A Comparison of Body Composition Analyzing Methods in Obese Swedish Children Measured During the Years 2008-2013

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Abbreviations

Methods

SF  Skinfold thickness
BIA  Bioelectrical Impedance Analysis.
ADP  Air displacement plethysmography
DXA  Dual-energy X-ray absorptiometry
HW  Hydrostatic weighing
ID  Isotope dilution
2C  Two-compartment
3C  Three-compartment
4C  Four-compartment

Terms of body composition

FFM  Fat free mass
FM  Fat mass
FFDM  Fat-free dry mass
%FM  Percent fat mass
TBW  Total body water
EBW  Extracellular body water
IBW  Intracellular body water

Anthropometrics

SAD  Sacral to abdominal diameter
BMI  Body mass index
Abstract
Key words: Obese, Children, Body composition, Skinfold thickness, Bioelectrical impedance analysis, BodPod, Air displacement plethysmography, three-compartment model, BMI.

Objective: Examine which simple body composition measuring methods are useful in deciding % fat mass obese children.

Method: Obese Swedish children (n=244) were examined with different methods. The methods that were compared were air displacement plethysmography (BodPod), bioelectrical impedance analysis, skinfold thickness and a three-compartment model. Correlations were made with FM% from each method with BMI, and methods were compared with ADP as reference model.

Results: The main result of the study showed that Air displacement plethysmography ($R^2=0.592$) was superior, and showed a moderate linear relationship of the % fat mass and BMI correlation which was significant. The three-compartment model ($R^2=0.563$), bioelectrical impedance analysis ($R^2=0.538$) and skinfold thickness ($R^2=0.464$) showed consistent results with ADP. Gender, age and BMI were also assessed individually. Females showed higher correlations than males. The youngest children (aged 3-7) showed higher correlations than older children. The group with the lowest BMI (20-25) showed higher correlations than children with higher BMI.

Conclusion: Data from a three-compartment model, bioelectrical impedance analysis and skinfold measurement are sufficient compared to the reference method air displacement plethysmography, when used in obese children. Age, gender and BMI affects the results from the methods mentioned, and needs to be taken into consideration.
**Sammanfattning**

Nyckelord: Obesitas, Barn, Kroppsammansättning, Hudvecksmätning, Bioelektrisk impedansmätning, BodPod, tre-kompartment modell, BMI.

Mål: Undersöka vilka enkla kroppsammansättningsmätmetoder som är användbara för att bestämma % fettmassa hos obesa barn.

Metod: Obesa svenska barn (n=244) undersöktes med olika metoder. Metoderna som jämförs är BodPod, bioelektrisk impedansmätning, kalipermätning av hudveck och en tre-kompartment modell. Korrelationer gjordes med % fettmassa från varje metod och BMI, och metoderna jämfördes med BodPod som var referensmetod.

Resultat: Huvudresultatet var att BodPod ($R^2=0,592$) var den starkaste mätmetoden, och visade ett mättligt linjärt samband av % fettmassa och BMI korrelationen. Alla mätmetoder var var signifikanta. Tre-kompartmentmodellen ($R^2=0,563$), bioelektrisk impedansmätning ($R^2=0,538$) and kalipermätning ($R^2=0,464$) visade adekvata resultat jämfört med referensmetoden BodPod. Påverkan av kön, ålder och BMI undersöcktes var för sig. Flickor visade sig ha högre korrelationer än pojkar. De yngsta barnen (ålder 3-7) visade sig ha högre korrelationer än äldre barn. Gruppen med lägst BMI (20-25) visade sig ha högre korrelationer än de med högre BMI.

Slutsats: Måtdata från en tre-kompartment modell, bioelektrisk impedansmätning och kalipermätning är adekvata jämfört med referensmetoden BodPod, för obesa barn. Ålder, kön och BMI påverkar resultaten från ovan nämnda metoder, och bör därför tas hänsyn till.
Introduction

Childhood obesity

Childhood obesity is a medical issue of increasing importance. The worldwide prevalence of obesity among preschoolers was in the beginning of 2013 estimated to 43 million (1). From 1990 to 2010, the worldwide increase in childhood obesity was 60% (2). In Sweden the amount of overweight children has doubled from 1986 to 2001 (3). In 2011, one in five Swedish schoolchildren were overweight and three percent were obese (4).

Childhood obesity is a risk factor for earlier onset of high blood pressure, diabetes type II and cardiovascular disease in adult life (5) (6). Additionally, psychological comorbidities, such as sleep disorders and attention deficit hyperactivity disorder are common (1). In addition, the economic impact of medical treatments for obesity may become a burden for society (7).

