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ASSESSING BODY COMPOSITION OF CHILDREN AND ADOLESCENTS
USING DEXA, SKINFOLDS, AND ELECTRICAL IMPEDANCE

by

Angela Mooney

A thesis submitted to the faculty of

Brigham Young University

in partial fulfillment of the requirements for the degree of

Master of Science

Department of Exercise Sciences

Brigham Young University

December 2009

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BRIGHAM YOUNG UNIVERSITY

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of a thesis submitted by

Angela Mooney

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ABSTRACT

ASSESSING BODY COMPOSITION OF CHILDREN AND ADOLESCENTS USING DEXA, SKINFOLDS, AND ELECTRICAL IMPEDANCE

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Department of Exercise Sciences

Master of Science

The purpose of this study was to determine the validity and reliability of four methods of estimating body composition in 331 participants (177 boys, 154 girls) between 12-17 years of age. Percent body fat (%BF) was assessed once on one day using DEXA and twice using the sum of two skinfold (SF) and three bio-electrical impedance analysis (BIA) devices: OMRON hand-to-hand BIA, TANITA 521 foot-to-foot BIA, and TANITA 300A foot-to-foot BIA. The same assessments were repeated on 79 of the participants on a second day.

DEXA was used as the criterion method of estimating %BF. The agreement between the estimates of %BF from the sum of two SF and the three BIA devices and DEXA was evaluated using linear regression and Bland-Altman

analyses. Although the two analyses generally led to similar conclusions about each of the four prediction methods, the specific interpretations of each analysis varied because of the inherent differences in the analyses. In an attempt to determine if any of the four prediction methods were interchangeable with DEXA, the 95% confidence interval (CI) and prediction interval (PI) around the line-of-best-fit through the data are reported.

The results of this study indicate that (a) all of the methods used in this study to estimate %BF were reliable within and between days, (b) the TANITA 300 BIA device performed poorly in both boys and girls and should not be used to assess body composition in children and adolescents, (c) none of the four prediction methods performed well in both boys and girls across the entire range of %BF values of the subjects in this study, (d) the sum of two SF, OMRON and TANITA 521 are acceptable for use in large population-based studies but are not recommended when the accurate assessment of body composition of an individual is critical, in which case (e) criterion methods of assessing body composition should be used.

ACKNOWLEDGMENTS

I would like to thank Ira and Mary Lou Fulton who provided the funding for this project and made everything possible. I would also like to thank Garrett Hoyt and Neil Nokes for being available and patient throughout the research project enough to see it through to the end. I would like to express my gratitude for Sandy Alger, Sharron Collier, and Amanda Aagard: the secretaries that made this project happen.

I would like to thank my graduate committee for their patience and guidance in finishing this project. I am also extremely grateful for the mentorship of Dr. Vehrs. He has been a very patient and wise advisor, whose guidance was invaluable in the finishing of this project and in the completion of my graduate degree.

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by

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Abstract

The purpose of this study was to determine the validity and reliability of four methods of estimating body composition in 331 participants (177 boys, 154 girls) between 12-17 years of age. Percent body fat (%BF) was assessed once on one day using DEXA and twice using the sum of two skinfold (SF) and three bio-electrical impedance analysis (BIA) devices: OMRON hand-to-hand BIA, TANITA 521 foot-to-foot BIA, and TANITA 300A foot-to-foot BIA. The same assessments were repeated on 79 of the participants on a second day.

DEXA was used as the criterion method of estimating %BF. The agreement between the estimates of %BF from the sum of two SF and the three BIA devices and DEXA was evaluated using linear regression and Bland-Altman analyses. Although the two analyses generally led to similar conclusions about each of the four prediction methods, the specific interpretations of each analysis varied because of the inherent differences in the analyses. In an attempt to determine if any of the four prediction methods were interchangeable with DEXA, the 95% confidence interval (CI) and prediction interval (PI) around the line-of-best-fit through the data are reported.

The results of this study indicate that (a) all of the methods used in this study to estimate %BF were reliable within and between days, (b) the TANITA 300 BIA device performed poorly in both boys and girls and should not be used to assess body composition in children and adolescents, (c) none of the four prediction methods performed well in both boys and girls across the entire range

of %BF values of the subjects in this study, (d) the sum of two SF, OMRON and TANITA 521 are acceptable for use in large population-based studies but are not recommended when the accurate assessment of body composition of an individual is critical, in which case (e) criterion methods of assessing body composition should be used.

Introduction

The prevalence of overweight and obesity in the American population is increasing. Children and adolescents have not been immune from the lifestyle patterns that affect body composition and health. Because the dramatic increase in obese and overweight children is relatively recent, it is difficult to determine risk of disease in children, especially since it is unknown as to how persistent obesity is over time. Even so, it is known that chronic diseases develop over time, therefore overweight and obesity at a young age will have a negative impact on chronic disease development (Wells, 2003). According to Wells (2003), body composition is affected by changes in disease status, physical activity levels, acute dietary changes, and age. Accurate assessments are necessary to evaluate body composition and changes in body composition across the age span of children and adolescents.

Body composition is one of the components of health-related physical fitness. Assessment of physical fitness, including body composition, is an important aspect of a physical education curriculum and the education of children and adolescents about healthy lifestyle choices. As such, it is important to have accurate, reliable and practical methods of assessing body composition in youth. Body fat can only be estimated using one of several methods available for use in children. The accuracy and reliability of body composition measurement methods vary based on the underlying assumptions of the methodology, what is actually being measured, the precision of the measurement, and the prediction equation that is used. In adults, there are several generally-accepted methods for estimating body composition, including dual-energy X-ray absorptiometry (DEXA),

total body potassium (TBK), isotope dilution for total body water (TBW), air displacement plethysmography (ADP), computed tomography (CT), bioelectrical impedance (BIA), and skinfold thickness (SF). However, the assessment of body composition in children challenges the underlying assumptions of body composition assessments because of the physiological changes in children that occur with normal growth and development (Lohman, 1986; Lohman *et al.* 1984; Testolin *et al.* 2000).

The aforementioned body composition estimation techniques vary in the number of body components they measure and thus vary in their accuracy in estimating body composition. The simplest model of the composition of the human body is the two-component model, fat and fat-free tissue. Multicomponent models have been developed to compartmentalize the composition of the body into three or more components. Multicomponent models allow body composition to be described and assessed in greater detail (Gately *et al.* 2003; Wells, 2003). Assessment of more body components accounts for the variability in the hydration and chemical properties of different body tissues. Assessments that are based on the four-component model are the most accurate assessments of body composition, but they are not practical for use in children in a variety of settings (Gately *et al.* 2003; Sopher *et al.* 2004). Dual-energy X-ray absorptiometry (DEXA) is known for its accuracy, speed, low radiation dose, and ease of use (Ellis *et al.* 1994; Gately *et al.* 2003; Gutin *et al.* 1996; Pietrobelli *et al.* 2003; Roubenoff *et al.* 1993) and has been used as a criterion method of assessing body composition in several studies (Bray *et al.* 2001; Elberg *et al.* 2004; Field *et al.* 2003; Okasora *et al.* 1999; Testolin *et al.* 2000). Visser *et al.* (1999) report that DEXA provides

a valid assessment of body composition when compared to the four-component model and CT as criterion methods. Gately *et al.* (2003) confirm that DEXA is a promising criterion method of assessing body composition when compared with the four-component model. Fields and Goran (2000) report that DEXA assessments of body composition in children are reliable. Due to the cost of DEXA scanners and the necessity for DEXA operators to be state certified practitioners, the use of DEXA is limited to laboratory and clinical settings.

Methods of assessing body composition in children in non clinical or laboratory settings need to be relatively inexpensive, easy to use and practical. Such methods include BIA and the sum of SF thickness measurements. There are a variety of easy-to-use BIA devices available for professional use; however, these devices typically use undisclosed proprietary equations or algorithms to estimate body composition, making it difficult to determine the validity of BIA methodology to accurately assess body composition. Although some of the BIA devices are designed to assess body composition in children and adolescents, the validity and reliability of their assessments is unknown. The sum of the calf and triceps skinfolds and the use of the Slaughter equation (Slaughter *et al.* 1988) is a popular and practical method of estimating body composition in children and adolescents due to its cost-efficiency and ease of use. Compared to other choices of skinfold sites, measuring calf and triceps skinfolds can be used to assess body composition of children in public settings (e.g., physical education classes) while remaining sensitive to issues of privacy.

The two purposes of this study were to (a) compare the estimates of body composition using three BIA methods and the sum of two SF to the estimates of body composition from DEXA, and (b) determine the within-day and between-day reliability of each method of assessing body composition in 12 – 17-year-old boys and girls.

Methods

Participants

Three hundred thirty-one participants (177 boys, 154 girls) between ages 12 to 17 years of age participated in this study. Exclusion criteria included any known conditions that adversely affect the accuracy of the body composition assessments. The body composition of girls was assessed when they were not menstruating. All participants were asked to refrain from eating or exercising three to four hours prior to each body composition assessment.

The methods for this study, including the informed consent document, were reviewed and approved by the Institutional Review Board (IRB) for the use of human subjects before data collection. To ensure informed consent, participating children completed an assent form and parents of participating children completed a parents' permission form.

Procedures

The body composition of each participant was assessed using the sum of two SF and three separate BIA devices. Each body composition assessment was performed twice on the same day to determine the within-day reliability of each prediction method. The

body composition of each participant was also assessed once using DEXA. To assess between-day reliability of each method, the same five assessments were repeated on 79 participants (47 boys, 32 girls) two to seven days later. The order of the five assessments was randomized on each day.

Height (cm) of each participant was measured and recorded using a calibrated wall scale to the nearest one-half centimeter, while body mass (kg) of each participant was measured and recorded using a digital scale (Ohaus Model CD-33, Ohaus Corporation, Pine Brook NJ, USA) to the nearest one-tenth of a kilogram. BMI (kg/m^2) was calculated from measured height and mass values.

Dual-Energy X-ray Absorptiometry

DEXA scans were performed using a Hologic QDR4500 Elite “Acclaim Series” scanner (Hologic Inc., Bedford, MA) and software version 11.2 with supplemental pediatric software. A single-scan mode was used for all participants. Manufacturer recommended operating procedures for whole-body scans were followed. All scans were performed by a state certified DEXA technician. Subsequently, a trained researcher analyzed all the scans to determine percent body fat (%BF) of each participant.

Skinfold Thickness Measurements

The triceps and calf skinfold thicknesses were measured on the right side of the body by a trained investigator with approximately 120 hours of experience, using a Harpenden skinfold caliper. The triceps skinfold was measured at the midline of the posterior aspect of the upper arm, midway between the acromion process of the scapula and the olecranon process of the ulna with the elbow flexed approximately 150 degrees.

A skinfold parallel to the long axis of the calf was measured on the medial side of the leg at the level of the maximal circumference with the knee flexed 90 degrees with the foot resting flat on a bench. Three measurements were taken at each site. If two measurements were the same, that value was used in the calculation of %BF, otherwise the average of three measurements within ± 2 mm was used. Percent body fat was calculated using the gender specific equations by Slaughter *et al.* (1988).

Bioelectrical Impedance Analysis

Three BIA analyzers were used to estimate the body composition of each participant by measuring the electrical impedance (ohms) to a small electrical current either between the two feet or between the two hands.

