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MEASUREMENT METHODS IN CHILDREN

by

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ABSTRACT

An Examination of Body Composition Measurement Methods in Children

by

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INTRODUCTION: Body-composition methods include underwater weighing (UWW), skinfold thickness (SKF), bioelectrical impedance (BIA), and the BOD POD. Although these techniques are used routinely, each has its inherent limitations, especially in children. PURPOSE: The purpose of this study was to examine the various methods of body composition in children. METHODS: The body composition of 7 boys between the ages of 12-14 (13.1 +/- 1.1 years) was determined using the BOD POD, UWW, SKF, and BIA. RESULTS: Percent body fat estimated from the BOD POD (21.9 +/- 7.8%BF) was not significantly different than the estimated percent fat from UWW (21.8 +/- 7.3%BF). CONCLUSION: The strong relationship between the BOD POD and UWW in this study suggests that the BOD POD is a valid method of measuring body composition in children.

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CHAPTER 1

INTRODUCTION

Body composition has been extensively studied in adult subjects; however, there is less research regarding children. Research using children as subjects pose several difficulties: Skinfold measurement requires removal of some clothing and underwater weighing is difficult for most children, especially non-swimmers. Other measures of body composition such as bioelectrical impedance, waist-to-hip ratio, and body mass index are all convenient methods but their validity have not been widely studied in children. The BOD POD presents a user-friendly technique for measuring children, however, little research has been done on children using the BOD POD.

Purpose of the Study

The purpose of this pilot study was to examine different body composition measurement methods in children. The study was conducted on 7 males between the ages 12-14 years.

There are a number of assumptions, limitations, and delimitations when using the BOD POD.

Clothing: Children should wear appropriate clothing while being tested. Subjects may wear spandex-style shorts or brief-style swimsuits (which is recommended by the manufacturer).

In the present study, subjects were instructed to bring a lycra bathing suit or cycling shorts to help adhere to the BOD POD protocol.

Non-dry, non-resting conditions: The subjects could be tested after UWW, which could lead to the subjects not being completely dry for the BOD POD testing. Also, presence in a tank of warm water could elevate the subjects' metabolism above resting states.

Delimitation: The subjects were tested in the BOD POD before UWW and in a rested state.

Thoracic Gas Volume (TGV) Prediction: The BOD POD allows for either a measured, predicted or entered TGV, and the manufacturer suggests that it be measured when possible. However, since there are discrepancies with reliability of TGV in children, predicted TGV was used in the study.

Subject gender: Biaggi et al. (1999) raised the possibility that the gender of the subject could affect the results obtained with the BOD POD. The authors reported a significant effect and the mean difference between the BOD POD and UWW was positive for females (1.0 +/- 2.5% BF) and negative for males (-1.2 +/- 3.1% BF). Fields et al. (2002) plotted the gender-specific means for studies in which mean differences were reported separately for males and females. In the analysis, the authors concluded it was impossible to separate the confounding effects of subject gender and %BF.

Delimitations: Biaggi et al. (1999) hypothesized that the gender effect observed in their study may have been attributable to the greater amount of body hair on men compared to women. Since the study was conducted on children ages 12-14, body hair was not of significant concern with the exception of hair on the head. However, a hair cap was worn during the BOD POD analysis, thus neutralizing the differences in head hair.

Body hair: Higgins et. al. (2001) attempted to determine the effect of body hair (scalp and facial) on ADP estimates of %BF. The presence of only a beard (facial hair and swimcap) resulted in a significant underestimation of %BF compared to the criterion method (the beard was removed and a swimcap was worn) (16.2% compared with 17.1%; $p < 0.001$ in the criterion method). The effect of scalp hair (no swim cap worn) resulted in a significant underestimation in %BF relative to the criterion method, either with facial hair (facial hair and no swimcap; 14.8%; $p < 0.001$) or without facial hair (no facial hair and no swimcap; 14.8%, $p < 0.001$).

Higgins et al. (2001) thought the underestimation in %BF may be caused by the effect of trapped isothermal air in the body hair on body-volume estimates. The study (Higgins et al., 2001) concluded facial hair should be kept to a minimum and a swimcap should be worn at all times to ensure accurate estimation of %BF when using the BOD POD.

Because the present study used children, facial hair was not be a factor, but a swimcap should have eliminated inaccuracies regarding scalp hair and the BOD POD.

Subject size: Wells and Fuller (2001) investigated the precision of measurement and body size in ADP across a wide range of body size. Wells and Fuller (2001) concluded the BOD POD shows good precision for BV and BD across a wide range of body size. Also, it was noted that if using pairs of BOD POD procedures, allowing the rejection of data where successive BD values differed by > 0.007 kg/l.