BMI is the most commonly used measurement for describing body constitution. BMI is calculated by dividing a person’s weight in kilograms with his or her height in meters squared (the formula for BMI is thus kg/m²). Individuals are considered overweight if their BMI exceeds 25, and obese if it exceeds 30. For children no specific ranges have been defined. Instead, population based centile curves are used, from where age referenced BMI and standard deviation are calculated (e.g. s-BMI). Children’s BMI varies with growth. For example, it increases during infancy, decreases during childhood and subsequently increases again during adolescence. (7)

In developed countries various environmental factors are thought to contribute to childhood obesity, including excess of energy-rich foods, less physical activity and changed means of transportation (7). Certain risk factors have been identified, such as time spent in front of the TV (8), socioeconomic status (9) and short sleep duration (10).

In addition, over 300 genes associated with obesity have been found. Some are monogenetic variations, for example mutations in the coding gene for the hormone leptin. Also, some chromosomal diseases are associated with obesity in children. The most common ones are Down’s and Turner’s syndrome. Other genetic syndromes giving rise to obesity include Prader-Willi, Bardet-Biedl and Albright’s syndrome (11).

Treatments of childhood obesity are mainly focused on either interventions at home or in the school environment. Unfortunately, the long term results of such non-surgical treatments have only shown minor to no weight loss at all. While medications like orlistat, acarbose, sibutramin and rimonabant do work, the side-effects and the need for life-long treatment usually outweigh the benefits. Surgical interventions are only performed on adolescent patients (i.e. not children). The most commonly used is gastric by-pass. Since there may arise potentially life threatening complications from surgery, this is usually considered as a last resort (12).
Body composition

Studying body composition is useful when determining if malnutrition is present, determining body fat percentage (%FM) and may give an indication of physical fitness (13).

There are changes in the body composition of growing children. As mentioned earlier about BMI, it fluctuates. The body composition changes are described differently. During the first year of life, there is a decrease in total body water (TBW), which is a part of fat free mass (FFM). During childhood and puberty the TBW increases and in fat mass (FM) decreases. An increase in FM is not seen again, until the growth in height ceases in adulthood. A decrease in FFM is then initiated in mid-life (Figure 1) (14)(15). Percent fat mass (% FM), is a value more commonly used than FM, is the FM in kilograms divided a person’s weight in kilograms.

It is today not possible to analyze all of the components of the human body. However, multiple methods for describing and analyzing the body composition have been developed that may to some extent complement each other and contribute to a better model (16). The following sections will briefly describe the most commonly ones used.

Figure 1. The changes in body composition during a human life. In this figure, the minerals, protein and water represents FFM. Fat represents FM.
Multi-compartment models

This is not a body composition measuring method, but uses the methods for more precise calculation of body composition. Multi-compartment models divide the body into different compartments of two, three, four or more. They are based on set chemical densities and the equations mentioned in this section. Multi compartments models that use more than three or more compartments are based on a minimum of two body composition measuring methods.

The first of these models that was used was the two-compartment (2C) model. This model divides the body into the previously mentioned fat mass (FM) and fat-free mass (FFM). These two compartments have different known densities, which are 0.9007 for FM and 1.1000 g/cm^3 for FFM. The following equation shows the physical and chemical assumptions made from a 2C model (13).

\[
\frac{1}{BD} = \frac{FM}{FM\text{ density}} + \frac{FFM}{FFM\text{ density}}
\]

Body density is calculated from body weight divided by body volume. All body composition measuring methods. If you know the human body density, you can calculate %FM with W.E Siri’s formula (% FM = (495 / Body Density) – 450), who also was the scientist that calculated the densities stated above(19).

The 2C model is not very accurate. It assumes that the TBW of FFM is the same in all individuals at all times, and doesn’t consider, e.g. hydration status. The densities that Siri calculated, were only based on data from five deceased male subjects (20)(13)(19).

With the three-compartment (3C) model you divide the FFM compartment into total body water (TBW) and fat-free dry mass (FFDM), also with set densities. The 3C model considers the individual differences in the hydration of the FFM (e.g. a hydrated person or a dehydrated person). This model assumes the following physical and chemical equation.

\[
\frac{1}{BD} = \frac{FM}{FM\text{ density}} + \frac{TBW}{H_2O\text{ density}} + \frac{FFDM}{FFDM\text{ density}}
\]

A four-compartment model (4C) is considered to more accurately describe the human body composition than the 2- and 3C models. (22)(23)(24)(25)(13). The model was developed using Dual-energy X-ray absorptiometry (DXA). DXA software can separate the values of FFM and bone mineral. Hence this model can consider four compartments, FM, bone mineral, TBW and residual compartments. The residual compartment is considered to consist of protein, soft tissue minerals and glycogen (26).

\[
\frac{1}{BD} = \frac{FM}{FM\text{ density}} + \frac{TBW}{H_2O\text{ density}} + \frac{BM}{BM\text{ density}} + \frac{RM}{R\text{ density}}
\]

The 4C model is often used as gold standard, and is used in studies to evaluate other body composition measuring methods. As mentioned above, there are more advanced models, such as the five- and six-compartment models. However, they are not widely used and will not be covered here (26).
Skinfold thickness
A caliper (a kind of plier) is used when measuring skinfold thickness (SF). The examiner pinches the skinfold and then measures the thickness (see figure 2 for the most common measuring locations).