OMRON. The OMRON (OMRON Healthcare Inc, Vernon Hills, IL) HBF306 body composition analyzer is a hand held hand-to-hand BIA device. The OMRON functions in one of two modes: athlete (active individuals 18-60 years of age) and normal (10-60 years of age). Based on the age criteria of the two modes, the %BF of all participants in this study were estimated using the normal mode. The participants' height, weight, age, and gender were entered into the OMRON. While standing with their feet slightly apart, the participant grasped the grip electrodes of the OMRON and held the OMRON in front of their body with the arms fully extended and parallel to the floor. Assessments took less than one minute to complete and %BF was recorded from the value shown on the machine's digital display.

TANITA 300A. The TANITA 300A (TANITA Corporation of America, Arlington Heights, IL) body composition analyzer is a foot-to-foot electrical impedance device.

The TANITA 300A functions in one of two modes: athlete and standard. The %BF of all participants in this study were estimated using the standard mode to remain consistent with the other electrical impedance devices. The participants' age, height, and gender were entered into the TANITA 300A. After zeroing the scale, the participants stood motionless on the foot electrode pads in bare feet while the device measured body weight and impedance. Assessments took less than one minute to complete and body weight and %BF were recorded from a printed copy of the assessment results.

TANITA 521. The TANITA 521 (TANITA Corporation, Tokyo, Japan) body composition analyzer is a foot-to-foot BIA device. The TANITA 521 functions in one of three modes: adult, child, and athlete. The %BF of all participants in this study was estimated using the child mode. The participants' height and gender was entered into the TANITA 521. After zeroing the scale, the participants stood motionless on the foot sensor pads in bare feet while the device measured body weight and impedance. Assessments took about one minute to complete and body weight and percent body fat values were recorded from the value shown on the display.

Statistical Analysis

Statistical analyses were performed using mixed linear models as implemented in R (R Development Core Team 2008) in the function 'lmer' (Bates *et al.* 2008). These models accommodate multiple sources of variability so that standard errors can be estimated appropriately. Mixed linear effects models were used for the data analysis because each subject had multiple observations from all five methods of body composition assessment.

The two estimates of %BF obtained from the sum of two SF, OMRON, TANITA 521A and TANITA 300 for each participant on the first day and the seventy-nine participants on the second day were averaged and compared to the corresponding DEXA estimate of %BF on the same day. This resulted in a total of 410 paired observations. Some of the electronic devices failed to display results in some trials, so the number of observations included in each analysis ranged from 401 to 410. The alpha level was maintained at $p < 0.05$.

The agreement between the estimates of %BF from DEXA and the sum of two skinfolds, OMRON, TANITA 521 and TANITA 300A were evaluated using linear regression and Bland-Altman analyses (Bland & Altman, 1986). A separate linear regression analysis was performed using DEXA as the criterion method as a function of each of the four prediction methods. A 95% confidence interval (CI) and prediction interval (PI) were calculated and plotted around the line-of-best-fit. Bland-Altman analyses include plots of the differences between the estimates of %BF from two methods (y-axis) against the mean of the two estimates (x-axis). We subtracted the %BF value obtained from DEXA from each of the four prediction methods so a negative residual represented an underestimation. The y-intercept and the slope of the line-of-best-fit for the data were determined. A 95% CI and PI were computed and plotted around the line-of-best-fit.

Results

Participant descriptive information is shown in Table 1 and estimates of %BF from each method are listed in Table 2 by gender and age. As expected, girls tended to have higher BMI and %BF values compared to their age-matched male counterparts.

A frequency distribution of %BF values (Table 3) shows the number of observations that fall within $\pm 3.5\%$, $\pm 5\%$, and more than 5% body fat of the DEXA assessment of %BF. The SF method had the highest number of observations within $\pm 3.5\%$ BF of DEXA. The two TANITA devices had the fewest observations within $\pm 3.5\%$ BF of DEXA.

The analysis of the data revealed day-to-day and trial-to-trial variance components for each method that were reasonable (Table 4), indicating that each of the four methods were acceptably reliable within and between days. The day-to-day variance of 0.29 %BF observed in the DEXA assessments confirms that it as a criterion method of assessing body composition.

The mixed model linear regression and Bland-Altman plots for each method are illustrated in Figures 1 – 4. Ideally, the regression analysis between each method and DEXA would indicate a line-of-best-fit through the data that had a y-intercept of zero and a slope of one, indicating a lack of bias and a highly correlated relationship between the two methods. The slopes and intercepts of the regression analysis for each method are shown in Table 5.

The ideal agreement between two methods would produce a Bland-Altman plot that revealed a bias (y-axis) that was consistent (slope = 0) across the range of %BF

values (x-axis) and not significantly different from zero. In the Bland-Altman plots, bias is illustrated by the line-of-best-fit through the data. When the slope of the line-of-best-fit through the data is significantly different from zero, a single-point estimate of the bias is not an accurate representation of the agreement between the prediction method and the criterion method because the bias varies across the range of %BF estimates (i.e., x-axis). When the slope of the line-of-best-fit is zero, the mean difference of the residuals (i.e., bias) is a fair representation of the agreement between the prediction method and the criterion method. A complete interpretation of bias determined from a Bland-Altman analysis also requires the determination of the 95% CI of the line-of-best-fit through the data. The 95% CI represents a range of values within which the line-of-best-fit, or bias, would be drawn. Taking into consideration the slope of the line and the CI in which it lies, it is reasonable to expect that the bias would vary across the range of %BF values. The computed bias would only be significant ($p < 0.05$) when the line representing a bias of zero fell outside the 95% CI of the line-of-best-fit through the data. Thus, it should be appreciated that even when the slope of the line-of-best-fit through the data is not statistically different from zero, the bias between the two methods cannot be assumed to be absolutely constant across the range of %BF values. For example, in this study, the slopes of the lines-of-best-fit through the data in the Bland-Altman plots for the TANITA 521 (Figure 3) were not significantly different from zero in either boys or girls, yet the bias varied by 1.83% BF in boys and 2.65% BF in girls across the range of percent body fat values of the subjects (Table 6). The bias between two methods of assessing %BF is significant when a bias of zero falls outside of the 95% CI of the line-of-best-fit.

In this study, because the slope of the line-of-best-fit through the data in the Bland-Altman plots was often significantly different from zero, estimates of the 95% CI at four different %BF values (i.e., 10, 20, 30 and 40% BF) were calculated (Table 6). The 95% CI around the line-of-best-fit indicates how well the prediction method estimates %BF in the population. The prediction interval (Table 6) around the line-of-best-fit through the data takes into consideration the slope of the line-of-best-fit, the distribution of data at a given point along the line-of-best-fit, as well as the variance between subjects and between trials and days. As such, the prediction interval represents the range within which 95% of the data lies and is thus an indication of how well the prediction method estimates %BF in an individual. Including the intercept and slope of the line-of-best-fit and the 95% CI and prediction interval around the line-of-best-fit provides an accurate representation of the data.

When the estimates of %BF from the sum of two SF measurements were regressed against those of DEXA (Figure 1, Table 5), the y-intercepts of the regression lines for boys (2.55% BF) and girls (6.92% BF) were significantly different from zero ($p < 0.0001$). The slopes of the regression lines for boys (0.76) and girls (0.73) were significantly different from one ($p < 0.0001$). The Bland-Altman plot for the sum of two SF measurements is also illustrated in Figure 1. Analysis of the data revealed that the slope of the line-of-best-fit through the data was significantly different from zero in boys (slope = 0.1209; $p = 0.0078$) but not in girls (slope = 0.0805; $p = 0.096$). The 95% CI of the line-of-best-fit through the data of the Bland-Altman plots shown in Table 6 and Figure 1 reveal that the sum of two SF consistently over-estimated DEXA %BF in boys

across the range of %BF values and the bias increased as %BF increased. In girls, the sum of two SF underestimated %BF at low %BF values and overestimated %BF at high %BF values. In girls, the bias was significant only at a %BF value of 40%.

When the estimates of %BF from the OMRON measurements were regressed against those of DEXA (Figure 2, Table 5), the y-intercept of the regression line was significantly different from zero in boys (3.39% BF; $p < 0.0001$) but not for girls (2.49% BF; $p = 0.71$). The slopes of the regression lines were significantly different from one for boys (0.76; $p < 0.0001$) but not for girls (0.96; $p = 0.54$). The Bland-Altman plot for the estimate of %BF from OMRON measurements is illustrated in Figure 2. Analysis of the data revealed that the slope of the line-of-best-fit through the data was not significantly different from zero in boys (slope = 0.0137; $p = 0.727$) but was for girls (slope = -0.1448; $p = 0.007$). The 95% CI and prediction intervals of the line-of-best-fit through the data of the Bland-Altman plots shown in Table 6 and Figure 2 reveal that OMRON performed well through the range of %BF values (except for at 20% BF) in boys but increasingly under-estimated DEXA %BF in girls at %BF values at and above 20% BF.

Regression of the estimates of %BF from the TANITA 521 measurements against those of DEXA (Figure 3, Table 5) resulted in regressions lines with a y-intercepts that were significantly different from zero in boys (4.50% BF; $p < 0.0001$) and girls (6.15% BF; $p < 0.0001$) and slopes that were significantly different from one for boys (0.7541; $p < 0.0001$) and girls (0.7068; $p < 0.0001$). The Bland-Altman plot for the estimate of %BF from TANITA 521 measurements is illustrated in Figure 3. Analysis of the data revealed that the slope of the line-of-best-fit through the data was not significantly different from

zero in boys (slope = 0.0612; $p = 0.146$) and girls (slope = 0.0883; $p = 0.103$). The 95% CI and prediction intervals of the line-of-best-fit through the data of the Bland-Altman plots shown in Table 6 and Figure 3 reveal that TANITA 521 performed well through the range of %BF values (except for at 10% BF) in boys but increasingly over-estimated DEXA %BF in girls at %BF values at and above 20% BF.

Regression the estimates of %BF from the TANITA 300 measurements against those of DEXA (Figure 4, Table 5) resulted in regression lines with a y-intercept that were significantly different from zero in boys (6.59% BF; $p < 0.0001$) and girls (12.43% BF; $p < 0.0001$) and slopes that were significantly different from one for boys (0.7897; $p < 0.0001$) and girls (0.5718; $p < 0.0001$). The Bland-Altman plot for the estimate of %BF from TANITA 300 measurements is illustrated in Figure 4. Analysis of the data revealed that the slope of the line-of-best-fit through the data was not significantly different from zero in boys (slope = -0.0162; $p = 0.727$) but was in girls (slope = 0.2382; $p < 0.0001$). The 95% CI and prediction intervals of the line-of-best-fit through the data of the Bland-Altman plots shown in Table 6 and Figure 4 reveal that TANITA 300 under-estimated DEXA %BF through the entire range of %BF values in boys and %BF in girls at %BF values at and below 30% BF.