Fasting and postprandial conditions: Gas in the stomach or intestine that is not accounted for can lead to an underestimated in body density (Db) and an overestimation of %BF when measure by UWW. The amount of gas in the stomach and intestine in the postprandial state can vary depending on the type and quantity of the food ingested.

Body Composition Validation: While it is assumed that UWW is the "gold standard" for measuring body composition, UWW has its own associated errors. There is an inherent and unavoidable trait of body composition validation studies conducted on human subjects in that the reference methods (in this case, UWW) against which the test methods were compared (BOD POD) have its own margin of error.

While UWW has been widely accepted as a reference standard, little information is available on intersystem reliability. With UWW, there is a lack of a standardized system and protocol. Lohman (1992) reported a standard deviation in BV of 0.0015 g/ml for two individuals measured by UWW at five different laboratories following the same protocol. These results might not reflect the true reliability between UWW systems due to the wide range of equipment and protocols used in different laboratories.

CHAPTER 2

REVIEW OF RELATED LITERATURE

Fields et al. (2002) reviewed body composition assessment via air-displacement plethysmography in adults and children. At that time, there were five studies conducted with children as the primary subjects between December 1995 and August 2001. The authors found that the average of the study means indicated that the BOD POD and UWW agreed within 1% BF for adults and children, whereas the BOD POD and DEXA agree within 1% BF for adults and 2% BF for children.

Wide variations among study means (-4.0% to 1.9% BF for BOD POD – UWW and -3.0% to 1.7% BF for BOD POD – DEXA) were possibly due in part to differences in laboratory equipment, study design, and subject characteristics and in some cases failure to follow the BOD POD's recommended protocol.

Of the five studies conducted on children between December 1995 and August 2001, comparing BOD POD to UWW (Nunez et al., 1999; Dewit et al., 2000; Fields and Goran, 2000; Lockner et al., 2000; Wells et al., 2000), two of them (Lockner et al., 2000; Fields and Goran, 2000) reported, on average, the BOD POD gave significantly different %BF measurements than did UWW. The results were in opposite directions (2.6 compared with -2.9% for Lockner et al., 2000; Fields and Goran, 2000, respectively). The other three studies (Nunez et al., 1999; Dewit et al., 2000; Wells et al. 2000) reported that %BF measured by the BOD POD was somewhat higher than that measured by UWW (0.6-1.2% BF), but not significantly so.

Fields et al. (2002) concluded that the BOD POD was a reliable and valid technique that is both quick and effective for evaluating body composition in a wide variety of subjects, including children.

Fields et al. (2005) continued to support air-displacement plethysmography as a suitable and reliable instrument in the assessment of body composition. However, the review (Fields et al., 2005) noted that only six studies (Demerath et al., 2002; Dewit et al., 2000; Fields and Goran, 2000; Lockner et al., 2000; Nunez et al., 1999; Wells et al., 2003) have been focused primarily on children and the results have been inconclusive.

Four of the studies mentioned in the 2005 review were analyzed in the 2001 review of air-displacement plethysmography (Fields et al., 2002). As discussed above, two of the studies yielded significant differences in percent body fat from the BOD POD compared to UWW (Lockner et al, 2000; Fields and Goran, 2000).

Demerath et al. (2002) conducted a study where the mean differences between UWW and the BOD POD were not significant in children. It should be noted that at the individual level, method differences were quite large (with 95% confident intervals ranging from approximately -9% to +7% body fat) and inter-method differences were particularly great in male children. ADP slightly overestimated percent body fat in leaner children and underestimated body fat in fatter children as compared to UWW.

In regard to the method differences at the individual level, a review of the literature showed that while mean differences in percent body fat using UWW and ADP are relatively low, individual-level differences are approximately +/- 6-8% in typical research settings.

The overestimation in %BF in leaner children and underestimated %BF in fatter children as compared to UWW in the Demerath et al. study stands in contrast to another study where ADP underestimated %BF in leaner children (Nunez et al., 1999).

The majority of studies comparing the BOD POD to UWW report a mean difference of less than 1%BF between the two methods (McCrory et al., 1995; Levenhagen et al., 1999; Fields et al, 2001). The average reported standard error of estimate is 2.7%BF (range = 1.8-3.6%BF) (McCrory et al., 1995; Collins et al., 1999; Fields et al., 2001), which is classified as "very good" by a subjective rating proposed by Lohman (1992).

Collins and McCarthy (2003) investigated the methodological precision of air displacement plethysmography for assessment of body composition in a sample of adults and concluded that the BOD POD retains excellent precision, however repeat measurements of BOD POD should be performed whenever possible to allow for erroneous volume measurement within one procedure.

Collins and McCarthy noted that, at the time of their study (2003), BOD POD-derived body composition had been demonstrated to have good agreement with that derived from UWW (McCrory et al., 1995; Biaggi et al., 2002; Levenhagen et al., 1999; Nunez et al., 1999: Fields et al., 2002).

