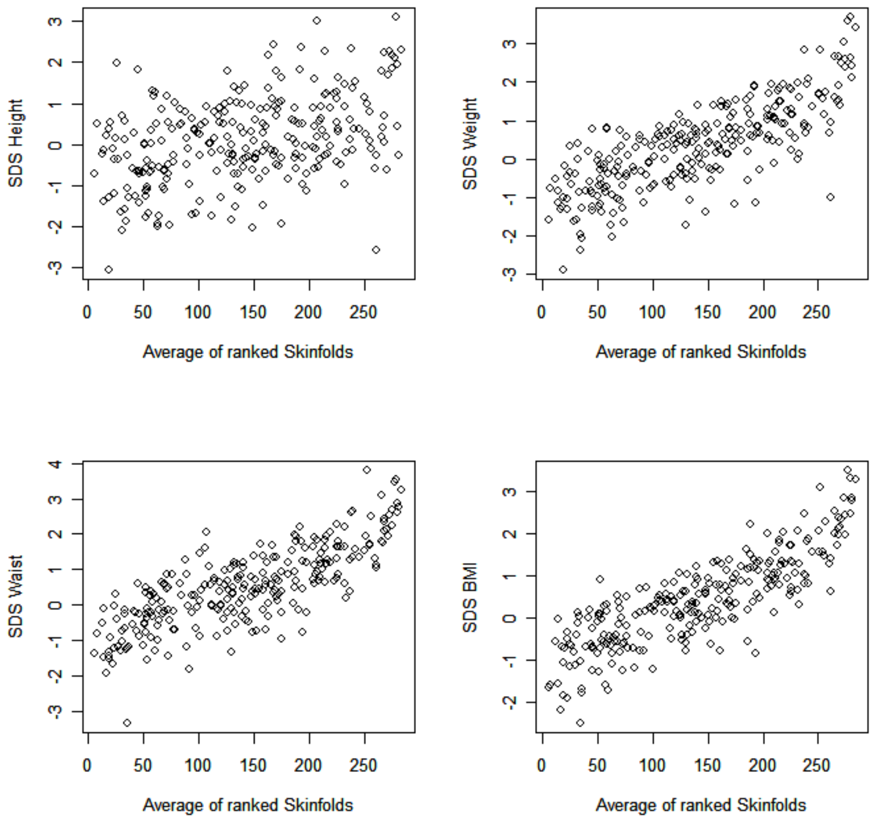

Figure 3.15. Average of ranked skinfolds vs. standard deviation scores (Girls)

Although BMI does not assess fat directly, it is currently considered as a measure of fatness, since it is used to determine whether a child is obese (or overweight) or not. Skinfold thicknesses provide a direct measure of (subcutaneous) fat. It is of interest then to see how the two individual skinfold SD scores relate to the BMI SD score.

Body mass index SD scores and skinfolds SD scores are strongly correlated (Table 3.15). The correlation with triceps and subscapular is about the same, being very slightly higher for girls than for boys. These relationships are shown in Figures 3.16 and 3.17. Spearman correlation coefficients were calculated in this thesis unless the requirements needed for Pearson correlation appeared to be met from plots. The Spearman correlation coefficient is more appropriate here as some of the relationships between variables are non linear.

	Boys		Girls	
	$\hat{\rho}$	95%C.I.	$\hat{\rho}$	95%C.I.
Triceps SDS	0.75	(0.69, 0.80)	0.78	(0.73, 0.82)
Subscapular SDS	0.78	(0.73, 0.82)	0.80	(0.75, 0.84)

Table 3.15. Spearman correlation coefficients between BMI SDS and Skinfolds SDS

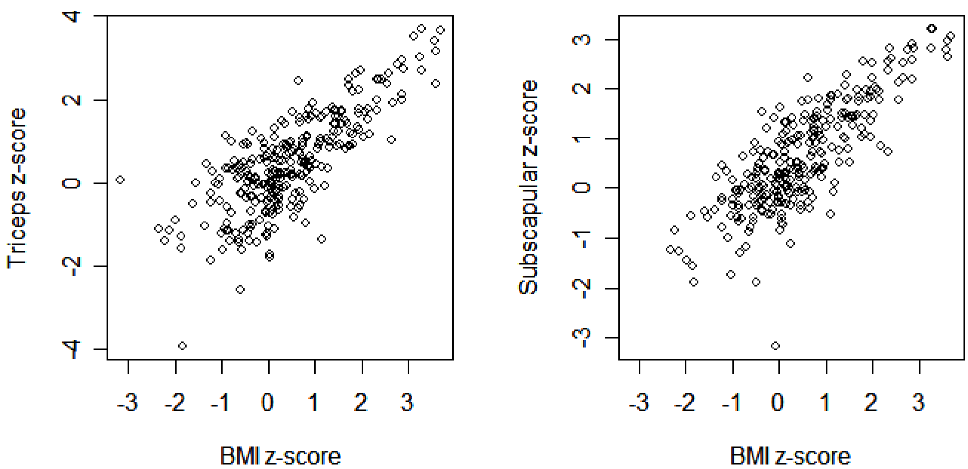

Figure 3.16. Body mass index (SDS) vs. Skinfolds (SDS) (Boys)

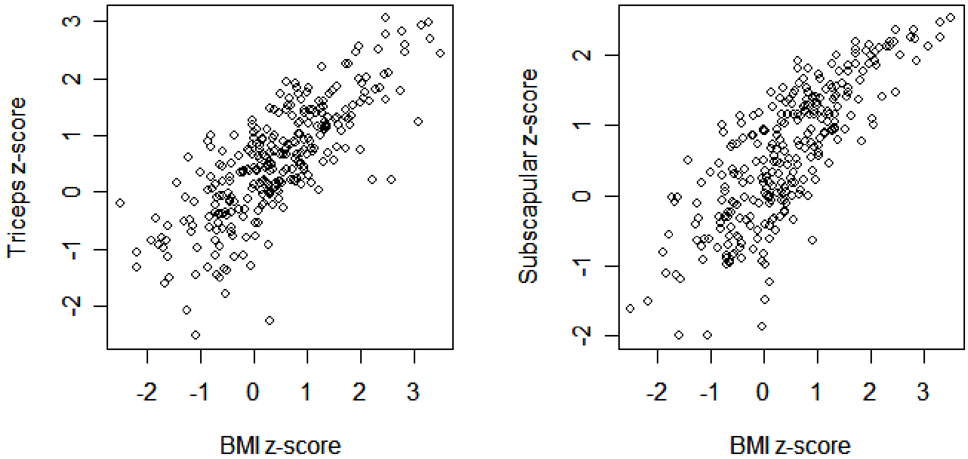

Figure 3.17. Body mass index (SDS) vs. Skinfolds (SDS) (Girls)

3.3 Adults' Anthropometric Data

Children's nutritional status might be influenced by the environment they grow up in. Therefore, collecting data on their families can be very informative. Some basic information was also recorded about the parent (almost always the mother) accompanying the child on the day of the examination. Anthropometric data (height, weight, waist circumference and hip circumference) was collected on 506 GMS women. The descriptive statistics are detailed in Table 3.16.

	Age(yr)	Height(cm)	Weight(kg)	Waist circumference(cm)	Hip circumference(cm)	BMI
Min	23.58	141.90	40.75	57.50	67.70	16.78
Q1	32.25	158.90	59.38	74.20	96.90	22.64
Median	36.63	163.00	67.50	80.40	102.70	25.06
Mean	36.27	163.10	70.74	83.30	104.90	26.59
Q3	40.17	167.40	78.20	90.55	111.30	29.32
Max	53.08	179.20	153.90	142.60	180.00	64.31
StDev	5.67	6.21	16.19	12.43	12.45	5.87
Missing	0	0	6	5	5	6

Table 3.16. Descriptive statistics for the mothers' anthropometric measurements

3.3.1 Body Mass Index Classification

As was done with the children in the previous section, their mothers were classified according to their body mass index.

While for children different classifications are available and there is not clear agreement about which one should be used, for adults there is general agreement and the International WHO cutoff points are widely accepted. Moreover, unlike the children's BMI cutoffs, these are independent of age and the same for both males and females. The cutoffs for adults are the following:

International WHO classification [WHO (WebPage)]

- Underweight: BMI < 18.50
- Normal: BMI 18.50 - 24.99
- Overweight: BMI 25 - 29.99
- Obese BMI ≥ 30

The mothers were classified following these criteria. The number of subjects in each category, as well as the corresponding percentages, are shown in Table 3.17 and Figure 3.18.

	n	%
Underweight	9	1.78%
Normal	238	47.04%
Overweight	141	27.87%
Obese	112	22.13%
Missing	6	1.19%

Table 3.17. Classification of the mothers based on their BMI

50% of the mothers have been classified as either overweight or obese. Whether these results are misleading because there is a confounding factor (such as high lean mass) will be explored further in Chapter 4, where lean mass and fat mass will be studied separately.

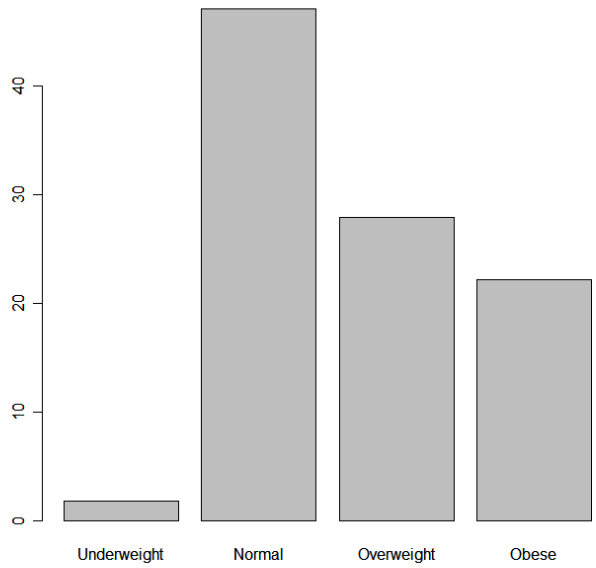

Figure 3.18. Barplot of Mothers BMI classification (%)

3.3.2 Waist to Hip Ratio

The waist to hip ratio was calculated by dividing the circumference of the waist by the circumference of the hips, giving a measure of central adiposity. The descriptive statistics are shown in Table 3.18.

The body mass index and the waist to hip ratio are both used as tools for assessing adiposity, overall and central, respectively. They are positively correlated (Spearman's correlation coefficient: $\hat{\rho}$=0.41, 95%C.I.:(0.34, 0.48)), as Figure 3.19 shows. Note that there is quite a lot of variation in BMI for a given value of waist to hip ratio and vice versa.

	Waist to Hip ratio
Min	0.658
Q1	0.749
Median	0.786
Mean	0.793
Q3	0.831
Max	0.965
StDev	0.061
Missing	5

Table 3.18. Waist to hip ratio descriptive statistics

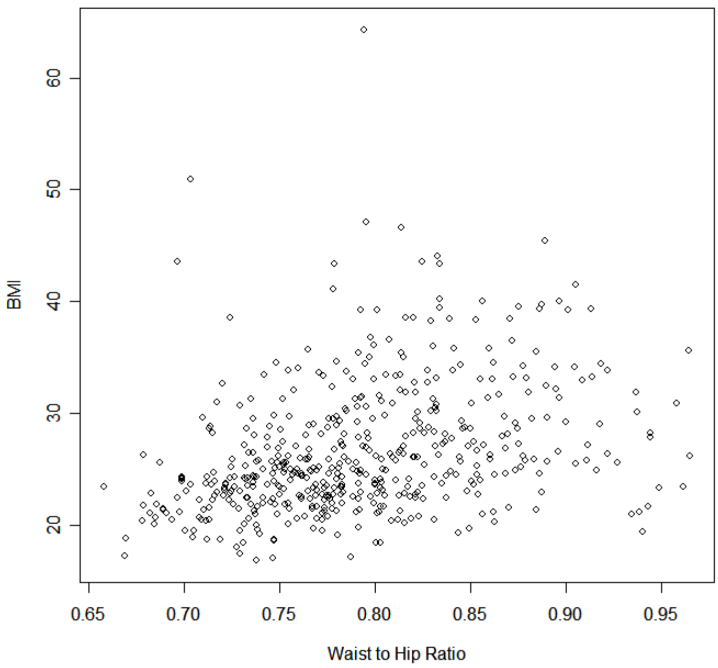

Figure 3.19. Scatterplot of BMI vs. Waist to Hip Ratio

3.4 Mothers vs. Children

There is a weak positive correlation between the mothers' BMI and the children's BMI SD Score (Spearman's correlation coefficient $\hat{\rho}$=0.22, 95%C.I.:(0.14,0.30), see Figure 3.20).

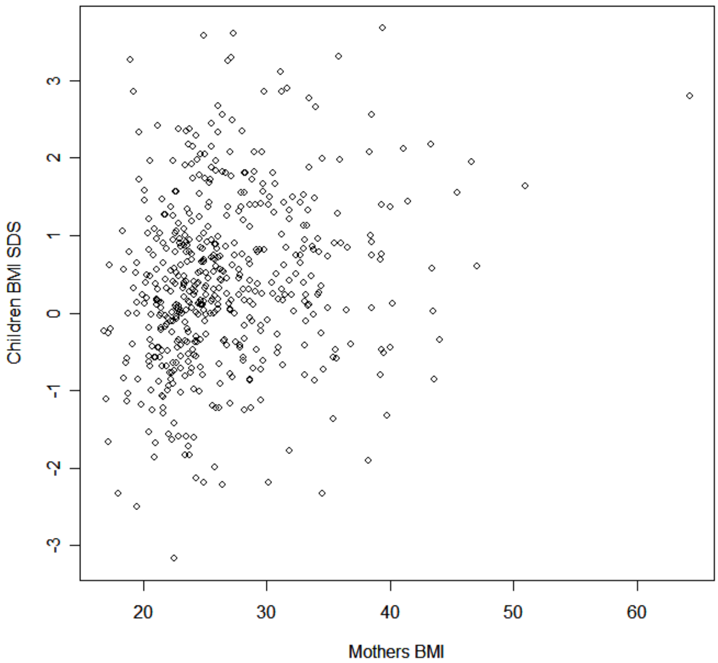

Figure 3.20. Scatterplot of mothers' BMI vs. Childen's BMI SDS

As we can see in Table 3.19, the prevalence of overweight and obese children is higher among those whose mothers are either overweight or obese than for those whose mothers are classified as normal. The % of overweight children is higher for obese mothers than for overweight mothers, and viceversa for obese children.

		Children		
		Normal	Overweight	Obese
Mothers	Normal	210 83.33%	20 7.94%	22 8.73%
	Overweight	101 70.14%	15 10.42%	28 19.44%
	Obese	76 68.47%	16 14.41%	19 17.12%

Table 3.19. Mothers vs. Children categorized in terms of BMI

Note: *% refers to row percentages. The underweight category was combined with the normal category because it caused problems when testing for association*

A Pearson chi-square test of association was carried out. There is a significant association (p-value 0.004) between mothers and children. In total, 507 mother-child pairs were compared. Looking at the diagonal, we can see that nearly half of them are in the 'correct' category, ie, both mother and child are in the same category. The (unweighted) kappa statistic is very close to zero ($\kappa = 0.077$, 95% C.I. (-0.000, 0.155)), indicating that the observed agreement between the ratings is no greater than that which could occur by chance. The % of overweight and obese children is higher for overweight and obese mothers, and this is reflected in the result of the test of association, but the proportion of children of overweight or obese mothers who are classified as normal is still fairly high, which affects the kappa statistic. Although these children are aged 7, and therefore they could become overweight or obese in the following years, the high prevalence of normal children among overweight and obese mothers at this stage of life is certainly hopeful.

The relationships between mothers and children will be explored further in Chapter 4, where we consider measures of body composition obtained from BIA.

Chapter 4

Results - Bioelectrical Impedance Analysis (BIA)

4.1 Children's data

In order to estimate values for TBW, LM and FM, we need equations which relate these variables to impedance. In children, as discussed in Chapter 2, they are reported to be as follows:

$$\text{TBW} = 0.61(\text{height}^2/\text{impedance}) - 0.63$$
$$\text{LM} = \text{TBW} / \text{h}$$
$$\text{FM} = \text{WT} - \text{LM}$$

Where

$$\text{h(boys)} = -0.000083\text{age} + 0.777$$
$$\text{h(girls)} = -0.0001667\text{age} + 0.794$$

And age is in months.

Since the hydration constant (h) depends on the sex of the subject, separate analyses were conducted for boys and girls.

	Weight(kg)	Height(cm)	Impedance(Ohms)	TBW(litres)	LM(kg)	FM(kg)	%Fat
Min	17.50	107.60	435.00	9.31	12.09	1.20	4.47
Q1	22.80	121.90	577.00	13.37	17.37	4.72	20.26
Median	25.60	125.60	619.50	14.93	19.41	6.11	24.98
Mean	26.50	125.40	618.90	15.12	19.64	6.85	25.05
Q3	28.70	129.40	658.00	16.80	21.84	7.85	29.30
Max	50.30	138.60	788.50	25.61	33.30	19.91	50.96
StDev	5.45	5.72	62.70	2.46	3.20	3.37	7.41
Missing	1	0	1	0	0	1	1

Table 4.1. Descriptive Statistics of TBW, LM and FM (Boys)

	Weight(kg)	Height(cm)	Impedance(Ohms)	TBW(litres)	LM(kg)	FM(kg)	%Fat
Min	16.55	108.10	468.50	8.01	10.28	2.28	10.33
Q1	22.60	121.10	607.50	12.62	16.18	6.10	26.20
Median	25.50	124.60	649.50	13.90	17.83	7.69	30.96
Mean	26.73	124.70	651.40	14.17	18.19	8.54	31.04
Q3	29.55	128.40	692.50	15.52	19.92	10.01	35.12
Max	52.10	140.10	844.50	24.47	31.45	23.79	55.88
StDev	5.88	5.82	68.90	2.41	3.10	3.68	7.19
Missing	1	0	4	5	5	5	5

Table 4.2. Descriptive Statistics of TBW, LM and FM (Girls)

By applying these equations to the children's data, the results summarized in Tables 4.1 and 4.2 were obtained. On average, the boys are slightly taller but not heavier than the girls. While they have higher TBW and LM values, the girls appear to have higher FM and %Fat values, as expected.