Discussion

In light of the increasing prevalence of overweight and obesity and national initiatives to combat physical inactivity and obesity, it is prudent to establish the validity and reliability of methods commonly used to assess the body composition of children and adolescents in the field. Valid and reliable methods are needed to provide credibility to

physical education programs, cross sectional and longitudinal studies, and various childhood interventions that include assessments of body composition. Valid and reliable methods are also needed to accurately assess changes in body composition over time, both in an individual and in a group. In this study, the agreement between the estimates of %BF using the sum of two SF, OMRON, TANITA 521 and TANITA 300 were evaluated using regression analysis and Bland-Altman analysis. The combination of the two analyses provided a thorough evaluation of the agreement between each of the four prediction methods and the criterion method (i.e., DEXA). Although the two analyses generally led to similar conclusions about each of the four prediction methods, the results from each analysis lead to different interpretations because of the differences in the analyses. For example, the data used in the regression analysis is highly correlated, whereas the correlation is removed in the Bland-Altman analysis by using the mean of the two methods (x-axis) and differences between the two methods (y-axis). The results of this study indicate that (a) all of the methods used in this study to estimate %BF were reliable within and between days, (b) the TANITA 300 BIA device performed poorly in both boys and girls and should not be used to assess body composition in children and adolescents, (c) none of the four prediction methods performed well in both boys and girls across the range of %BF values of the subjects in this study, (d) the sum of two SF, OMRON and TANITA 521 are acceptable for use in large population-based studies but are not recommended when the accurate assessment of body composition of an individual is critical, in which case (e) criterion methods of assessing body composition should be used.

This study is unique in that multiple estimates of percent body fat using the sum of two SF and three BIA devices were compared to the estimates of percent body fat derived from DEXA in 331 twelve to seventeen year old boys and girls. Recent body composition studies have reported validity of the same devices used in this study in small sample sizes (Wells *et al.* 1999; Parker *et al.* 2003; Lintsi *et al.* 2004), limited samples of just boys (Lintsi *et al.* 2004; Parker *et al.* 2003), or narrow age ranges (Hosking *et al.* 2006; Lazzer *et al.* 2003; Lintsi *et al.* 2004). Our study is also unique in its analysis of data which we think more accurately depicts the results. Although many recent studies have used the Bland-Altman method for reporting body composition results (Cleary *et al.* 2008; Hosking *et al.* 2006; Jebb *et al.* 2000; Lazzer *et al.* 2003; Lintsi *et al.* 2004; Parker *et al.* 2003; Tyrell *et al.* 2001; Wells *et al.* 1999), most have over-simplified their data analysis by not including a regression analysis of the data, not reporting gender differences in the data, reporting a single value of the bias between two methods of assessing body composition without reporting the slope of the line-of-best-fit through the data, or not reporting the confidence interval of the line-of-best-fit through the data. Thus, the results from previous studies are difficult to interpret and infer across adolescence. Likewise, it is difficult to discern if the bias reported in the literature accurately depicts the data and the agreement between two methods of assessing body composition.

The results of this study (Table 5, Table 6, Figure 1) suggest that the sum of two SF overestimated %BF in the boys participating in this study and that the magnitude of the overestimate increased as body fatness increased. In girls, the sum of two SF underestimated %BF at low %BF values and overestimated %BF at high %BF values

(Table 5). Wells *et al.* (1999) reported that four different SF prediction equations underestimated %BF as determined by a four-compartment model in 8 – 12-year-old boys and girls. Parker *et al.* (2003) reported the sum of two SF (triceps and subscapular) underestimated the criterion estimate of %BF in 10 – 14-year-old boys. The PI reported in this study (Figure 1) concur with the wide limits of agreement reported by Wells *et al.* (1999) and Parker *et al.* (2003). The discrepancies between this study and that of Wells *et al.* (1999) and Parker *et al.* (2003) may be attributed, in part, to differences in ages and nationality of the subjects as well as the SF sites used to estimate %BF. These results are not encouraging as the sum of SF measurements is often used in physical education classes to estimate body composition of children and adolescents. Accumulating evidence questioning the validity of SF to estimate %BF may provide impetus for future research to derive new SF equations for use in children and adolescents.

In this study, the regression analysis (Table 5) indicated that the OMRON device overestimated %BF in boys and that the overestimate increased with increasing body fatness. The Bland-Altman analysis also revealed a small increase in the bias with increasing levels of body fatness which was significant only at 20% BF (Table 6). This was likely due to the distribution of data and narrowing of the confidence interval at 20% BF (Table 6). The Bland-Altman analysis also revealed wide prediction intervals around the line-of-best-fit in boys (Figure 2). Lintsi *et al.* (2004) reported a non significant bias of 0.2% BF between OMRON 306 and DEXA assessments of %BF in 17 – 18-year-old boys. Lintsi *et al.* (2004) did not report confidence intervals or limits of agreement around the line-of-best-fit of the Bland-Altman plots. In this study, the regression

analysis indicated that the OMRON device performed well in girls (i.e., intercept = 0 and slope = 1; Table 5), yet the Bland-Altman analysis revealed an increasing underestimate of %BF by the OMRON with increasing levels of body fatness (Table 6). Based on the findings of this study, the OMRON performs well in boys but not in girls. The simplicity of the OMRON as a hand-held device makes its use among children and adolescents promising. Additional research is required to further evaluate the efficacy of the OMRON in assessing the body composition of children and adolescents.

The TANITA 300 performed poorly in both boys and girls. In boys, the TANITA 300 underestimated %BF across the range of %BF values. In girls, the TANITA 300 underestimated %BF at low levels of body fatness and overestimated %BF at high levels of body fatness (Figure 4, Table 6). The results of this study concur with those of Hosking *et al.* (2006), who also reported bias and limits of agreement that were not uniform across the range of %BF values of nine-year-old boys and girls. They reported bias and limits of agreement at the 25th, 50th, and 75th percentiles of %BF. Hosking *et al.* (2006) concluded that the TANITA 300 underestimated %BF in girls of all levels of body fatness, and overestimated %BF in boys with low levels of body fat and underestimated %BF in boys with higher levels of body fat. The gender differences between our study and that of Hosking *et al.* (2006) are likely due to the differences in age and developmental stage of the subjects. Based on the results of this study, the large biases and prediction intervals make the TANITA 300 a poor choice for assessing body composition in children and adolescents.

A regression analysis indicated that the TANITA 521 BIA device tended to overestimate %BF in boys and girls and that the overestimate increased with increasing levels of %BF. The Bland-Altman analysis indicated that in boys and girls, bias between the TANITA 521 and DEXA increased as %BF increased. In girls, the bias was significant at 20%, 30%, and 40% BF. The results of this study concur with those of Parker *et al.* (2003) who reported that the TANITA 521 overestimated %BF in 10 – 14-year-old boys with a large bias and wide limits of agreement. Because of its ease of use and application in a variety of settings, additional research to further evaluate the validity of the TANITA 521 in assessing the body composition of children and adolescents is warranted.

When the bias between a prediction method and a reference method is large and the prediction interval is also large, the prediction method is not recommended for assessing the body composition of an individual. When the bias and its 95% CI between a prediction method and a reference method is small, the prediction method may be used to assess body composition of large groups. Based on the results of this study, the wide prediction intervals of the sum of two SFs, OMRON and TANITA 521 preclude their use in assessing body composition in an individual. The results of this study and that of others raise the question as to the best method of assessing body composition in individuals, for example in physical education settings, when criterion methods are not available or feasible. Certainly, the assessment of body composition of children is important for a variety of reasons, but based on the results of this study, the validity of body composition assessments in such settings remains suspicious. Assessing body

composition in children and adolescents in the public schools using questionable methods undermines the purpose and value of the assessment. Accumulating evidence suggests that the development of valid and reliable assessments of body composition in children and adolescent requires renewed attention.

The large bias and wide prediction intervals associated with the TANITA 300 make it a poor choice for assessing body composition. The results of this study confirm that when an accurate assessment of percent body fat for an individual is needed, a criterion method should be used. Although practical to use, because none of the non reference methods evaluated in this study performed well in both boys and girls, their use and interpretation of results requires caution.

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Table 1. Participant Descriptive Characteristics

Age and Gender	Height (m)	Body Mass (kg)	BMI (kg·m ⁻²)
BOYS			
12 (n=36)	155.4 ± 5.9	48.1 ± 11.2	19.8 ± 3.9
13 (n=28)	161.9 ± 10.7	50.4 ± 10.9	19.2 ± 3.7
14 (n=36)	166.8 ± 7.1	53.7 ± 7.9	19.2 ± 2.4
15 (n=35)	172.8 ± 7.4	63.5 ± 14.1	21.1 ± 3.8
16 (n=18)	173.9 ± 9.3	64.8 ± 8.8	21.5 ± 3.2
17 (n=24)	178.2 ± 6.6	69.6 ± 7.2	22.0 ± 3.0
Total (n=178)	167.1 ± 10.9	57.1 ± 13.1	20.3 ± 3.5
GIRLS			
12 (n=21)	152.1 ± 7.8	43.6 ± 7.9	18.7 ± 2.6
13 (n=31)	159.0 ± 7.8	52.7 ± 10.6	20.8 ± 3.5
14 (n=19)	161.1 ± 7.3	59.6 ± 12.1	22.9 ± 4.2
15 (n=41)	162.6 ± 6.5	57.4 ± 7.7	21.7 ± 2.8
16 (n=24)	165.5 ± 5.5	57.9 ± 9.7	21.1 ± 3.2
17 (n=18)	163.5 ± 5.7	61.7 ± 7.8	23.1 ± 2.6
Total (n=154)	160.8 ± 7.8	55.5 ± 10.6	21.3 ± 3.4
COMBINED (n=332)	164.2 ± 10.1	56.4 ± 12.0	20.8 ± 3.5

All values represent the mean ± SD.

Table 2. Percent Body Fat Estimates

Age and Gender	Body Fat (%)				
	DEXA	TANITA 300	TANITA 521A	OMRON	SKINFOLDS
BOYS					
12 (n=36)	21.8 ± 9.1	15.9 ± 8.4	19.9 ± 8.5	21.8 ± 8.4	22.3 ± 9.6
13 (n=28)	17.2 ± 7.9	12.5 ± 8.2	16.1 ± 9.4	16.6 ± 7.9	19.1 ± 8.7
14 (n=36)	14.1 ± 4.6	9.6 ± 4.7	13.1 ± 5.4	14.6 ± 5.8	15.5 ± 5.3
15 (n=35)	15.9 ± 6.2	12.8 ± 6.3	16.7 ± 6.4	17.6 ± 7.6	18.2 ± 7.2
16 (n=18)	13.3 ± 4.1	12.5 ± 6.8	14.7 ± 6.4	15.2 ± 5.2	15.9 ± 7.7
17 (n=24)	12.9 ± 1.5	9.9 ± 3.3	13.7 ± 4.6	15.2 ± 4.3	16.2 ± 6.8
Total (n=178)	16.3 ± 7.2	12.3 ± 6.9	15.7 ± 7.4	17.1 ± 7.3	18.1 ± 7.9
GIRLS					
12 (n=21)	24.6 ± 5.5	18.5 ± 6.9	25.7 ± 6.3	23.9 ± 4.4	22.3 ± 4.3
13 (n=31)	25.9 ± 6.4	23.7 ± 8.3	27.2 ± 6.2	24.6 ± 5.6	26.9 ± 7.3
14 (n=19)	29.4 ± 6.9	27.3 ± 7.5	30.8 ± 7.5	26.3 ± 6.7	29.5 ± 6.8
15 (n=41)	25.7 ± 6.5	24.9 ± 6.6	28.6 ± 6.8	24.0 ± 5.5	26.7 ± 6.4
16 (n=24)	25.4 ± 5.0	24.4 ± 5.8	27.8 ± 5.6	23.3 ± 4.9	26.0 ± 5.6
17 (n=18)	27.5 ± 3.9	25.4 ± 5.7	31.5 ± 4.3	26.0 ± 3.4	28.3 ± 5.3
Total (n=154)	26.2 ± 6.0	24.1 ± 7.2	28.4 ± 6.5	24.5 ± 5.3	26.5 ± 6.4

All values represent the mean ± SD for the first trial on the first day.