When compared to UWW, Wagner et al. (2000) concluded that the BOD POD systematically underestimated body density, whereas McCrory et al. (1995) reported the BOD POD to be a reliable and valid method for assessing %BF when compared to UWW.

Vescovi et al. (2001) compared the estimation of %BF using BOD POD and UWW in a heterogeneous (age and %BF) sample of the population. The study (Vescovi et al., 2001) also attempted to determine whether there were differences between the two methods among lean (n = 32), average (n = 34) and overweight (n = 29) subsets of the sample.

Mean body density using the BOD POD was not significantly different when compared to UWW, which corresponded to a non-significant difference in %BF (Vescovi et al., 2001). Data for the subsets revealed a significant overestimation of %BF for BOD POD compared to UWW for lean individuals while no difference was found in the average or the overweight.

The study (Vescovi et al., 2001) concluded the BOD POD was a highly reliable method and valid when compared to UWW for a heterogeneous sample of adults. However, the authors found the BOD POD to be less reliable when measuring lean individuals and recommended further investigation on the matter.

Fields et al. (2002) reviewed body composition assessment via air-displacement plethysmography in adults and children looking at studies where either UWW or DXA were used as the criterion.

The authors found that the average of the study means indicated that the BOD POD and DXA agree within 1% BF for adults and 2% BF for children.

Wide variations among study means (-4.0% to 1.9% BF for BOD POD – UWW and -3.0% to 1.7% BF for BOD POD – DXA) were likely due in part to differences in laboratory equipment, study design, and subject characteristics and in some cases failure to follow the manufacturer's recommended protocol (Fields et al., 2002).

Ball (2005) investigated the inter-device variability of the BOD POD by performing duplicate tests using two BOD POD units located in the same laboratory. The study concluded that no clinically significant differences in BD and %BF estimates existed between the BOD POD units and the inter-device variability of the BOD POD has minimal impact on %BF estimates.

Ball (2005) observed that comparisons of BOD POD against DXA report mean %BF differences ranging from 0.5 to 3%BF and standard error of estimates ranging from 2.4 to 3.5%BF.

Radley et al. (2005) compared percentage body fat from DXA and air displacement plethysmography. The study found that BOD POD estimates of percentage fat were highly correlated with those of DXA in both male and female subjects. They compared percentage body fat estimates determined by BOD POD using both the Siri (1961) and Lohman (1986) equations and DXA in a sample of overweight and obese children. The actual mean difference between DXA and BOD POD percentage fat estimates, revealed no consistent gender disparity (Radley et al., 2005). For all subjects, differences in DXA and BOD POD estimates of percentage fat were not significantly related to age, weight, height, hip or thigh measurements.

All BOD POD percentage fat estimates were significantly correlated to those derived by DXA ($r = 0.90$ to 0.93, $p < 0.001$). These findings are comparable with those previously reported in children by Nunez et al. (1999) ($r = 0.90$) and Lockner et al. (2000) ($r = 0.94$).

Ball and Altena (2004) compared the BOD POD to DXA in men, pointing out that most studies attempting to validate the BOD POD as a body composition method have compared it to UWW (Koda et al., 2000 is an exception). Ball and Altena (2004) found that the BOD POD estimates of %BF were significantly ($p < 0.01$) higher than estimates from DXA. Ball and Altena (2004) found that although the two methods (BOD POD and DXA) were highly correlated (0.94), the mean difference of 2.2% was significant ($p < 0.01$). There was a trend for the difference to be greater in subjects with higher percentages of body fat ($p < 0.0001$).

Elberg et al. (2004) attempted to determine the ability of the BOD POD and formulas based on triceps skinfold thickness and BIA to estimate changes in body fat over time in children. The criterion method of measuring body composition in this case was DXA. SKF and BIA were highly correlated with DXA ($p < 0.001$). No mean bias for estimates of percentage body fat change was found for the BOD POD compared with DXA for all subjects examined together, and agreement between body fat estimation by BOD POD and DXA did not vary with race or gender. The authors (Elberg et al., 2004) concluded that BOD POD performed better than triceps skinfolds thickness or BIA for measuring changes in body fat in children.

Compared to UWW, Collins and McCarthy (2003) found that less acceptable agreement has been shown using DXA as a criterion method of validation, citing a number of sources as examples of this trend (Sardinha et al., 1998; Collins et al., 1999; Nunez et al., 1999; Lockner et al., 2000; Weyers et al., 2002).

Maddalozzo et al. (2002) examined the validity of the BOD POD and DXA (Elite 4500A. Hologic, Inc.) techniques for assessing %BF of young women (19.4 +/- 1.4 years). %BF was estimated to be 24.3 (SE = 1.1) and 23.8 (SE = 0.8) using the BOD POD and DXA techniques. The study (Maddalozzo et al., 2002) found exact matches, in terms of %BF, in 10 of the 43 participants (23.3%). Maddalozzo et al. (2002) concluded that their data supported the concurrent validity of the BOD POD and DXA techniques for assessing %BF in young women.