Comparing with reference values

Values for TBW, LM and FM for children about the same age as the GMS children were found in the literature [Fomon et al. (1982)]. These values were calculated using a theoretical model based on total body water (TBW), total body potassium (TBK) and total body calcium (TBCa). Both sets of values are presented in Tables 4.3 and 4.4.

	Fomon et al. (1982)	ALSPAC (1999)	GMS (2007)
Age	7	7.50 ± 0.21	7.45 ± 0.46
Height	121.7	126.12 ± 5.39	125.40 ± 5.72
Weight	22.85	25.74 ± 4.39	26.50 ± 5.45
TBW	15.12	15.71 ± 2.34	15.12 ± 2.46
LM	19.92	20.42 ± 3.05	19.64 ± 3.20
FM	2.93	5.32 ± 2.70	6.85 ± 3.37
%Fat	12.80	20.14 ± 7.38	25.05 ± 7.41

Table 4.3. Mean ($\pm$ s.d.) for TBW, LM and FM (Boys)

	Fomon et al. (1982)	ALSPAC(1999)	GMS (2007)
Age	7	7.50 ± 0.21	7.47 ± 0.45
Height	120.6	125.27 ± 5.48	124.70 ± 5.82
Weight	21.84	25.84 ± 4.81	26.73 ± 5.88
TBW	14.15	14.49 ± 2.18	14.17 ± 2.41
LM	18.18	18.61 ± 2.80	18.19 ± 3.10
FM	3.66	7.24 ± 3.14	8.54 ± 3.68
%Fat	16.80	27.29 ± 7.48	31.04 ± 7.19

Table 4.4. Mean ($\pm$ s.d.) for TBW, LM and FM (Girls)

The ALSPAC children are a bit taller and less heavy than the GMS children. In particular, they are slightly leaner and not as fat as the GMS children. Both the GMS and ALSPAC children are taller and heavier than the reference children, but the values for TBW and LM are nearly the same, specially for the GMS children. This is very encouraging in terms of the validity of the impedance method, given that the methodology used in Fomon et al. (1982) is purely theoretical and therefore completely different to the impedance approach.

These results suggest, as already noted in Chapter 3, that there might have been a trend increase in body fat among children through the years.

The lean mass and fat mass values were then standardized, resulting in the lean and fat indices (as previously described in Chapter 2). Equations to obtain these indices had been derived previously using as reference subjects the ALSPAC children (aged 7-11 y)[Sherriff et al. (to appear)]. These equations were applied to the GMS children to produce lean and fat indices adjusted for both height and age. Then, an internal standardization of the FM and LM values was carried out following the same approach as for the ALSPAC cohort but estimating the parameters of the regression models from the GMS data. Both sets of indices were then compared as means of validating the existing equations.

4.1.1 External Standardization (ALSPAC Equations)

As discussed previously in Chapter 2, the following indices had been derived using ALSPAC data, by regressing FM and LM respectively on both height and age and subsequently standardizing the residuals.

Lean Index (LM Index)

$$Boys = (log(LM) - (0.66232 + 0.019 \cdot Height - 0.0006 \cdot Age))/0.1 \tag{4.1}$$

$$Girls = (log(LM) - (0.43348 + 0.02 \cdot Height - 0.0004 \cdot Age))/0.1 \tag{4.2}$$

Fat Index (FM Index)

$$Boys = (FMt - (-3.11176 + 0.038 \cdot Height + 0.0008 \cdot Age))/0.589 \tag{4.3}$$

$$Girls = (FMt - (-1.49851 + 0.028 \cdot Height - 0.0007 \cdot Age))/0.398 \tag{4.4}$$

Where FMt is a Box-Cox transformation with parameters λ= 0.14 for boys and $\lambda = 0.03$ for girls.

Values of these indices were obtained for the children in the GMS, with the results summarized in Table 4.5 and Figures 4.1 and 4.2.

	Boys		**Girls**	
	LM Index	FM Index	LM Index	FM Index
Min	-2.96	-2.75	-2.52	-2.95
Q1	-0.89	0.08	-0.68	-0.02
Median	-0.27	0.59	-0.06	0.47
Mean	-0.27	0.63	-0.04	0.51
Q3	0.37	1.16	0.56	1.02
Max	3.00	2.96	2.51	3.17
StDev	1.03	0.87	0.97	0.87
Missing	0	1	5	5

Table 4.5. LM Index and FM Index Descriptive Statistics

For both boys and girls, the LM index and FM index histograms look fairly symmetric, although the FM index might be slightly skewed. The FM index histogram is clearly shifted to the right for both groups (mean 0.63 for boys and 0.51 for girls). This would represent a further increase in fat mass with respect to the ALSPAC children, who were already known to have a problem of excess fat.

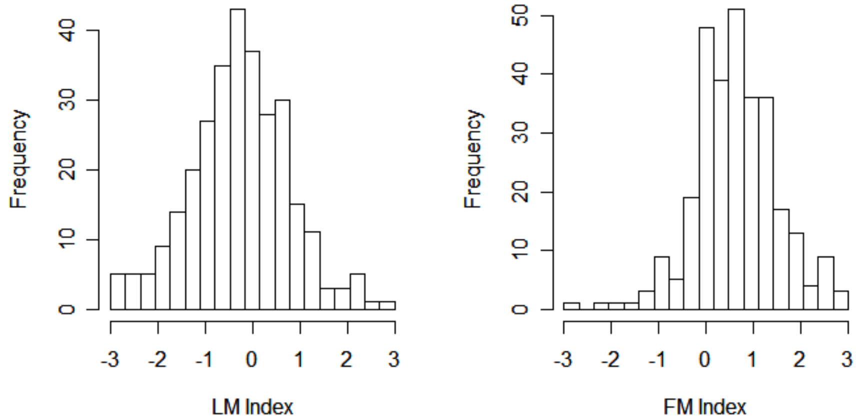

Figure 4.1. Histograms of LM and FM indices (Boys)

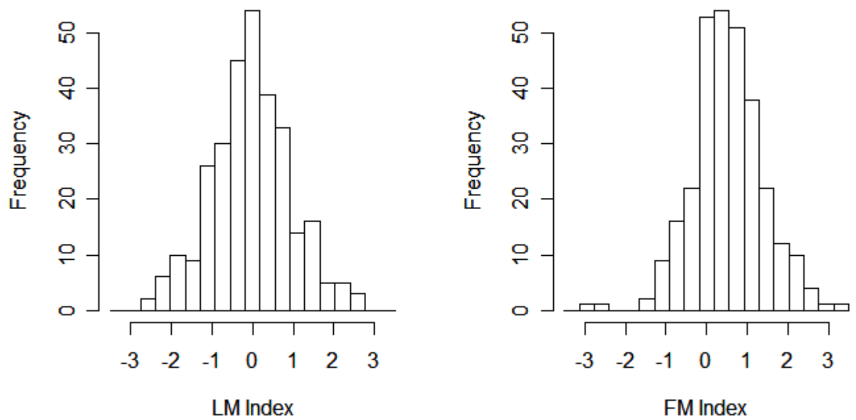

Figure 4.2. Histograms of LM and FM indices (Girls)

The FM index standard deviation for both boys and girls is 0.87, which is rather small in comparison with the value 1 that is expected from the construction of the indices. This is probably due to the fact that there is less variance in the fat mass at younger ages, possibly due to effects of puberty later on. The equations were derived on ALSPAC children aged 7-11 years, while the GMS children are all about 7.

The LM index presents a shift in the opposite direction, being slightly shifted to the left. This shift is more prominent in boys (mean -0.27 for boys, -0.04 for girls). It would mean a decrease in lean mass with respect to the ALSPAC cohort. Whether this is just an artifact of the method, or a longstanding difference between children in the Gateshead and Avon areas, or a real change over time is open to discussion, although it could well reflect the fact that children are less active nowadays and hence develop less muscle mass.

4.1.2 Internal Standardization

Following the same approach, fat mass and lean mass were regressed on height (and age) to derive a lean index and fat index respectively using the GMS children data (note that the method applied to the GMS data in the previous section was derived on the ALSPAC children).

Both the histograms and the QQ-plots of the lean and fat masses suggested the need for a transformation. Therefore, LM and FM were log transformed to achieve normality. Also, the need for a Box-Cox transformation was checked, but in all cases the parameter for the transformation was very close to zero. Age was not significant in any case and therefore it was not included in the different models. This is possibly due to the small age range the data set covers (6.4 - 8.6 years).

Lean Index

- ***Boys***

Log(LM) was regressed on height and age. Age was not significant (p-value= 0.975) and therefore it was taken out of the model. The intercept was not significant either(p-value= 0.171).

The distributional assumptions are met for this model. The residuals are approximately normally distributed (residual standard error 0.101) with constant variances (see Figure 4.3).

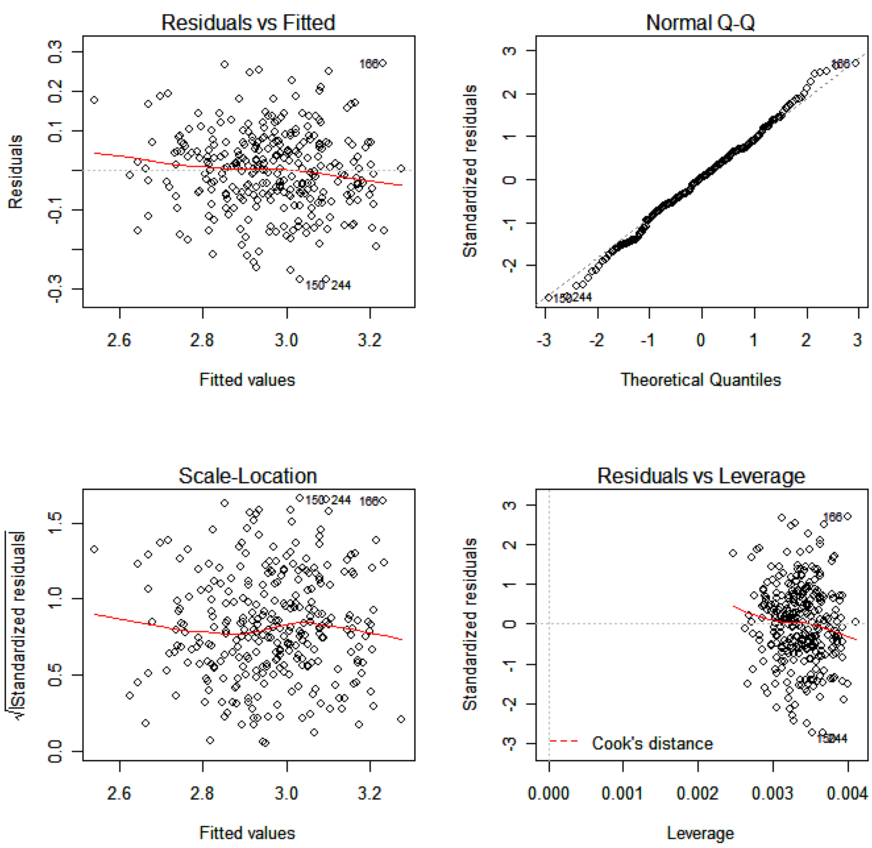

Figure 4.3. Diagnostic plots for the model : Log(LM) = 0.02363Height (Boys)

The residuals from regressing log(LM) on height were then standardized resulting in the LM index.

The LM index for boys using internal standardization would therefore be as follows:

$$LMIndex_{Boys} = \{log(LM) - 0.02363 \cdot Height\}/0.101 \qquad (4.5)$$

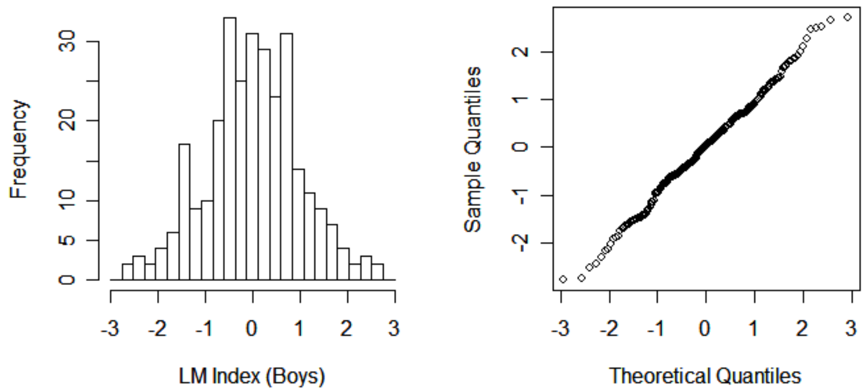

Figure 4.4. Histogram and QQ-Plot of Lean Index (Boys)

Both the histogram and the QQ-plot suggest that the LM index for boys is roughly normally distributed with mean 0 and variance 1.

- ***Girls***

In a similar way, log(LM) was regressed on height and age for the GMS girls data. The age term was not significant (p-value= 0.729) and neither was the intercept (p-value= 0.741).

The LM index for girls using an internal standardization would be as follows:

$$LMIndex_{Girls} = \{log(LM) - (0.02315 \cdot Height)\}/0.105 \qquad (4.6)$$

Both the histogram and the QQ-plot show that the LM index for girls is roughly normally distributed with mean 0 and variance 1.

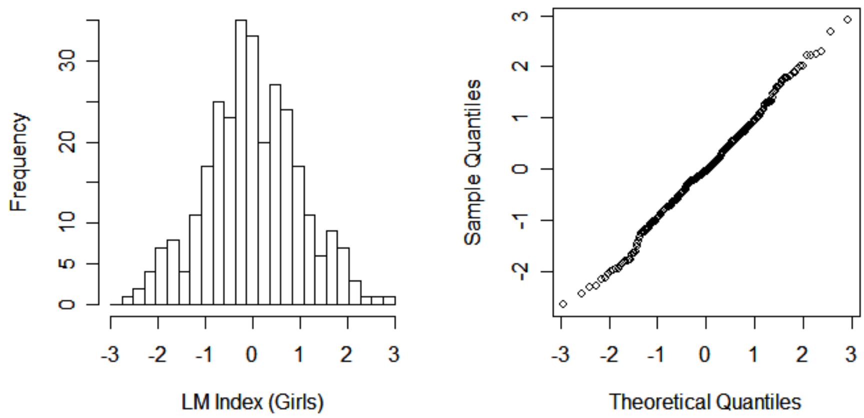

Figure 4.5. Histogram and QQ-Plot of Lean Index (Girls)

Fat Index

- ***Boys***

Log(FM) was regressed on age and height. Age was not significant (p-value= 0.779) and therefore it was not included in the model.

The residuals have constant variance and are fairly normally distributed, although there is still some skewness, but that is the best fit the data allows for, given that fat mass is highly skewed. The residual standard error (0.396,R-square 18.5%) is rather big compared to the lean mass standard error. To try and improve the fit, the fat mass was transformed using a Box-Cox transformation. However, the improvement with respect to the logged data was insignificant and the simplest model (log) was chosen.

The FM index for boys using an internal standardization would be as follows:

$$FMIndex_{Boys} = \{log(FM) - (-2.343536 + 0.033231 \cdot Height)\}/0.396 \quad (4.7)$$

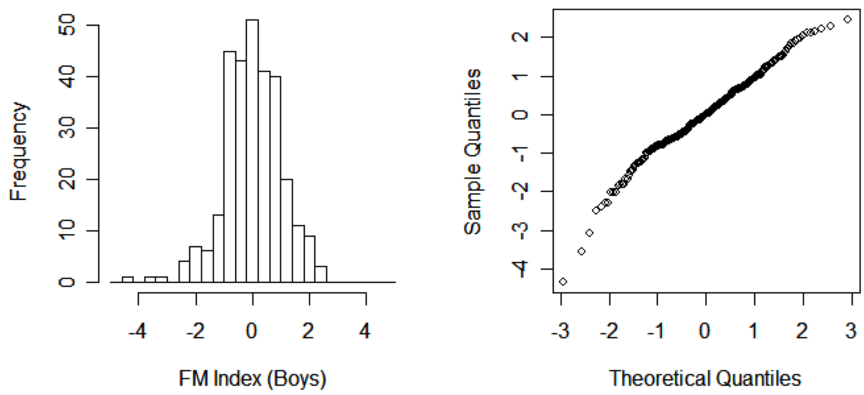

Figure 4.6. Histogram and QQ-Plot of Fat Index (Boys)

The histogram looks fairly symmetric, except for a few points on the left side. These points correspond to very small children, and our results might suggest that the measurement of bioelectrical impedance is not so reliable in such cases.

- ***Girls***

Similarly, log(FM) was regressed on height and age. Age was not significant (p-value= 0.324). As happened when modeling FM in boys , the residuals have constant variance but are still a little bit skewed (residuals standard error 0.316, R-squared 34.62%).

The FM index for girls using an internal standardization would be as follows:

$$FMIndex_{Girls} = \{log(FM) - (-2.864640 + 0.039540 \cdot Height)\}/0.316 \quad (4.8)$$

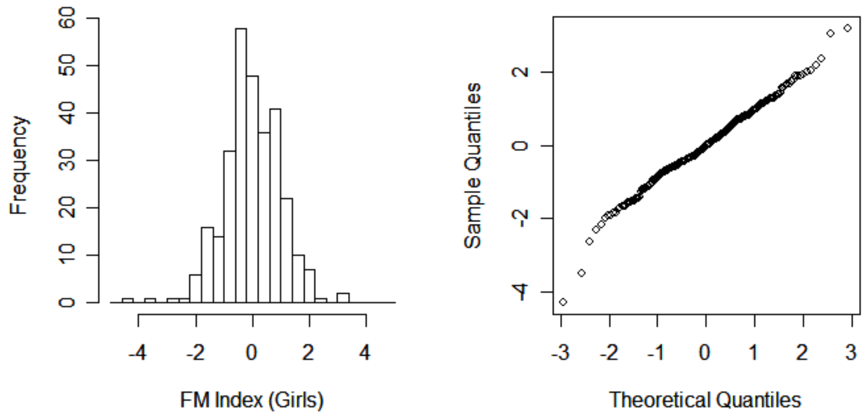

Figure 4.7. Histogram and QQ-Plot of Fat Index (Girls)

4.1.3 Comparing the two approaches

The lean and fat indices obtained from the two different approaches (external and internal standardization) are compared in this section.