The first equations for calculating FM from skinfold thickness (SF) were designed by J. Matiega in the early 1920’s. Calculating % FM from skinfolds relies on the assumption that 40-60 % of an individual’s total body fat is subcutaneous (28). Equations were constructed for calculating % FM from SF, but were initially imprecise. In 1998, an equation was designed by Slaughter et al, which is today considered to be the most accurate for children and adolescents (29).

The advantages of measuring of skinfold SF are that it is both cheap and easy to access. It is not invasive, nor does it expose the subject for radiation. Since it is portable, it may be used as a field method. A disadvantage with SF is the high dependency of the examiners skills (30).

![Figure 2. Common anatomical locations used for measuring SF (31).](image)

Circumferences
Circumferences are both used as a tool for determining growth in healthy children and used for measuring distribution of local adiposity. Anatomical positions for measuring circumferences in Sweden include the waist, hip, mid thigh, calf, mid upper arm, neck and sacral to abdominal diameter (SAD). Worldwide there are more than 17 anatomical locations used for measuring (28).

Circumferences can be used to calculate body part ratios. For example waist-to-hip ratio, which is sometimes better measurement for truncal adiposity (32). Another common ratio is waist-to-height ratio, which is suggested to be a predictor for elevated blood pressure in children and adolescents (33). For reproducible results, it is important that the subjects measured all assume the same position and that anatomical landmarks are used for orientation. It is also important to use a flexible measuring tape, that does not extend itself from heavy use (28).
Hydrostatic weighing

Hydrostatic weighing (HW) means that subject is put on a chair and weighed, and then submerged into a basin of water while exhaling air from the lungs. Then the subjects immersed weight is then measured underwater by a scale (mechanical or cell-based) connected to the chair (34). HW is based on Archimedes’ principle, which states that the upward force that is exerted on a body immersed in a fluid, whether fully or partially submerged, is equal to the weight of the fluid that the body displaces. HW is based on following equation:

\[
\frac{\text{density of body}}{\text{density of water}} = \frac{\text{weight of body}}{\text{weight of body} - \text{weight of immersed body}}
\]

Hydrostatic weighing (HW) was the only used method for deciding body composition in children for a long time (36)(34). Its use however, has decreased since the introduction of newer methods(37)(38).

The advantage is that HW is accurate. The disadvantages of HW are that it’s not easy accessible, expensive and that it causes discomfort for the subject (16).

Dual energy X-ray absorptiometry

This method uses two x-ray beams with different frequencies on the examined subject. The ray with higher energy output will be absorbed less by adipose tissue. The analyzing software will get two images and can calculate fat and bone mineral masses by comparing these two images.

Advantages with DXA are high precision and accuracy. There are however some disadvantages. DXA is very expensive, it is also non-portable and exposes the subject for radiation. The results have also shown to be different measuring the same subjects but using different brands of scanners (39).

Bioelectrical Impedance Analysis

Bioelectrical Impedance Analysis (BIA) uses electricity to decide body composition. Electrodes placed on limbs send weak currents through the body to each other and is measured in a computer. The software on the connected computer uses tailored equations for calculating body compartments. BIA can calculate different water compartments from the body’s electrical resistance (Impedance) (37).

BIA can determine the total body water (TBW) content, because TBW contains more water and ions (e.g. better conductance) than the less conductive parts of FFM (e.g. proteins and bone mineral). The certain subgroups of water compartments that can be measured with BIA are intracellular water (ICW) plus extracellular water (ECW). ICW plus ECW equals TBW. (40). BIA can also determine the amount FM, since it is also less conductive.

Advantages are that BIA is considered portable, relatively cheap and safe. This makes BIA a good field method. BIA can be used in all populations, which means there are equations for different ages, genders and pathologic conditions (e.g. obesity). A disadvantage with BIA is that it may be difficult to determine which equations to use, since there are so many. Another disadvantage of BIA is that it is not standardized in regular healthcare, and is because there are multiple ways to measure, with different frequencies, different placements of electrodes and different brands of the equipment (37).
Air displacement plethysmography

Air displacement plethysmography (ADP) is based on pressure change inside an enclosed space (Figure 3). Boyle’s law states that pressure and volume are inversely related (\( \frac{P_1}{P_2} = \frac{V_1}{V_2} \)), at a constant temperature. The space is divided into two chambers, one for reference and one for measuring. Dividing the two chambers is a movable diaphragm, which makes it possible for air volume change in each chamber.

Pressure change is measured in the reference chamber, with a person in the measuring chamber. Advanced equations then calculate body densities, weighing in factors as body weight and functional residual lung capacity (FRC). FRC can be determined from estimations of gender and weight, or by a spirometer. The subject should wear light and tightfitting clothes when measured, to eliminate faulty volume measurement. The BodPod is the most common brand of ADP, which started being used clinically in the late 90’s.