Dixon et al. (2005) compared percent %BF estimated by the BOD POD and bioelectrical impedance (BIA) with UWW. BIA measurements (Athletic mode) were conducted using a Tanita body fat analyzer (model TBF-300A). UWW was used as the criterion measurement. BIA consistently underestimated %BF, significantly so ($p < 0.01$), for this athletic group (Division III collegiate wrestlers with a mean %BF of 14.5 for UWW) of subjects.

Dixon et al. claimed that the BOD POD seemed to demonstrate a consistent pattern of underestimating %BF when compared with UWW in men, particularly lean subjects (Collins et al., 1999; Levenhagen et al., 1999; Stafford et al., 1998).

The Collins et al. (1999) study reported that the BOD POD underestimated %BF by a mean difference of 1.9% when compared with UWW in a sample of male collegiate football players. Similarly, Levenhagen et al. (1999) reported a mean difference of -2.9% for %BF estimated by ADP compared with UWW for a group of healthy adult men.

Ballard et al. (2004) compared the BOD POD and DXA in female collegiate athletes and 24 female non-athletes. The study found no significant difference when measuring percent body fat between the BOD POD and DXA. The authors concluded that the BOD POD was a reliable method of assessing body composition in female collegiate athletes and non-athletes.

Vescovi et al. (2002) examined the accuracy of %BF estimates in female college athletes obtained by the BOD POD using the BOD POD, using UWW as the criterion method. %BF estimates were also obtained by SKF. A lean subset of the sample was also examined for accuracy. Residual lung volume was measured on land in the same seated position as for underwater weighing by the nitrogen-dilution method (Wilmore, 1969).

Mean %BF estimated for the entire sample by the BOD POD (21.2 +/- 5.9%) was significantly greater than that determined by UWW (19.4 +/- 6.4%) and SKF (18.8 +/- 5.5%). Results from the lean subject subset had similar findings where estimated %BF by the BOD POD (17.1 +/- 3.7%) was significantly higher than %BF estimates by UWW (14.3 +/- 2.8%) and SKF (15.2 +/- 3.2%). No significant differences were found between %BF values obtained using SKF and those obtained using UWW and mean differences for the entire sample and lean subset were -0.6 +/- 5.9% and 0.8 +/- 2.9%, respectively.

The results from Vescovi et al. (2002) indicated that the BOD POD significantly overestimated %BF by 8% in female athletes and by 16% for a leaner subset of female athletes compared with UWW. It was concluded (Vescovi et al., 2002) that SKF might be more accurate than those obtained by the BOD POD for female college athletes. The findings in Vescovi et al. (2002) did not support the use of the BOD POD for the determination of %BF in female college athletes. The authors believed the use of SKF seemed more appropriate for more accurate estimates of body composition within the group of female college athletes.

A study by Vescovi et al. (2002) reported that the BOD POD overestimated %BF significantly compared to UWW and that skinfolds were more accurate in estimating %BF of lean female athletes. Ball and Altena (2004) had a problem with this conclusion because UWW was used as the criterion method. In fact, Ball and Altena argued that the

BOD POD might have been very accurate in estimating %BF in their (Vescovi et al., 2002) sample. In two recent studies (Ball and Altena, 2004; Ball and Swan, 2004), Ball and Altena (2004) found that SKF underestimated significantly compared to DXA by about 3-5% BF. Adding this amount to the Skinfold mean of the data of Vescovi et al. (2002) would yield a %BF similar to their BOD POD mean.

McCrory et al. (1998) reported no significant impact on the results when TGV was predicted in adults, but other studies presented a significant impact on %BF when measured or predicted TGV was used, especially in children (Demerath et al., 2002; Buchholz et al., 2004). Ball (2005) reassessed inter-device reliability by comparing %BF estimates from the two BP units using predicted TGV to compare results with Collins et al. (2004). The agreement in %BF estimates between the two BP units, in terms of mean difference (0.5 +/- 1.2%BF), 95% limits of agreements (-1.9-2.9%BF) and within-subject CV (3.1 +/- 2.2%), was found to be better than that observed by Collins et al. (2004), and was similar to that calculated using measured TGV in this study (Ball, 2005).

Body composition estimates by the BOD POD are based primarily on the measurement of body mass, body volume and TGV. Of the three measurements, Ball (2005) found that the body volume measurement appeared to contribute to the largest source of difference in %BF estimates between the two BOD POD units (BP1 and BP2). Ball (2005) observed a 54 ml difference in mean body volume between BP1 and BP2, 81% of the difference could be explained by differences in body volume, while body mass and TGV explained 13 and 6%, respectively. Ball (2005) suspected that the difference in body volume measurements is most likely a combination of mechanical and physiological changes. Possible physiological sources of error include perspiration, breathing rate/pattern and subject positioning. Possible mechanical sources of error include rigidity of the chamber shell and repeatability of door closure.