The main difference one finds when comparing the two sets of indices is that the age term, which appears in the external indices, does not come into the models for the internal indices. This is probably due to the fact that the GMS children are all about 7 years old, and therefore there is not enough variability in age as to include it in the model. The external indices were derived on the ALSPAC children, aged 7-11 years old.

Each of the four indices was compared with the corresponding one using a Bland-Altman plot, as shown in Figure 4.8. Spearman's correlation coefficients were also calculated for each pair of results, as shown below.

Spearman's Correlation Coefficients

LM Indices Boys: 0.954   95% C.I.: (0.942, 0.963)

FM Indices Boys: 0.998 95% C.I.: (0.998, 0.999)

LM Indices Girls: 0.981 95% C.I.: (0.976, 0.985)

FM Indices Girls: 0.965 95% C.I.: (0.956, 0.972)

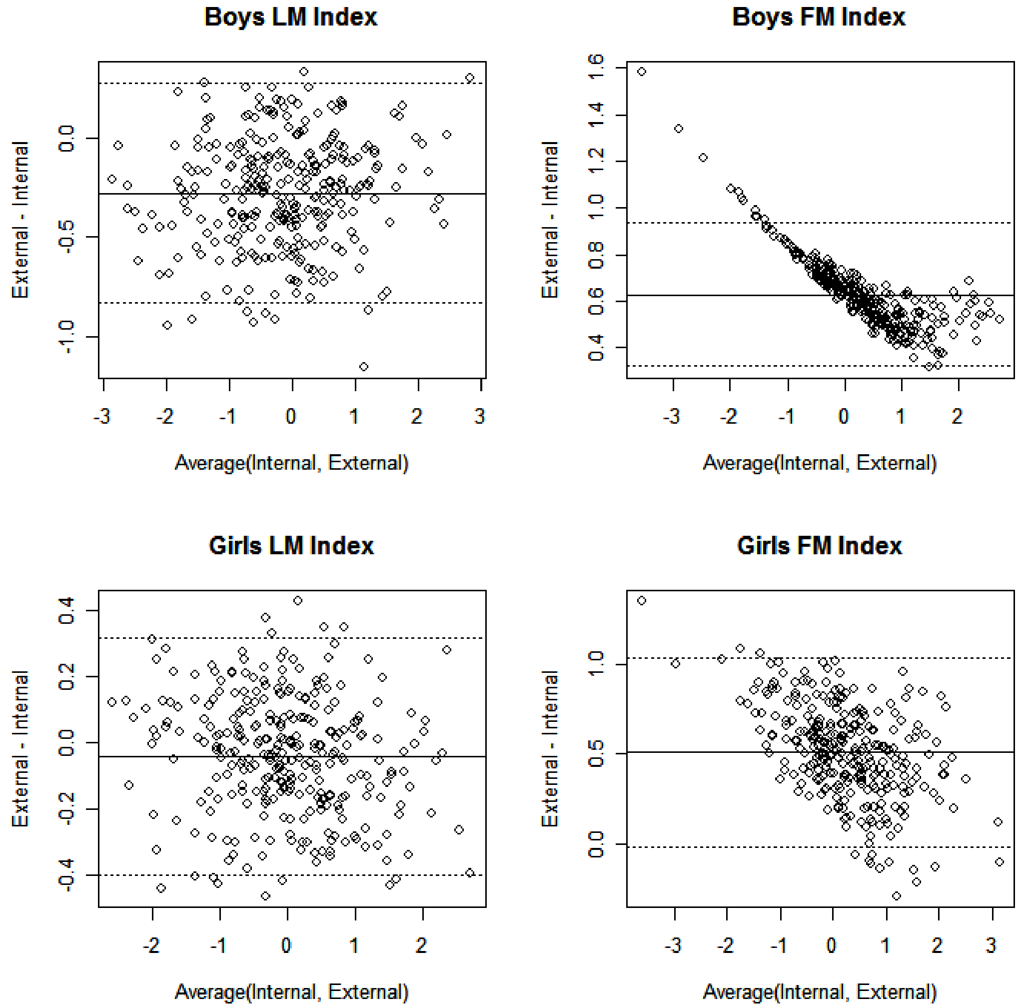

Figure 4.8. Bland-Altman plots of internal vs. external standardization

The Spearman's correlation coefficients, detailed above, are all very close to one, which demonstrates that the two sets of indices are strongly associated. However, there are some issues about the agreement between the two approaches. For the LM index, the average of the difference is less than zero for both boys and girls, while for the FM index it is greater than zero. There does not seem to be any systematic pattern of differences for the LM index. On the other hand, the FM index shows a clear relationship between the average and the difference of the two sets of values. This might be due to the problem with using the variance for the ALSPAC data in calculating the external FM index. The variability in the externally standardized index is too small (0.87 for both boys and girls) compared with the intended value of 1, which means that the distribution of index values has light tails compared with the Normal. So, for relatively small children, the external index values will be systematically closer to the centre of the distribution (and therefore larger) than the internal index values, but vice versa for relatively large children.

The results presented and discussed from now on are based on the externally standardized indices.

4.1.4 FM Index against LM Index

The lean and fat indices were plotted on a scatter diagram (boys and girls separately). Different symbols and colours were used for those children classified (under the UK National BMI classification) as underweight (red triangle), overweight (green square) or obese (blue solid point).

The lean and fat indices seem to be negatively correlated in both boys and girls. Such a relationship is reasonable, since these indices are the lean and fat mass raw values transformed, and these two have to add up to weight, in such a way that if, say, the lean mass increases, the fat mass would have to decrease, so that the equation FM + LM = weight still holds.

Looking at the plots horizontally, one can find, for the same FM index range of values, children classified as normal, overweight and obese. The difference between these three would be in the LM index, with the overweight and obese children having greater LM indices than the normal ones.

It is worth pointing out the fact that those children (boys specifically) classified as underweight present normal (around zero) FM indices and extremely low LM indices (see Figure 4.9). Several children, classified as either normal or overweight using BMI, present negative FM indices.

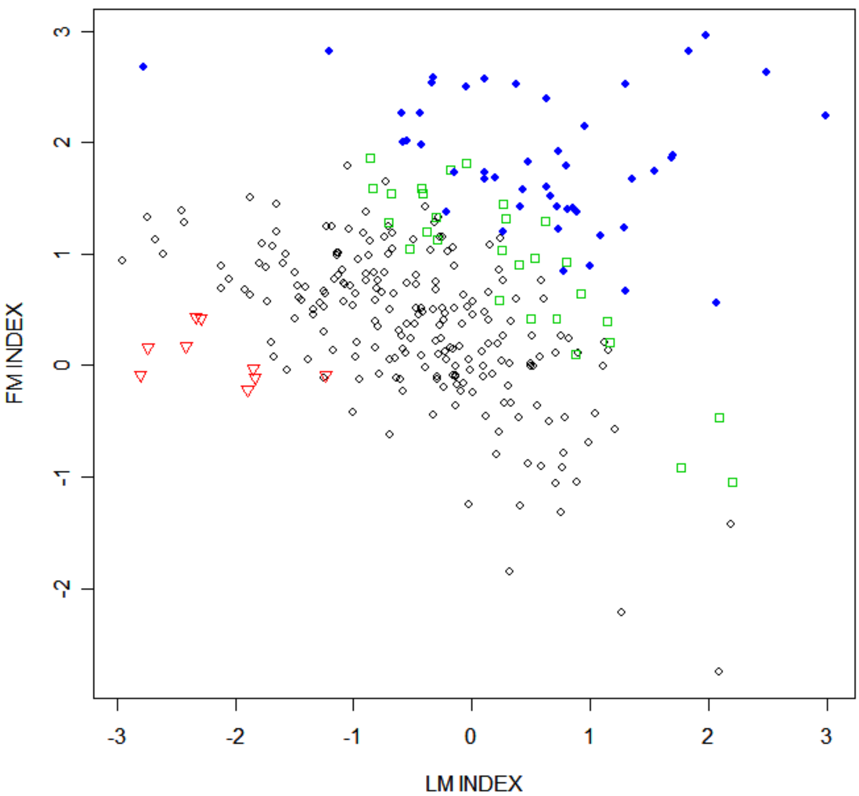

Figure 4.9. LM Index vs. FM Index (Boys)

The girls' plot looks slightly different (Figure 4.10). Three of the girls classified as underweight have normal FM indices (around zero). The rest of the underweight's FM indices are negative. There is just one girl classified as overweight whose FM index is negative.

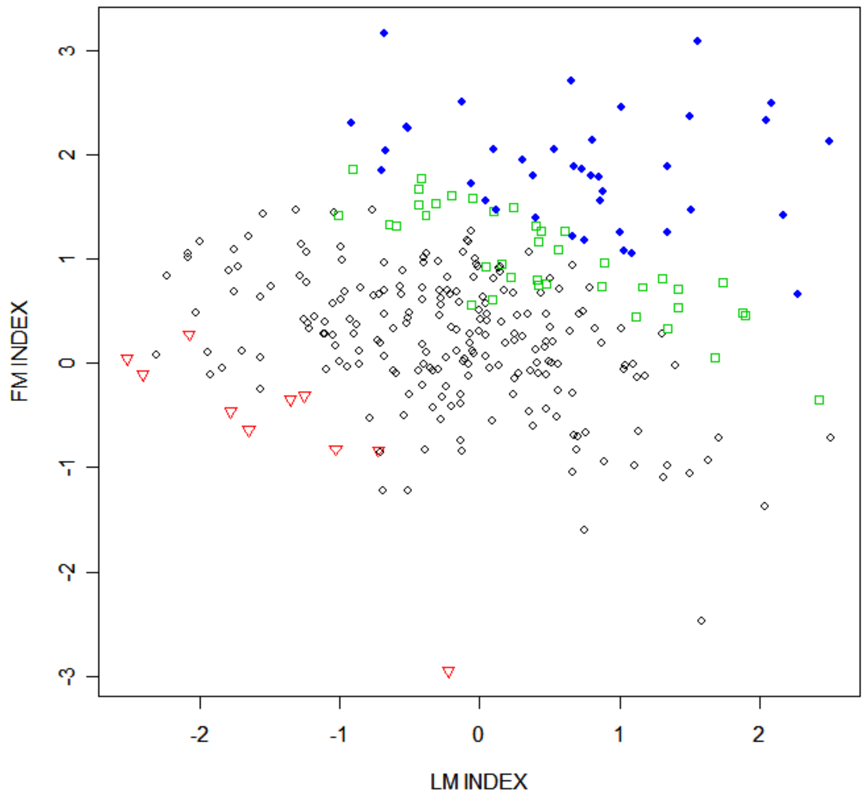

Figure 4.10. LM Index vs. FM Index (Girls)

4.1.5 Relationship of the FM and LM Indices to other measurements

Spearman's correlation coefficients were calculated between the lean and fat mass indices and the standard deviation scores calculated in Chapter 3 (Table 4.6).

The LM and FM indices should not be associated with height (since they have been adjusted for that variable). However, there is a very mild positive association with height standard deviation scores for the boys' LM index and the girls' FM index. Both indices are somewhat positively correlated with weight, waist and specially with body mass index SDS. Note that, for boys, the LM index is more strongly correlated with weight than the FM index, while for girls it is the other way around. The highest correlation for both sexes is given by FM index and skinfolds standard deviation score. These relationships are shown in the scatterplots below (Figures 4.11 - 4.14).

	Boys		**Girls**	
	LM Index	FM Index	LM Index	FM Index
Height SDS	0.15 (0.03,0.25)	0.03 (-0.09,0.14)	0.10 (-0.01,0.21)	0.17 (0.06,0.28)
Weight SDS	0.48 (0.39,0.56)	0.41 (0.31,0.50)	0.45 (0.35,0.54)	0.59 (0.51,0.66)
Waist SDS	0.42 (0.33,0.51)	0.53 (0.45,0.61)	0.42 (0.32,0.51)	0.65 (0.57,0.71)
BMI SDS	0.59 (0.51,0.66)	0.61 (0.53,0.67)	0.59 (0.51,0.66)	0.72 (0.67,0.77)
Skinfolds[a]	0.31 (0.20,0.42)	0.69 (0.62,0.75)	0.31 (0.20,0.41)	0.75 (0.69,0.80)

Table 4.6. Spearman correlation coefficients and 95% C.I. for FM and LM Indices (Children)

(Skinfolds[a] = average of triceps and subscapular standard deviation scores)

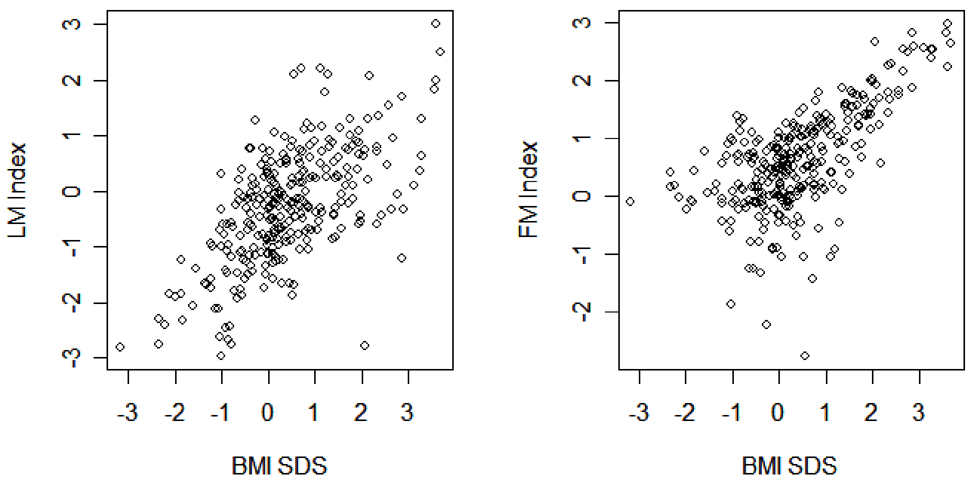

Figure 4.11. Lean and fat indices vs. standard deviation scores of BMI (Boys)

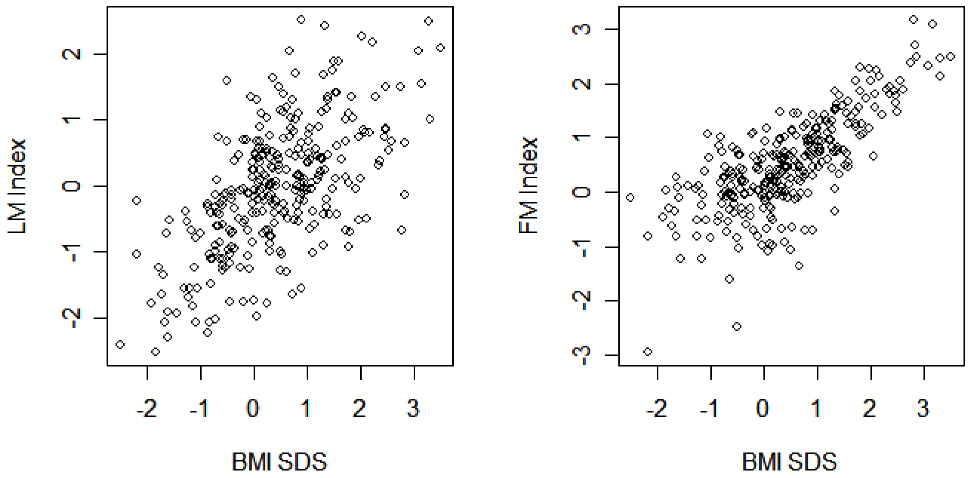

Figure 4.12. Lean and fat indices vs. standard deviation scores of BMI (Girls)

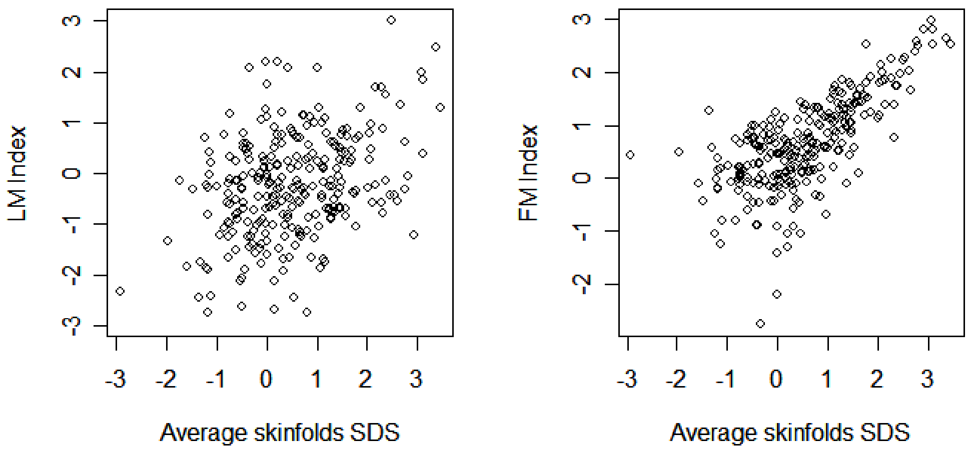

Figure 4.13. Lean and fat indices vs. average of skinfolds standard deviation scores (Boys)

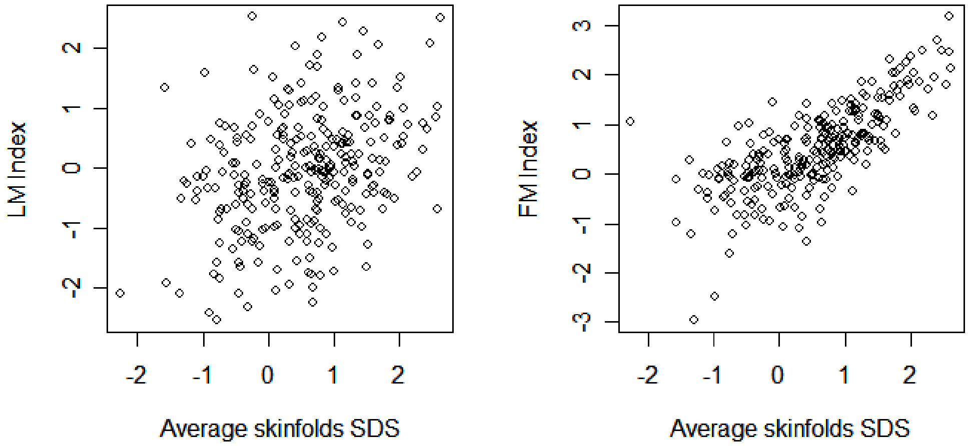

Figure 4.14. Lean and fat indices vs. average of skinfolds standard deviation scores (Girls)

4.1.6 Is there a social class effect?

"Social inequalities in health are a growing public health concern"[Langnäse et al. (2002)]. A large number of studies report an inverse relationship between socioeconomic status and obesity, i.e., the lower the status, the higher the prevalence of obesity. This relationship is particularly strong in women, rather than in men or children[Sobal & Stunkard (1989)].