Advantages of ADP include precise measurements, non-invasiveness and the fact that it is not user dependent. However, it is expensive, the equipment is not portable, and some subjects may experience claustrophobia.

Figure 3. ADP principle model (41)
**Rationale**

The common opinion is that no single body composition method 100% accurate. Further research is considered to be needed in this field (42)(43).

Due to increasing prevalence of child obesity, it is important that there exists reliable body composition measuring methods that can easily be transported and used in smaller clinics, also called field methods. BIA and SF are considered as field methods (44).

There have been some studies assessing the different methods above in children (45)(29)(46). The largest study to date was a review which concluded that ADP were the most reliable method used in children for deciding body volume (29).

Concerning obese children in particular, there have been some studies as well. There is one study comparing BIA against Isotope dilution (a body composition measuring method not mentioned in the introduction) in obese children (47). Another one compares BIA, ADP and DXA (48). Both studies show that one method for measuring body composition should be used for following the changes of % FM in each individual. It is not recommended switching one measuring method for another.

A lot of studies that are focusing on child body composition measuring show contradictive results, for example: One study suggests that the only single analyzing method that is comparable with a four-compartment model in at deciding % FM, is ADP (49). While another study suggests that DXA is the superior one in healthy children (46).

The goal is finding a superior method that describes fatness. In this study, correlations of % FM measured from each method is compared to BMI. No current study has tested this in an obese population. Studies have tested the same correlations as we intend in healthy children. However, they examine the opposite relationship, if BMI is a good measurement for %FM measured by DXA (50)(51).

Different factors such as age, gender and BMI is assessed in this study to examine how it effects the correlations of %FM from each method with BMI.

It is expected that the 3C model would be the most accurate method compared with BMI (24). ADP is expected to be the superior method to BIA and SF, as ADP is used as reference method for this study (29). This will be proven if the correlations of % FM with BMI show a strong linear relationship that is significant.

**Ethics approval**

The local ethical committee approved the study (2012/107).
Methods

Design of the study
This study is non-experimental, retrospective, descriptive, qualitative of different methods (52).

The study population
The study population used was every child admitted to Uppsala Children’s hospital’s unit for overweight and obese children and adolescents. The data had been collected from 2008 until December 2013. The control subjects that were used were all children that had been enrolled in any approved study at the clinic.

The inclusion criteria, was that the study subjects should have done three of the body composition methods examined (SF, BIA, ADP, 3-compartment).

The exclusion criteria were situations when the body composition measurement has not been performed according to good clinical standard (e.g. small children who have problems sitting still during BodPod-measurements).

Collection of data
The data from each admitted child was stored in the unit for overweight and obese children and adolescents at Uppsala Academic hospital. Data was archived in folders, with either boys or girls, ranging from the years 2008 to 2013. All data collected is from the first visit to the clinic.

The following base data was collected: Date of visit, Age, Gender, Height, Weight, BMI, Circumferences (Waist, Hip, Waist-to-hip ratio, Upper thigh, Neck and Sacral-to-abdominal), SF (Biceps, Triceps, Subscapular, and Suprailiacal), which staff member that measured, %FM from SF, BIA ICW, BIA ECW, BIA TBW, %FM from BIA, %FM from 3C model, body density from ADP and %FM from ADP.

Procedures of measuring body compositions
There was a predetermined schedule for procedure at admittance for the subjects to the clinic (appendix).

Circumferences and SF
A 150 cm heavy-duty measuring tape of the brand West Germany was used for measuring circumferences. The caliper used was a Harpenden Skinfold Caliper, Baty international, Model RH15 9LB. Two different persons have performed the measuring during 2008-2013. SF was measured at a minimum of 2 times on each location, and a mean value was used for calculating %FM.

Bioelectrical impedance analysis
The used BIA equipment was an InBody S20. Subjects were in horizontal position, and one electrode on both hands and feet. Subjects were wearing clothes. Measurements were performed as from the instruction manual provided from the manufacturer.
**Air displacement plethysmography**
The used model was the BodPod (LmiTech BodPod®). Functional residual capacity was determined with BodPod software. Measurements were performed as from the instruction manual provided from the manufacturer. Children were examined in swimwear. Densities were calculated with Siri and Lohman equations (53).

**Three-compartment model**
The 3C model used in this study is based on equations made by Forslund et al (25). It is based on data from both SF and BIA measurements.

**Statistics**
All statistic calculations were made in IBM SPSS v.22. Correlations were assessed as 2-tailed and with the Pearson correlation coefficient ($R^2$). The correlation ($R^2$) results were interpreted as following:

0 = No linear relationship

0.3-0.5 = A weak linear relationship

0.5-0.7 = A moderate linear relationship

0.7-1.0 = A strong linear relationship

1.0 = A perfect linear relationship

The base data p-values were calculated by comparing mean difference from study subjects and controls with independent t-tests. Significance level of p-values were set as <0.05.
Results

Results are shown in a series of tables. Data was collected from all registered patients and controls (n=363). Controls were then identified and separated from the study population data (n=58). There were 33 male and 25 female controls. Ages ranged from 6-17 among controls.

