BODY COMPOSITION AND BODY MASS INDEX IN 5-YEAR-OLD CHILDREN

BY

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Abstract

Background: Body mass index [BMI, weight in kg/(height in cm^2)] (BMI) is the most commonly employed indicator of body fatness in children with a BMI between the 85th and 95th %ile considered overweight and >95th%ile as obese. Limited data has related BMI and body composition in children, and it is unclear how well BMI assesses fatness in children. It is also unclear what, if any, maternal characteristics correlate with adiposity in children.

Objective: To describe BMI and body composition in 5-year- old children and to examine if BMI at earlier ages or maternal characteristics predict body composition at 5 years of age.

Methods: Fifty 5-6 year old children from the KU Docosahexaenoic Outcomes Study (KUDOS) provided weight, height, body composition by air displacement plethysmography (ADP) (BodPod ®), and the maternal variables of interest. ADP has been validated to assess body composition [fat (as % and kg) and fat free mass (FFM, % and kg)] in children. BMI percentiles were calculated using the CDC gender and age specific charts. Mean, standard deviations, and ranges were calculated for variables of interest for normal and for overweight/obese groups. Pearson correlations were performed between BMI percentiles and body composition variables. T-tests and an ANOVA were run to compare groups.

Results: BMI percentiles were significantly correlated with % fat (r=0.44, p=0.002). The mean %fat (range) for normal weight children was 25.2% (13-38%, n = 36) and for overweight/obese children was 26.5% (16-35%, n = 14) (p=0.48) evidence that BMI is a poor predictor of individual body fatness. Body fat (%) was not significantly related to race (p = 0.09) or gender (p=0.31). Fat mass (FM, kg) at 5 years of age was significantly different between children of mother's who had inadequate compared to excessive gestational weight gain (GWG) ($p = 0.04$). Maternal BMI was positively correlated with fat free mass [FFM, kg ($p < 0.001$)] but not FM or % fat.

Conclusion: There was significant overlap in % fat between children identified by BMI as normal and overweight/obese. The use of the BMI, as recommended by the American Academy of Pediatrics, to identify children who should receive counseling on weight management appears to have serious limitations. More research is needed to determine the accuracy of BMI in children and what predicts excess adiposity in childhood.

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Chapter 1

INTRODUCTION

The relationship between BMI and body composition measures has not been reported specifically in 5 year-old-children using ADP to measure body composition, and only a few studies have measured body composition in 5 year old children using this method (1-3). Most body composition research in children encompasses large age ranges and uses less reliable instruments. Examining younger children who are closer in age and using more valid instruments to measure body composition could improve our understanding of which children are too fat and elucidate factors that may contribute to excess body fatness. The relationship between BMI and body composition in children is controversial, and research concerning the factors that impact body composition is lacking - particularly in 5-year-old children. We studied the relationships of BMI to body composition (ADP, BodPod®) and explored maternal and infant predictors of adiposity in 5 year-old-children.

Research in children at age 5 is needed because it is generally believed that accumulating excess fat in the first few months of life and between the ages of 5-7 may be factors in the development of obesity (4). Data show that body composition varies considerably for this age group and that % fat is a strong predictor of FM in adolescence (5). Detection of excess adiposity at this age may prevent a trajectory towards obesity in later childhood, adolescence, or adulthood. Knowledge of contributing factors (e.g., gestational weight gain (GWG), maternal weight status, and maternal smoking during pregnancy) could help pediatricians understand who might benefit from counseling.

Purpose of the Study

The purpose of this study was to examine the body composition measures of children at 5 years of age in the KUDOS cohort and to compare them to BMI percentiles. We also sought to examine if maternal characteristics, i.e., maternal pregnancy weight status, GWG, smoking during pregnancy, maternal education, and income; or the child's characteristics, i.e., gender, race, breastfeeding duration, and BMI at 2, 3, and 4 years, were significant covariates related to body composition at 5 years of age.

Primary research questions

1. What is the FM, %fat, FFM, and % FFM of 5 year-old children?
2. How do BMI percentiles relate to FM, % fat, FFM, and % FFM in children 5 years of age?

Secondary research questions

3. Does maternal BMI, gestational weight gain (inadequate, adequate, excessive), smoking during pregnancy, or breastfeeding duration (days), predict FM, % fat, FFM, or % FFM at 5 years?
4. Does BMI at 2, 3, or 4 years of age relate to FM, % fat, FFM, or % FFM at age 5?

Chapter 2

LITERATURE REVIEW

Introduction

According to data from the National Health and Nutrition Examination Survey (NHANES) of 2009-2010, 12.1% of children 2-5 years of age are obese as defined by body mass index (BMI) percentiles (6). For children 2 to 19 years of age, BMI percentiles between the 85th-95th or above the 95th percentile define overweight and obesity, respectively. Obesity and overweight early in life are associated with cardiovascular disease risk factors (7, 8), gallbladder disease, sleep apnea, diabetes in childhood (9) and obesity in adulthood (8, 10) and increases the risk of chronic disease later in 1ife.

BMI is used as an indicator of body fat; however, the ability of BMI to assess adiposity in children has been studied very little. BMI is a measure of weight in relation to height and, therefore, does not consider frame size or distinguish fat free mass (FFM) from fat mass (FM) (11). Fat is thought to contribute more to the development of these chronic diseases than body weight (12). Researchers have compared BMI-for-age percentiles to more valid means of measuring body fat in children such as dual energy x-ray absorptiometry (DXA), bioelectrical impedance analysis (BIA), computerized axial tomography (CT), underwater weighing (hydrodensitometry), total body water (TBW), skin fold thickness, air displacement plethysmography (ADP), and the four compartment model.

The data comparing adiposity measured by these means with BMI in children are with large age ranges and are inconclusive. Examining younger children of a more consistent age could provide valuable information about adiposity at earlier ages and during critical periods of development.

It is also not clear what factors may predict obesity in childhood, but data using BMI show that parental obesity, excessive gestational weight gain, maternal smoking, short duration of breastfeeding, high rate of postnatal weight gain, and obesity at a young age may predict obesity in childhood and adolescence. However, data examining the correlation between these predictors and adiposity using body composition techniques in children are inconclusive.

The relationship of BMI to body composition is still unclear, and the evidence for this relationship and the factors that impact body composition is lacking - particularly in children younger than 6 years. It has been suggested that changes in BMI better reflect changes in FFM and that % fat does not correlate with BMI percentiles until the BMI percentile is ≥85th% in older children (13, 14). It is important to determine the validity of BMI to assess adiposity as this is a commonly used tool for pediatricians and to identify common predictors of body fatness in childhood so that these may be used to assess risk and prevent the adverse health outcomes.

Critical periods for the development of obesity in children

Research in children at age 5 is needed because it is thought that accumulating excess fat between the ages of 5-7 may be a factor in the development of later obesity (4). Data show that body composition varies considerably at this age and that % fat is a strong predictor of FM in adolescence (5). Detection of excess adiposity and its relationship to contributing factors (such as gestational weight gain, maternal weight status, and maternal smoking during pregnancy) at this age may help prevent a trajectory towards obesity in later childhood, adolescence, or adulthood.

Comparison of the methods of measuring body composition

Adiposity can be measured in a variety of ways that differ in their feasibility, risk, cost, and accuracy. In children, some methods are more feasible than others. Underwater weighing requires exhalation of all possible air in the lungs and may be difficult for children. In addition, Wells et al. (15) reported that DXA did not permit measurement of several children due to their weight or size. In addition, methods such as DXA and CT involve radiation exposure and should be minimally used in children. Methods such as DXA, MRI's, CT's, and underwater weighing may be difficult to complete or inappropriate for children and are not readily available for testing (16).

Underwater weighing, DXA, magnetic resonance images (MRI's), CT, and ADP are also costly in comparison to skin fold thickness and BIA. Due to their low cost and ease of use, skin fold thickness and BIA are useful in large population studies of children. However, these methods are not as accurate due to variance in hydration or degree of fatness.

The 4 compartment model is regarded as the gold standard of accuracy for measuring body composition; it estimates bone, body water, and body density and uses these estimates to estimate body fat (17). However, it is expensive and time-consuming, which makes it unfeasible for evaluating individuals or populations (18). ADP is less costly and less invasive than underwater weighing and less hazardous than DXA. In a study of children and adults, 92% preferred ADP to underwater weighing (19). Nevertheless, data shows that the accuracy and agreement of body fat measurements by ADP differs among studies in young children.