It was of interest to investigate whether the differences in social class implied differences in body composition in the GMS children. Social class data about the GMS families was collected when the children were born (1999-2000).

The Townsend Score of Material Deprivation per enumeration district or electoral ward (ED) was derived using data about unemployment (% of economically active residents aged 16-59/64 who are unemployed), car ownership (% of private households who do not possess a car), owner occupation (% of households not owner occupied) and overcrowding (over 1 person per room). This information was taken from the 1991 census [Avonweb (Webpage)]. Participants were asked which council (electoral ward) they lived in and Townsend scores were then calculated for each electoral ward and re-assigned to each participant. Then the Townsend Score was split into quintiles (as recommended by Avonweb (Webpage)), with the lowest quintile (i.e. the lowest scores) signifying the most affluent wards and the highest quintile (i.e. the highest scores) signifying the most deprived wards.

Tables 4.7 and 4.8 show the lean and fat indices and standard deviation scores split into the five deprivation score quintiles. There does not seem to be any trend across the different deprivation categories for girls. For boys, on the other hand, waist standard deviation score shows a significant trend (p-value 0.013). Looking at Table 4.8, one realizes that there is an increasing trend from quintile 1 to quintile 4, and then the values decrease again in quintile 5.

Although FM index does not increase significantly towards the most deprived quintiles, according to the p-values, by looking at the tables one can see that FM index slowly rises from quintile 1 to quintile 5 for girls, and from quintile 1 to quintile 4 for boys.

		n	FM Index	LM Index	SDS BMI	SDS Waist	SDS Height	SDS Weight
Least	1	65	0.44±0.77	-0.26± 0.99	0.25±1.06	0.34±1.06	0.23±1.03	0.31±1.08
deprived	2	58	0.56±0.79	-0.51±0.85	0.21±0.96	0.39±0.83	0.19±0.87	0.28±0.79
	3	66	0.64±0.98	-0.13±1.21	0.56±1.27	0.74±1.18	0.19±1.00	0.50±1.28
Most	4	57	0.97±0.79	-0.09±1.05	0.82±1.26	0.92±1.29	-0.03±1.07	0.55±1.34
deprived	5	47	0.55±0.97	-0.41±0.92	0.35±1.12	0.67±1.16	0.29±0.96	0.40±1.19
	P-value linear trend		0.086	0.815	0.099	0.013	0.783	0.372

Table 4.7. Social class effect (Boys)

		n	FM Index	LM Index	SDS BMI	SDS Waist	SDS Height	SDS Weight
Least	1	40	0.42±0.87	-0.02±1.07	0.29±1.20	0.29±1.24	-0.11±1.03	0.15±1.19
deprived	2	69	0.51±0.88	0.02±0.94	0.52±1.15	0.66±1.18	0.41±1.07	0.58±1.15
	3	71	0.55±0.98	-0.10±0.99	0.49±1.23	0.68±1.30	0.21±1.09	0.45±1.28
Most	4	61	0.55±0.81	-0.01±0.98	0.49±0.86	0.61±0.90	-0.05±0.97	0.32±0.89
deprived	5	59	0.58±0.79	-0.06±0.92	0.38±0.97	0.47±1.00	-0.04±1.04	0.23±1.11
	P-value linear trend		0.647	0.763	0.772	0.550	0.506	0.853

Table 4.8. Social class effect (Girls)

4.2 Adults' data

4.2.1 Total body water, lean mass and fat mass

The GMS adults data set consists of 506 young adult females aged 36.27 ± 5.67 y. (age range 23.58 - 53.08). Values for TBW, LM, FM and %FM were produced according to the following predictive equations (as discussed in Chapter 2):

- TBW = 0.66*(height^2/impedance) (litres)
- LM = TBW / 0.732 (kg)
- FM = weight - LM (kg)
- %FM = FM*100/weight (%)

Summary statistics were then calculated for different variables (Table 4.9), obtaining:

	Weight(kg)	TBW(liters)	LM(kg)	FM(kg)	%Fat
Min	40.75	20.02	27.35	3.74	7.18
Q1	59.38	28.96	39.56	18.05	30.39
Median	67.50	31.80	43.44	24.26	36.02
Mean	70.74	32.32	44.15	26.64	36.23
Q3	78.20	34.86	47.62	33.49	42.95
Max	153.90	58.43	79.82	92.07	59.83
StDev	16.19	5.18	7.08	12.08	9.30

Table 4.9. Descriptive Statistics for TBW, LM and FM (Mothers)

To check whether the values we obtained for TBW, LM and FM using this particular resistivity constant seemed reasonable, we looked for some reference values from previous studies (values are means ± s.d):

1. The paper by Hewitt et al. (1993) reports the following values for females:

n	19	32
Age(yr)	32.6 ± 6.0	70.0 ± 4.7
Weight(kg)	59.6 ± 8.0	65.2 ± 10.2
TBW(litres)	31.2 ± 3.2	29.8 ± 3.2
LM(kg)	43.9 ± 4.2	41.0 ± 4.2
%Fat	26.0 ± 5.4	36.4 ± 6.1

2. The paper by Chumlea et al. (2001) reports the following values for females:

n	124	130	104	
Age(yr)	20-29	30-39	40-49	mean
Weight(kg)	62.4 ± 12.4	63.6 ± 13.7	68.5 ± 15.5	64.6
TBW(litres)	32.0 ± 5.0	33.2 ± 4.5	33.0 ± 5.6	32.7
LM(kg)	44.1 ± 6.2	43.1 ± 5.3	43.5 ± 6.6	43.6
%Fat	28.5 ± 8.8	30.4 ± 8.2	35.0 ± 8.9	31.1
FM(kg)	18.4 ± 8.8	19.9 ± 9.3	24.8 ± 10.9	20.8

When comparing these two papers, it was noticed that, although the values for TBW and LM were fairly similar in young adult females, this was not the case for weight and %fat. There seems to be an increasing trend in weight in the period from 1993 to 2001. Since the LM remains constant, this increase is wholly due to an increase in body fat.

Similar values to those in the references mentioned above were obtained in the GMS sample for LM and TBW, but there is a mean increase in weight of about 6 kg with respect to 2001 and about 11 kg with respect to 1993. As a result, the percentage of body fat has also increased from 26.0 ± 5.4% in 1993 to 31.1% in 2001 to 36.0 ± 9.5% in 2007.

If we look at the %fat values in Hewitt et al. (1993) for older females (36.4 ± 6.1 kg) we can see that these are more similar to the values we obtained (36.04

$\pm$ 9.48 kg). Also, the GMS women have weight values (70.64 $\pm$ 15.53 kg) that are closer to the values for older females (65.2 $\pm$ 10.2 kg) rather than to the ones corresponding to similar aged females (59.6 $\pm$ 8.0 kg). So, the results presented in this section do not seem to be impossible or inherently unreasonable. They just reflect a secular trend to increased fatness in the population of young to middle-aged women.

4.2.2 How well do Tanita machines assess body composition?

A number of current weight scales provide automatically not only total weight, but lean, fat and %fat values as well. The algorithms these manufactured machines apply to provide such information is only known to the manufacturers. Values for lean mass, fat mass and %fat obtained from a Tanita machine were recorded for the GMS women. On the other hand, the same variables were calculated based on equations found in the literature concerning this topic, as explained in Section 4.2. To compare the two sets of results, the Bland-Altman method was applied.

The sample mean of the difference between the two lean mass values (see Figure 4.15) is under zero (-1.19 kg), meaning that the Tanita machine, on average, predicts slightly higher values of lean mass than the method presented in this thesis. The limits of agreement are quite wide, varying between -7.84 kg and 5.46 kg. Moreover, there is a strong relationship between the means and the differences.

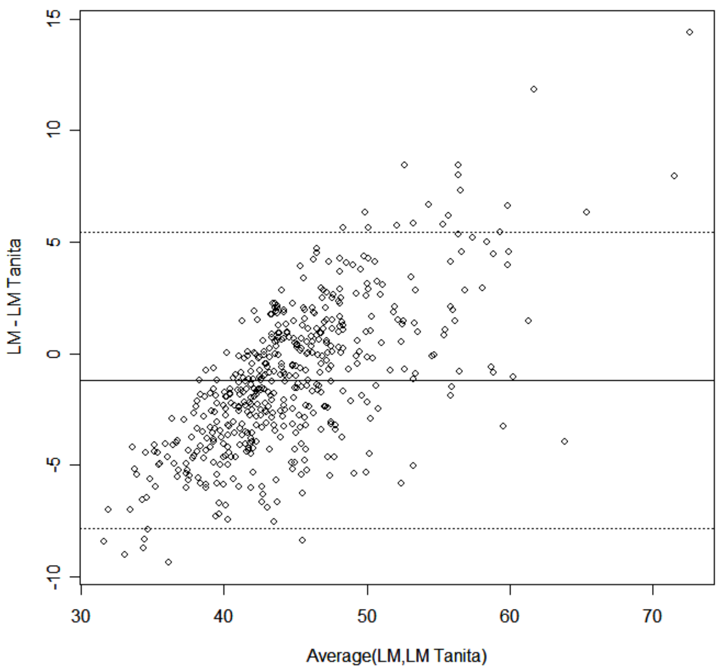

Figure 4.15. Bland-Altman Method (LM)

Looking at Figures 4.16 and 4.17, the mean of the difference between the two fat mass values and the two %fat values are above zero (1.20 kg and 1.97% respectively), and therefore, the Tanita machine is predicting slightly smaller values of fat mass than this method. The limits of agreement are as wide as before(-5.45kg - 7.85kg for fat mass, -7.75% - 11.69% for %fat), indicating poor agreement between the two sets of values.

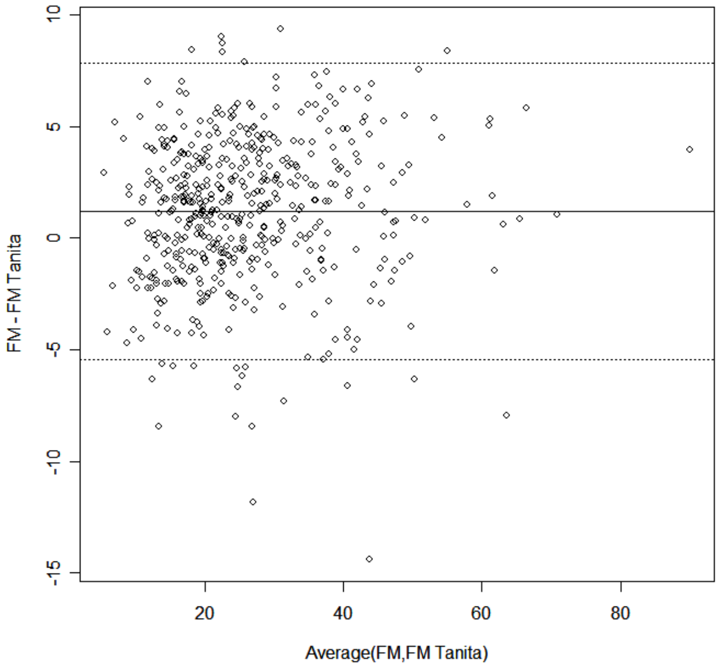

Figure 4.16. Bland-Altman Method (FM)

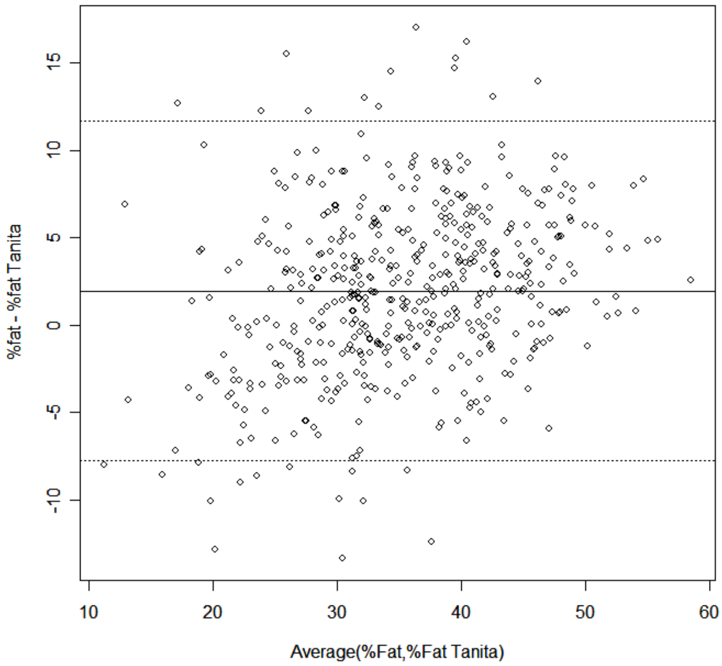

Figure 4.17. Bland-Altman Method (%Fat)

The fact that the plot for lean mass shows some kind of relationship which does not happen for fat mass is really odd, given that LM+FM=Total weight for each individual for both methods. The following theoretical results might help explain this better. From Figure 4.15, the covariance between the average and the difference of LM and LM_T (Tanita value) is positive:

$$\text{Cov}(\text{LM - LM}_T, \text{LM} + \text{LM}_T) > 0 \quad \text{and therefore}$$

$$Var(LM) - Var(LM_T) + Cov(LM, LM_T) - Cov(LM, LM_T)$$
$$= Var(LM) - Var(LM_T) > 0$$

Hence,

$$Var(LM) > Var(LM_T) \tag{4.9}$$

Similarly,

$$Cov(FM - FM_T, FM + FM_T) = Var(FM) - Var(FM_T) \tag{4.10}$$

On the other hand, FM = wt - LM. Taking variances on both sides:
Var(FM) = Var(wt - LM)
= Var(wt) + Var(LM) - 2Cov(wt,LM)
= Var(wt) + Var(LM) - 2Cov(FM + LM,LM)
=Var(wt) + Var(LM) - 2Cov(FM,LM) - 2Var(LM)
= Var(wt) - 2Cov(FM,LM) - Var(LM)

Hence,

$$Var(FM) = Var(wt) - 2Cov(FM, LM) - Var(LM) \tag{4.11}$$

And similarly,

$$Var(FM_T) = Var(wt) - 2Cov(FM_T, LM_T) - Var(LM_T) \tag{4.12}$$

Substracting Var(FM_T) from Var(FM):
Var(FM) - Var(FM_T) = 2Cov(FM_T,LM_T) - 2Cov(FM,LM) + Var(LM_T) - Var(LM)
From (4.10),
Cov(FM - FM_T, FM + FM_T) = 2Cov(FM_T,LM_T) - 2Cov(FM,LM) - Cov(LM - LM_T, LM + LM_T)
And therefore:
Cov(FM,LM) = Cov(FM_T,LM_T) - 1/2*(Cov(FM - FM_T, FM + FM_T)+Cov(LM - LM_T, LM + LM_T))

Which means that

$$Cov(FM_T, LM_T) > Cov(FM, LM) \tag{4.13}$$

Hence, the Bland-Altman plots presented above are consistent as long as:

a) Var(LM) $>$ Var(LM$_T$)

b) Cov(FM$_T$,LM$_T$) $>$ Cov(FM,LM)

Variances and standard deviations were then calculated for each of the four variables, as well as covariances and correlation coefficients.

<u>Results from equations in the literature</u>

Var(LM) = 50.173 Var(FM) = 146.006

S.d.(LM) = 7.083 S.d.(FM) = 12.083

Cov(FM,LM) = 33.101

<u>Tanita results</u>

Var(LM$_T$) = 23.820 Var(FM$_T$) = 138.735

S.d.(LM$_T$) = 4.881 S.d.(FM$_T$) = 11.779

Cov(FM$_T$,LM$_T$) = 50.415

<u>Spearman's correlation coefficients</u>

Corr(FM,LM) = 0.290

Corr(FM$_T$,LM$_T$) = 0.838

The numbers just confirm the theoretical results detailed above.