Ball (2005) found a disparity related to gender, where there was a significant difference in %BF estimates between BOD POD 1 and BOD POD 2 for women (0.8%BF), but not for men (0.1%BF). Ball believed this result could be due to the relatively higher variance in body fatness for women (range 13-43%BF; SD = 6.4) compared to men (range 12-32%BF; SD = 5.7) and may have resulted in a higher random error of %BF measurements. However, the magnitude of the difference in %BF between the two units for either men or women did not appear to be clinically significant (0.8 vs. 0.1%BF).

Levenhagen et al. (1999) observed a limitation within gender findings. Levenhagen et al. (1999) found a significant underestimation for men (16%) and overestimation for women (7%) when comparing values from the BOD POD to UWW. Their sample, however, consisted of only 10 men and 10 women, which may weaken their argument of a gender bias when using the BOD POD.

McCrory et al. (1995) and Vescovi et al. (2001) reported no differences in %BF between the BOD POD and UWW in samples heterogeneous in gender and body composition. However, Sardinha et al. (1998) found a mean difference of -2.6% for %BF measured by the BOD POD compared with DXA for a group of men, whereas Levenhagen et al. (1999) reported a 7% overestimation and a 16% underestimation of %BF for women and men, respectively, when the BOD POD was compared to UWW. The Vescovi et al. (2002) study supported the findings of Levenhagen et al. (1999) where there was an 8% overestimation of %BF for their (Vescovi et al., 2002) sample of women.

Wells et al, 2003 concluded that pediatric rather than adult equations for lung volume estimation should be used in children for the BOD POD. The equations of Crapo et al. (1982), derived in adults and incorporated into the BOD POD software, significantly underestimated FRC in children in comparison to the values obtained from child-specific equations (Wells et al., 2003).

Wells et al. (2003) also concluded that, although the use of adult equations for SAA calculation was not found to generate bias in the youth population, it was suggested that children's equations should be used in this context too, to minimize error in very thin or fat subjects.

Elberg et al. (2004) analyzed both the Siri and Lohman age-adjusted models for determining the validity of the BOD POD when measuring changes in %BF. Both BOD POD methods (Siri and Lohman) estimated the change in percentage body fat imperfectly, but acceptably, compared with DXA, with the Siri estimates of change in percentage body fat agreeing better with DXA than estimates made with the Lohman age-adjusted model (Elberg et al., 2004). The authors (Elberg et al., 2004) also found better agreement between DXA and estimates of percentage body fat made with the Siri equation than estimates made with the Lohman model in their previous cross-sectional study (Nicholson et al., 2001). Elberg et al. (2004) believed that with the data collected it was safe to conclude that it is not necessary to apply the Lohman model's corrections to the Siri equation to determine change in percentage body fat in growing children and adolescents.

In males, the Radley et al. (2003) study supports the results of Roemmich et al. (1997), finding an ADPSIRI %BF overestimation (0.7%). The Siri (1961) equation assumes a greater DFFM (1.1 g/cm3) than would be found in children (Lohman, 1986), thus producing an overestimation in %BF, Radley et al. (2003) argued. Radley et al. (2003) explained the smaller magnitude of the overestimation of %BF in their study (0.7% compared to 5.2 and 3.4%) by the greater age in their sample (14.87 +/- 0.41 y compared to 10.9 +/- 0.3 and 13.4 +/- 0.5 y), and thus a resultant DFFM closer to 1.1 g/cm3.

Radley et al. (2003) found the results in females using the Siri (1961) equation to be surprising. Similar to boys, the authors expected that female adolescents should have a DFFM lower than 1.1 g/cm3 (Lohman, 1986), therefore resulting in an over-prediction of %BF. These findings are supported by Nunez et al. (1999) and Nicholson et al. (2001), who reported an underestimation ADPSIRI in female subjects, by 0.1 and 3.0%, respectively. Radley et al. (2003) noted the possibility of a systematic error in BV measurements in female subjects, however they explained it was not possible to determine if the under-prediction is a function of gender or body fat content (Fields et al., 2002).

All methods in Elberg et al. (2004) were highly correlated with DXA ($p < 0.001$). No mean bias for estimates of percentage body fat change was found for the BOD POD (Siri equation) compared with DXA for all subjects examined together, and agreement between body fat estimation by the BOD POD and DXA did not vary with race or gender. Estimates of change in percent body fat were systematically overestimated by BIA equations (1.37 +/- 6.98%; $p < 0.001$) (Elberg et al., 2004). Triceps skinfold thickness accounted for only 13% of the variance in percentage body fat change. The findings in the study (Elberg et al., 2004) were supported by a prior study of 22 adults who underwent weight loss (Weyers et al., 2002).