From the remaining cases, the subjects passing both inclusion and exclusion criteria’s were identified (n=246). Among the study subjects, 139 were male and 107 were female. Ages among study subjects ranged from 3-18. BMI among study subjects ranged from 20-54. Non-significant p-values are marked in bold. Correlation coefficient is mentioned in the text as $R^2$.

In table 1 below, the base data from study subjects are compared to the controls. As expected the study subjects had a higher BMI, larger waist circumference and a much higher %FM than the controls.
Table 1. Base data for the study subjects and controls.

<table>
<thead>
<tr>
<th>Category</th>
<th>Means</th>
<th>Standard Deviation</th>
<th>N</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subjects</td>
<td>Controls</td>
<td>Subjects</td>
<td>Controls</td>
</tr>
<tr>
<td>Age</td>
<td>12,4</td>
<td>11,4</td>
<td>±3,4</td>
<td>±3,4</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>89,2</td>
<td>45,0</td>
<td>±30,6</td>
<td>±16,8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>160,5</td>
<td>153</td>
<td>±17,6</td>
<td>±20,4</td>
</tr>
<tr>
<td>BMI</td>
<td>33,4</td>
<td>18,4</td>
<td>±6,2</td>
<td>±3,0</td>
</tr>
<tr>
<td>Circumferences (cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waist</td>
<td>106,9</td>
<td>67,9</td>
<td>±17,7</td>
<td>±10,0</td>
</tr>
<tr>
<td>Hip</td>
<td>108,9</td>
<td>79,3</td>
<td>±17,3</td>
<td>±11,7</td>
</tr>
<tr>
<td>Waist-Hip ratio</td>
<td>0,97</td>
<td>0,86</td>
<td>±0,13</td>
<td>±0,07</td>
</tr>
<tr>
<td>Neck</td>
<td>37,0</td>
<td>29,5</td>
<td>±5,8</td>
<td>±3,5</td>
</tr>
<tr>
<td>Upper thigh</td>
<td>62,6</td>
<td>44,2</td>
<td>±9,9</td>
<td>±8,6</td>
</tr>
<tr>
<td>SAD</td>
<td>25,2</td>
<td>-</td>
<td>±4,7</td>
<td>-</td>
</tr>
<tr>
<td>SF measurements (mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biceps</td>
<td>18,0</td>
<td>6,2</td>
<td>±5,8</td>
<td>±2,1</td>
</tr>
<tr>
<td>Triceps</td>
<td>28,2</td>
<td>11,3</td>
<td>±7,0</td>
<td>±3,6</td>
</tr>
<tr>
<td>Subscapular</td>
<td>33,0</td>
<td>8,5</td>
<td>±9,7</td>
<td>±4,2</td>
</tr>
<tr>
<td>Suprailiacal</td>
<td>31,9</td>
<td>8,6</td>
<td>±9,1</td>
<td>±4,6</td>
</tr>
<tr>
<td>%FM</td>
<td>32,5%</td>
<td>18,2%</td>
<td>±5,2%</td>
<td>±6,2%</td>
</tr>
<tr>
<td>BIA measurements (L)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICW</td>
<td>22,9</td>
<td>18,2</td>
<td>±8,0</td>
<td>±6,2</td>
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<tr>
<td>ECW</td>
<td>14,1</td>
<td>17,0</td>
<td>±4,9</td>
<td>±6,7</td>
</tr>
<tr>
<td>TBW</td>
<td>37,3</td>
<td>29,3</td>
<td>±12,6</td>
<td>±9,6</td>
</tr>
<tr>
<td>%FM</td>
<td>42,6%</td>
<td>18,0%</td>
<td>±6,9%</td>
<td>±7,7%</td>
</tr>
<tr>
<td>3C model Caliper+BIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%FM</td>
<td>38,3%</td>
<td>18,3%</td>
<td>±5,6%</td>
<td>±6,8%</td>
</tr>
<tr>
<td>ADP measurements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%FM</td>
<td>46,1%</td>
<td>21,4%</td>
<td>±6,4%</td>
<td>±8,4%</td>
</tr>
<tr>
<td>Body density (g/cm³)</td>
<td>0,995</td>
<td>1,050</td>
<td>±0,012</td>
<td>±0,020</td>
</tr>
</tbody>
</table>

* = SAD had not been measured in controls so the p-value could not be calculated.
The results from correlations from the entire study group (Table 1) showed moderate linear relationships in $R^2$ and were all significant (except for SF that showed a weak linear relationship). The reference method, ADP, showed the highest $R^2$.

Table 2. Correlations made from all study subjects.