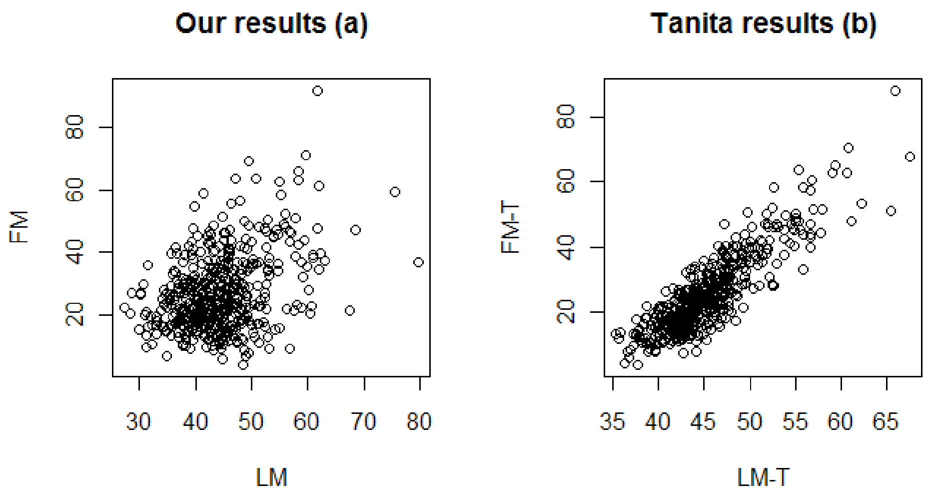

Figure 4.18. Plot of FM vs. LM

Previous studies suggest that high values of fat mass entail an increase in lean mass. Hence, we would expect a weak relationship between lean and fat mass, which is seen in Figure 4.18.(a) for our method. The correlation coefficient between Tanita fat and lean mass values, above 0.8, is far too high (see Figure 4.18.(b)). According to previous studies, such a strong relationship seems just unbelievable.

4.2.3 Lean Index and Fat Index

The method used to obtain lean and fat indices for children was adapted to produce lean and fat indices for their mothers, adjusting only for height. Due to the age range of the data set, adjusting for age is not necessary. While changes in lean and fat mass happen during infancy and might happen again during elderly, in young adults the body composition is fairly settled.

Lean Index

Lean mass was skewed and therefore had to be transformed to achieve normality. A Box-Cox transformation with parameter λ = -0.59 was tried in the first place. An easier transformation of the data is always preferred, and therefore the transformation -1/LM (which would be a Box-Cox transformation with parameter λ = -1) was tried as well. Although -1 was not included in the confidence interval for λ, it was borderline (see Figure 4.19).

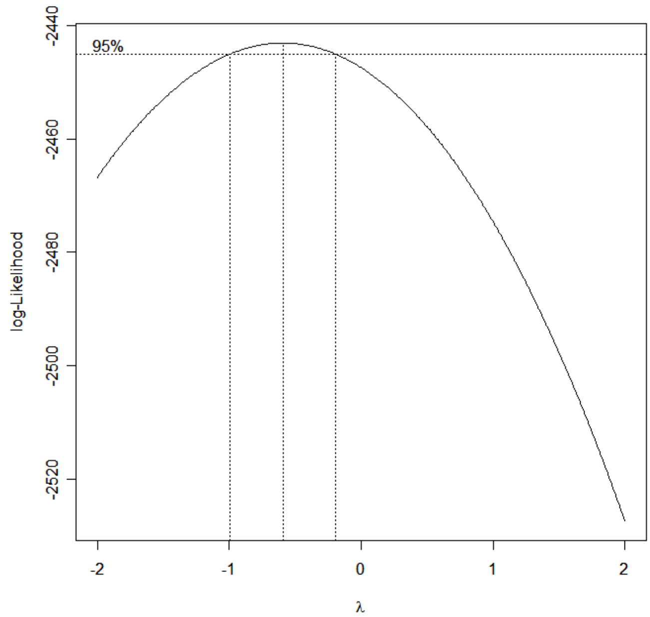

Figure 4.19. Box-Cox transformation of LM

The modelling was done for both transformations, finding no significant differences between them. Therefore, the easiest transformation was adopted, and -1/LM was regressed on height. The distributional assumptions for the linear model were met.

The **LEAN INDEX** equation for adults would be as follows:

$$\textbf{LM Index} = ((-1/LM) - (-0.06745 + 0.0002714 \cdot height))/0.003164 \quad (4.14)$$

As Figure 4.20 shows, the LM index is roughly normally distributed with mean 0 and variance 1.

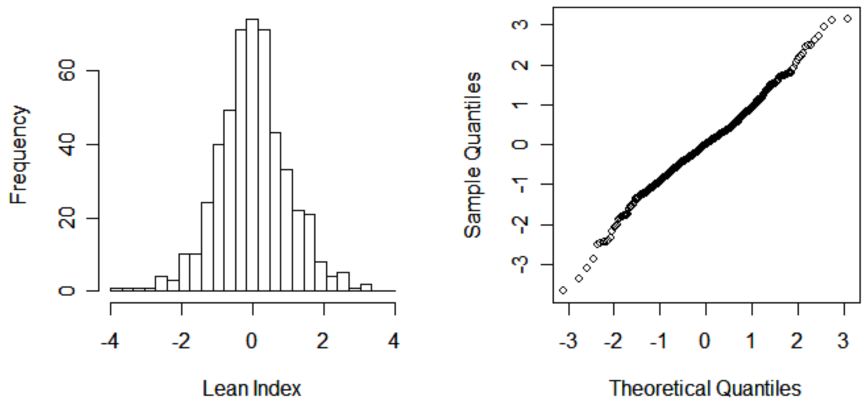

Figure 4.20. Histogram and QQ-Plot of Lean Index Values (Mothers)

Fat Index

Fat mass was also skewed and hence transformed to achieve normality. A Box-Cox transformation with parameter $\lambda = 0.17$ was tried in the first place. In order to find a simpler model, the transformation log(FM) (which corresponds to a Box-Cox transformation with parameter $\lambda = 0$) was tried as well. Although 0 was not included in the confidence interval for λ, it was borderline (see Figure 4.21).

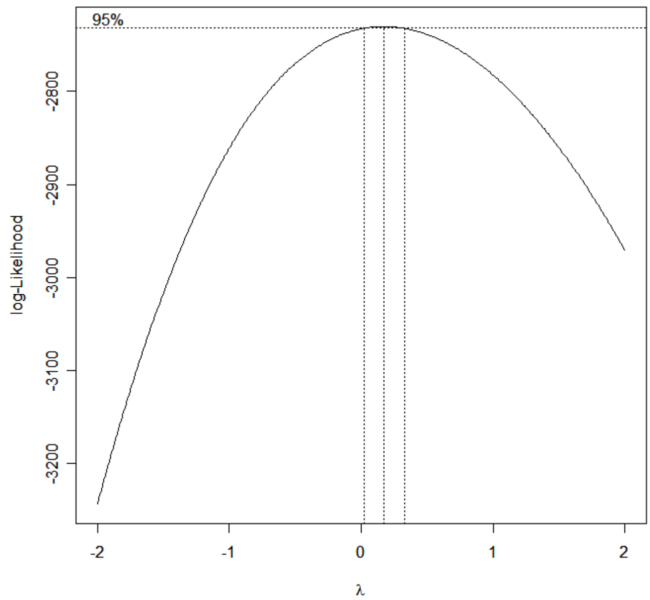

Figure 4.21. Box-Cox transformation of FM

The modelling was done for both transformations, finding no signficant differences between them. Therefore, the easiest transformation was chosen, and log(FM) was regressed on height.

The **FAT INDEX** equation for adults would be as follows:

$$\textbf{FM Index} = (log(FM) - (1.711203 + 0.009028 \cdot height))/0.4494 \qquad (4.15)$$

As Figure 4.22 shows, the FM index is roughly normally distributed with mean 0 and variance 1.

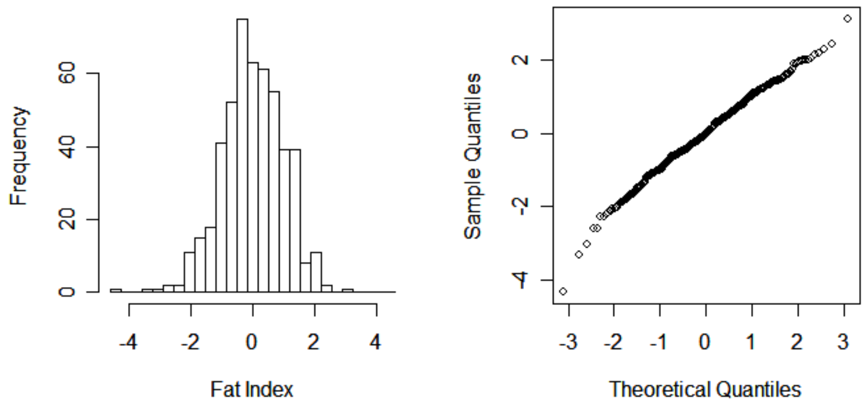

Figure 4.22. Histogram and QQ-Plot of Fat Index Values (Mothers)

FM Index against LM Index

Figure 4.23 shows the FM index values plotted against the LM index values. Different colours and shapes were used depending on how the subjects were classified according to their BMI: red triangle underweight, black point for normal, green square for overweight and blue solid point for obese.

For nearly all (except for one) the subjects classified as underweight, both indices are under zero. Three women classified as obese present fat indices under zero and high lean indices instead. There is a number of subjects either classified as overweight or obese whose fat index values are quite similar, with the difference that those classified as obese have higher lean indices.

There is a clear diagonal stratification among the four groups. This is due to the fact that the indices have been adjusted for height, and so has the body mass index, which is being used here as the classification criteria.

One can look at LM index and FM index individually projecting on the x and y axis respectively. Doing this, we can see that there is no horizontal stratification for FM index (and neither for LM index). Thus, if we look at a specific horizontal range of values, e.g. FM index between 0 and 1, we find supposedly normal, overweight and obese subjects with similar values of FM index but different values of LM index.

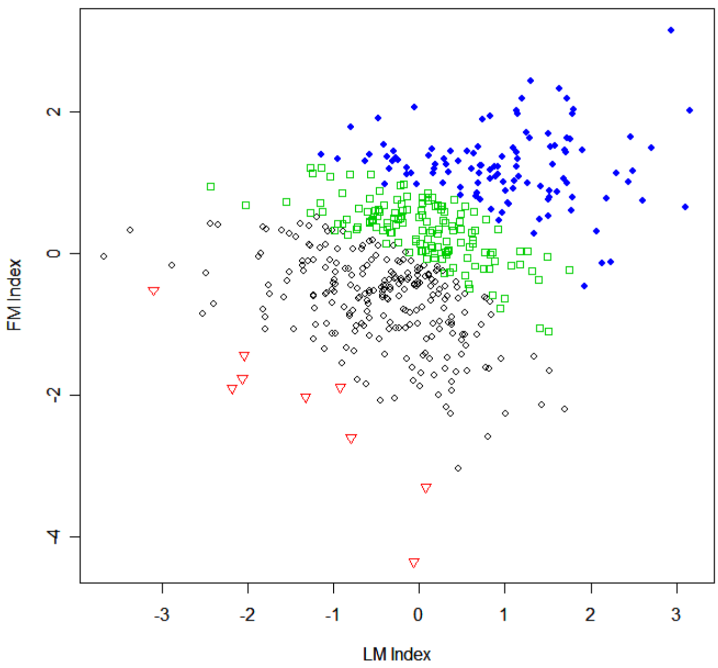

Figure 4.23. LM Index vs. FM Index (Mothers)

4.2.4 Relationship of the FM and LM Indices to other measurements

Spearman correlation coefficients were calculated between the LM and FM indices and the rest of the variables. The estimated coefficients, as well as 95% C.I., are given in Table 4.10.

	LM Index		FM Index	
	$\hat{\rho}$	95%C.I.	$\hat{\rho}$	95%C.I.
Weight	0.57	(0.51, 0.63)	0.85	(0.82, 0.87)
Height	-0.02	(-0.11, 0.07)	0.01	(-0.07, 0.10)
BMI	0.60	(0.54, 0.65)	0.90	(0.89, 0.92)
Waist	0.49	(0.42, 0.56)	0.86	(0.84, 0.88)
Hip	0.52	(0.45, 0.58)	0.85	(0.82, 0.87)
Waist to Hip	0.19	(0.11, 0.28)	0.39	(0.32, 0.47)

Table 4.10. Spearman correlation coefficients for LM and FM Indices (Mothers)

There is no association between the indices and height, as expected. FM index is strongly correlated with the rest of the measurements (except for the waist to hip ratio, with which the correlation is not as strong). LM index is correlated as well with all the variables apart from height, but in a weaker way than the FM index. It is interesting the fact that FM index is more correlated with waist circumference or hip circumference on their own than with the waist to hip ratio, since the ratio is meant to be a better measure of central adiposity.

4.2.5 Is there a social class effect?

Possible differences in fat and lean mass indices due to social class effects were studied on the GMS women, as previously done on the GMS children. Figure 4.24 shows the lean and fat indices split into the five Townsend score quintiles (1 being the most affluent and 5 the most deprived). There is an increasing trend in FM index towards the most deprived wards, which is in agreement with the results reported in previous studies. On the other hand, there doesn't seem to be a defined trend in the LM index, although the fifth quintile shows values clearly lower that the rest.

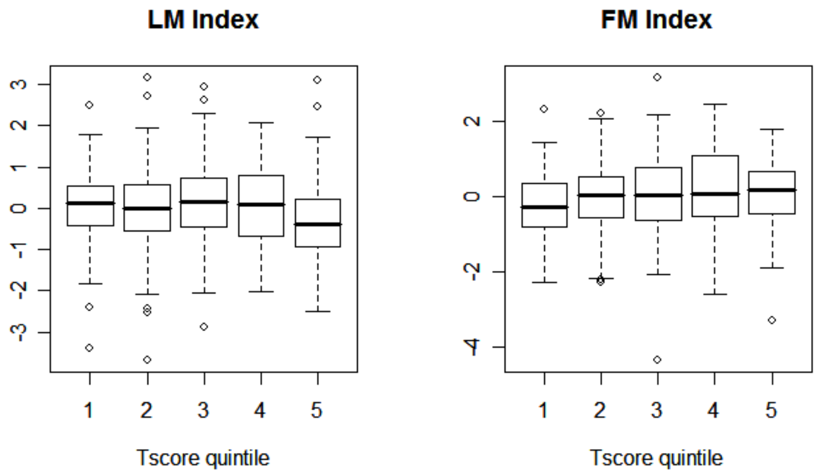

Figure 4.24. Box-plots of LM Index and FM Index for Townsend Score

Apart from LM and FM indices, another four variables (waist to hip ratio, BMI, weight and height) were studied, as shown in table 4.11. P-values from a one way ANOVA with linear trend across the five quintiles are included. The p-value for the LM index is significant ($p = 0.042$). However, this is probably due to the fact that the values in the fifth quintile are much lower that the rest, but we can't really say there is a linear trend. Actually, if we look at the values in the first four quintiles, they decrease and increase in turn. There doesn't seem to be a significant linear trend in either weight, height or BMI. However, both the FM index and the waist to hip ratio (both of them measurements of fatness) show a significant increasing linear trend. Once again, this raises the issue of how valid body mass index (BMI) is when assessing nutritional status.

	Tscore quintile	n	LM Index	FM Index	Waist to hip ratio	BMI	Weight	Height
Least	1	93	0.042 ± 0.956	-0.229 ± 0.885	0.784 ± 0.062	25.460 ± 4.871	68.06 ± 13.29	163.60 ± 6.12
deprived	2	113	0.014 ± 0.994	-0.024 ± 0.941	0.789 ± 0.064	26.450 ± 5.726	70.39 ± 14.94	163.00 ± 6.28
	3	114	0.169 ± 0.984	0.062 ± 1.113	0.793 ± 0.058	27.430 ± 6.765	73.47 ± 18.16	163.70 ± 6.15
Most	4	92	0.048 ± 0.945	0.150 ± 1.062	0.798 ± 0.065	27.450 ± 5.891	72.43 ± 17.74	162.00 ± 6.62
deprived	5	89	-0.301 ± 1.035	0.076 ± 0.908	0.802 ± 0.054	26.090 ± 5.237	68.91 ± 13.77	162.80 ± 5.92
	P-value (linear trend)		0.042	0.016	0.027	0.237	0.482	0.181

Table 4.11. Social class effect (Mothers)

4.2.6 Another data set: the 1000 Family Study

Similar equations to predict TBW, LM and FM were applied to BIA data from the 1000 Family Study data (see Chapter 1 for details), in an effort to validate the methodology, as well as investigate how the equations performed when being applied to men. A hand-to-leg Holtain machine was used to measure impedance on 406 subjects (179 males + 227 females) aged around 50. However, different impedance methods provide different results, and therefore the equations applied to the GMS data can not be applied to this data set without modification. While the hydration constant is still the same (h=0.732) the resistivity constant (ρ) differs. The literature concerning studies using the Holtain machine is scarce and the most suitable value for ρ is unclear. Here we decided to use $\rho = 0.714$. This value was proposed by Kushner & Schoeller (1986). This particular value was chosen because it was the one among those available in the literature which best predicted TBW compared with reference values from the past [Chumlea et al. (2001)].

The equations applied in the 1000 Family data set were hence:

$$\mathrm{TBW} = 0.714(\mathrm{ht}^2/\mathrm{Z})$$

$$\mathrm{LM} = \mathrm{TBW}\ /\ 0.732$$

$$\mathrm{FM} = \mathrm{wt}\ \text{-}\ \mathrm{LM}$$

The results obtained were compared to historical data available in the literature, as shown on Tables 4.12 and 4.13. The 1000 Family men are slightly shorter and less heavy than the males in Chumlea et al. (2001). The estimated TBW values in the 1000 Family men are smaller as well, and so are the estimated lean mass values (since lean mass is proportional to total body water). The estimated fat mass values are about the same. The 1000 Family females are shorter than the females in Chumlea et al. (2001) and a little bit less heavy. The estimated TBW value are about the same, but the estimated LM values are slightly higher.

Given the uncertainty about which value of resistivity constant to use, it is not possible to say much about the validity of the method based on this analysis.

	Chumlea et al. (2001)	Chumlea et al. (2001)	1000 Family
n	101	87	179
Age(yr)	40 - 49	50 - 59	50
Height(cm)	178.9±8.1	176.8±7.3	173.32±6.43
Weight(kg)	82.2±11.7	85.2±13.7	81.03±12.72
TBW(l)	45.7±6.7	46.9±7.4	43.18±5.84
LM(kg)	61.7±7.4	62.5±8.5	58.99±7.98
FM(kg)	20.4±8.3	22.8±8.2	22.04±8.85
%fat	24.3±7.8	26.2±6.6	26.51±8.25

Table 4.12. 1000 Family values compared with historical data (Males): sample mean ± s.d.