Some data show that in comparison to other methods, ADP can underestimate (20-23) body fat percentage. Specifically, data show that ADP can underestimate % fat in leaner children and overestimate it in overweight children (19). ADP does not seem to be reliable for all individuals, particularly in child subgroups (24) less than 35 kilograms (kg) (20), and has a large variation in children less than 50 kg (19), however, ADP measured body fat within 1-2% of underwater weighing for these children. In addition, when the pediatric insert was used in the BodPod®, ADP was found not to accurately assess % fat when compared to TBW (2). Yet, when the ADP with the pediatric option in children 2-6 years of age was compared with the 4 compartment model (the gold standard), it was found to be accurate and precise (3). In addition, Wells et al. showed ADP in 5 to 7 year old children to have a bias of <0.5% when compared to TBW (1). Other data shows that ADP significantly correlates with DXA measurements (21, 22, 24-27) and the 4 compartment model (17, 28). Fields et al. shows ADP as the only method to be accurate when compared to DXA, HW, and TBW to assess body fat defined by the 4 compartment model (17). The differences in these results may be due to the reference method used.

While ADP may have shown some error, other methods result in error as well. Data shows DXA underestimating % fat in leaner subjects and overestimating in participants with high body fat when compared to four compartment model (29). DXA has wide limits of agreement when compared to the gold standard 4 compartment model, and data shows that DXA can underestimate lean mass (LM) or overestimate and underestimate FM (15, 30).

More research needs to be done assessing the bias and accuracy of ADP in younger children and also reference values for this method. Regardless of these conflicting results, ADP is less risky, less expensive, and more accurate than these other measures and can be used to assess adiposity in children 5 years or more (1).

Comparison of BMI and body composition in children

Body composition has been compared to BMI in a variety of age groups. In adults, BMI has demonstrated acceptable accuracy; however, some data shows that BMI can incorrectly classify people. In studies with participants 18-80 years of age, BMI has been shown to correctly classify only two thirds of the participants (31), e.g., 30% of those classified as lean had a body fat percentage in the obesity range (32). Clinically, BMI is used to screen adults for adiposity despite the variability noted above, however, similar studies have not been done in 5-year-old children.

The research on body composition in this age group has focused on validating different body composition methods rather than comparing body composition to BMI. The few studies that do compare body composition and BMI in this age group mostly use DXA, skin folds, and BIA to determine body composition (5, 12, 16, 33). As previously discussed, skin folds and BIA may not be the most accurate measure of body composition, and many studies using DXA include older children.

In addition, most of the studies of children include large age ranges such as the ages of 3-18, and few studies exist for children younger than 5-6 years of age due to different factors such as feasibility, cost, accuracy, and risk of body composition techniques. Some methods are inappropriate or unavailable for these children. For instance, the BodPod® recently developed a pediatric option for children 6 months to 5 years. This pediatric adaption includes a seat for safety, a smaller cylinder for calibration, and software adaptions(2). Without this option, body composition assessment was limited to those 5 years and older for the BodPod and 6 months and younger for the PeaPod® (an instrument for infants using ADP). Even if the methods are available to measure this age group, the tests may be difficult to perform or inaccurate.

Of the studies examining a large range of ages, the data show varying results for children 3-18 years of age. The data show that BMI underestimates body fat in children (16, 34), that body fat percentages of children vary considerably within the BMI categories of normal, overweight, and obese (12, 35), and that an association between BMI and FM only exists for those with a BMI for age greater than the 85th percentile (36). Confirming these results, one study shows that BMI and body fat percent in children 6-12 years of age has a curvilinear relationship (13). Researchers have shown that BMI percentiles accurately estimate body fat excess and correlate with BMI in a variety of populations (11, 18, 37), but these correlations vary in strength (11, 14).

Studies show BMI to be a useful tool correctly identifying overweight or obese (based on body fat) children with a high specificity of 83-96.7% (37, 38). However, data also show that BMI incorrectly classifies children as overweight or obese with a varied and low sensitivity of 24-100% (37-39). These sensitivity and specificity data are consistent with the theory that BMI is able to correctly classify those that are actually overweight and obese but unable to classify those with high FFM. They also show that BMI may be underestimating the number of children who actually have excess fat but may weigh proportionally to their height (39).

Overall, these data show that BMI does not always accurately estimate body fat in children. However, research is limited for smaller age ranges. A large age range including the age of puberty (a time for increasing body fat) may bias results. Examining younger ages during fewer years could provide valuable information for detecting adiposity at earlier ages. The relationship of BMI to body composition in children is still unclear, and the evidence for this relationship and the factors that impact body composition is lacking - particularly in preschool age children.

The research focusing on children 6 years of age and younger show that body composition varies widely in this age group (10 fold in 4-5 year-old-children) and that BMI and various body composition components correlate differently among studies (5, 14, 16, 40). Eisenmann et al. uses BIA, DXA, and skin fold measures to show that body fat percentage correlate only moderately and that BMI and FM correlated more strongly than BMI with FFM (16). Similarly, Tyrell et al. shows in 5-11 year-old-children that BMI better predicts FM than % fat or FFM which is inconsistent with results of other studies (40). On the other hand, others have found in older children that BMI correlates more with FFM index and that increases in BMI correlate more with increases in FFM, suggesting that BMI is not a precise indicator of FM for growing children (14). Body composition varies in this age group due to many factors such as gender, race, genetics, lifestyle, etc., and the relationship between body fat percentage and BMI for this group has not been extensively examined and remains unclear.

Predictors of obesity in childhood

Gestational weight gain

Recent studies and data show a relationship between gestational weight gain (GWG) and offspring adiposity at various ages. Gestational weight gain greater than the 2009 Institute of Medicine (IOM) pregnancy weight gain guidelines has been associated with greater infant (41-43) and childhood adiposity (41, 43-45), weight for age and length for age (46), and adolescent adiposity (47). Data show these associations to be intensified for mothers who were underweight (45) or overweight (42) during pregnancy and had excessive GWG. In particular, data show that GWG is associated with BMI throughout life, and that only half of this association is reduced when birth weight and BMI through age 14 is considered. (48). However, some have found only an association for maternal pre-pregnancy BMI instead of GWG (49).

Maternal BMI

It is difficult to determine the individual impact of maternal BMI, birth weight, and GWG on infant anthropometrics and adiposity, but maternal BMI is thought to be a significant predictor of offspring weight and adiposity. Data show that maternal BMI is a significant predictor for greater offspring birth weight (50, 51), greater weight for age, and weight for length but not length for age at 6 months (46), implying that greater maternal BMI causes greater infant weight compared to length. These associations are present regardless of GWG and race (51) but birth weight can somewhat mediate this effect (52). In addition, some studies that examine this association in childhood show maternal BMI as a significant risk factor for childhood obesity (53), however, it is difficult to distinguish maternal BMI from paternal obesity, smoking, education, and economic status which are also associated with childhood obesity (53-55).

Few studies have examined the association between maternal BMI and infant adiposity. Data do show that infants born to normal weight mothers have less % fat and FM but have more FFM compared to infants born to overweight and obese mothers (56). In addition, children 9 years of age born to women with high pre-pregnancy BMI had a greater FM index (49). These data support that maternal BMI is a significant risk factor for higher birth weight, weight later in infancy, and adiposity. However, it is difficult to determine the individual impact of these factors, and data supporting the association between offspring adiposity and maternal BMI is very limited.

Birth weight

Higher birth weight is associated with higher fat mass later in life, but data show that birth weight is associated with LM or FFM as well (57, 58). Other studies do not find a relationship between birth weight and body composition (59) or BMI in adulthood (60). The data supporting these theories are inconclusive. High birth weight was a significant predictor of body fat percentage and FM in children between 5 and 18 years of age (61, 62), but other data show that birth weight was not significantly associated with FM, body fat percentage, FMI, or trunk FMI in children (58, 63). Infants born LGA have been shown to accrue an excessive amount of fat between 3-6 years of age compared to infants born SGA (64). Different results among studies may be due to differences in methods used and the age of body fat assessment. The relationship may be further confounded by the association of low birth weight with excessive neonatal weight gains and later elevated FM.