Elberg et al. (2004) found no significant differences from DXA in estimation of change in percent body fat in African American subjects for both ADP methods.

Collins et al. (2004) studied the effect of race and musculoskeletal development on the accuracy of estimates of %BF via the BOD POD. Estimates of %BF were made with the BOD POD, UWW, DXA and the criterion, a 4C model in 64 black and white men, who were either resistance trained or served as controls.

There was no main effect of race on the validity of estimating %BF by the BOD POD (Collins et al., 2004). There was however, a significant effect of musculoskeletal development on the validity of the estimation of %BF from the BOD POD; the mean difference in %BF between %BF by the BOD POD and %BF by 4C was less in the resistance trained (1.5%BF) than in the control group (5.3%), but a large SEE of 5.5% was observed for the resistance trained (Collins et al., 2004).

The authors (Collins et al., 2004) concluded that race does not affect the accuracy of estimating %BF by the BOD POD and that estimations of %BF via the BOD POD is more accurate in larger individuals with high musculoskeletal development as a group, but warns that individual results were highly variable.

Use of the Schutte equation (Schutte et al., 1984) is a common practice for estimating %BF from BD in black males. However, Collins et al. (2004) points to studies using multi-component models (Millard-Stafford et al., 2001; Visser et al., 1997) that parallel their own findings which indicate that the use of race-specific equations are "unfounded and invalid (Collins et al., 2004)." The assumption underlying the rationale for using such equations is that higher bone density and muscularity in blacks would translate into a higher DFFM. However, current techniques that simultaneously measure bone mineral and body water provide contrasting evidence. Because the mineral fraction is relatively low (< 7% of the fat-free mass), any potential effect on the DFFM is small and is more than offset by increased body water fraction (Collins et al., 2004). And, resistance-trained individuals (blacks and whites) may have a DFFM lower than the assumed 1.1 g/ml -1 (Millard-Stafford et al., 2001; Modlesky et al., 1996). In Collins et al. (2004), the black males did not have a DFFM above 1.1 g/ml -1, consistent with Visser et al. (1997) and Millard-Stafford et al. (2001). Wagner and Heyward (2001) also indicate that the Schutte equation (Schutte et al., 1984) systematically overestimated %BF in black men (87% of sample) and proposed another race-specific equation (Collins et al., 2004). Therefore, Collins et al. (2004) stated that there is no biological basis for a race-specific equation to estimate %BF from BD.

There are a group of multivariable regression equations that estimate directly % fat mass from various skinfold thicknesses, without its logarithmic sum. Slaughter et al (1988) equations proposed for prepubertal, pubertal and postpubertal males and females are the most commonly used (Rodriguez et al., 2005).

Rodriguez et al. (2005) observed that the set of Slaughter et al. (1988) equations, performed by triceps and subscapular (TS) and by triceps and calf (TC) skinfolds, showed the best agreement in the whole sample of male and female adolescents.

According to Rodriguez et al. (2005), in a study of skinfold equation regarding male adolescents, only the equations of Slaughter et al (1988) might be appropriately used. In the Rodriguez et al. (2005) article, Slaughter et al. (1988) and Brook (1971) equations showed the lowest error and biases were not dependent on body fat. The authors postulated that the Brook (1971) equation could be used in female adolescents and Slaughter et al. (1988) equations in males and females to predict body fatness in epidemiological studies or in clinical settings.

Parker et al. (2003) used the equations of Slaughter et al. (1988) to estimate body fatness, on the grounds that these provided greatest accuracy relative to reference (two-component) models in previous studies (Reilly et al., 1995).

Janz et al. (1993), in a cross-validation of the Slaughter skinfold equations, found all of the Slaughter SKF equations to be reliable.

CHAPTER 3

METHODOLOGY

Collection of Data

Seven boys (13.14 +/- 1.14) participated in the study. The subjects are described in Table 4. Body composition of seven boys 12-14 years of age (13.1 +/- 1.1 years) was measured via the BOD POD, UWW, SKF, BIA, and BMI. Mean body mass of the subjects was 63.7 +/- 18.9 kg. Criterion for inclusion was based on a sample of the general population of children. Subjects were recruited from the local community by the UNLV faculty. Measurements were performed in the afternoon on the same day within a 2-hour period for all subjects.

The order of testing of the body composition was done with an emphasis on subjects being tested lastly using the UWW technique to minimize potential error from subject saturation in the water and possible changes in body temperature.

Participant written informed consent along with parental/guardian informed consent were obtained before testing (see appendix).