	Chumlea et al. (2001)	Chumlea et al. (2001)	1000 Family
n	104	135	227
Age(yr)	40 - 49	50 - 59	50
Height(cm)	165.0±5.5	164.8±5.4	161.40±5.97
Weight(kg)	68.5±15.5	71.7±15.4	69.04±13.79
TBW(l)	33.0±5.6	32.9±4.8	32.81±4.89
LM(kg)	43.5±6.6	43.2±6.2	44.82±6.68
FM(kg)	24.8±10.9	28.3±11.8	24.22±11.45
%fat	35.0±8.9	38.2±9.1	33.79±10.54

Table 4.13. 1000 Family values compared with historical data (Females): sample mean ± s.d.

4.3 Mothers vs. Children

There is a general belief that fatter parents tend to have fatter children and the same in the opposite direction, ie., that leaner parents would have leaner children as well. Such a possible relationship has been studied over the years. It is of interest to explore this using the GMS families. Children and mothers' body mass index have already been compared in Chapter 3. Here, the relationship between children and mothers' lean and fat indices was studied. Each of the four indices (2 for children, 2 for mothers) was plotted against each other, as shown on Figures 4.25, 4.26, 4.27 and 4.28. Spearman correlation coefficients were calculated in each case.

Mothers and children lean indices and fat indices are positively correlated (Figures 4.25 and 4.26). There does not seem to be any significant correlation between mothers FM index and children LM index (Figure 4.27), but there seems to be a very mild positive correlation between mothers LM index and children FM index (Figure 4.28).

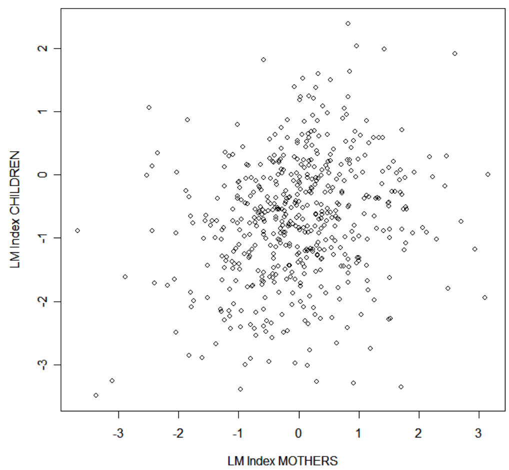

Figure 4.25. Children's LM Index vs. Mothers' LM Index ($\hat{\rho}$=0.22, 95%C.I.:(0.14, 0.30))

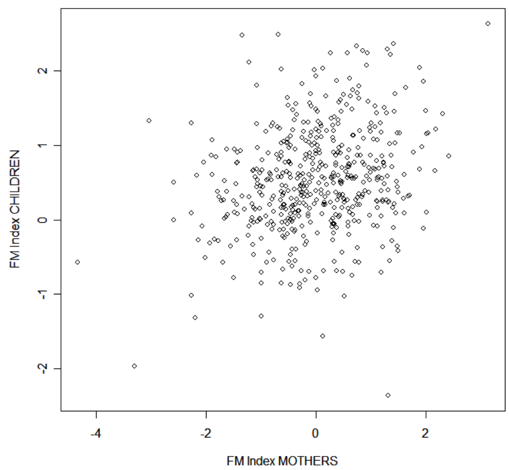

Figure 4.26. Children's FM Index vs. Mothers' FM Index ($\hat{\rho}$=0.23, 95%C.I.:(0.15, 0.31))

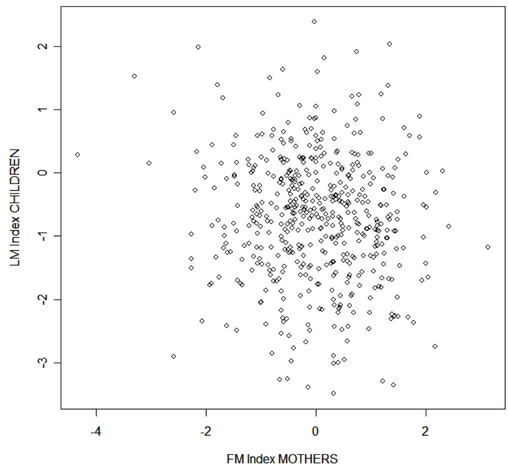

Figure 4.27. Children's LM Index vs. Mothers' FM Index ($\hat{\rho}$=-0.07, 95%C.I.:(-0.16 0.01))

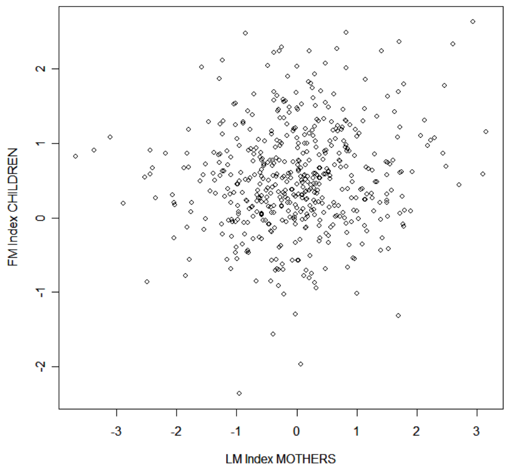

Figure 4.28. Children's FM Index vs. Mothers' LM Index ($\hat{\rho}$=0.10, 95%C.I.:(0.02 0.19))

Chapter 5

Results - Bony Frame Data

In the previous two chapters, various methods of assessing body composition have been discussed. Different methods address different questions, and they might be used in combination for a more complete assessment. As already discussed in Chapter 2 (see Section 2.5), frame size should be considered to accurately assess the nutritional status of a person and, particularly, of a child. The bony frame is not equal for every child (of the same age). Hence, two children of the same age might have the same amount of fat mass but different frame size. This would result in one of the children being heavier and looking bigger than the other, but not necessarily fatter. However, the latter is probably the first conclusion one would draw.

Five measurements of bony frame were taken on each GMS child at shoulders, elbow, wrist, hips and knee. All the measurements are in millimeters (mm). The following 11 values were removed because they looked either univariate or bivariate outliers:

Boys: knee=62mm (Id 259), hips= 286mm (Id 375), hips=283mm (Id 715) and hips=294mm (Id 849).

Girls: hips=295mm (Id 45), hips=294mm, (Id 369), hips=297mm, (Id 381), elbow=71.00mm, (Id 457), hips= 297mm (Id 893), hips=296mm, (Id 903) and hips = 320mm (Id 986).

These values were treated as missing data in the analysis.

Boys and girls were studied separately. The descriptive statistics of the five measurements are given in Tables 5.1 and 5.2.

	Shoulders(mm)	Elbow(mm)	Wrist(mm)	Hips(mm)	Knee(mm)
Min	234.00	42.00	36.00	170.00	68.00
Q1	270.00	50.00	41.00	194.00	75.00
Median	279.00	52.00	43.00	202.00	78.00
Mean	280.50	52.45	43.01	204.20	78.64
Q3	291.00	55.00	45.00	212.50	82.00
Max	328.00	73.00	53.00	266.00	99.00
StDev	16.17	3.94	2.99	15.94	4.94
Missing	25	21	21	30	22

Table 5.1. Descriptive Statistics of bony frame measurements (Boys)

	Shoulders(mm)	Elbow(mm)	Wrist(mm)	Hips(mm)	Knee(mm)
Min	237.00	41.00	33.00	170.00	61.00
Q1	268.00	49.00	40.00	195.00	72.25
Median	279.00	51.00	42.00	204.00	75.00
Mean	279.80	51.03	42.38	206.10	75.84
Q3	291.00	53.00	44.00	214.00	79.00
Max	322.00	62.00	52.00	290.00	98.00
StDev	16.79	3.73	2.82	18.77	5.13
Missing	27	21	20	32	20

Table 5.2. Descriptive Statistics of bony frame measurements (Girls)

On average, the boys have slightly bigger values (except for the hips), as expected. However, the difference between boys and girls is minimal. This is probably because these children are quite young (around 7 years old) and therefore the differences in body shape between genders are not clearly established yet.

In total, 266 boys and 265 girls (n=531) have all five bony frame measurements complete. Pearson correlation coefficients (instead of Spearman's) were calculated between each pair of bony frame measurements (Tables 5.3 and 5.4); all are only moderate. Figures 5.1 and 5.2 suggested the assumptions for calculating Pearson correlation coefficients were met.

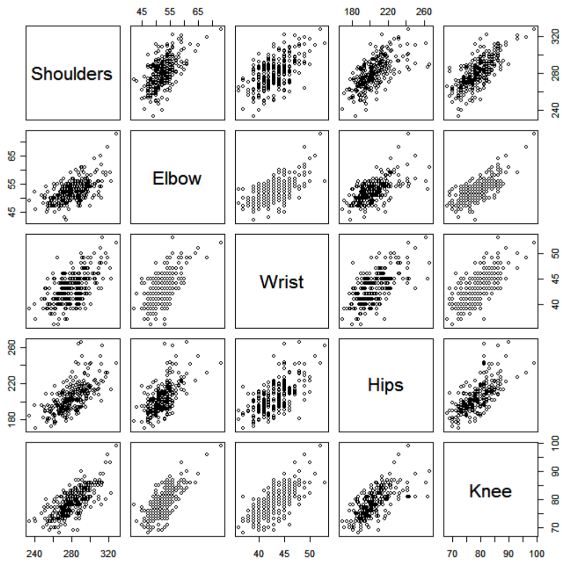

Figure 5.1. Scatterplots of bony frame measurements (Boys)

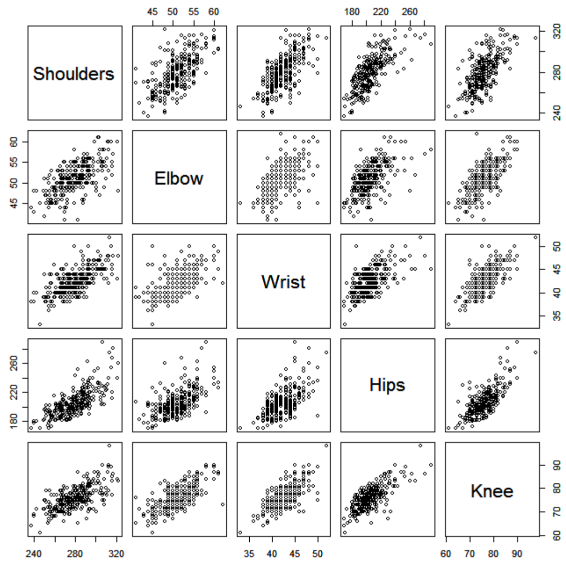

Figure 5.2. Scatterplots of bony frame measurements (Girls)

	Shoulders	Elbow	Wrist	Hips	Knee
Shoulders	1.00	0.59	0.58	0.65	0.72
Elbow	0.59	1.00	0.62	0.64	0.73
Wrist	0.58	0.62	1.00	0.62	0.70
Hips	0.65	0.64	0.62	1.00	0.67
Knee	0.72	0.73	0.70	0.67	1.00

Table 5.3. Pearson correlation coefficients for bony frame data (Boys)

	Shoulders	Elbow	Wrist	Hips	Knee
Shoulders	1.00	0.63	0.65	0.72	0.65
Elbow	0.63	1.00	0.58	0.58	0.72
Wrist	0.65	0.58	1.00	0.59	0.68
Hips	0.72	0.58	0.59	1.00	0.72
Knee	0.65	0.72	0.68	0.72	1.00

Table 5.4. Pearson correlation coefficients for bony frame data (Girls)

5.1 Principal Components Analysis

A principal components analysis was carried out on the correlation matrix of the data. The idea is to find a reduced number of (uncorrelated) linear combinations of the original variables that explain most of the variability in the data. Loadings less than 0.1 have been omitted from Tables 5.5 and 5.6.

Boys

Importance of components:

	PC1	PC2	PC3	PC4	PC5
Standard deviation	1.9014	0.6560	0.6177	0.5997	0.4618
Proportion of Variance	0.7230	0.0861	0.0763	0.0719	0.0427
Cumulative Proportion	0.7230	0.8091	0.8854	0.9573	1

Loadings:

	PC1	PC2	PC3	PC4	PC5
Shoulders	-0.438	-0.687	0.237	0.378	-0.371
Elbow	-0.444	0.319	-0.732	0.156	-0.375
Wrist	-0.434	0.599	0.633		-0.226
Hip	-0.442	-0.259		-0.851	
Knee	-0.476			0.328	0.814

Table 5.5. Loadings for the principal components (Boys)

The first principal component explain 72.30% of the variance and is basically the average of the five (standardized) bony frame measurements. The second component is a weighted contrast between trunk measurements and limb measurements and explains a further 8.61% of the variance. The third and fourth principal components each explain roughly the same proportion of variance as the second, but are harder to interpret.

Girls

Importance of components:

	PC1	PC2	PC3	PC4	PC5
Standard deviation	1.9013	0.6738	0.6429	0.5732	0.4349
Proportion of Variance	0.7230	0.0908	0.0827	0.0657	0.0378
Cumulative Proportion	0.7230	0.8138	0.8965	0.9622	1

Loadings:

	PC1	PC2	PC3	PC4	PC5
Shoulders	-0.452	-0.408		0.675	0.404
Elbow	-0.434	0.723	-0.243	0.324	-0.353
Wrist	-0.433		0.866		-0.238
Hip	-0.448	-0.493	-0.419	-0.359	-0.500
Knee	-0.468	0.251		-0.554	0.636

Table 5.6. Loadings for the principal components (Girls)

For girls, the results from the principal components analysis are very similar to the boys. The first component is just the average of the five (standardized) measurements (accounting for 72.30% of the variance) and the second component is again a weighted contrast between the trunk and the limbs (which accounts for a further 9.08% of the variance). The third and fourth principal components each explain roughly the same proportion of variance as the second, but are harder to interpret.

The form of the first principal component backs up the idea of using the average of the five standardized bony frame measurements as a single, or univariate measure of stature for a child - see Section 5.2. If a more detailed picture is required, the second principal component suggests examining average trunk and limb measurements separately (or the contrast between them) - see Section 5.4. Between them, these two components explain over 80% of the variance in bony frame measures, so no further use is made of the other components in what follows.

5.2 Average of bony frame measurements

Although most of the papers (as reviewed in Chapter 2) agree on the need to consider the bony frame when assessing body composition, there is not a gold standard to do so.

As a first approach to handling this data, each of the five variables was (internally) standardized with reference to the sample mean and standard deviation. To have a single measure of stature for each child, the average of the five standardized values was taken.

	Min	Q1	Median	Mean	Q3	Max	StDev	*Missing*
Boys	-1.916	-0.583	-0.128	-0.001	0.541	3.531	0.846	31
Girls	-2.343	-0.528	-0.128	-0.013	0.431	2.464	0.831	37

Table 5.7. Descriptive Statistics of the Average of standardized bony frame measurements

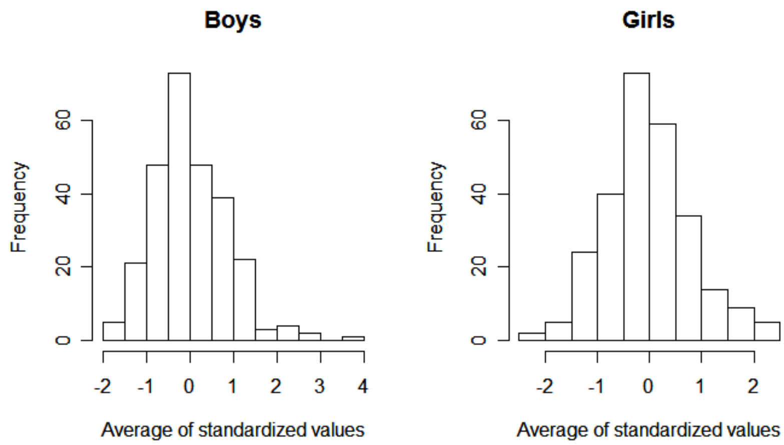

Figure 5.3. Histograms of the average of standardized bony frame values

The girls data looks fairly symmetric while the boys data appears to be right-skewed.

We explored how the bony frame data relates to the rest of the variables. To do so, Spearman correlation coefficients (and 95%C.I.) between the average standardized bony frame measurement and the standard deviation scores (presented in Chapter 3) and LM and FM indices (calculated in Chapter 4) were calculated as shown in Table 5.8.

	Boys		Girls	
	$\hat{\rho}$	95%C.I.	$\hat{\rho}$	95%C.I.
Height SDS	0.73	(0.67, 0.78)	0.69	(0.62, 0.75)
Weight SDS	0.86	(0.83, 0.89)	0.87	(0.83, 0.89)
BMI SDS	0.67	(0.60, 0.73)	0.76	(0.70, 0.80)
Waist SDS	0.71	(0.64, 0.76)	0.75	(0.69, 0.80)
Subscapular SDS	0.54	(0.44, 0.62)	0.64	(0.57, 0.71)
Triceps SDS	0.53	(0.43, 0.61)	0.60	(0.52, 0.68)
LM Index	0.46	(0.35, 0.55)	0.41	(0.30, 0.50)
FM Index	0.21	(0.09, 0.32)	0.48	(0.38, 0.57)

Table 5.8. Spearman correlation coefficients for the standardized average of bony frame with SDS and LM and FM Indices

The average of the bony frame data (standardized) yields high correlation with the height and weight standard deviation scores, as expected; a taller child will probably have a bigger bony frame (for supporting the whole body), and therefore higher weight. Girls have higher correlation coefficients with body mass index, waist and fat index than boys.

In particular, the relationship with BMI standard deviation scores was analyzed . The averaged bony frame is meant to be a measure of size. BMI is currently being used as a measure of fatness (since it is used to assess obesity), but it could well be considered as a measure of size. It is of interest then to study how these two relate to each other.

Figure 5.4 shows the average standardized bony frame plotted against the BMI standard deviation scores. As we can see, for both boys and girls the frame size is highly correlated with the BMI z-score ($\hat{\rho}$=0.67 for boys, $\hat{\rho}$=0.76 for girls).