Rate of infant weight gain

Rapid weight gain in the first months of life is positively related to childhood (65-70) and adolescent BMI (70), and it has also been related to increased adiposity in childhood (70, 71) and adulthood (72). Rapid weight gain has also been associated with LM, height, and BMI but not body fat (73). Some data show that increased weight gain during specific periods are more critical to the development of obesity (60, 73, 74). Another study found that the relationship between accelerated weight gain in infancy and higher body fat at 2 to 6 years of age was lost after correction for birth weight, maternal smoking habits, and maternal weight (75). The lack of consistency in results may also be due to some other variable such as the age of fat assessment, the body composition method used or failure to account for confounding variables such as birth weight, maternal weight, feeding, or maternal smoking habits.

Maternal smoking

Maternal smoking has been linked to increased overweight and obesity (BMI) in childhood (76) and adolescence (77), but few studies examine the relationship between body composition and maternal smoking. In addition, the data to support this relationship are inconsistent. Children 3-5 years of age are twice as likely to be overweight if parents are overweight and smoke (55). However, data show no difference in fat mass of offspring whose mothers smoked throughout pregnancy and whose mothers did not smoke (78). Furthermore, maternal smoking has also been associated with both FM and LM (79).

Several factors make it difficult to determine the individual impact of smoking on later overweight and obesity. The amount and length of time smoking complicates this association as data show that children whose mothers quit smoking had a lower mean BMI than those whose mothers did not quit (80, 81) while other studies do not examine this or the prevalence of childhood obesity was only slightly lowered if mothers quit during pregnancy (82). In addition, data show that children with smoking mothers are shorter in childhood (76) or have lower birth lengths (83) than children without smoking mothers perhaps contributing to the increased BMI. Maternal smoking is a factor for low birth weight or SGA infants (76, 84), and some researchers suggest that the “catch up” weight gain of these infants is the cause of increased adiposity. However, some data show that an association exists regardless of birth weight (85). This association is further complicated by data that suggest that women who smoke are less likely to breastfeed (76) and that infants who breastfeed grow less quickly than formula fed infants (84). In another study, the association between smoking and later overweight and obesity was only present for infants who breastfed for less than 6 months (81).

Feeding method and duration

Breastfeeding and its duration has been shown to be protective against the development of later overweight and obesity by BMI (86-89) or fatness (90). This relationship is not simple as some data show that the disadvantages or benefits of breastfeeding disappear in later ages (87, 91) and that there may be a specific duration of breastfeeding that provides benefits (87). It could be that breastfeeding benefits infants during the first 6 months of life by decreasing rate of growth (68, 91), and later overweight and obesity is impacted more by other environmental, maternal, or genetic factors (89, 92).

Race

It is generally believed that body fat differs between many races including European, Asian, non-Hispanic black, Mexican-Americans, and others. Pacific Island or Maori children are more likely to be overweight or obese in comparison to European and Asian children (40, 93). Hispanics can be twice as likely as non-Hispanic children to be overweight at 4 years of age (66). Data show body fat to vary between non-Hispanic white, non-Hispanic black, and Mexican-American boys (94). In addition, non-Hispanic black children have a lower body fat percentage than other children at a given BMI, and Asian girls have a higher body fat percentage (95, 96). The theory of race being a determinant of body fat needs more data and development especially in children.

Gender

Women generally have more body fat than men in adulthood. In childhood, data show that girls have greater body fat than boys (40, 63, 97). Other data show girls have greater body fat than boys as early as 3 years of age (16). Independent of other factors, female infants have been associated with greater body fat (98).

Conclusion

The relationship between body composition and BMI is unclear due to different ages and methods used, especially in children 5 years of age. In addition, the impact of factors associated with greater BMI on body composition in children is unclear. More research is needed to determine the ability of BMI to accurately assess the adiposity of children 5 years of age and which factors most impact body composition. A greater understanding of BMI’s ability to detect excess adiposity in children can help identify and intervene for children at risk for the development of obesity and the comorbidities associated.

Chapter 3

MATERIALS AND METHODS

Background

The study participants are 5 year old male and female children and offspring of the participants from the KUDOS cohort trial. The KUDOS cohort is a randomized, double-blind, placebo-controlled Phase III Clinical Trial where participants were randomized to receive capsules of algal oil (3 capsules per day of 200 mg each) or the same amount of soy/corn oil with no docosahexaenoic acid. Three hundred and fifty women between the ages of 16 and 35.99 years enrolled for this study during their 8th to 20th week of gestation from January 2006 through November 2009.

Women were not enrolled for this study if they were less than 16 or greater than 35 years of age, had a BMI >40, were expecting multiple infants, had serious illnesses (e.g., cancer, diabetes, lupus, hepatitis, sexually transmitted diseases, not HIV positive), had diabetes or gestational diabetes at baseline, or high blood pressure for any reason. These women must have been available by phone, agreed to consume capsules until delivery, able to return to the study center for delivery, and able to provide an informed consent in English.

Design

All infant and maternal data were collected prospectively for the primary study. Anthropometric data were measured at return visits at 6 weeks, 4 months, 6 months, 9 months, 12 months, and 18 months of age and birthday appointments from 1 to 5 years. Parents enrolled in the KUDOS trial provided consent for follow up of offspring anthropometric data (height or length, weight, and head circumference) and body composition data. Body composition was determined at the 5 year visit. Analysis proceeded after body composition measures were completed.

Sample

Body composition data of children aged 5 years old were collected using the BodPod® by air displacement plethysmography (ADP) starting January 2012. By February 2013, we completed body composition measures on 51 children. They are the subgroup analyzed for this analysis. We anticipate that the final sample will be about 170 children.

Research Setting

The three hundred fifty women in the KUDOS cohort trial were recruited from University of Kansas Medical Center (KUMC), St. Luke's Hospital, and Truman Medical Center in Kansas City, Kansas or Missouri. Researchers recruited potential participants at prenatal clinic visits, and other participants were recruited through various media methods. All postnatal research appointments took place at KUMC, and these partipcants returned for these infant follow up appointments at 6 weeks, 4, 6, 9, 12, and 18 months, and biannually thereafter. Body composition measures were obtained in the Department of Dietetics and Nutrition at KUMC at the 5 year follow up visit.

Ethics

The KUDOS cohort study was previously approved by Human Subjects Committee at University of Kansas Medical Center (HSC#11406). Participants provided written consent for the measure of offspring body composition before the 5 year visit (see

Appendix A for a copy of the consent form). All use of this information adhered to the Health Insurance Portability and Accountability (HIPAA), which is a federal law protecting the private health information of individuals.

Instrumentation

For this study, an infant scale and length board, pediatric floor scale, and a wall-mounted stadiometer, were used to collect anthropometric data. The BodPod® was used to determine body composition. EpiInfo ™ [Center for Disease Control and Prevention (CDC), Atlanta, GA] version 3.5.3 and 3.5.4 was used to calculate anthropometric measures and percentiles from birth to 5 years, and the percentiles are based on CDC's 2000 growth charts. These values were calculated using the Add Statistics function of the Epi Info™ Nutrition application. Another birth growth chart was used to compare, using percentiles, the newborns birth weight with other infants born at the same gestational age (99).

Air displacement plethysmography and densitometry

The BodPod® is a two compartment model which uses density to measure body two compartments of the body – fat mass and fat free mass (100). The two compartment model is based on the equation in **Equation 1** (100). It can be rearranged to show % fat which then can be used to calculate % FFM, FM, or FFM as shown in **Table 1**. Density is calculated by dividing mass by volume. The BodPod® which uses air displacement plethysmography (ADP) calculates a subject's volume, and an electronic scale, as part of the BodPod®, is used to measure mass (or weight). Different equations are used to calculate body composition based on gender, age, race, and degree of obesity, these are shown in **Table 2**.