Table 3. Number of estimates of percent body fat falling within various ranges of the DEXA value.

	Method of Estimating Percent Body Fat			
	Skinfolds	OMRON	TANITA 521	TANITA 300
< -5%	35	70	66	262
~3.5% to > 5%	45	94	48	107
0 to > ~3.5%	224	279	228	268
0 to < 3.5%	335	241	301	134
3.5% to < 5%	87	52	64	23
> 5%	90	62	98	22
Unrecorded	0	18	11	0

Total number of trials for each method equaled 816.

Table 4. Variance components of each of the four body composition prediction methods.

	Day-to-Day Variance	Trial-to-Trial Variance
Skinfolds	± 3.12	± 1.75
OMRON	± 2.44	± 1.22
TANITA 521	± 1.62	± 1.79
TANITA 300	± 2.42	± 0.79
DEXA	± 0.29	Not Applicable

The day-to-day variance is the between day variance.

Trial-to-trial variance is the within day variance.

Table 5. Regression analyses of each of the prediction methods.

	BOYS		GIRLS	
	Intercept	Slope	Intercept	Slope
Skinfolds	2.55 ^a	0.76 ^b	6.93 ^a	0.73 ^b
OMRON	3.39 ^a	0.76 ^b	2.49	0.97
TANITA 521	4.50 ^a	0.75 ^b	6.15 ^a	0.71 ^b
TANITA 300	6.59 ^a	0.79 ^b	12.43 ^a	0.57 ^b

a = intercept is significantly different from zero.

b = slope is significantly different from one.

Table 6. Bias, confidence intervals, and prediction intervals for each of the four body composition prediction methods.

	Bias	BOYS				GIRLS				
		95% CI		Prediction Interval		95% CI		Prediction Interval		
Skinfolds										
10 %BF	0.90	0.16	1.64 *	-5.89	7.69	-1.12	-2.80	0.57	-8.07	5.84
20 %BF	2.11	1.54	2.68 *	-4.66	8.88	-0.31	-1.15	0.50	-7.11	6.49
30 %BF	3.32	2.26	4.38 *	-3.51	10.15	0.49	-0.18	1.17	-6.28	7.28
40 %BF	4.53	2.81	6.25 *	-2.43	11.49	1.30	0.15	2.75 *	-5.60	8.21
OMRON										
10 %BF	0.58	-0.19	1.35	-6.74	7.90	0.54	-1.20	2.28	-6.94	8.03
20 %BF	0.72	0.11	1.32 *	-6.59	8.02	-0.91	-1.72	-0.09 *	-8.23	6.42
30 %BF	0.85	-0.32	2.03	-6.52	8.22	-2.36	-3.12	-1.59 *	-9.67	4.96
40 %BF	0.99	-0.91	2.89	-6.54	8.51	-3.80	-5.48	-2.13 *	-11.27	3.66
TANITA 521										
10 %BF	-0.99	-1.79	-0.21 *	-8.61	6.61	0.64	-1.34	2.63	-7.17	8.46
20 %BF	-0.38	-1.07	0.30	-7.98	7.21	1.53	0.51	2.55 *	-6.10	9.16
30 %BF	0.22	-1.09	1.54	-7.45	7.91	2.41	1.70	3.12 *	-5.18	10.01
40 %BF	0.84	-1.27	2.94	-7.02	8.69	3.29	1.77	4.81 *	-4.42	11.01
TANITA 300										
10 %BF	-3.94	-4.70	-3.19 *	-11.96	4.08	-5.72	-7.51	-3.94 *	-13.9	2.45
20 %BF	-4.10	-4.93	-3.27 *	-12.13	3.92	-3.34	-4.23	-2.45 *	-11.37	4.69
30 %BF	-4.26	-5.86	-2.67 *	-12.40	3.87	-0.96	-1.83	-0.09 *	-8.99	7.07
40 %BF	-4.42	-6.90	-1.96 *	-12.78	3.93	1.42	-0.34	3.18	-6.75	9.59

The 95% confidence interval (CI) represents the CI of the line-of-best-fit at each level of percent body fat (%BF). The prediction interval represents the range within which 95% of the data are expected. The CI and prediction intervals are illustrated in Figures 1 – 4.

* = the bias of zero lies outside of the 95% confidence interval (CI) of the line-of-best-fit through the data in the Bland-Altman plot.

Figure Legends

Figure 1

Skinfold Performance Compared to DEXA. Upper graphs illustrate the regression of percent body fat predicted from skinfold measurements against DEXA assessments for boys (left) and girls (right). Lower Bland-Altman plots illustrate the agreement between skinfold assessments of body composition to DEXA assessments for boys (left) and girls (right). The 95% confidence interval (CI) is illustrated adjacent to the line-of-best-fit through the data. Upper and lower predictions intervals are also illustrated on each graph.

Figure 2

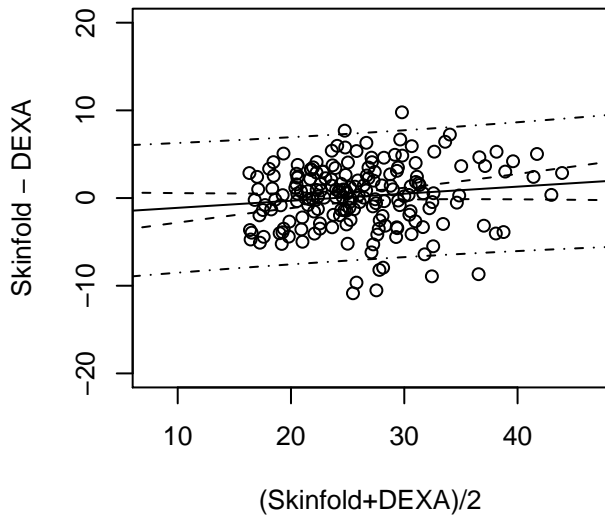
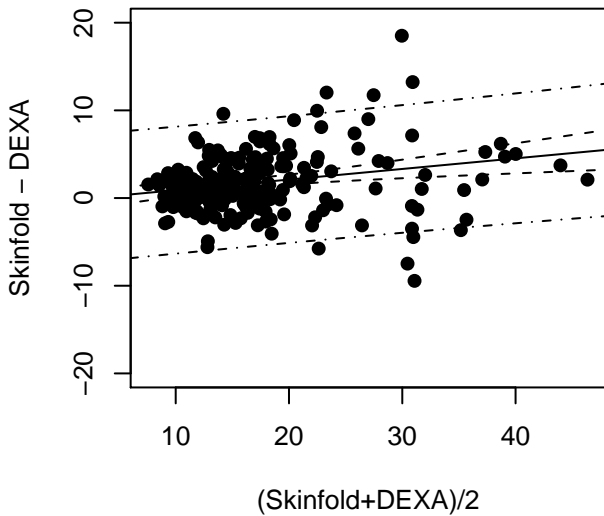
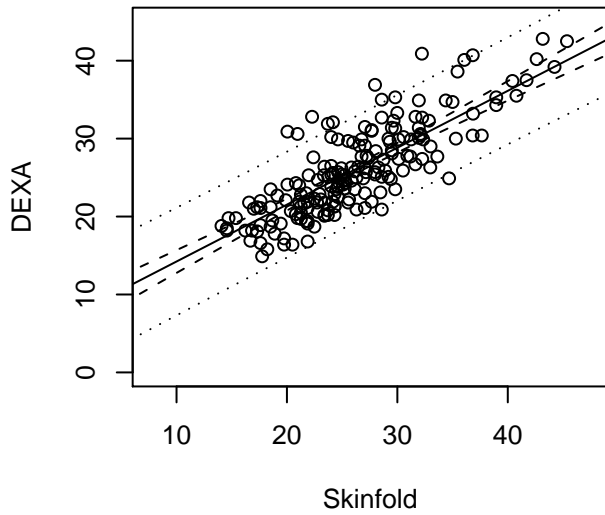
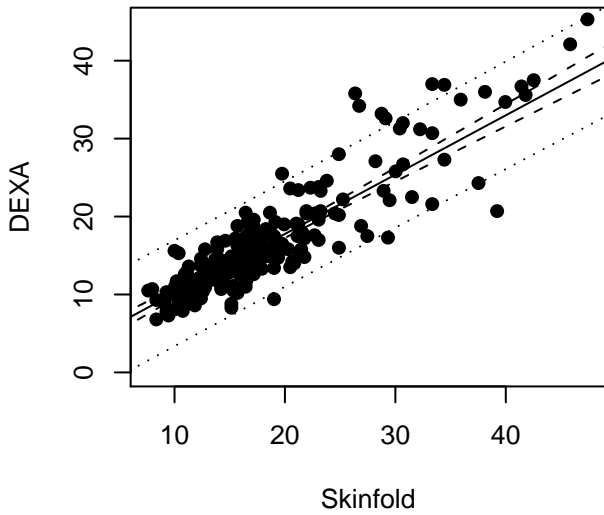
OMRON Performance Compared to DEXA. Upper graphs illustrate the regression of percent body fat predicted from the OMRON against DEXA assessments for boys (left) and girls (right). Lower Bland-Altman plots illustrate the agreement between OMRON assessments of body composition to DEXA assessments for boys (left) and girls (right). The 95% confidence interval (CI) is illustrated adjacent to the line-of-best-fit through the data. Upper and lower predictions intervals are also illustrated on each graph.