<table>
<thead>
<tr>
<th>Variables</th>
<th>N</th>
<th>Correlation coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMI vs SF %FM</td>
<td>245</td>
<td>0.464</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BMI vs BIA %FM</td>
<td>244</td>
<td>0.538</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BMI vs ADP %FM</td>
<td>210</td>
<td>0.592</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BMI vs 3C (SF +BIA) %FM</td>
<td>245</td>
<td>0.563</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Here are the results when assessing both genders in the study subjects (Table 3). Females showed higher correlation coefficients than the males. ADP showed highest $R^2$ for females, while SF showed the highest $R^2$ for males. There are 30% more males than females in this study.

Table 3. Correlations made for gender.

<table>
<thead>
<tr>
<th>Variables</th>
<th>N</th>
<th>Correlation coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male subjects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI vs SF %FM</td>
<td>138</td>
<td>0.671</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BMI vs BIA %FM</td>
<td>137</td>
<td>0.569</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BMI vs ADP %FM</td>
<td>120</td>
<td>0.503</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BMI vs 3C (SF +BIA) %FM</td>
<td>139</td>
<td>0.454</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

| **Female subjects**        |     |                         |         |
| BMI vs SF %FM              | 107 | 0.746                   | <0.01   |
| BMI vs BIA %FM             | 107 | 0.682                   | <0.01   |
| BMI vs ADP %FM             | 107 | 0.778                   | <0.01   |
| BMI vs 3C (SF +BIA) %FM    | 90  | 0.705                   | <0.01   |
In this study it was examined if any of the methods were superior in any certain ages of the study group. The study population was divided into quartiles of age (Tables 4), with the largest group in ages 12-15. Ages 3-7 showed the highest $R^2$ from BIA, ADP and 3C model in this study.

Table 4. Correlations made from age quartiles.

<table>
<thead>
<tr>
<th>Variables</th>
<th>N</th>
<th>Correlation coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age 3-7</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI vs SF %FM</td>
<td>26</td>
<td>0,481</td>
<td>0,013</td>
</tr>
<tr>
<td>BMI vs BIA %FM</td>
<td>26</td>
<td>0,885</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs ADP %FM</td>
<td>15</td>
<td>0,846</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs 3C</td>
<td>26</td>
<td>0,854</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>(SF +BIA) %FM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Age 8-11</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI vs SF %FM</td>
<td>64</td>
<td>0,386</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs BIA %FM</td>
<td>65</td>
<td>0,553</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs ADP %FM</td>
<td>59</td>
<td>0,557</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs 3C</td>
<td>64</td>
<td>0,537</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>(SF +BIA) %FM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Age 12-15</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI vs SF %FM</td>
<td>104</td>
<td>0,581</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs BIA %FM</td>
<td>104</td>
<td>0,619</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs ADP %FM</td>
<td>92</td>
<td>0,571</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs 3C</td>
<td>104</td>
<td>0,659</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>(SF +BIA) %FM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Age 16-19</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI vs SF %FM</td>
<td>51</td>
<td>0,177</td>
<td>0,214</td>
</tr>
<tr>
<td>BMI vs BIA %FM</td>
<td>49</td>
<td>0,442</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs ADP %FM</td>
<td>44</td>
<td>0,660</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs 3C</td>
<td>51</td>
<td>0,404</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>(SF +BIA) %FM</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The data was examined in four groups with different intervals of BMI in the study subjects (Tables 5). BMI intervals chosen were 20-25, 25-30, 30-40 and 40-55. Higher correlations were found among the smallest individuals in the BMI 20-25 group.

Table 5. Correlations made from subjects with different BMI ranges.

<table>
<thead>
<tr>
<th>Variables</th>
<th>N</th>
<th>Correlation coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BMI 20-25</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI vs SF %FM</td>
<td>22</td>
<td>0,057</td>
<td>0,801</td>
</tr>
<tr>
<td>BMI vs BIA %FM</td>
<td>22</td>
<td>0,727</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs ADP %FM</td>
<td>13</td>
<td>0,748</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs 3C</td>
<td>22</td>
<td>0,676</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>(SF +BIA) %FM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BMI 25-30</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI vs SF %FM</td>
<td>55</td>
<td>0,167</td>
<td>0,224</td>
</tr>
<tr>
<td>BMI vs BIA %FM</td>
<td>56</td>
<td>0,189</td>
<td>0,163</td>
</tr>
<tr>
<td>BMI vs ADP %FM</td>
<td>50</td>
<td>0,435</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs 3C</td>
<td>55</td>
<td>0,177</td>
<td>0,195</td>
</tr>
<tr>
<td>(SF +BIA) %FM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BMI 30-40</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI vs SF %FM</td>
<td>132</td>
<td>0,134</td>
<td>0,124</td>
</tr>
<tr>
<td>BMI vs BIA %FM</td>
<td>131</td>
<td>0,165</td>
<td>0,059</td>
</tr>
<tr>
<td>BMI vs ADP %FM</td>
<td>118</td>
<td>0,253</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs 3C</td>
<td>132</td>
<td>0,183</td>
<td>0,036</td>
</tr>
<tr>
<td>(SF +BIA) %FM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>BMI 40-55</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI vs SF %FM</td>
<td>36</td>
<td>-0,027</td>
<td>0,877</td>
</tr>
<tr>
<td>BMI vs BIA %FM</td>
<td>35</td>
<td>0,354</td>
<td>0,037</td>
</tr>
<tr>
<td>BMI vs ADP %FM</td>
<td>29</td>
<td>0,505</td>
<td>&lt;0,01</td>
</tr>
<tr>
<td>BMI vs 3C</td>
<td>36</td>
<td>0,238</td>
<td>0,163</td>
</tr>
<tr>
<td>(SF+BIA) %FM</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Discussion