Equation 1. Two compartment model equation[1]

$$\frac{1}{D_B} = \frac{F}{D_F} + \frac{FFM}{D_{FFM}}$$

D_B = body density, F = fat mass, D_F = density of fat mass, D_{FFM} = density of fat free mass

[1] BOD POD *Gold Standard* Body Composition Tracking System Operator's Manual

Table 1. Equations used to calculate body composition variables.[1]

	Equation
% fat	$\% \text{ fat} = \left(\frac{D_F D_{FFM}}{D_B(D_{FFM} - D_F)} - \frac{D_F}{D_{FFM} - D_F} \right) * 100$
FM (kg)	$\frac{(\%\text{fat})(M_B{}^{2})}{100\%}$
% FFM	100 - %fat
FFM (kg)	$M_B - FM$

[1] BOD POD *Gold Standard* Body Composition Tracking System Operator's Manual

[2] M_B = subject's body volume

Table 2. Formulas for estimating the densities of fat mass and fat free mass in different populations.[1]

Name	**Equation**	**Population**
Siri	$\%fat = (4.95/D_B - 4.50)*100$	General Population
Schutte	$\%fat = (4.374/D_B - 3.928)*100$	African American and Black males
Ortiz	$\%fat = (4.83/D_B - 4.37)*100$	African American and Black females
Brozek	$\%fat = (4.57/D_B - 4.142)*100$	Lean and obese individuals
Lohman	$\%fat = (C_1^1/D_B - C_2^1)*100$	Children ≤ 17 years

[1] BOD POD *Gold Standard* Body Composition Tracking System Operator's Manual

To calculate volume, the BodPod® measures the difference between the volume of the empty test chamber and the volume of the test chamber with the participant (101). The difference between these volumes is the volume of the participant. To estimate the volumes of the chambers with and without a participant, a diaphragm, which sits between the test and the references chambers, oscillates (101). The pressure changes due to the oscillating diaphragm, and the extent to which pressure changes indicates the volume of each chamber.

The underlying principle of this volume measurement is the relationship between pressure and volume according to Boyle's Law which holds that under stable temperature conditions, pressure will proportionally and inversely change as volume changes (100). However, the air in the chambers is not under a constant temperature, so an equation based on Poisson's law is used. It accounts for the ratio of the temperature of the air at a stable volume to the temperature at a stable pressure (100). Thoracic gas volume (TGV) is also measured to measure lung volume and corrects the raw volume calculated (100). Using the volume of the test chamber, participant body volume then can be calculated using calibration variables and the volume of the test chamber (100).

Hydrostatic weighing also measures body composition in this way, however, the BodPod® uses air to measure the volume of the participant rather than water. Fields et al. found that ADP gave an unbiased and valid measure of body composition in 9-14 year old children when compared to DXA, HW, and TBW using the 4 compartment model as the reference (17). In 2-6 year old children, ADP with the pediatric option has shown to be valid and reliable compared to DXA and TBW with the 4 compartment model as the reference method (3). The BodPod® has shown to be accurate and valid for this population.

Data Collection

Anthropometric Data

Infant birth weights and lengths, gestational age at delivery, and size for gestational age were obtained from participant's medical records. Gestational size was categorized – 1 for small for gestational age (SGA), 2 for appropriate for gestational age (AGA), and 3 for large for gestational age (LGA). Birth weight percentile was estimated using the CDC birth to 36 months growth charts along with the other infant growth chart. Participants' weight and height was measured yearly. At 1 year, a weight without clothing was obtained, and a recumbent length was taken. At 2, 3, 4 and 5 years, weights were taken with a light layer of clothing, and a standing height was taken per protocol. Infant and pediatric scales are used and measurements are made to the nearest gram or ounce for weight and nearest 0.1 cm for height. Scales are calibrated annually.

Body Composition Data

At age 5, body composition was measured using the BodPod®. Participants wore a swimsuit and swim cap, and the participant's weight and height was measured prior to testing. FM, % fat, FFM, and % FFK data were measured and recorded.

Maternal Data

Mother's BMI was collected at the entry to the study and obtained from obstetric records at both the first and last prenatal clinic visit. Pre-pregnancy weight was self-reported at the 6 week post-partum visit. GWG was calculated by the difference in weight between first and last clinic visits or using the self-reported pre-pregnancy weight in the absence of the first clinic visit measurement, and it was categorized according to the 2009 IOM guidelines. Categories 1, 2 and 3, respectively, had inadequate, appropriate and excessive weight gain according to those guidelines.

Mother's race, ethnicity, and education years along with paternal education years was obtained at the 6 week post-partum visit. Income was based on zip code at the time of enrollment using the Mid America Regional Council's Metro Dataline demographics highlight table (102).

Mothers reported smoking status before, during, and after pregnancy at the 6 week post-partum visit. Smoking was quantified as "pack years" which considers duration in years and amount of cigarettes smoked in packs. Pack years during pregnancy was estimated using 40 weeks gestation as the duration of each pregnancy.

Duration of breast or formula feeding was estimated at each return visit. Breastfeeding or formula feeding was self-reported, and the start and stop dates for each were obtained. Breast feeding duration was categorized into 4 categories – category 1 for 0-6 days of breastfeeding, category 2 for 7-42 days, category 3 for 43-120 days, and category 4 for greater than 120 days of breastfeeding. This was done due to the timing of the return visits.

Data Analysis

Data are reported as means ± standard deviations. Correlation analyses were conducted to determine the relationship between BMI percentiles and body composition as well as possible earlier predictors of obesity and body composition. These data are reported as Pearson *r* correlation coefficients. Further analyses were done between GWG and body composition and race and body composition using a one-way ANOVA and a t-test respectively. Data are assumed to fall into a normal distribution and a *p* value less than 0.05 was considered statistically significant. All these analyses were performed using the data analysis package in Microsoft Excel 2010 and SPSS 20.0 Software (SPSS, Chicago, IL).

Chapter 4

RESULTS

The following section reports the sample characteristics, body composition measures, and the relationship between these measures.

Sample

Fifty mothers and their children provided data for this study. Body composition measures were collected for 51 5-year-old children, offspring from the participants of the KUDOS cohort. Demographic information was collected prospectively during participation in the KUDOS trial. One subject was removed from these analyses so as not to bias this first exploratory analysis of the data because the child was an extreme outlier.

Maternal Characteristics

Thirty mothers identified themselves as white only, 3 as white and Hispanic, 1 as native Hawaiian or Pacific Islander, 1 as Asian, and 16 as black. Maternal BMI was calculated from the first prenatal clinic visit weight and height, and GWG was estimated from the difference between the weight at the first prenatal clinic visit and the last. Twenty-nine women had excessive GWG, while 15 had adequate and 6 had inadequate GWG in this sample. Smoking during pregnancy as pack year was used in analysis. Forty one women were used when comparing breastfeeding duration to body composition, as 9 women did not breastfeed. Maternal demographic data are shown in **Table 3** (mean ± standard deviation, SD).

Table 3. Maternal Characteristics

Characteristic[1]	**Mean ± SD**	**Range**
Mean age (years)	26.1 ± 5.5	16 – 36
BMI (kg/m2)	26.6 ± 4.9	17.6 – 35.9
Smoking during pregnancy (pack years)	0.05 ± 0.10	0 – 0.5
Maternal Education (years)	13.7 ± 2.6	8 – 20
Income (dollars)	43,913 ± 18, 103	18,333 – 999,494

[1] n= 50

Offspring characteristics

Of the 50 children measured at the 5 year visit, 23 were reported as white only, 6 as white and Hispanic, 1 as Asian, 16 as black, and 4 as two or more races at birth by the mother. Twenty-eight of the participants were female, and 22 were male.

Anthropometrics

Weight and length/ height were measured at birth and every 6 months after birth until the 5 year appointment and used to calculate anthropometric percentiles for age. At birth, thirty-three infants were AGA, 1 was SGA (weight <5th %ile) and 16 were LGA (weight >95th %ile). Two participants were low birth weight, weighing 2043 and 2443 grams at birth. These data are shown in **Table 4** (mean ± SD).

Table 4. Birth anthropometrics

Anthropometric	n = 50
Gestational age (weeks)	39.36 ± 1.44[1]
Birth weight (grams)	3362.80 ± 510.83
Birth length (cm)[2]	49.73 ± 2.48
Weight for age percentile (%)	46.13 ± 29.43
Length for age percentile (%)[2]	50.94 ± 27.94
Weight for length percentile (%)[2]	53.11 ± 23.49

[1] mean ± SD

[2] n = 49

Weight and length or height was taken at 6 weeks, 4 months, 6 months, 9 months, 12 months, 18 months, 2 years, and on the child's 6 month anniversaries thereafter. Length was taken until the 2 year visit, and a standing height was taken thereafter. These weight and height measures were converted to weight-for-height percentiles until age 2. After age 2, BMI, BMI percentile, weight-for-age percentile, stature-for-age percentile, and weight-for-stature percentile were determined.