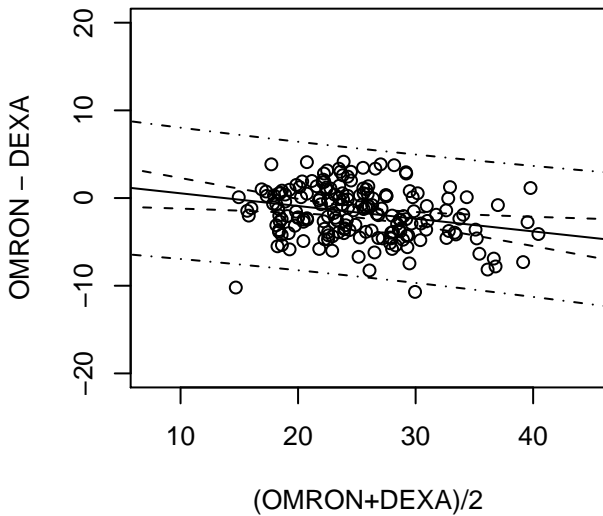
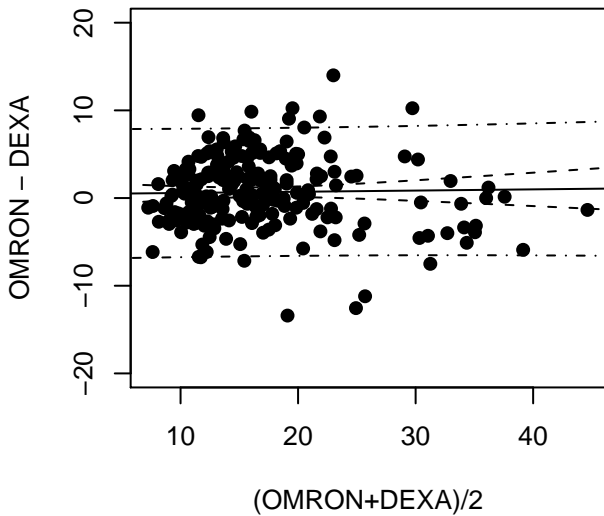
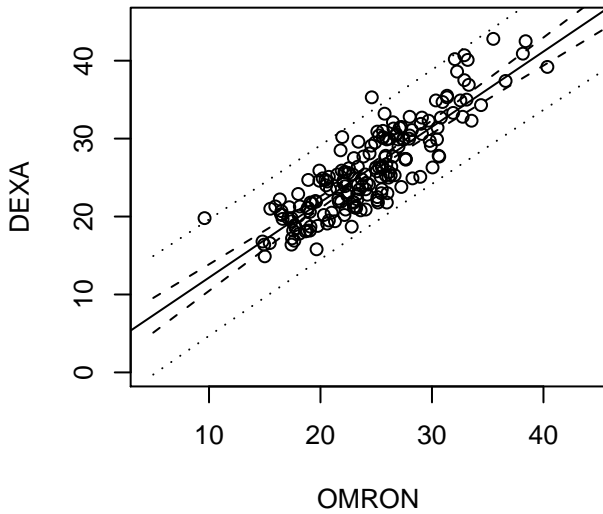
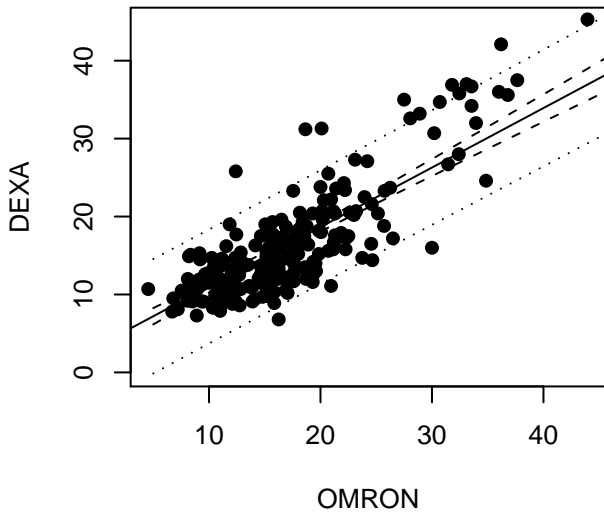
Figure 3

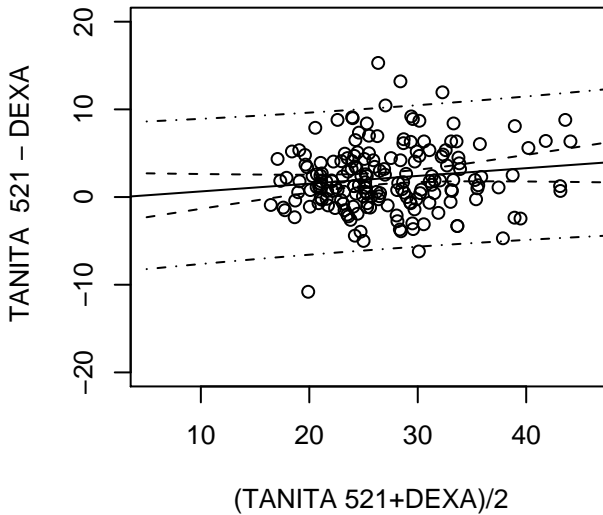
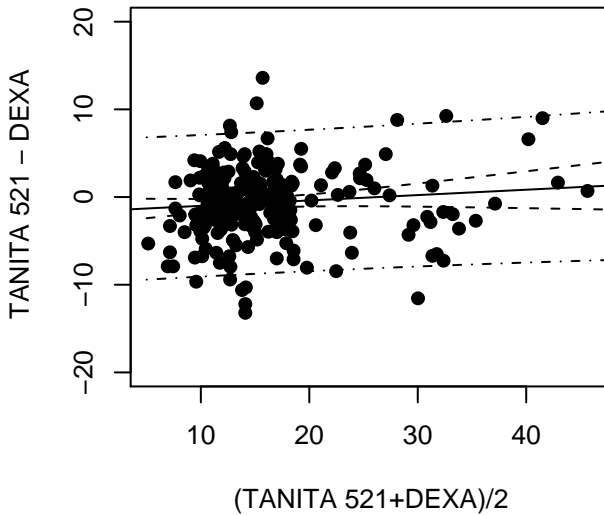
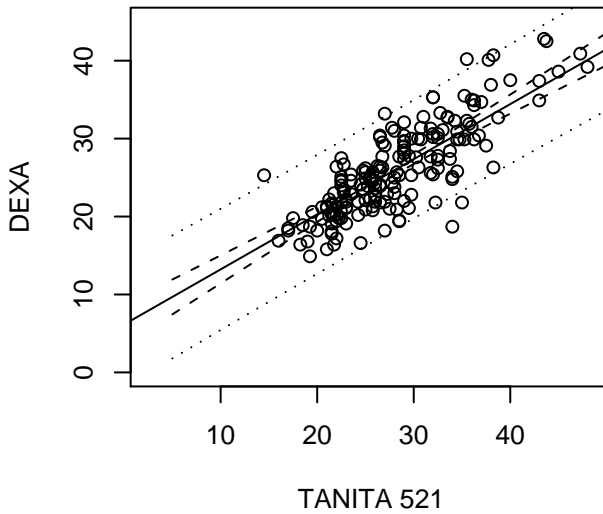
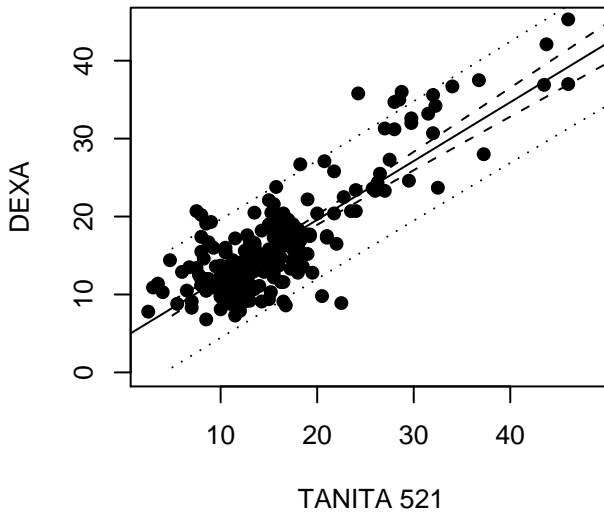
TANITA 521 Performance Compared to DEXA. Upper graphs illustrate the regression of percent body fat predicted from the TANITA 521 against DEXA assessments for boys (left) and girls (right). Lower Bland-Altman plots illustrate the agreement between the TANITA 521 assessments of body composition to DEXA assessments for boys (left) and girls (right). The 95% confidence interval (CI) is illustrated adjacent to the line-of-best-fit through the data. Upper and lower predictions intervals are also illustrated on each graph.

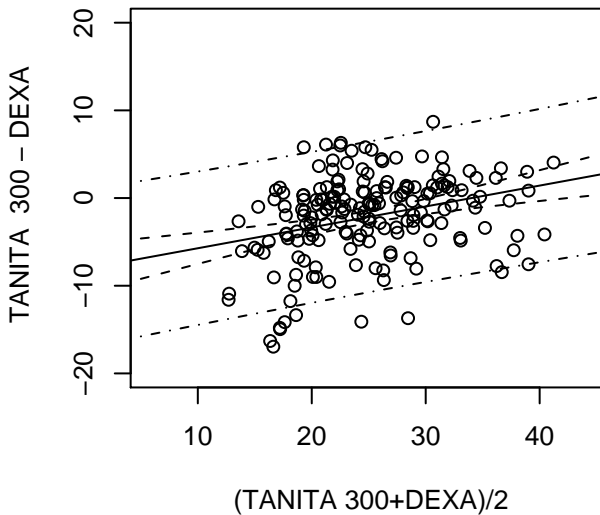
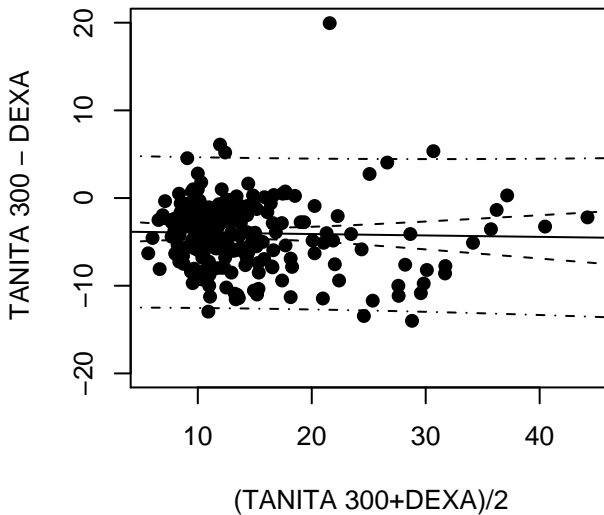
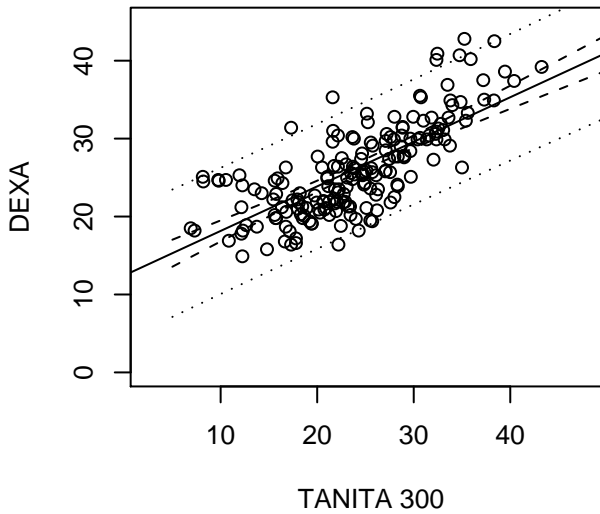
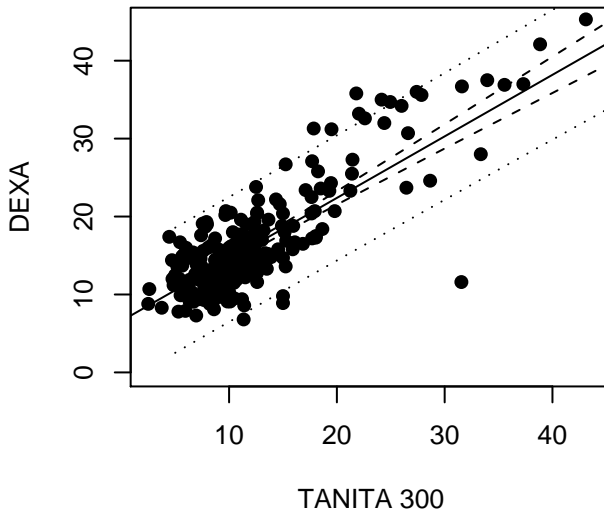
Figure 4

TANITA 300 Performance Compared to DEXA. Upper graphs illustrate the regression of percent body fat predicted from the TANITA 300 against DEXA assessments for boys (left) and girls (right). Lower Bland-Altman plots illustrate the agreement between TANITA 300 assessments of body composition to DEXA assessments for boys (left) and girls (right). The 95% confidence interval (CI) is illustrated adjacent to the line-of-best-fit through the data. Upper and lower predictions intervals are also illustrated on each graph.