Main results
The purpose of this study was determining how BMI correlate with various body composition methods, both field methods and more elaborate clinical methods. It is important to know which methods are most useful in this population. Certain factors affecting the correlations were taken into consideration, such as gender, age and BMI. The main result of the study showed that ADP had the highest correlation with BMI, and showed a moderate ($R^2=0.592$) linear relationship of the %FM and BMI correlation which was significant. That ADP would be best was somewhat expected, as some previous research supports this in normal weight children (29).

Unexpectedly, BMI correlated better than the 3C model ($R^2=0.563$), which in theory may be questionable (13). But ADP has been shown to be equal to a 4C model in one study (49). The explanation for this may be that the 3C model was based on the measurements from BIA and SF. If it would have been based on ADP and BIA, the $R^2$ might have been higher than ADP.

BIA ($R^2=0.538$) and SF ($R^2=0.464$) were close behind the 3C model. Since all methods showed conformity in $R^2$, close to how the reference method (ADP) performed, they may all be useful in obese children. All correlations for the study group were significant, and showed weak to moderate linear relationships (Table 2).

Base data
Base data shows that the study population results are significantly higher in all the variables measured compared to the control group (Table 1). The patients tended to be somewhat older than the control ($p=0.054$; table 1), but this should not have affected the results substantially. The obese children were taller than the control group. However, this is in line with a previous study showing that obese children are generally taller than normal weighted children (54); and not because the possible small difference in age.

Gender
Interestingly, there seemed to be a difference in correlations when comparing genders (Table 3). The females had strong (except SF, which was moderate) linear relationship correlations throughout all of the methods examined and the superior method was ADP. While the males (Table 3) only showed moderate linear relationships and the superior method was SF. That SF was superior in this case was not expected.

All the correlations made from the females showed strong linear relationships compared to males (except for SF). Females generally start puberty earlier than males, and this might affect the results positively, which is the biggest difference from males that come to mind (54). Data for puberty was not collected for this study, but is documented in folders, and could be used to confirm that more females had hit puberty when measurements took place.
Age
The most prominent group was the 3-7 year olds (table 5), where the correlations had strong linear relationships with all methods (except for SF, which was weak). These were the strongest correlations in this entire study. Earlier research in normal weighted Swedish 4-year olds shows weak linear relationship correlations ($R^2 = 0.39$) which was significant.

Our higher correlations from 3-7 year old obese children may be because these subjects were obese. Normal weighted children in the same ages have very low BMI. These obese children had a normal BMI for adults, which could affect our results positively.

The 3-7 year olds was also the smallest group in number of subjects (n=26) and still show significant correlations and high $R^2$ values. However, one previous study found that body composition results determined by ADP in children <35 kg should be interpreted with caution (55). This includes most of the 3-7 year olds in our study.

In the age quartiles 8-11 year olds and 12-15 year olds, the linear relationship was only moderate. In the group aged 16-19 the linear relationships was weak. All correlations were significant, except for SF in the group aged 16-19.

The subjects in these groups tended to have higher BMI’s as well as being older, which may be the source of error.

BMI
The group with BMI 20-25 was noticeable, with a strong linear relationship of correlations from both BIA ($R^2=0.727$) and ADP ($R^2=0.748$). This was expected since the methods originally have been developed for normal weighted individuals.

ADP was prominent in all BMI groups, which was the only significant method in all the groups. ADP correlations showed a strong ($R^2=0.748$) linear relationship in the group with BMI 20-25. However, it showed a weak ($R^2=0.253$) linear relationship in the group with BMI 30-40.

The reason why the group with BMI 20-25 showed higher correlations is probably because this group contain the 3-7 year olds, which had a similar pattern of high $R^2$, when the age quartiles were assessed (Table 5). The 3-7 year old quartile has generally lower BMI, as mentioned above; a normal adult BMI could affect the results positively. Adult BMI has been shown to affect results when measuring with ADP and DXA, by up to a variance of 37% in fat mass (56). And this may be the case in children as well.
**Weaknesses of this study**
Using correlations of BMI with %FM to compare methods for measuring body has not been done in any other studies. This makes it harder to evaluate the results and compare them with studies striving for a similar goal (e.g. decide which methods are most useful).