The average weight, weight-for-age, height, height-for-age, and weight-for-height percentiles from each visit are shown in **Table 5** (mean ± SD). All participants from 6 weeks to 18 months had length measured on a length board using standardized procedures. One weight was omitted from analysis because it appeared inaccurate, and one length was not performed because subject wore leg braces.

Table 5. Mean anthropometric measures and percentiles from 6weeks to 18 months

	Mean ± SD				
Age	Weight (kg)	Weight for age (%)	Length (cm)	Length for age (%)	Weight for length (%)
6 weeks	4.72 ± 0.66	58.44 ± 26.00	55.42 ± 2.34[1]	51.90 ± 26.36[1]	52.28 ± 28.66[1]
4 months	6.71 ± 0.76	63.93 ± 22.70	63.23 ± 2.15	65.41 ± 22.39	49.78 ± 26.61
6 months	7.79 ± 0.88	60.04 ± 25.09	67.07 ± 2.68	63.43 ± 23.71	55.21 ± 27.32
9 months	9.03 ± 0.90	55.06 ± 25.59	71.79 ± 2.36	62.86 ± 24.71	59.50 ± 26.92
12 months	10.00 ± 1.00[1]	53.61 ± 27.11[1]	75.59 ± 2.57	61.10 ± 24.19	60.11 ± 26.03[1]
18 months	11.52 ± 1.31	51.61 ± 29.30	82.28 ± 3.12	58.75 ± 26.65	56.85 ± 28.02

[1] n = 49

The average weight, height, BMI, BMI percentile, weight-for-age percentile, stature-for-age percentile, and weight-for-stature percentile for measures from 2 years through 5 years are shown in **Table 6** (mean ± SD). Three participants at the 2 year visit and 1 participant at the 3 year visit refused standing heights, so lengths were used for heights in these participants. Epi Info ™ was unable to calculate BMI, BMI percentiles, and stature-for-age percentiles for 4 participants for the 2 year visit, so percentiles were calculated by hand. The age of 16 participants who were just under the age of 2 at the 2 year visit, were rounded to 2 years in order to calculate the anthropometric percentiles using Epi Info™ software.

Table 6. Mean anthropometrics and percentiles for ages 2-5 years

	Mean ± SD			
Age	Stature for age (%)	Weight for age (%)	BMI (kg/m^2)	BMI (%)
2yr	55.16 ± 26.42	57.18 ± 27.09	17.18 ± 1.44	61.04 ± 26.24
3yr	49.64 ± 27.32	60.33 ± 26.53	16.62 ± 1.31	64.07 ± 25.08
4yr	54.33 ± 26.40	61.68 ± 25.65	16.33 ± 1.30	66.72 ± 26.34
5yr	56.12 ± 27.04	60.36 ± 27.12	16.22 ± 1.44	65.13 ± 26.24

Body Composition

Body composition was measured on 51 children, but 1 participant was excluded from analysis as an outlier in body fatness. The mean age at which body composition was measured was 5.15 ± 0.22 years. Thirty seven children were approximately 5 years of age, and 13 were approximately 5.5 years of age. The mean, median, and range of %fat, FM, FFM, and % FFM of the children in this sample are shown in **Table 7** (means ± SD).

Table 7. Mean body composition measures for children 5 years of age

		Mean ± SD	Median	Range
Fat	%	25.56 ± 5.57	25.15	13.6 - 38.60
	kg	5.06 ± 1.48	4.74	2.28 - 8.60
FFM	%	74.44 ± 5.57	74.85	61.40 - 86.40
	kg	14.56 ± 2.25	14.60	11.12 - 21.66

Relationship between BMI percentiles and body composition at age 5

Table 8 shows the correlations (Pearson *r*, *p* value) between body composition measures at age 5 and the BMI percentile. The correlation between % fat and BMI percentile was lower than that with FM or FFM. All of these correlations are statistically significant.

BMI percentile cutoff values and body composition

The results from the t-test for differences between children with normal weight (BMI <85th percentile) and overweight and obese (BMI >85th percentiles) and body composition are shown in **Table 9.** No significant difference in % fat or % FFM between children below the 85th percentile and above the 85th percentile was found. FM and FFM significantly differ by these percentile categories for overweight and obesity but not the % fat or the % FFM.

Table 8. Correlations between body composition measures and BMI percentiles

		r	***p* value**
Fat	%	0.44*	0.002
	kg	0.70*	<0.001
FFM	%	-0.44*	0.002
	kg	0.55*	<0.001

*Correlation is significant at the $p \leq 0.05$ level (two-tail)

Table 9. Body composition by cutoff BMI percentiles at 85th percentile

		BMI percentile cutoffs			
		BMI percentile <85th % n = 36	BMI percentile >85th % N = 14	t- stat	*p* value[2]
Fat	%	25.2 ± 5.6[1]	26.5 ± 5.5	-0.72	0.48
	kg	4.6 ± 1.2	6.1 ± 1.6	-3.60	0.0008*
FFM	%	74.8 ± 5.6	73.5 ± 5.5	0.72	0.48
	kg	13.6 ± 1.6	16.9 ± 2.0	-6.12	<0.000001*

[1] mean ± SD

[2] *p* values calculated with a t-test

*difference is significant at the $p \leq 0.05$ level (two-tail)

Relationship between earlier BMI percentiles and body composition at age 5

The correlations (Pearson *r*, *p* values) between BMI percentiles at earlier ages and body composition measures are shown in **Table 10**. As the children aged, the correlation increased between BMI percentiles and all body composition measures. The correlations between FM and FFM and BMI percentiles was greater than the correlations between % fat and % FFM for all body composition measures at all years except for FFM at age 4. The correlation between % fat or % FFM and BMI percentiles was only significant at ages 4 and 5. This correlation was significant, however, for FM and FFM at every age except for FFM at age 2.

Table 10. Body composition at age 5 and BMI percentiles from 2-5 years

		BMI percentiles for ages							
		2yr		**3yr**		**4yr**		**5yr**	
		r	***p* value**	***r***	***p* value**	***r***	***p* value**	***r***	***p* value**
Fat	%	0.18	0.216	0.23	0.112	0.47*	<0.001	0.44*	0.002
	kg	0.32*	0.026	0.41*	0.004	0.63*	<0.001	0.70*	<0.001
FFM	%	-0.18	0.216	-0.23	0.112	-0.47*	<0.001	-0.44*	0.002
	kg	0.34	0.18	0.42*	0.002	0.40*	0.04	0.55*	<0.001

*Correlation is significant at the $p \leq 0.05$ level (two-tail)

Earlier predictors of obesity

The correlations (Pearson *r*, *p* values) between these earlier predictors of obesity (e.g. maternal BMI, smoking during pregnancy, and feeding type and duration) are shown in **Table 11**. The correlations were greater between FM and FFM than % fat and % FFM for maternal BMI, smoking, maternal education, and income. The correlations were greater for % fat and % FFM when compared to breastfeeding duration. However, the correlation between maternal BMI and FFM was the only statistically significant result.