Appendix A

Prospectus

Chapter 1

Introduction

As the obesity trend increases among adults and children, it has become necessary to find accurate and practical methods for assessing percent body fat. According to Wells¹, body composition is easily affected by changes in disease status, physical activity levels, acute dietary changes, and age. Accurate body composition assessment techniques are necessary to evaluate these changes and to determine health risks associated with obesity. As more information is available on body composition in children, fitness and health care professionals and physical educators will be better able to assess obesity and overweight status in children and determine risk associated with excess adiposity.

Obesity and overweight are associated with an increased risk for diabetes, heart disease, hypertension, high cholesterol, stroke, and certain cancers in adults². Since the increases in obese and overweight children are relatively recent, it is difficult to determine risk of disease in children, especially since it is unknown as to how persistent obesity is over time. Even so, it is known that chronic diseases develop over time, therefore overweight and obesity at a young age will have a negative impact on chronic disease development.¹

In children, overweight and obesity are defined using body mass index (BMI, kg/m^2) for age growth charts. The BMI is an anthropometric measurement which is commonly used as an indicator of overweight and obesity due to the simplicity of its

calculation and its association with health. Nevertheless, BMI is not a estimate of adiposity.^{1,2}

Body fat can only be measured using one of several different methods available for use in children. Methods vary in the accuracy and reliability of their estimates of body composition due to the underlying assumptions of the methodology, what is actually being measured and the precision of the measurement, and the prediction equation that is used. Dual-energy X-ray absorptiometry (DEXA) is known for its accuracy, speed, low radiation dose, and ease of use³⁻⁷ and has been used as a criterion method of assessing body composition in several studies.⁸⁻¹² Due to the cost of DEXA scanners and the necessity for DEXA operators to be state certified practitioners, the use of DEXA is limited to laboratory and clinical settings. Other methods of assessing body composition include bioelectrical impedance analysis (BIA) and the sum of skinfold thickness measurements, both of which are advantageous for use in children in a variety of settings because of their ease of use and practicality.

Statement of the Problem

The prevalence of overweight and obesity is increasing among children in the United States. Reliable, accurate, and easy-to-use body composition assessments are necessary to assess excess adiposity in a variety of settings. The validity and reliability of BIA devices used to estimate body composition in children is not well reported in the literature. In addition, in the wake of emerging technologies (e.g., DEXA), it is appropriate to confirm the validity of equations used to predict body composition from the sum of skinfold measurements.

Statement of Purpose

The purpose of this study is to determine the validity and reliability of four methods of estimating body composition in adolescent boys and girls 12 to 17 years of age. The validity of three BIA methods and the sum of two skinfolds will be established by comparing their estimates of body composition to that of the criterion method, DEXA.

Hypotheses

Research Hypotheses

1. Variance in percent body fat estimated using the sum of two skinfold thicknesses is the same as the variance in the percent body fat estimated by DEXA.
2. Variance in percent body fat estimated by the OMRON hand-to-hand BIA device is the same as the percent body fat estimated by DEXA.
3. Variance in percent body fat estimated by the TANITA 300A foot-to-foot BIA device is the same as the percent body fat estimated by DEXA.
4. Variance in percent body fat estimated by the TANITA 521 foot-to-foot BIA device is the same as the percent body fat estimated by DEXA.

Null Hypotheses

1. Variance in percent body fat estimated using the sum of two skinfold thicknesses is not the same as the variance in the percent body fat measured by DEXA.
2. Variance in percent body fat estimated by the OMRON hand-to-hand BIA device is not the same as the percent body fat estimated by DEXA.
3. Variance in percent body fat estimated by the TANITA 300A foot-to-foot BIA device is not the same as the percent body fat estimated by DEXA.

4. Variance in percent body fat estimated by the TANITA 521 foot-to-foot BIA device is not the same as the percent body fat estimated by DEXA.

Definition of Terms

Air displacement plesmythography (ADP or BOD POD) – a body composition assessment method that predicts body density and percent body fat based on estimates of body volume using measures of air displacement.

Bioelectrical impedance analysis (BIA) – a method for estimating body composition based on measures of electrical impedance (ohms) to a small electrical current, either between the two feet, or between the two hands. This method assumes electrolyte-rich tissues are better conductors of electricity than adipose tissue, and measures of impedance can differentiate between fat-free mass and fat mass.

Body Composition – a general term used to describe the components of the human body, such as fat mass and lean body mass.

Body Mass Index (BMI) – a ratio between weight in kilograms and height in meters squared (kg/m^2). BMI is used as an indicator in determining weight status (underweight, normal weight, overweight, and obese).

Dual-energy x-ray absorptiometry (DEXA) – a diagnostic test used to assess body composition based on estimates of fat, lean, and bone mineral masses retrieved from a two x-ray energy system.

Fat-free mass (FFM) – the weight of all body tissues, including water, bone mineral, and skeletal muscle, minus the extractable fat.

Fat mass (FM) – the weight of body fat, including essential lipids.

Hydrodensitometry – an assessment tool of body composition based on principles of water displacement and assumed densities of the fat mass and fat-free mass.

Multicomponent model (4-C model) – the measurement of multiple fat-free body compartments, including mineral, bone, and water to estimate a fourth compartment, body fat. The multicomponent model is believed to be more accurate than the two-compartment model because it takes into account differences in density of fat-free mass.

Obesity – defined in adults as a $BMI \geq 30 \text{ kg/m}^2$ and in children as being above the 95th percentile of the Center for Disease Control (CDC) national BMI-for-age growth charts.

Overweight – defined in adults as a $BMI \geq 25 \text{ kg/m}^2$ and in children as being above the 85th percentile of the Center for Disease Control (CDC) national BMI-for-age growth charts.

Percent body fat (BF%) – the percentage of total body weight that is adipose tissue.

Skinfold thickness (SF) – a method of estimating body density and percent body fat from the sum of two or more measurements of skinfold thickness.

Delimitations

Participants in this study will include 180 male and female adolescents, ages 12-17. Body composition will be measured by five different methods.

Limitations

1. The same technician will not take all of the body composition measurements: two certified radiation technicians will operate the DEXA, while the principal

investigator will estimate body composition using the three BIA methods and the sum of two skinfolds.

2. Participants in this study will be recruited from a relatively homogenous sample in Utah. The participants will be the children of faculty at Brigham Young University and therefore may not be representative of the adolescent population.

Assumptions

1. Female participants are not menstruating at the time of the study.
2. Participants will come to the lab fasting and will have rested four hours prior to the start of the data collection.
3. The pediatric software for the DEXA and the electrical impedance equations are appropriate for measurements in children.

Chapter 2

Review of Literature

Approximately two-thirds of the adult population in the United States is overweight or obese and the prevalence of obesity in children is increasing². Being overweight or obese increases the risk for cardiovascular disease, type 2 diabetes, and certain types of cancer¹. The National Institute of Health has not differentiated the definitions of overweight and obesity in children, but overweight children are described as being in the 95th percentile of the CDC national growth charts.

Due to the association of excess body fat and health, body composition is one of the five health-related components of physical fitness. As such, the assessment of body composition is an important component of a complete physical fitness assessment. Assessments of body composition can be used to objectively determine a person's current body composition, track changes in body composition over time, and stratify risk of obesity related diseases. Body composition assessment can also be used as an educational and motivational tool for individuals beginning or continuing to make lifestyle behavioral changes related to physical activity and diet. Body composition assessments in children are of equal importance.

Assessing Body Composition

There are several generally-accepted methods for measuring body composition in adults, including dual energy x-ray absorptiometry (DEXA), total body potassium (TBK), isotope dilution for total body water (TBW), air displacement plethysmography (ADP), computed tomography (CT), bioelectrical impedance (BIA), and skinfold thickness (SF).

Validity of a body composition assessment method is determined by comparing the outcome (usually body fat percentage) of the method to that of a body composition assessment method that has been accepted as a criterion method. DEXA has become an accepted criterion method of assessing body composition. DEXA is known for its accuracy, reliability, speed (scans take approximately 10 min), ease of use, and low radiation exposure.³⁻⁷

Every method of assessing body composition is based on specific underlying assumptions that, if accepted, add credibility to the method. The assumptions are usually related to what is actually being measured by the method and its relationship to adipose tissue. For example, some methods assume a constant density of muscle or adipose tissue or a constant water content of muscle tissue. The assessment of body composition in children challenges the underlying assumptions of body composition assessments because of the physiological changes in children that occur with normal growth and development. Changes in hydration, protein content, bone mineral content, and potassium (K^+) concentration that normally occur with aging are related to the differences in body composition in children and adults.¹²⁻¹⁴

With the increasing prevalence of obesity among children, it is necessary to determine the validity of methods commonly used to assess body composition in children in a variety of settings.¹⁵ The primary need in the field of body composition research in children is to identify accurate, convenient, and cost-efficient methods for assessing body composition.

Body composition assessment methods

Methods of assessing body composition can be classified according to how and what the method is actually measuring. Methods of assessing body composition are either property- or component-based. Property-based body composition assessments estimate an unknown component from a measurable quantity, such as estimating body fat percentage from skinfold measurements.¹⁶ Some property-based methods of assessing body composition include DEXA, BIA, SF, and hydrodensitometry.¹⁶ Property-based techniques provide a foundation for all in vivo methods, which comprise all body composition measurement techniques of living subjects.¹⁶ Property-based methods are statistically derived and based on mathematical principles and relationships between the different components.¹⁶ Component-based measurement techniques are based on the relationship between a known and unknown component and are proposed to be an expansion of property-based methods.¹⁶

Assessments of body composition can also be classified as either direct or indirect measurement methods.¹⁷ These types of methods separate the atomic, molecular, cellular, tissue-system and whole-body levels for measuring body composition and categorize them based on their in vivo or in vitro measurements.¹⁷ Indirect methods combine direct measurements and the relationship between known measurable components and unknown components to estimate body composition and body fat percentage.¹⁷ The indirect methods are based on the components derived from the direct methods, and are thus limited by the direct methods.¹⁷ Since most of the direct measurement methods are whole-body or tissue-system level measurements, body composition research is limited,

until reliable measurement techniques can be developed for the atomic, molecular, and cellular levels.¹⁷ Whole-body level assessments are direct, but they are limited by assumptions that the unknown atomic, molecular, cellular, and tissue-system levels are steady-state.¹⁷ The most accurate measurements of body composition are made from in vivo techniques in cadavers. In living humans, it is necessary to use theoretical assumptions when measuring body fat in live subjects.¹

Four-Component Model

The simplest model of the composition of the human body is the two-component model, fat and fat-free tissue. Multicomponent models have been developed to compartmentalize the composition of the body into three or more components. Multicomponent models allow body composition to be described (and assessed) in greater detail.^{1,4} Assessment of more components of the body accounts for the variability in the hydration and chemical properties of different body tissues. Methods used to assess body composition based on multicomponent models, specifically the four-component model (4-C), have been used as criterion methods of assessing body composition.