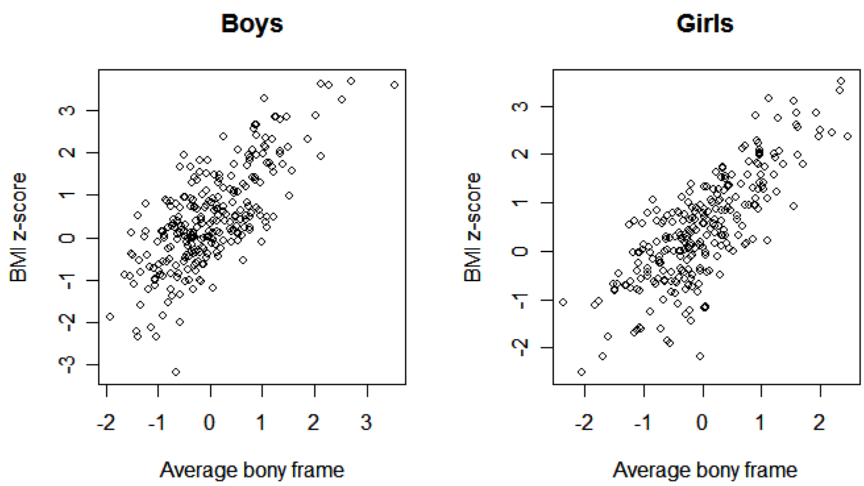

Figure 5.4. Scatterplots of the average of the standardized bony frame values vs BMI SDS

Hence, high values of body mass index are associated with high values of frame size. This would support the idea that frame size should be taken into account when assessing body composition, specifically when assessing obesity. Obesity is currently defined on the basis of a high BMI, but the 'extra' weight which implies a high body mass index does not necessarily mean excess fat, but could mean a large bony frame.

Figures 5.5 and 5.6 show the relationship between bony frame and skinfolds. The correlation with subscapular and triceps is about the same, being higher for girls than for boys. The plots for boys and girls look slightly different; for girls there is a clearer positive relationship along the whole range of values (specially for triceps), while for boys the correlation value seems to be influenced by the values at the top end.

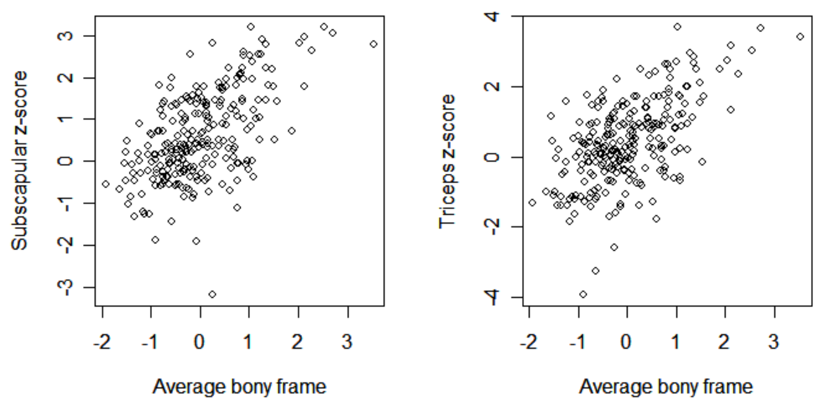

Figure 5.5. Scatterplots of the average of the standardized bony frame values vs Skinfold SDS (Boys)

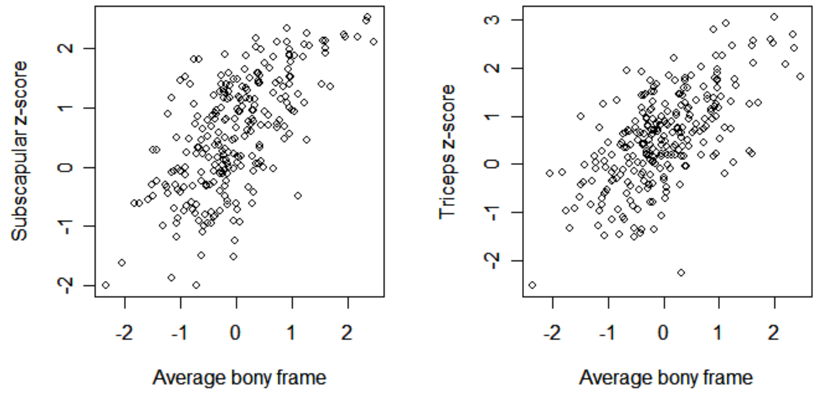

Figure 5.6. Scatterplots of the average of the standardized bony frame values vs Skinfold SDS (Girls)

It is also of interest to look at the relationship with the lean and fat indices separately. The plots of the average standardized bony frame against the lean index (Figure 5.7) seem reasonable, since we would expect a fairly strong positive correlation.

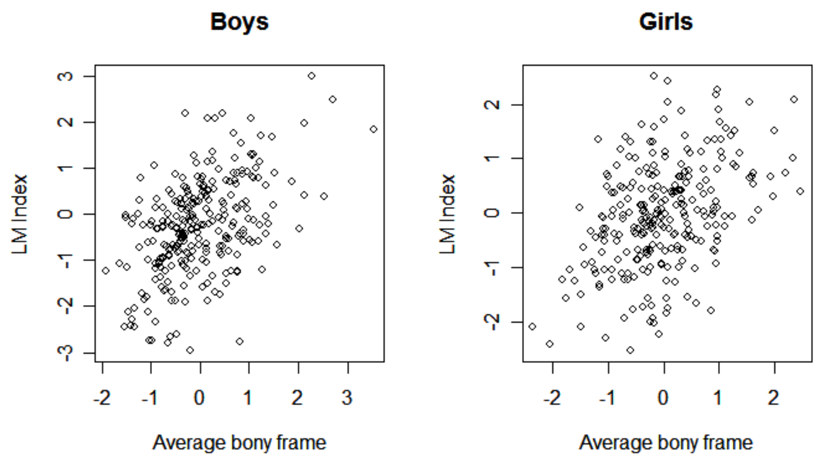

Figure 5.7. Scatterplots of the average of the standardized bony frame values vs LM Index

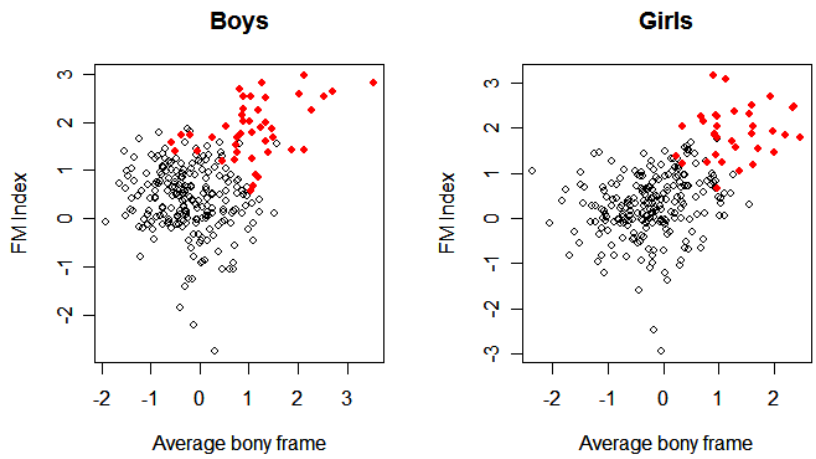

Figure 5.8. Scatterplots of the average of the standardized bony frame values vs FM Index

Red points: Obese children
Black points: Rest of the children

In principle, there should not be any relationship between fatness and bony frame. However, if we look at the plots of bony frame against the fat index (Figure 5.8), there seems to be a slightly positive correlation, which is stronger for girls ($\hat{\rho}$=0.21 for boys and $\hat{\rho}$=0.48 for girls). These correlation coefficients are influenced by the points at the top right corner (red points). If we took these points away, there would not be such a strong relationship. These points were checked and correspond to children classified as obese in terms of their BMI z-score.

Different explanations could explain the previous plots. One could be that the red points actually correspond to obese children and therefore it is more difficult to get accurate bony frame measurements because of the subcutaneous fat. This would lead to measurements errors. Another reason could be that fatter children will develop more lean mass to support the fat mass [Forbes & Welle (1983)], and hence larger bony frame in response to the excess weight.

The children had been classified earlier (Chapter 3) as underweight, normal, overweight or obese using the UK National BMI percentile classification. The standardized average of the bony frame measurements was represented using a box plot. The data was split into four categories according to the BMI classification mentioned before (Figure 5.9).

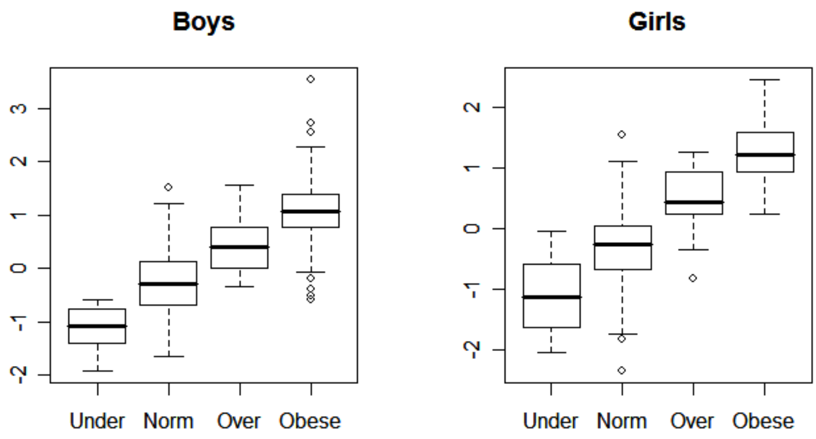

Figure 5.9. Box-plots of the standardized average of bony frame (BMI categories)

The plots show an increasing trend from underweight towards obese. This is a bit concerning, given that obesity is defined as an excess of fat, and therefore, there is no apparent reason to think that an obese child must have a bigger bony frame than a normal child. It's very difficult to get appropriate measurements of some parts of the skeleton on fat children. Hence, the values might not be reliable. However, as has already mentioned, it could be possible that fatter children have bigger bony frame. On the other side, one could argue that BMI does not distinguish between fat and lean mass, and therefore it could lead to a misclassification.

5.3 Social class

Potential differences in bony frame across the Townsend score quintiles (described in Chapter 4) were investigated. Table 5.9 shows mean±s.d of the averaged bony frame for the five quintiles (1 being the most affluent and 5 the most deprived). There does not seem to be any particular trend in bony frame due to a social class effect.

Tscore quintile		Boys n	Boys Average bony frame	Girls n	Girls Average bony frame
Least	1	59	-0.06±0.83	38	-0.14±0.88
deprived	2	57	-0.15±0.61	64	0.15±1.00
	3	57	0.11±0.94	65	0.09±0.87
Most	4	55	0.11±1.01	58	-0.05±0.66
deprived	5	44	-0.02±0.79	56	-0.11±0.85
P-value (linear trend)			0.363		0.737

Table 5.9. Bony frame data into Townsend Score quintiles: mean ± s.d.

5.4 Trunk and limbs

The second component from the principal component analysis suggested looking at trunk and limb measurements separetely, or a contrast between them. The five measurements were combined into two new variables: trunk, which comprises shoulders and hips, and limbs, which comprises elbow, wrist and knee. This was done by taking the average of the corresponding standardized variables. The relationships with the z-scores and lean and fat indices are summarized in Tables 5.10 and 5.11.

	Trunk		Limbs	
	$\hat{\rho}$	95%C.I.	$\hat{\rho}$	95%C.I.
Height SDS	0.71	(0.64, 0.76)	0.68	(0.61, 0.74)
Weight SDS	0.80	(0.75, 0.84)	0.83	(0.79, 0.86)
BMI SDS	0.60	(0.52, 0.67)	0.68	(0.61, 0.74)
Waist SDS	0.70	(0.64, 0.76)	0.66	(0.58, 0.72)
LM Index	0.34	(0.23, 0.44)	0.48	(0.39, 0.57)
FM Index	0.24	(0.12, 0.35)	0.21	(0.09, 0.32)

Table 5.10. Spearman Correlation Coefficients for Trunk and Limbs (Boys)

	Trunk		Limbs	
	$\hat{\rho}$	95%C.I.	$\hat{\rho}$	95%C.I.
Height SDS	0.67	(0.59, 0.73)	0.65	(0.58, 0.72)
Weight SDS	0.83	(0.79, 0.86)	0.82	(0.77, 0.85)
BMI SDS	0.72	(0.66, 0.77)	0.71	(0.65, 0.77)
Waist SDS	0.75	(0.69, 0.80)	0.69	(0.63, 0.75)
LM Index	0.31	(0.20, 0.42)	0.45	(0.36, 0.54)
FM Index	0.53	(0.44, 0.61)	0.39	(0.29, 0.49)

Table 5.11. Spearman Correlation Coefficients for Trunk and Limbs (Girls)

For boys, the main difference between the limbs and the trunk is in the correlation with the LM index ($\hat{\rho}$= 0.34 for trunk and $\hat{\rho}$= 0.48 for limbs). Also, the limbs have slightly higher correlation with weight and body mass index and smaller with waist and FM index.

For girls, the difference between the correlation of the limbs and the trunk with the LM index is of the same order as in boys. However, there is a greater difference between the correlations with the FM index.

Again, the correlation with the FM index is highly influenced by a few points on the top right corner of the corresponding scatter graph (see Figures 5.10 and 5.11).

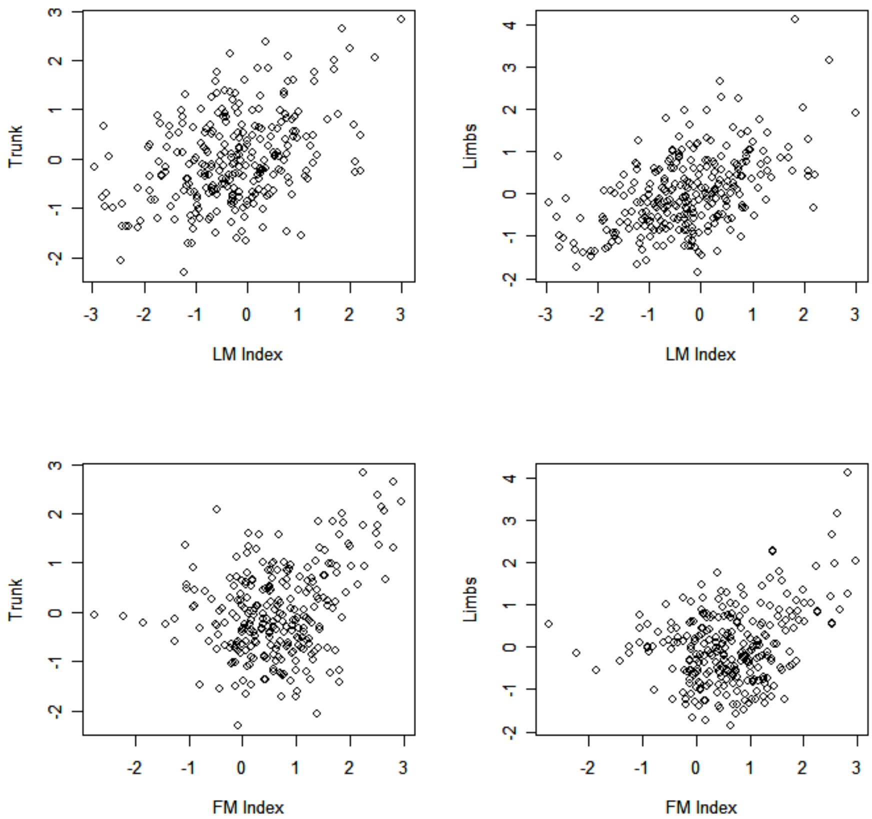

Figure 5.10. Standardized average of trunk and limbs vs LM Index and FM Index (Boys)

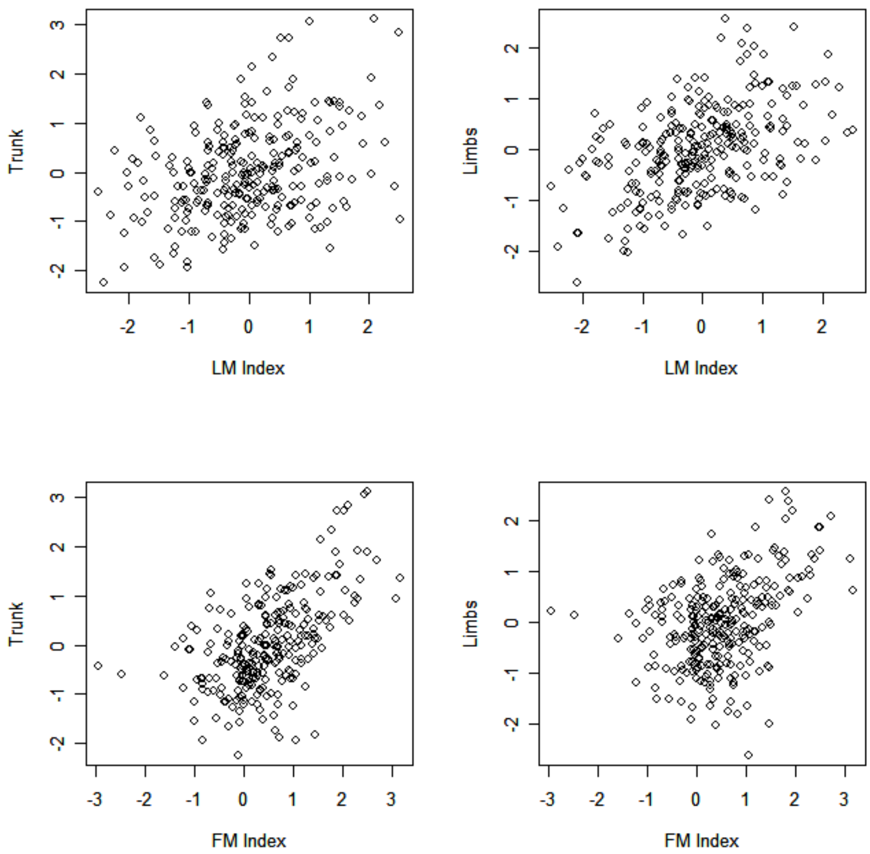

Figure 5.11. Standardized average of trunk and limbs vs LM Index and FM Index (Girls)

5.5 What is the best measure of frame size?

As previously discussed in Chapter 2, there is general agreement about the characteristics a good measure of body frame must have. These are:

a) High correlation with body mass (weight)

b) High correlation with fat free mass

c) Minimal association with fat mass

According to this, correlation coefficients with weight, lean mass(LM) and fat mass(FM) were calculated for each of the five bony frame measurements, as well as for the standardized average, trunk and limbs (Tables 5.12 and 5.13). Recall that we are now looking at correlation with FM and LM rather than fat index and lean index. The main reason for not using the indices here is that they have been adjusted for height, and the bony frame data has not.