Table 11. Body composition at age 5 and possible early predictors of obesity

		Early predictors									
		Maternal BMI		**Smoking during pregnancy**		**BF days**		**Maternal education**		**Income**	
		r	***p* value**	***r***	***p* value**	***r***	***p* value**	***r***	***p* value**	***r***	***p* value**
Fat	%	0.03	0.84	-0.09	0.52	0.19	0.19	0.03	0.86	-0.05	0.71
	Kg	0.27	0.06	-0.19	0.19	0.07	0.63	0.05	0.75	-0.11	0.46
FFM	%	-0.03	0.84	0.09	0.52	-0.19	0.19	-0.03	0.86	0.05	0.71
	kg	0.47*	<0.001	-0.20	0.17	-0.15	0.35	0.10	0.51	-0.09	0.54

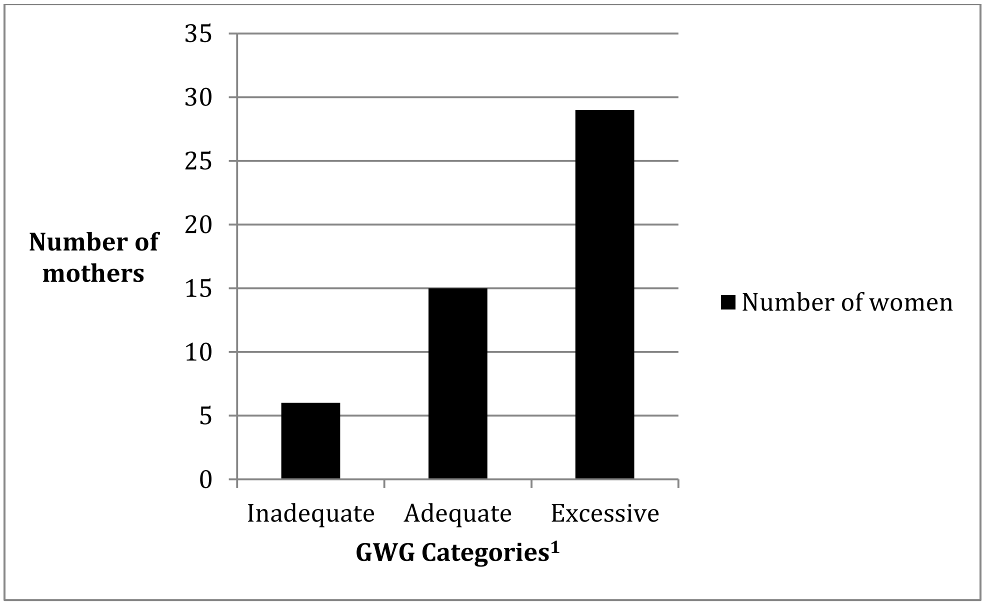
*Correlation is significant at a *p* value ≤ 0.05 level (two-tail)

Figure 1 shows the number of mothers in this sample who gained inadequate, adequate, or excessive weight gain during pregnancy. One-way ANOVAs show that there is a statistically significant difference in FM at 5 years of age among GWG categories, with an increase in the amount of body fat from inadequate to adequate to excessive GWG (F = 3.75, p = 0.03). There was not a statistically significant difference in % fat (*p* = 0.22), % FFM (*p* = 0.22), FFM (*p* = 0.08) between the GWG categories. In post hoc analysis, there was only a significant difference in FM between the inadequate and excessive GWG groups (*p* = 0.04). These data are shown in **Table 12**.

Body composition measures were also not significantly different for this sample according to race as seen in **Table 13**. Thirty two of these children were non-black, and 18 of them were black. The black children had an actual lower mean % fat and higher mean % FFM. Fat mass was also lower and FFM was higher in black children compared to the other children, but there was more variance among black children. However, these differences were not statistically significant.

Body composition also did not differ by gender as seen in **Table 14**. Girls had somewhat higher % fat and FM and somewhat lower % FFM and FFM than boys, however, these differences were not statistically significant.

Figure 1. Number of mothers by GWG category



[1]Categories according to the 2009 IOM Guidelines

Table 12. GWG categories and body compostion at 5 years

		GWG categories				
		Inadequate	Adequate	Excessive	F value	*p* value[2]
Fat	%	22.3 % ± 5.1[1]	25.0 % ± 6.2	26.5 % ± 5.2	1.80	0.22
	kg	3.9 ± 1.2	4.7 ± 1.6	5.5 ± 1.4	3.75	0.03*
FFM	%	77.7 % ± 5.1	75.0 % ± 6.2	73.5 % ± 5.2	1.56	0.22
	kg	13.2 ± 0.5	14.0 ± 2.0	15.1 ± 2.4	3.14	0.08

[1] mean ± SD
[2] *p* values calculated with a one way ANOVA
*Difference is significant at the $p \leq 0.05$ level (two-tail)

Table 13. Body composition at age 5 by race

		Non-Black n = 32	**Black** n = 18	T- stat	*p* value[2]
Fat	%	26.6 ± 5.5[1]	23.8 ± 5.5	1.7	0.09
	kg	5.2 ± 1.4	4.7 ± 1.7	1.2	0.25
FFM	%	73.4 ± 5.5	76.2 ± 5.5	-1.7	0.09
	kg	14.4 ± 2.2	14.9 ±2.4	-0.8	0.45

[1] mean ± SD

[2] *p* values (two-tail) derived from t-test, significance set at ≤ 0.05

Table 14. Body composition by gender

		Male n = 22	**Female** n = 28	T- stat	*p* value[2]
Fat	%	24.6 ± 4.9[1]	26.3 ± 6.0	1.04	0.31
	kg	5.0 ± 1.0	5.1 ± 1.5	0.4	0.69
FFM	%	75.4 ± 4.9	73.7 ± 6.1	-1.04	0.31
	kg	15.0 ± 2.5	14.2 ± 2.0	-1.2	0.24

[1] mean ± SD

[2] *p* values (two-tail) derived from t-test, significance set at <0.05

Chapter 5

DISCUSSION

The purpose of this study was to examine the body composition measures in children 5 years of age, compare them to BMI percentiles, and investigate the relationship between maternal characteristics, i.e., maternal pregnancy weight status, GWG, breastfeeding duration, and smoking and BMI at 2, 3, and 4 with body composition at age 5.

Body composition in children at 5 years of age

In the current study, the % fat in 5 year-old-children averaged about 25.6% and varied from 13.6 % to a maximum of 38.6 %, nearly a 3-fold difference. To my knowledge, there are only 3 studies to date that used ADP to measure at least one body composition variable and included children at 5 years. This lack of studies is mainly due to the inability of the BodPod® (COSMED, USA) to assess children younger than 5 years; however, recently a toddler adaption became available for children less than 5 years of age. The studies using this adaption have found results similar to the current study.

Fields et al. used ADP with the toddler adaption and compared it to the 4 compartment model; they found the average % fat in 2-6 year old children to be 25.6 % with a range from 18.4 – 33.7 (3). Wells et al. used ADP and found the average % fat to be 16% for boys and 20 % for girls 5-7 years of age (1). Using ADP, Crook et al. found average % fat to be 19.3% and 20.6% to be the average of 3-5 year old children (2). The results from Fields et al. more closely parallel the results from the current study. The differing results may depend upon sampling differences or age ranges of the sample.

Studies which used DXA found a 4 fold difference in percent body fat among 4-5 year old New Zealand girls (5) and average body fat percentages of 19.2 % in children 3 to 8 years of age (16), 13.7 % for children 3-6 years of age (12), and 20.1 % for boys and 25.5% for girls at 6 years of age (103). Bocca et al. used BIA and found body fat percentages to be 28.6-29.0% for children 3-5 years of age (104). Elia et al. used the 4 compartment model and found body fat to range from 4.2 – 43.5% with an average of 20.97 among 6-9 year old children (105). Data from NHANES IV for children 5-18 years of age show the % fat at age 5 for boys was 14% and for girls was 15.4% based on skin fold thickness (106). The averages from DXA and skin fold thickness data are quite a bit lower than the average found in the current study. These differences may be due to large age ranges, sampling differences, or different methods.

The averages for % fat in the current study are most similar to the studies using ADP, but they are also alike the studies that use similar ages, smaller age ranges, but different methods. It is also possible that the difference between the current study and others is due to actual higher body fat percentages in our sample.

The FM for the current study averaged to be 5.06 kg and range from 2.28 kg to a maximum of 8.60 kg. Goulding et al. showed a 10 fold difference between the lowest and highest values for FM (1.4 kg -14.3 kg) (5), while the current study only shows an almost 4 fold difference. Eisenmann et al. shows FM ranging from 1.0 kg to 15.4 kg (16). While FM for the current sample did not vary this widely, it varied most in comparison to the other body composition measures. The average FM in the current study is similar to that of other studies – 4.8 kg (boys), 6.1 kg (girls) (103), and 6.4 kg (105).

Average FFM was 14.56 kg and ranged from 11.12 kg to 21.66 kg which is a twofold difference. FFM in other studies varied from 10.7 to 23.8 kg (16) or from 11.4-20.6 kg (5), which are similar to the current study. Other studies show average FFM to be 17.0 kg for girls and 17.7 kg for boys (103) and 19.7 kg (105). These results are similar, but variations may exist due to method, age, and sampling differences.