The 4-C model combines measurements of total body water (TBW), body density (B_D), and total bone mineral (M) to estimate the fourth compartment, body fat.^{4,18} Methods that assess the four-components of the body are chemically based and are difficult and tedious to perform.^{4,18-19} Although assessments that are based on the 4-C model are accurate assessments of body composition, they are not practical for use in children in a variety of settings.^{4,18} Due to the nature of the assessments that are based on

the 4-C model, there has been a need to develop and accept other methods of assessing body composition in children as criterion methods.

Dual-Energy X-Ray Absorptiometry

The assessment of body composition by DEXA separates the body into three compartments and assumes a constant protein to mineral ratio in the fat-free dry tissue. Since the DEXA method is a multicomponent method, it is advantageous over other methods, such as SF and ADP, which assess body composition based on the two-component model.²⁰ DEXA provides a practical alternative criterion method for assessing body composition.

DEXA assessments of body composition have been validated using the 4-C model as a criterion method.^{18-19,21} Visser et al.²¹ reports that DEXA provides a valid assessment of body composition when compared to the 4-C model and CT as criterion methods. Gately et al.⁴ confirms that DEXA is a promising criterion method of assessing body composition when compared with the 4-C model. Fields et al.²² reports that DEXA assessments of body composition in children are reliable.

DEXA has been used as the criterion method of assessing body composition in several studies. Okasora et al.¹¹ compared body fat percentage obtained from BIA against the body fat percentage obtained from DEXA. Field et al.¹⁰ used DEXA as a reference method in a study designed to validate BMI as a useful measurement tool for adiposity in children. Elberg et al.⁹ used DEXA as a reference method for comparing the accuracy of SF, BIA, and ADP. Most importantly, Elberg et al.⁹ showed that the DEXA was shown to be a reliable criterion method for comparing other assessment of body composition. Bray

et al.⁸ showed that DEXA is an appropriate criterion method for measuring body composition in a longitudinal study.

There is some disagreement about whether DEXA should be referred to as a “gold standard.” DEXA was designed to estimate bone density and does so accurately. The ability of DEXA to estimate body composition may be less precise.⁷ It is unclear as to whether or not DEXA can account for differences in fat free mass between subjects due to hydration.⁷ DEXA is also limited because of the potential bias in measuring anterior-posterior thickness and the differences in thin and obese subjects.⁷ DEXA is limited because it cannot accurately measure soft tissue overlying bone.¹ Other studies have concluded that certain body composition measurement methods should not be used interchangeably due to differences in percent body fat estimates.^{5,15,23}

Testolin et al.¹² showed the DEXA method is a valid tool for measuring body composition in children. The DEXA method has overestimated body fat percentage when compared with the 4-C model in obese and overweight children.⁴ Despite the variability shown in the DEXA method, it is commonly used as a reference method in body composition assessment studies in children.

Hydrodensitometry

Historically, hydrodensitometry has been used as the criterion methods of assessing body composition. Although it remains a valid and reliable technique, it has, for all practical purposes, been replaced by ADP.

Although hydrodensitometry is a valid method of assessing body composition in children, the method is labor intensive and difficult to perform with children because of

their inability to master the necessary breathing technique.¹⁰ In addition, equations used to predict body density, and subsequently, body fat percentage, must be age-specific to account for the normal changes in hydration and density of the fat mass and fat-free mass in growing children.^{6,10} The fat mass and fat-free mass values measured by DEXA are comparable with those from hydrodensitometry.¹⁰

Skinfold Thickness

The use of SF measurements is generally accepted as a practical, valid, and reliable method of assessing body composition in children and adults. Due to the changes in hydration and the density of the fat-free mass which normally occur in growing children, age-specific equations are required to predict body fat percentage from the sum of skinfold measurements in children.^{14,24} Slaughter has developed a well-accepted equation for children that accounts for the differences between children and adults.²⁵ The Slaughter equation uses the sum of two skinfolds (e.g., triceps and calf) to calculate body fat percentage in children.²⁵ Goran et al.²⁴ showed a strong correlation between body composition predicted from the Slaughter equation and DEXA.

Bioelectrical Impedance Analysis

BIA is a quick, easy, and relatively cheap method for assessing body composition. BIA assessments of body composition are based on the conductance of body tissues with a high concentration of water.^{6,24} Due to the simplicity in measurement technique and the portable equipment, BIA is a practical method of assessing body composition in children.^{11,26-27} BIA has been cross-validated against TBW²⁷ and TBK.²⁸ Goran et al.²⁴ showed that estimates of body composition from measurements of skinfold thicknesses

and BIA are comparable with estimates of body composition using DEXA, although estimates from BIA were slightly less precise than the estimates from the sum of skinfold thickness measurements. Bell et al.²⁶ showed the leg-to-leg electrical impedance method is comparable to TBW estimates and therefore potential body composition estimates. Goss et al.²⁹ showed that SF thickness measurements are comparable with the foot-to-foot electrical impedance method. When the subject adheres to proper hydration guidelines and refrains from exercise prior to BIA measurements, BIA has been shown to be a reasonable assessment of body fat percentage.²⁹ Schaefer et al.²⁸ state that BIA is a reliable method for measuring body composition in children within a normal range of body fat percentage. Eisenkolbl et al.³⁰ states that the BIA underestimates body fat percentage in obese subjects. Okasora et al.¹¹ also states that BIA is a relatively accurate method for assessing body fat percentage when compared to DEXA method, but BIA underestimates body fat percentage in obese subjects. Body position, nutritional and hydration status of subjects, time of day, electrode placement, body temperature, and the use of proper equations are all important considerations when using BIA to assess body composition.⁶

It should be noted that BIA devices vary in the way they measure the impedance to a small electrical current through the body. Traditionally, this has been measured by placing electrodes on the hand and feet and measuring impedance in the supine position. The BIA devices used in this study measure impedance hand-to-hand using a hand-held device in the upright position and foot-to-foot by stepping on two sensors on a platform

that resembles a weight scale. Although these methods are designed by the manufacturer to be used in children, reports of validity and reliability are lacking.

Summary

Research has shown that DEXA is an accurate method of assessing body composition and can be used as a criterion method in children. Studies reporting the validity and reliability of hand-to-hand and foot-to-foot BIA devices used in this study to assess body composition in children are lacking. In addition, in the wake of new technologies (e.g., DEXA), is it appropriate to confirm the validity and reliability of the Slaughter equations to estimate body composition in children.

Chapter 3

Methods

Participants

One hundred and eighty participants between 12-17 years of age will be asked to participate in this study. Each age will be represented by an equal number of male ($n = 15$) and female ($n = 15$) participants. Exclusion criteria include any known conditions that may adversely affect the accuracy of the body composition assessments. Pre-screening questions will also attempt to include a balance of weight ranges at each age-level (see Appendix A).

This study and informed consent process will be reviewed and approved by the Institutional Review Board (IRB) for the use of human subjects at Brigham Young University (BYU) prior to the collection of data. Participants will be recruited through flyers sent to faculty and staff at Brigham Young University (BYU). Participating children will complete an assent form and parents of participating children will complete a parents permission form prior to data collection to ensure informed consent (see Appendix A). As an incentive to participate in this study, participating children will receive a Cinemark movie gift certificate each time they participate in this study.

This study will be conducted as part of a large scale children's study which involves two other thesis research projects. All three research projects will be conducted concurrently. There will be an overlap of participants, participant recruitment, organization of data collection, data collection, and data entry. The body composition data collected in this study will be used as descriptive data for the other two studies.

Procedures

Appointments for children to participate in this study will be made with parents. During the initial contact, parents will be asked the questions included in the Pre-participation Questionnaire. Responding “yes” to any of the questions will exclude a child from participating in this study. After meeting the inclusion criteria, parents will be instructed to have their child(ren) (a) wear athletic shorts and a T-shirt to the appointment, and (b) refrain from eating or exercising 3- 4 hours before the appointment. Appointments for the females will be scheduled when they are not menstruating.

Participants will report to the Exercise Physiology Lab (121 Richards Building) in the Human Performance Research Center at BYU to have their body composition assessed twice by each of five different methods: dual-energy x-ray absorptiometry (DEXA), the sum of two skinfolds, and three different electrical impedance devices. Eighteen males and 18 females evenly distributed across the age span will be asked to return to the laboratory two to seven days later to repeat all five assessments of body composition. The order of the five assessments will be randomized during each set of assessments. The purpose of repeating all five assessments on each participant on one day and repeating the assessments in 36 participants on a second day is to determine the within- and between-day reliability of each method of assessing body composition.

Height (cm) of each participant will be measured and recorded using a calibrated wall scale to the nearest one-half centimeter. Body weight (kg) of each participant will be measured and recorded using a digital scale (Ohaus Model CD-33, Ohaus Corporation,

Pine Brook NJ, USA) to the nearest one-tenth of a kilogram. BMI (kg/m^2) will be calculated from measured height and weight values.

Dual-energy X-ray Absorptiometry

DEXA scans will be performed using a Hologic QDR4500 Elite “Acclaim Series” scanner (Hologic Inc., Bedford, MA) and software version 11.2 with supplemental pediatric software. A single scan mode will be used for all participants. Manufacturer recommended operating procedures for whole-body scans will be followed. Each scan will take about seven minutes. Although bone mineral content (BMC), bone mineral density (BMD), fat mass (FM) and fat-free mass (FFM) are included in individual reports, only percent body fat data will be discussed in this paper. All scans will be performed by a Utah State certified DEXA technician. Scans will be analyzed by the same technician to determine percent body fat of each participant.

Skinfold Thickness Measurements

Skinfold thickness of two sites will be measured on the right side of the body by a trained and experienced investigator using a Harpenden skinfold caliper. The triceps skinfold will be measured at the midline of the posterior aspect of the upper arm, midway between the acromion process of the scapula and the olecranon process of the ulna with the elbow flexed. A skinfold parallel to the long axis of the calf will be measured on the medial side of the leg at the level of the maximal circumference with the knee flexed 90° with the foot resting flat on a platform. Three measurements will taken at each site. If two measurements are the same, that value will be used in the calculation of percent body

fat, otherwise the average of three measurements within ± 2 mm will be used. Percent body fat will be calculated using the gender specific equations by Slaughter et al.²⁵

Bioelectrical Impedance Analysis

Three different electrical impedance devices will be used to estimate body composition of each participant. Each of the devices measures the electrical impedance (ohms) to a small electrical current either between the two feet or between the two hands. The electrical impedance is measured by placing the hands or feet on sensor pads.