						Standardized		
	Shoulders	Elbow	Wrist	Hips	Knee	Average	Trunk	Limbs
Weight	0.74	0.77	0.69	0.84	0.83	0.91	0.87	0.86
Height	0.77	0.60	0.62	0.70	0.72	0.80	0.81	0.73
LM	0.72	0.65	0.69	0.70	0.80	0.84	0.78	0.80
FM	0.51	0.62	0.47	0.68	0.58	0.66	0.65	0.62

Table 5.12. Pearson's correlations for bony frame measurements and weight, height, LM and FM (Boys)

						Standardized		
	Shoulders	Elbow	Wrist	Hips	Knee	Average	Trunk	Limbs
Weight	0.77	0.69	0.70	0.89	0.84	0.91	0.89	0.84
Height	0.77	0.62	0.67	0.71	0.69	0.80	0.79	0.75
LM	0.73	0.64	0.74	0.73	0.79	0.84	0.78	0.81
FM	0.63	0.57	0.50	0.82	0.69	0.74	0.78	0.65

Table 5.13. Pearson's correlations for bony frame measurements and weight, height, LM and FM (Girls)

For boys, the one which has the highest correlation with both weight and lean mass is the average. The smallest correlation with fat mass is given by the wrist measurement. For girls, the situation is slightly different. Again, the highest correlation with weight and lean mass is given by the average, and the correlation is of the same order as for the boys. However, the association of the average with fat mass is greater for the girls($\hat{\rho}$= 0.74) than it was for the boys ($\hat{\rho}$= 0.66). Wrist has still the smallest correlation with fat mass. Note than, in general (except for elbow) the correlations with fat mass are higher for girls than for boys, especially for the hips ($\hat{\rho}$= 0.82 girls, $\hat{\rho}$= 0.68 boys).

There does not seem to be a great difference between the trunk and the limbs measurements, although the correlation with fat mass is slightly smaller for the limbs.

Pearson's Partial Correlations

Apart from the characteristics already mentioned, it has also been suggested that a good measure of frame size should have:

a) Good correlation with LM beyond the level produced by height alone.

b) Little or no association with body fat beyond that which can be accounted for by associations with LM.

Hence, Pearson partial correlations were calculated on the basis of the relationships cited above (Table 5.14).

	Boys		**Girls**	
	LM|Height	FM|LM	LM|Height	FM|LM
Shoulder	0.32	0.36	0.34	0.44
Elbow	0.38	0.55	0.32	0.41
Hip	0.35	0.64	0.40	0.76
Wrist	0.41	0.31	0.45	0.20
Knee	0.56	0.48	0.54	0.51
Average(std)	0.58	0.70	0.59	0.70
Trunk(std)	0.43	0.63	0.44	0.71
Limbs(std)	0.55	0.58	0.56	0.50

Table 5.14. Pearson's partial correlations for LM and FM

For both boys and girls the standardized average yields the highest correlation with lean mass conditioned on height. However, the correlation with fat mass (conditioned on lean mass) is a bit concerning ($\hat{\rho}$= 0.70). For girls this is a bit smaller than the correlation with fat mass alone ($\hat{\rho}$= 0.74) but for boys ($\hat{\rho}$= 0.66) it is a bit higher.

The limbs appear to perform slightly better than the trunk, for they yield higher correlation with LM conditioned on height and smaller with FM conditioned on LM. The trunk measurements are reported to be less reliable, since they are more susceptible to measurement errors (due to the layer of subcutaneous fat). This might explain the fact that they seem to be more strongly associated with fat than the limbs.

Chapter 6

Discussion and Conclusions

6.1 Summary of Results

6.1.1 Body Mass Index and other Anthropometric Data

The use of anthropometric measures is probably the most common way of assessing body composition. It is quick, easy, painless and does not involve any particular knowledge about a specific subject. Several anthropometric measurements in children and adults have been analyzed in this thesis.

In children, the LMS method was applied to obtain standard deviation scores for height, weight, waist circumference and body mass index. This is a well established and recognized method for processing children's anthropometric data. It allows us to adjust the values for age as well as compare them with the UK children population in 1990, so that conclusions can be drawn of how the body composition has evolved in the past 18 years. The results reflect an increase in the four variables with respect to the UK 1990 children.

The children were classified, depending on their BMI, into underweight, normal, overweight or obese following two different criteria, the UK National and the IOTF international cutoffs. The results from the two classifications differed, with the UK National criterion classifying many more children as obese, the difference being greater for boys. The use of one or the other criteria allows comparison of obesity rates at national (UK) or international (IOTF) level.

Despite being one of the indices most widely used nowadays, body mass index is a controversial measure, which might confound size with fatness, to the extent of misclassifying subjects. Although it is used as a tool for identifying obesity, it does not distinguish between lean and fat mass. Changes in BMI during childhood are reported to be mainly driven by increases in lean mass rather than fat mass [Maynard et al. (2001)]. "Both lean and fat mass are highly correlated with BMI, such that it acts as a proxy for both but can distinguish neither"[Wells (2001)]. Hence, one should be careful when interpreting its value. Alternative methods which can distinguish between fat and lean mass, such as BIA, might be more suitable for the assessment of obesity. Another important issue to consider is that body mass index varies systematically with age during childhood, and therefore the value itself lacks meaning unless it is adjusted for age. The LMS method allows this, transforming the values into body mass index z-scores.

For the mothers, fewer anthropometric measurements were available (height, weight, body mass index, waist circumference and hip circumference). Waist to hip ratio was calculated, as a measure of central adiposity. It was well correlated with body mass index, although great variability was found between the two sets of values. The mothers were classified as well in terms of their body mass index according to the WHO international cutoff values; 50% of them were classified as either overweight or obese. The body mass index relationship between mothers and children was explored. Although it was significant, they were weakly correlated. The results showed a very mild tendency for overweight and obese mothers to have overweight or obese children at age 7 years.

Possible differences due to social class were investigated in terms of the Townsend score. In general, there were not any significant trends, not for children, neither for mothers, except for the waist to hip ratio, which was significant for mothers and boys, but not for girls. Overall, we could say that social class differences did not come up in body composition, when studied using these anthropometric measures.

6.1.2 Skinfolds

It was also possible to apply the LMS method on skinfold thicknesses data, but just for two (triceps and subspacular) of the four measurements taken. However, the reference values the method is based on date from 1975. The need for up to date reference values was already suggested by Paul et al. (1998). However, the results which made them think that new standards were necessary were completely in the opposite direction to the results presented in this thesis, for they got considerably lower scores in relation to the Tanner standards, while we got higher values than expected. Paul et al. (1998) studied skinfold thickness on infants aged under 2, and data was collected between 1984 and 1988. The GMS children were aged 7 and data was collected in 2007. The differences in the results might be due to changes in skinfold thicknesses trends since 1975 or just to differences in the subjects under study. Hence, it could be that skinfold thicknesses decreased during a particular period after 1975 but then increased again to keep on rising until now. It could also mean that problems with excess fat do not develop until children reach a certain age.

The literature was reviewed looking for another way of processing skinfolds data. Most of the studies suggested using skinfold thicknesses to predict % fat. The most suitable equations according to the characteristics of the GMS data set were applied, but conflicting results were obtained, suggesting that at least one of the equations used must be wrong.

We tried to use all four skinfold measurements by ranking each variable and taking the average of the four. However, this approach does not allow for external standardization. Relationships with other measures (waist circumference, weight and body mass index) were studied, showing strong correlation at the extremes but nearly no relationship for values in the middle range.

6.1.3 Bioelectrical Impedance Analysis

Bioelectrical impedance data was used to predict total body water, lean and fat mass. Fat mass and lean mass values were compared to historical data (for both children and adults) and good agreement was found. However, it would have been of interest to have a reference gold standard method (e.g. DEXA) on the GMS sample for direct comparison. BIA has been shown to be efficient and reliable in numerous studies, and the work presented in this thesis is very encouraging in terms of the validity of the particular statistical modelling approach adopted here.

The prediction equations for children were taken from a paper by Sherriff et al. (to appear). The literature was reviewed to find the corresponding equations for adults. While the hydration constant (relating total body water to lean mass) is fairly well established, the resistivity constant (which relates impedance to total body water) was particularly difficult to find. The use of different devices and methods, under different conditions, makes it difficult to extrapolate the formulas from one study to another. Whenever we tried to apply the equations used on the GMS women to another data set, the lack of standardization was an obstacle. Hence, a different resistivity constant had to be used when applying the equations to the 1000 Family data.

The results we obtained for adults and those automatically produced by Tanita machines were compared, showing poor agreement. An odd relationship was detected when studying correlation between lean and fat mass Tanita values. The equations these machines use remain unknown for everyone except the manufactures themselves, and therefore, definite conclusions about their adequacy cannot be drawn. However, the results presented here suggest they are not very reliable. This is a matter of concern, given that these kind of machines are currently in use. The imprecise and incorrect assessment of body composition would lead to deceptive results which might mislead people about their actual status.

Equations derived on the ALSPAC children were applied to the GMS children to obtain lean and fat indices adjusted for height and age. The need of adjusting for height (as a means of adjusting for size) was already pointed out by Wells (2001), based on the idea that lean and fat mass depend on height, and therefore, we cannot compare, for example, two children with the same lean mass but different heights (and the same for fat mass). It is known that lean and fat mass change considerably during infancy and therefore, adjusting for age is also necessary.

When applying the ALSPAC indices to the GMS children, an issue was detected in the fat index, for its variance was lower than the expected value of 1. This might be due to differences in the age range between the two sets of data. The residual standard deviation was not constant among the ALSPAC data itself, differing for different age groups (7-11). The possibility of using age specific residual standard deviations for the fat index was suggested and hence, the standard deviation corresponding to ALSPAC children aged 7 was used. Even though, the fat index variance was considerably smaller than one. These indices should be revised so that the cause of this problem is found and sorted. We also tried to internally standardize lean and mass with respect to the GMS data. Because all GMS children were about the same age, the age term was not significant. Poor agreement (in fat index) was found when comparing the two sets of results. The lack of agreement is probably highly influenced by the variance issue mentioned before.

When looking at the possible differences in body composition due to social class, fat index (for boys) and waist z-score showed a a 'u' shaped relationship with deprivation score. This relationship was also observed for weight gain in first year in this cohort [Wright et al. (2006)].

Equations to calculate fat and lean indices (adjusted for height) were derived on the GMS women. For women, body mass index was strongly correlated with fat index (0.90) and moderately correlated with lean index (0.60). Waist and hip were more correlated with fat on their own than waist to hip ratio. While no social class effect was found in anthropometric measurements, lean and fat indices showed a significant trend (decreasing and increasing respectively) towards the most deprived quintiles. When the relationship between mothers and children's lean and fat indices was studied, it was found that they were positively but weakly correlated. A positive but weaker correlation was also found between mothers lean index and children fat index.

6.1.4 Bony Frame Data

Literature relating to bony frame was reviewed looking for the best way of analyzing these data. Despite the fact that it has been widely explored across the years, standard methodology has not been established yet. Without a gold standard, the more 'natural' approach was taken; the variables were standardized and the average of the five was calculated, providing a single measure of size. The results from the PCA supported this idea. We also looked at combining limb (elbow, wrist and knee) and trunk (shoulders and hips) measurements into two new variables, but no great differences between the two were observed, although the correlation coefficient with fat index was slightly higher for trunk, specially for girls.

Correlation coefficients with weight, lean mass and fat mass and partial correlations with lean mass conditioned on height and fat mass conditioned on lean mass were calculated, as suggested in the literature. In general, girls showed higher correlations with fat mass than boys. The average of the standardized bony frame seemed to perform well, as it yielded strong correlation with weight, lean mass and lean mass conditioned on height. However, the correlation with fat mass was high and, once having adjusted for lean mass, it remained about the same. This could reflect the fact that fatter children often have bigger bony frames; high values of fat mass are reported to be accompanied by high values of lean mass. The overall increase of weight that this would mean would result in the development of a bigger bony frame in order to support the excess weight. Despite this, it seems likely that bony frame is being confounded by fat, particularly in the heaviest children.

6.2 Comparison of Different Methods (Children)

Four different methods of assessing body composition were analyzed in this thesis: body mass index, skinfolds, BIA and bony frame. The relationships between them might help to understand better which aspect of the human body each of them is actually measuring.

Body mass index z-score and skinfolds z-score are strongly correlated for both boys ($\hat{\rho}$=0.75 triceps, $\hat{\rho}$=0.78 subscapular) and girls ($\hat{\rho}$=0.78 triceps, $\hat{\rho}$=0.80 subscapular).

Body mass index (z-score) and lean index are fairly strong correlated ($\hat{\rho}$=0.59 for both boys and girls), which is in agreement with results from previous studies [Maynard et al. (2001)]. For boys, the correlation between fat index and body mass index (z-score) was also fairly strong but about the same order ($\hat{\rho}$=0.61) as for lean index, while for girls it was clearly stronger ($\hat{\rho}$=0.72).

Skinfold thickness is strongly correlated with fat index, particularly for girls ($\hat{\rho}$=0.69 for boys, $\hat{\rho}$=0.75 for girls) and slightly correlated with lean index ($\hat{\rho}$=0.31 boys and girls $\hat{\rho}$=0.31).

Bony frame (average of standardized values) is fairly strong correlated with body mass index z-score ($\hat{\rho}$=0.67 for boys, $\hat{\rho}$=0.76 for girls) and moderately correlated with skinfolds z-score ($\hat{\rho}$=0.53-0.54 boys, $\hat{\rho}$=0.60-0.64 for girls).

The correlation between bony frame and lean index is moderate ($\hat{\rho}$=0.46 for boys, $\hat{\rho}$=0.41 for girls). While the correlation for boys between bony frame and fat index is low ($\hat{\rho}$=0.21), for girls it is even stronger ($\hat{\rho}$=0.48) than for the lean index.

6.3 Discussion of Comparisons

Body mass index is strongly correlated with skinfold thicknesses and fat index, both of them measures of fatness. However, the fact that it is fairly strongly correlated with lean index as well would mean that body mass index is probably not the best method for assessing obesity. The correlation between bony frame, a measure of size, and body mass index is also quite strong, suggesting that body mass index might be a measure of size rather than fatness.

Lean and fat mass are not completely independent. Hence, we would expect a weak correlation between lean index and skinfolds, and that is what the results show. On the other hand, skinfolds and fat index are strongly correlated. This is very encouraging, for both of them are measures of fatness. We would also expect fairly strong correlations between lean index and any measure of size and weaker correlations between fat index and size.

We would expect the correlation between bony frame and the lean and fat indices to be higher for the lean index, and the correlation with fat index to be fairly weak. This happens for boys, but not for girls, for whom the correlation with fat index is much greater than the correlation with lean index. The correlations between bony frame and skinfolds are greater than expected. This could be due to the fact that bony frame is being confounded with fat; taking reliable bony frame measurements can be difficult in very big children due to the layer of subcutaneous fat. It could also mean that bony frame and fat are positively related to each other, with fatter children having bigger bony frames.

In light of these results, the lean and mass indices seem to perform fairly well when assessing body composition. Body mass index, traditionally used for assessing obesity, should be used as an indicative criterion rather than a decisive one. Bony frame, as a measure of size, seems to behave as expected for boys but not for girls. There is a clear difference between boys and girls in how the different measurements of fatness and size relate to each other; fatness and size seem to be more strongly associated for girls than for boys.

6.4 Future Work

The work presented here could be extended; this thesis just shows some of the large number of relationships that could be explored in this field. Data was analyzed cross-sectionally, but the GMS is a longitudinal study, which tracked the children from birth until age 7. Development of obesity across time or relationships between infant characteristics and later adiposity could be studied.

Skinfold thicknesses are currently used either to predict %fat or as a measure of subcutaneous fat. Should skinfold thicknesses be used to predict %fat, standardization of the equations to do so remains to be done. However, other methods (such as bioelectrical impedance analysis) might be better for predicting

%fat, and therefore skinfold thickness should just be used to provide an idea of the amount of subcutaneous fat. For this, updated reference data are needed.

Lean and fat indices for adults were presented in this thesis. It would be of interest to implement these indices on other data sets and see how they perform. However, this should be done carefully, for there are limitations due to the characteristics of the sample. When applying these indices on a different age range data set, the constants used to calculate raw fat and lean mass values might differ. Also, we do not know whether the indices should be different for males. In order for lean and fat indices for adults to become a valid method for assessing body composition, they ought to be explored further.

Lean and fat indices are currently used for ranking individuals. It would be useful to derive a classification criteria so that cutoff values based on fat index are available. This could either replace or complement the current assessment based solely on body mass index. But, should a tool for assessing obesity be based merely on the fat index? High values of fat mass are associated with high values of lean mass, and therefore lean index might have to be considered as well in some way.

The average of standardized bony frame measurements is proposed here as a measure of size. However, the high correlation between bony frame and fat mass could well mean that measuring bony frame is highly confounded by fat, particularly in heaviest children. Hence, the measurements would not be reliable and therefore not helpful as proxy for lean mass. Further research on bony frame should be carried out, so that relationships with other measurements of the body can be explored further and reliable conclusions can be drawn.

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