FFM averaged to be 74.4 % of body weight and ranged from 61.4% to 86.4 %. Moon et al. used DXA to show average FFM to be 76.2 % for boys and 71% for girls (103), consistent with this study. This measure is a reciprocal value of % fat, so it varies similarly with % fat.

Nevertheless, studies with different age ranges, sample sizes, and methods have similar results to the current study. However, the differences that do exist suggest that for this age group, body composition varies widely and more specific, reference data are needed for these methods in order to better assess excess adiposity in childhood. Little reference data for ADP are available for this age. Wells et al. has developed some reference data for ADP with the 4 compartment model (107), but more research needs to be done in order to develop reference values for this age group.

Gender and racial differences in body composition at age 5

In the current study, girls had 1.64 % higher mean % fat and 0.17 kg more FM than boys; boys had 0.75 kg more FFM and 1.64 % more % FFM than girls. Other studies have also found differences in body composition by gender (16, 36, 97, 108). However, the difference for each body composition measure between girls and boys was not statistically significant in the current study, most likely due to a limited sample size or that body fat does not differ until later ages. Data from Maynard et al. shows that increases in BMI correlated more with FFM until adolescence when increases in BMI correlated more with body fat (109). Data from the current study and others could suggest that body composition does not differ by sex until adolescence.

On average, non-black children had 2.81 % more fat and less % FFM than black children. Non-black children had 0.5 kg more FM and 0.5 kg less FFM than black children. These results are similar to those of other studies who show that black children have less body fat and more lean mass than other children (36, 108). However, the difference in body composition between non-black and black children was not statistically significant. This may be due to a limited sample size also as the difference in % fat between non-black and black children was almost significant ($p = 0.09$).

Relationship between BMI percentiles and body composition at age 5

In the current study, BMI percentiles at age 5 significantly and positively correlate with % fat ($r = 0.44$, $p = 0.02$), FM ($r = 0.70$, $p < 0.001$), and FFM ($r = 0.55$, $p < 0.001$). It significantly and negatively correlates with % FFM ($r = -0.44$, $p = 0.002$). These results suggest that BMI percentiles vary and trend with FM, FFM, and % fat. However, in further analyses, these data show that BMI percentiles and the cutoff values for overweight and obesity (greater than the 85th percentile) may not be the best indicator of excess adiposity relative to overall mass for this age for several reasons.

First, the correlation between BMI percentiles and FM or FFM is greater than it is for % fat and % FFM, and these relationships are shown in **Figure 2**. These correlations are similar to those with BMI percentiles at earlier ages and to other studies. Demerath et al. (14) and Maynard et al. (109) show that increases in BMI percentile in later childhood correlated more with changes in fat free mass index (FFMI) or FFM than with change in % fat. Other data show that BMI has a stronger relationship with FM than with % fat or FFM when controlling for age (16). Data from the current study and others suggest that BMI may be an indicator of overall mass rather than adiposity as a portion of body weight.

In addition, BMI percentiles in the current study only accounted for 19.4% of the variance in % fat and % FFM (R = 0.1936), while it accounted for 30 % of the variance in FFM (R = 0.3025) and about 50% in FM (R = 0.49) as shown below in Figure 2. In adults, BMI has shown to explain 75% of the variance, but in children it has been much more variable (11). Some data in children show BMI to explain less than 40% of the variance in body fat (11), which is similar to the results of the current study.

Finally, data for this sample show that body composition for children grouped by BMI percentile cutoffs for overweight and obesity (greater than the 85th percentile) varies greatly (**Table 19)**. Both the highest % fat and % FFM is found in normal BMI percentiles rather than the percentiles classified as overweight or obese. In addition, percent fat varied the most in the normal BMI percentiles. The greatest FM and FFM, however, were found within the obese BMI percentile as to be expected. Flegal et al. also showed that adiposity varied greatly most often between the 75th and 85th percentile for

BMI – also in the normal BMI percentiles, similar to the results of the current study (108). Freedman et al. showed that children with a BMI percentile in the overweight range were most often misclassified as only half of these children had a corresponding body fat with their overweight status (35).This data and the data from the current study show that BMI percentile cutoffs may not always detect excess adiposity, and more research needs to be done in order to know that BMI percentile cutoffs for overweight and obesity are detecting excess adiposity in children.

Further analyses show that % fat and % FFM do not differ statistically between BMI percentiles above and below the 85th percentile (*p* values = 0.48, tables 10 and 13). However, there is a statistically significant difference between these groups for FM and FFM (*p* value <0.001 for FM and FFM, tables 11 and 12). These data further confirm the suggestion that BMI percentiles and the cutoffs for overweight are more effective at detecting mass than excess fat relative to mass.

BMI percentiles may not be able to adequately capture the ratio of fat to lean mass well because it is a ratio of masses which can have varying composition of fat mass and fat free mass. These two masses offset each other so that an increase in one is a decrease in another with possibly the same weight (36). BMI would not be able to capture this ratio if the weight were the same. Thus, these data suggest that BMI percentiles may not be the best indicator for excess adiposity, but instead it may reflect the overall mass in children at 5 years of age.

Figure 2. Correlations of BMI percentiles at age 5 with % fat, FM, FFM, and % FFM.