This study has not adjusted for if the children had started puberty or not. This makes it harder to know if the results in different age groups are affected. The difference between genders suggests that it does.

All of these methods have been developed for adults. When it comes to children, there are fewer studies performed compared to adults. In the adult population, results from ADP is much more sensitive in correlations of BMI and % FM (56).

A weakness of this study is that we used unadjusted (or “raw” BMI), and not age adjusted s-BMI. In the future, data from this study could be used for this purpose. S-BMI or BMI-for-age has been shown to be better for deciding the amount of FFM instead of FM (51).

**Strengths of this study**
This study had a sufficient amount data for 244 of subjects, which is gives the results credibility for assessing a large number of obese children in all ages.

Even though regular BMI has its limitations in children (7), it is still sometimes used and supported as a measure of fatness in children (50)(51).

Noticeable with our study is that some children have a BMI of 20. A BMI <25 does not mean that the child has a healthy weight. In children a BMI of 20 is significantly overweight, and the younger the child is the more overweight it would be. All children in this study have been determined obese when admitting them to the special clinic (57).
Methods
The study population was not selected randomly. All subjects were admitted from a certain vicinity to Uppsala. The 59 persons were removed from the study due to exclusion criteria’s, which also might have affected the results negatively because of fewer subjects. A significant number of excluded subjects had data for at least two methods which we wanted to examine, which would have affected the results.

The results from circumferences and SF may affect the results, since these are both very user dependent methods. The data for which person that was examining each subject is registered, and could be analyzed in future studies. It also assumes that all subjects had 60-40% of the fat subcutaneous, which may not always be the case.

The only method considering the hydration status of the subjects is BIA, which means that the other methods may give a false value of %FM. A dehydrated person may have a falsely high value, and an overhydrated person may have a falsely low value.

One source of error may have been that all documentation was in folders, since some data was missing which excluded subjects from the study. This may not happen if everything is stored on computer servers.

Other factors may be differences in routines of measuring, since the data has been collected during five years. This is one of the reasons that some anthropometric values (e.g. SAD) only are documented in a part of subjects, since it was introduced more recently into the examination routines.

Conclusion
Data from a three-compartment model, bioelectrical impedance analysis and skinfold measurement are sufficient compared to the reference method air displacement plethysmography, when used in obese children.

Age seems to affect the methods the most. Gender seems to show better results for females. BMI affects the results from the methods mentioned. All three of these factors need to be taken into consideration when performing these body composition measuring methods in obese children.

Future research in this area is needed for more conclusive results concerning which body composition methods should be preferred when deciding %FM in obese children.
References


18. mml-math-3.gif (GIF-bild, 230 × 31 pixlar) - Skalad (0%) [Internet]. [cited 2014 Feb 10]. Available from: http://jap.physiology.org/content/85/1/238/embed/mml-math-3.gif


21. mml-math-5.gif (GIF-bild, 344 × 31 pixlar) - Skalad (0%) [Internet]. [cited 2014 Feb 10]. Available from: http://jap.physiology.org/content/85/1/238/embed/mml-math-5.gif


27. mml-math-7.gif (GIF-bild, 407 × 31 pixlar) - Skalad (0%) [Internet]. [cited 2014 Feb 10]. Available from: http://jap.physiology.org/content/85/1/238/embed/mml-math-7.gif


35. 7e2646fd061ae0d892a52df67430600c.png (PNG-bild, 533 × 46 pixlar) - Skalad (0%) [Internet]. [cited 2014 Feb 10]. Available from: http://upload.wikimedia.org/math/7/e/2/7e2646fd061ae0d892a52df67430600c.png


41. How-it-Works-BP.jpg (JPEG-bild, 310 × 449 pixlar) - Skalad (0%) [Internet]. [cited 2014 Mar 12]. Available from: http://www.uoguelph.ca/bodycomp/images/How-it-Works-BP.jpg


Appendix

This is the average schedule for the day at the clinic.

The child needs to be fasting from 22:00 the night before admittance.

8:15-08:45 Peripheral venous catheterization with blood samples, weight and length measurements.
8:45 Measuring of basal metabolic rate
09:00 Administering 75g oral glucose solution
09:05 Measuring blood insulin and glucose levels
09:15 Measuring blood insulin and glucose levels
09:30-09:45 Blood sampling, basal metabolic rate
09:45-10:00 Body composition measuring with BIA and circumferences
10:00-10:15 Blood sampling, basal metabolic rate
10:15-10:30 Skinfold thickness
10:30-10:45 Blood sampling, basal metabolic rate
10:45-11:00 BodPod
11:00-11:15 Blood sampling, basal metabolic rate
11:15-11:30 Briefing of activity registering diary and activity tracker
11:30-12:15 Briefing of standardized diet
12:15-12:45 Submaximal cardio workout with measurements of pulse and basal metabolic rate