Height and Weight: Body mass (weight) was measured using the calibrated BOD POD electrical scale. Body mass was also measured on a balance beam scale.

Height was measured to the nearest one-half inch using a wall-standing stadiometer with subjects standing erect with feet flat on the floor without footwear.

Body Mass Index - BMI: Body Mass Index was determined based on the height and weight of each subject.

For children and teens, BMI is age- and gender-specific and is often referred to as BMI-for-age. After BMI is calculated for children and teens, the BMI number is plotted on the CDC BMI-for-age growth charts (see appendix) to obtain a percentile ranking. Percentiles are the most commonly used indicator to assess the size and growth patterns of individual children in the United States. The percentile indicates the relative position of the child's BMI number among children of the same gender and age.

BMI for children is calculated by dividing a person's weight by the square of their height, where:

BMI = Weight in kilograms / Height in meters2 (CDC)

BMI-for-age weight status categories and the corresponding percentiles are shown in table 1.

Circumference Measurements– Waist-To-Hip Ratio: Circumference measurements were made on all of the subjects by the same investigator. All circumference measurements were made to the nearest 0.5 cm using an inelastic tape in accordance with the Anthropometric Standardization Reference Manual (Lohman, 1988). Waist measurement was recorded at the minimal horizontal circumference between the ribs and the iliac crest. Hip circumference was measured at the maximum circumference over the buttocks.

BOD POD: Body volume was measured using the BOD POD whole body air displacement plethysmography (Life Measurement, Concord, CA) and software version 3.1.0, in accordance with the manufacturer's operation instructions.

All measurements were performed by the same investigator. Before any measurements are taken, a system testing calibration, using a cylinder of a known volume (50.284 liters), and manual calibration of the scales, using 'two 10-kg weights', were completed. After the calibration, subjects were weighed and then entered the BOD POD chamber wearing only a tight-fitting swimsuit (with the exception of one subject, who wore mesh shorts) or cycling/lycra shorts and a swim cap.

To calculate raw body volume, two 50-second measurements were performed. If these measurements are within 150 mL or 0.2% (whichever is larger), they were accepted, and the mean volume was used for further calculations. If these requirements were not met, a third test was administered.

SKINFOLDS (SKF): Skinfold thickness was measured by a trained technician, who completed a test-retest reliability study with Lange Skinfold calipers. The instrument used was a Lange Skinfold caliper, which conforms to specifications established by the committee of the Food and Nutrition Board of the National Research Council of the United States.

Percentage body fat was estimated using the 2-site Skinfold Formula, triceps and subscapular (Slaughter et al., 1988).

The Skinfold measurements were taken at the arm (triceps, at vertical fold on the back of the upper arm midway between the shoulder and elbow joints) and back (scapula, a diagonal fold on the interior angle of the scapula). All SKF measurements were taken on the same day by the same trained investigator. The Slaughter (1988) equation was used to determine body fat percent through skinfold thickness. See table [X] for the Slaughter equation chart.

Bioelectrical Impedance – BIA: Bioelectrical impedance was measured using a trained technician, using the Tanita Instrument in accordance with the manufacturer's operation instructions. Spencer et al. (2003) had shown that the estimation of % TBF in young men using a stand-on footpad analyzer is closely related to results obtained using the more time-consuming tetrapolar analyzer. Jebb et al. (2000) summarized that the Tanita body fat analyzer is a valid alternative method to other impedance-based prediction techniques for the measurement of body fat. The subjects removed their shoes, socks and any metal jewelry before measurement.

Underwater Weighing – UWW: UWW was measured by the same investigators, using the equipment at the University of Nevada, Las Vegas Exercise Physiology Laboratory. The subjects were in as little clothing as possible (swim trunks or lycra shorts). After being weighed on land, the subject got wet before entering the underwater weighing tank by showering. Most importantly, the hair was fully saturated with water before entering the tank. A weight jacket with sinker weights (sinkers) was weighed under water before being placed on the subject. The subject then had the weight jacket placed on them to help keep the body underwater without effort. The subject used a snorkel to breathe while underwater. When ready, the subject submerged himself entirely under the water. When ready, the subject was instructed to expire some air and hold their breath. After the time of exhalation, the underwater weight was recorded by printing the underwater weight with the attached computer and printer. The subject was then prompted to lift their head out of the water and breathe into the re-breathing bag, with approximately eight inhalations and exhalations into the bag to conclude the test.

CHAPTER 4

FINDINGS OF THE STUDY

Analysis of Data

Mean average of the BOD POD was 21.94 (+/- 7.8%) compared to 21.8 (+/- 7.3%) for UWW. There was no statistically significant difference between the two methods (see table 5).

Mean average of the SKF was 23.2% (+/- 7.7%) compared to 21.8 (+/- 7.3%) for UWW. There was no statistically significant difference between the two methods (see table 6).