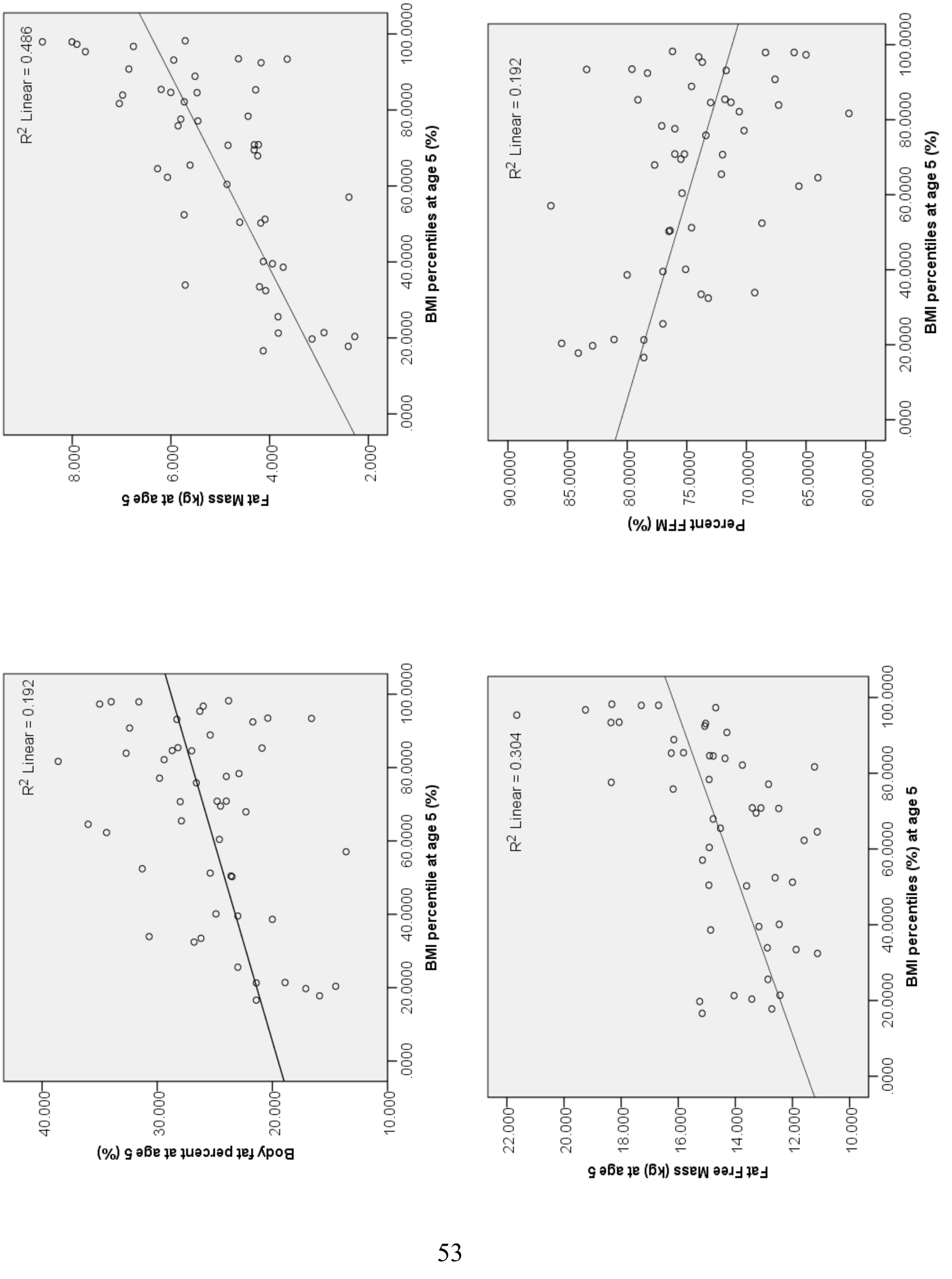


Table 15. Ranges of body composition measures by BMI percentile cutoffs

		BMI percentiles (%)		
		<85th	85-95th	≥95th
Fat	%	13.6 – 38.60	16.6 – 32.4	23.8 – 35.0
	kg	2.275 – 7.046	3.644 – 6.852	5.711 – 8.604
FFM	%	61.4 – 86.4	67.6 – 83.4	65 – 76.2
	kg	11.123 – 18.346	14.296 – 18.356	14.687 – 21.655

While there are no cutoff points and ranges for % fat defining overweight and obesity in children, there are some that are frequently used in research for adults – 20.1-24.9% and 30.1-34.9% for overweight in males and females and > 25% and >35% for obese in males and females, respectively (32). Using these same cutoff points for this sample, 9 males and 4 females were overweight, and 10 males and 3 females were obese. Using BMI percentiles, 4 males and 4 females were overweight, and 2 males and 4 females were obese. Body fat percent cutoffs used in adults detected more adiposity in children than did BMI percentiles, further showing that BMI percentiles have limitation in this population. However, these percentile cutoffs may not be appropriate to use for this age group.

Earlier BMI percentiles and body composition at age 5

No previous studies have compared BMI percentiles at these early ages to body composition at age 5. In the current study, BMI percentiles at 3, 4, and 5 significantly correlated with FM and FFM, and at 2 years only FM significantly correlated. Also, correlations between FM and FFM were greater at all ages than % fat and % FFM except at age 4 for FFM. These results suggest that BMI percentiles at this young age may only be a good indicator for actual mass at 5 years of age rather than excess adiposity at age 5. A trend between increasing correlation measures between body composition and BMI percentiles was noticed with increasing age which suggests that BMI percentiles may be a better indicator later in childhood. The ability of BMI to detect excess adiposity in adults and older adolescents has been shown (10), but it may not be a valid indicator until after 5-6 years of age.

Earlier predictors of obesity

The current study examined the relationship between GWG, smoking during pregnancy, maternal BMI, education, income, and breastfeeding duration with body composition at age 5. There was a significant difference for FM (p value = 0.03) only between the inadequate and excessive GWG groups (p value = 0.04). Maternal BMI only significantly correlated with FFM ($r = 0.47$, $p < 0.001$). Smoking during pregnancy, breastfeeding duration, maternal education, and income did not significantly correlate with any body composition measure.

The relationship between maternal BMI and offspring body composition suggests that offspring of women with larger BMIs have greater mass but not necessarily greater % fat or FM. Women that may be taller and have a larger body frame do not necessarily have infants that have higher % fat. However, women with excessive GWG may have offspring with greater FM but not greater % fat which is more central to health consequences. Yet, this difference was only present between those who gained inadequate weight and those who gained excessive. The association between inadequate weight gain and lower birth weight or infants with less actual mass (and possibly children) may explain this difference.

The lack of a relationship of % fat and excessive GWG is contrary to results of recent studies using body composition (41, 42) and to other studies using BMI as the adiposity measure. Our results may not agree with those using body composition measures due to our limited sample size. In this sample, maternal BMI and BMI percentile at age 5 correlated positively and significantly ($r = 0.429$, $p = 0.001$). Studies using BMI as the adiposity measure in children may find a relationship between GWG and offspring BMI, but our data suggest that this relationship is present only for BMI but not necessarily % fat.

The lack of a significant relationship between offspring body composition and smoking, breastfeeding duration, income, and maternal education is contrary to other studies. This may also be related to a limited sample size.

Limitations

The sample size of 50 participants was the main limitation in this study. Increasing the sample size could provide more statistically significant results. The sample size also limited the amount of analyses we could perform.

Some of the variables were self-reported such as smoking and education which are not the most reliable type of data. We used GWG from the first prenatal clinic visit to avoid self-report of pre-pregnancy BMI, however, the gestation timing of the first prenatal clinic visit varied among somewhat among these women. We also gathered maternal BMI from the first prenatal clinic visit, and weight gained during pregnancy before this time could have also varied among the women.

We also did not include in analysis other factors that could influence our body composition results such as TV time, dietary habits, or physical activity. TV time greater than the American Academy of Pediatrics recommendations (110), poor dietary habits (111), and limited physical activity levels (112) has been linked to greater % fat in children.

The statistics utilized and these data can only reflect correlation and not causation. These results only suggest a relationship (or a lack of one), and cannot reflect causation. However, they can suggest variability of body composition among young children.

Chapter 6

SUMMARY

The prevalence of overweight and obesity is increasing among children in the United States. BMI, a common measure of adiposity, may not be accurately detecting excess adiposity in children, and body composition methods are not routinely used to assess excess fat in this population.

In this study, BMI percentiles and body composition correlated significantly at age 5. However, BMI percentiles were only able to account for 50% or less of the variance in body composition measures. BMI percentile cutoffs for overweight and obesity were unable to capture the highest % fat of the sample. BMI percentiles more frequently correlated with FM or FFM. These results suggest that BMI may correlate more with actual mass than with excess adiposity in relation to overall mass.

In addition, common predictors of greater BMI percentiles in children such as maternal BMI, GWG, smoking, education, income, and breastfeeding did not correlate with body composition, but maternal BMI did significantly correlate with FFM in this study. These results suggest that common predictors of greater BMI may not predict excess fat in children.

However, these results could be affected by the sample size. Future studies should use body composition methods and include larger sample sizes while reporting on specific ages to more clearly understand body composition in children. More research is needed to identify the best method for assessing excess adiposity in children and reference data for that method. BMI percentiles may not be the best indicator for diagnosing overweight or obesity, but it may be used as a screening measure for more assessment and intervention.

Chapter 7

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Appendix A

Consent form for The effects of DHA on pregnancy and infant outcome

CONSENT FORM
THE EFFECTS OF DHA ON PREGNANCY AND INFANT OUTCOME
(Addendum to HSC #11406)

You have enrolled in the University of Kansas HSC #11406 to evaluate whether taking a supplement of DHA can influence pregnancy and infant outcomes. As part of the study, we are interested in your child's growth, and we have measured his/her weight, length and head circumference at each visit. We have recently obtained an instrument that allows us to obtain information about your child's body fat and muscle mass. Now that your child is 5 years of age, we would like to measure his/her body fat and muscle mass. The results would add to the measures of growth we already have on your child. To complete the test, your child will wear a swimsuit and sit inside an egg shaped pod so the space they take up inside the pod can be measured. The procedure is simple, non-invasive and takes approximately 5 minutes to complete. We can show you the chamber if you would like to see it before you decide to have your child participate. Participation in this additional activity is optional. You can remain in the main study even if you are not interested in this measurement. The use and disclosure of your child's information in the main study also applies to this optional measurement. We will keep the data confidential just as we have with all of your other personal information. If you agree to let us measure the body fat and muscle mass of your child, please check the "yes" box; if you do not agree, please check the "no" box.

Yes ☐

No ☐

____
Type/print Subject's Name

______________________________ __________ ____________
Signature of Subject Time Date

____
Type/Print Name of Person Obtaining Consent

_____________________________________ ____________
Signature of Person Obtaining Consent Date

____
Type/Print Name of Principal Investigator

______________________________ ____________
Signature of Principle Investigator Date

HSC # 11406
HSC Approval Date 11/04/11-5/24/12
Assurance #FWA 00003411