OMRON. The OMRON (OMRON Healthcare Inc, Vernon Hills, IL) HBF306 body composition analyzer is a hand held hand-to-hand electrical impedance device. The OMRON functions in one of two modes: athlete (active individuals 18-60 years of age) and normal (10-60 years of age). Based on the age criteria of the two modes, the percent body fat of all participants in this study will be estimated using the normal mode. The participants' height, weight, age, and gender will be entered into the OMRON. While standing with their feet slightly apart, the participant will grasp the grip electrodes of the OMRON and hold the OMRON in front of their body with the arms fully extended and parallel to the ground. Assessments take about one minute to complete and percent body fat will be recorded from the value shown on the display.

TANITA 300A. The TANITA 300A (TANITA Corporation of America, Arlington Heights, IL) body composition analyzer is a foot-to-foot electrical impedance device. The TANITA 300A functions in one of two modes: athlete and standard. The percent body fat of all participants in this study will be estimated using the standard mode to remain consistent with the other electrical impedance devices. The participants' age,

height, and gender will be entered into the TANITA 300A. After zeroing the scale, the participants will stand motionless on the foot electrode pads in bare feet while the device measures body weight and impedance. Assessments take about one minute to complete and percent body fat will be recorded from a printed copy of the assessment results.

TANITA 521. The TANITA 521 (TANITA Corporation, Tokyo, Japan) body composition analyzer is a foot-to-foot electrical impedance device. The TANITA 521 functions in one of three modes: adult, child, and athlete. The percent body fat of all participants in this study will be estimated using the child mode. The participants' height and gender will be entered into the TANITA 521. After zeroing the scale, the participants will stand motionless on the foot electrode pads in bare feet while the device measures body weight and impedance. Assessments take about one minute to complete and percent body fat values will be recorded from the value shown on the display.

Statistical Analysis

Age data will be recorded in years and months in order to accurately report percent body fat data across the age span of the participants. The DEXA assessment of percent body fat will be considered the criterion measure of body composition. Percent body fat values determined from the sum of two skinfolds and the three electrical impedance devices will be compared to percent body fat values determined from the analysis of DEXA scans. All statistical analysis will be performed using Statistical Analysis Software (SAS) with the alpha level maintained at $p < 0.05$.

Estimation of variance components (subject, day, and trial) will be made using proc mixed. Proc reg will be used to regress percent body fat estimated from each

method across the age span of the subjects. The slope and intercept of each method's regression line will be compared to the slope and intercept of the DEXA method.

Interpretation of the results of this study and appropriate conclusions will be based on the statistical analysis of the data.

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Appendix A1

Pre-visit Study Description and Screening

Pre-visit Study Description and Screening

The following brief description of the study will be given to parents when they initially call for information and make an appointment.

This study is designed to evaluate the accuracy of several methods of measuring body composition in teenagers. You must bring your son/daughter to BYU. Your son and daughter may be asked to repeat all of the tests on another day. Participation in this study will take about 30 minutes. If your son or daughter wants the results of the tests, they will be given to him/her with an explanation of what they mean. Your son or daughter will receive a \$5 movie pass for participating in this study. To participate in this study, your son or daughter must:

- be between the ages of 12-17
- not be receiving treatment for an illness
- not be taking medications
- not be anemic, bulimic, or anorexic
- not be pregnant
- not be menstruating

In order for the body composition assessments to be as accurate as possible, we ask that your son or daughter come to their appointment:

- having fasted (other than water) for 4 hours
- not having exercised (other than normal daily living activities) for 4 hours
- wearing gym shorts and t-shirt

Written informed consent will be obtained during the first visit.

Appendix A2

Pre-Body Composition Assessment Questionnaire

Pre-Body Composition Assessment Questionnaire

The following questions will be asked (verbally) of each participant during each visit.

These questions are related to conditions which may affect the accuracy of body composition measurement and confirm compliance with pre-participation instructions.

Answering “yes” to any of these questions may result in rescheduling the appointment.

Yes No

- Have you eaten in the last 4 hours?

 - Have you exercised in the last 4 hours?

 - Do you (or have you had) have swelling of the ankles?

 - Are you currently taking any medications?

 - Are you menstruating?
-

Appendix A3
Parental Consent Form



PARENTAL PERMISSION FOR A CHILD TO PARTICIPATE AS A RESEARCH SUBJECT

Title: Validity and Reliability of Body Composition Assessments
in Children and Adolescents

Introduction. The purpose of this research project is to find out the accuracy of body composition measurements in children and adolescents using machines that are used in many public schools. The predictions of body composition from these machines will be compared to another measurement which is considered to be the most accurate. Pat Vehrs, Ph.D., a faculty member in the Department of Exercise Sciences is conducting this project.

Procedures. Your child has been asked to participate in this study because he/she meets the criteria for participation. Your son or daughter can participate in this study if he/she is 12-17 years of age, is not currently pregnant, menstruating, anorexic, bulimic, anemic, or taking medications. As a participant in this research project, your son/daughter will be asked to:

- a. Not eat or drink (except water) and avoid exercise for four (4) hours prior to participation.
- b. Answer questions about conditions that might affect the accuracy of the measurements.
- c. Have his/her height and weight measured.
- d. Have his/her body composition measured using the following methods:
 - Skinfold thicknesses will be measured on the triceps (back of the arm) and the calf (lower leg) using a skinfold caliper. The measurement will be made while "pinching" the skin and then measuring the thickness of the fold with the caliper. This measurement takes about 1 minute and will be repeated twice.
 - A small portable handheld machine will measure the resistance to a very small electrical current while holding the machine in the hands. Two other machines will also measure the resistance to a small electrical current while standing with bare feet on a scale with two foot sensor pads. Your child will not feel the electrical current and it is not harmful. These three measurements take about one minute each and will be repeated twice.
 - Using dual energy x-ray absorptiometry (DEXA) your son/daughter will be asked to lie quietly on a table while a lens above him/her moves back and forth scanning the body. The DEXA measurement takes about 8-10 minutes and will be done only once.
- e. In total, all the measurements will take about 30 minutes (depending on waiting time if there is a group of children participating at the same time).
- f. Your son or daughter may be asked to return on another day and repeat the measurements.

Risks and Discomforts. There are minimal, if any, risks and discomforts associated with participating in this study. The DEXA scan exposes participants to a very small radiation dose that is many times less than a dental x-ray or a chest x-ray. The bio-electrical impedance machines use a current of 800 microamps (800/1,000,000 of an amp) which is so small that your child will not be able to feel it. Your child may feel some discomfort from pinching the skin when measuring skinfold thickness. There are no other risks that we know of in any of the body composition measurements. If an accident or injury were to occur during your son's/daughter's participation, you will be consulted in deciding how to proceed. If you are not available, any necessary and appropriate medical facilities or services will be contacted immediately. If this were to occur, you will be responsible for the payment of medical services.

Benefits. As a benefit from participating in this study, your son/daughter will be given information about the results of the body composition measurements and what they mean. Any questions or concerns that you or your son/daughter have about the results will be explained. Your son's/daughter's participation in this study will also advance our understanding of how body composition should be measured, in for example, physical education programs in the public schools.

Confidentiality. All information gathered about your son/daughter during this study will be confidential. The researchers will keep his/her information confidential by only sharing their results with them. We will remind your son/daughter to not share their results with others if they do not want others to know the results from the tests. Group data obtained from this research project may be published or presented in professional journals and conferences, but individual results and personal information will remain confidential.

Compensation. Your son/daughter will receive one \$5 Cinemark movie pass each time (day) he/she participates in this study. The movie pass will only be given if all of the measurements are completed. If your son/daughter returns on a second day to repeat the measurements, he/she will receive a second movie pass.

Participation. Your son's/daughter's participation in this research study is entirely voluntary. You or he/she may chose to not participate at any time. The researcher may terminate your son's or daughter's participation in this study if they are unable to follow instructions, unwilling to have one or more of the measurements done, or if it is difficult to schedule appointments. Your son or daughter may also be told he/she cannot participate or be asked to participate later if certain conditions exist, such as menstruation, pregnancy, anemia, bulimia, or anorexia (since these conditions affect the accuracy of body composition measurements).

Questions about the research. If you have questions regarding this study, you may contact Pat Vehrs Ph.D. at 801-422-1626, by email at pat_vehrs@byu.edu or in person in 116B Richards Building.

Questions about your rights as a research participant. If you have questions regarding your rights as a research participant, you may contact Christopher Dromey, PhD, IRB Chair by phone at 801-422-6461, in person or by mail at 133 TLRB, Brigham Young University, Provo, UT 84602, or by email at Christopher_Dromey@byu.edu.

I give consent for my child(ren) to participate in this research study.

Name of Parent or Guardian

Name of child(ren)

Signature of Parent or Guardian

Date

Signature of Principle Investigator or Assistant

Date

Appendix A4
Subject Assent Form



Validity and Reliability of Body Composition Assessments in Children and Adolescents

You are being asked to participate in this research study because you are between 12-17 years of age. The purpose of this research project is to find out if machines used to measure body fat are accurate in boys and girls. The predictions of body fat from these machines will be compared to another measurement which is considered to be the most accurate. Pat Vehrs, Ph.D., a faculty member in the Department of Exercise Sciences is conducting this research project.

You will be asked to:

- a. Answer questions about conditions that might effect the accuracy of the measurements.
- b. Have your height and weight measured.
- c. Have your body fat measured using five different machines. The thickness of a skinfold on the back of your arm and your lower leg (calf) will be measured using a skinfold caliper. The resistance to a very small electrical current will be measured using three different machines. You will not be able to feel the electrical current and it is not dangerous. These four measurements take about 1 minute each and will be done twice. For the last test, you will lie very still on a table while a lens above you moves back and forth scanning your body. This measurement will take about 8-10 minutes and will be done only once.
- d) All the measurements will take about 30 minutes.
- e) You may be asked to return on another day and repeat the measurements.

There are minimal, if any, risks and discomforts associated with participating in this study. The body scan exposes you to very small amounts of radiation (less than an x-ray at your dentist's or doctor's office). You will not be able to feel the small electrical current and it is not harmful. You will feel a pinch when we take the skinfold measurement.

When we are done, we will give you the results of each of the tests and tell you what they mean. All of your test results and personal information will be kept confidential. We will not share your results with anyone else. Do not share your results with others if you do not want others to know the results from the tests.

You will receive one \$5 Cinemark movie pass each time (day) you finish all of the tests. If you come back on a second day to repeat the tests, you will get one more movie pass.

Your participation in this research study is entirely voluntary. You can chose not to participate or stop participating at any time. The researcher may end your participation in this study if you cannot follow instructions, can't do one of the measurements, or if it is difficult to schedule an appointment. You may also be told that you cannot participate or be asked to participate later if you are pregnant, menstruating, anemic, bulimic, or anorexic.

If you have questions regarding this study, you may contact Pat Vehrs Ph.D. at 801-422-1626, by email at pat_vehrs@byu.edu or in person in 116B Richards Building. If you have questions regarding your rights as a research participant, you may contact Christopher Dromey, PhD, IRB Chair by phone at 801-422-6461, in person or by mail at 133 TLRB, Brigham Young University, Provo, UT 84602, or by email at Christopher_Dromey@byu.edu.

I voluntarily consent to participate in this research study.

Name

Signature

Date

Signature of Principle Investigator or Assistant

Date