Mean average of the BIA was 20.8% (+/- 7.6%) compared to 21.8 (+/- 7.3%) for UWW. There was no statistically significant difference between the two methods (see table 7).

A t-test was used to test whether or not the mean subject differences in the BOD POD were significantly different from UWW, where: $t(6) = .384$; $p > 0.05$.

The difference between the BOD POD and UWW was not significant beyond the 5% level.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Discussion of Results

The results obtained in this study associate with the results from prior investigation regarding the accuracy of the BOD POD when using UWW as the criterion. As mentioned in Chapter 2, four of the studies mentioned in the 2005 review were analyzed in the 2001 review of air-displacement plethysmography (Fields et al., 2002). Two of the studies yielded significant differences in percent body fat from the BOD POD compared to UWW (Lockner et al, 2000; Fields and Goran, 2000).

Demerath et al. (2002) also observed results where the mean differences between UWW and the BOD POD were not significant in children. Wells et al. (2003) reported a mean bias of less than 0.5% when measuring the degree of accuracy for the BOD POD versus multi-compartment models. The study concluded that accuracy of the BOD POD was high for the whole group (children aged 5-7 yrs of age).

While UWW continues to remain the "gold standard" for measuring body composition, the BOD POD is rapidly becoming an effective technique for determining body composition and is less intimidating than UWW, where it does not require the subject to be submerged underwater.

The difference of 0.13%BF in this pilot study associates with the other studies done on children (Nunez et al., 1999; Dewit et al., 2000; Fields and Goran, 2000; Lockner et al., 2000; Wells et al., 2000). See Table 8 for the results of the other studies regarding children and the BOD POD.

As mentioned in Chapter 2, a review by Fields et al (2003) revealed that two previous studies observed a significant difference between the BOD POD and UWW, while the other three studies reported no significant difference.

The findings in this study also found a slight overestimation of %BF, but not significantly so, which agrees with Nunez et al., Dewit et al. (2000) and Wells et al. (2000).

BMI appeared to overestimate body fat in the leaner subjects and underestimated body fat in the subjects who appeared to have less muscle mass than the norm. This was consistent with the CDC (CDC.gov) reporting similar findings.

This is an important finding since the BOD POD is a less invasive method for measuring body composition in children and may be used for a larger percentage of the youth population when compared to UWW. Also, there was a strong relationship between SKF and UWW as well as BIA and UWW. Further investigation may improve the accuracy of the BOD POD for assessing body composition in children and provide an alternative to UWW. Regarding BIA and UWW, a larger population study may have produced different results. The same logic can be applied to SKF and UWW as well as the BOD POD and UWW.

Conclusions and Recommendations for Further Study

Future research should be applied to determining the accuracy of the BOD POD in children when compared to UWW. The results have been inconclusive in terms of statistical significance and a large population study on children is recommended to help determine the accuracy of the BOD POD.

APPENDIX

Table 1: BMI Table For Children

Weight status category	Percentile range
Underweight	Less than the 5th percentile
Healthy weight	5th percentile up to the 85th percentile
At risk of overweight	85th to less than the 95th percentile
Overweight	Equal to or greater than the 95th percentile

Table 2: Trend Towards Underestimation %BF in Men and Overestimation %BF in Women.

Reference	N	Char	%BF ADP	UWW	% Diff
Vescovi et al., 2002	80	F	21.2	19.4	8.5
Vescovi et al., 2002	39	F-L	17.1	14.3	16.4
Levenhagen et. Al., 1999	10	M-L	15.7	18.6	15.6
Collins et al., 1999	69	M-L	15.1	17	11.2
Stafford et al., 1998	40	M-L	9.9	14	29.3
Collins et al., 1998	50	M-L	15	18	16.7
Vescovi et al., 2001	32	M-L, F-L	16.4	14.1	14
Vescovi et al., 2001	29	M-OW, F-OW	29.9	30.8	2.9
Levenhagen et al., 1999	10	F-OW	31.2	29.2	6.4
Yee and Kern, 1998	28	F-OW	37.7	37.5	0.5
Yee and Kern, 1998	30	M-OW	27.1	26.5	2.2

McCrory et al., 1995	68	M-AVE, F-AVE	25.2	25.4	0.8

Table 3: Subject Results: %BF

	BODPOD	UWW	SKF	BIA	BMI	WtHr
1	8.30%	9.10%	10.90%	9.00%	19.5	0.8
2	19.30%	20.70%	23.60%	23.50%	20.9	0.8
3	34.80%	34.50%	36.80%	34.00%	29.4	0.9
4	22.70%	21.80%	19.80%	22.00%	24	0.8
5	23.60%	22.70%	25.70%	20.50%	24.4	0.8
6	22.30%	21.70%	23.50%	20.50%	20.2	0.8
7	22.60%	22.20%	22.10%	16.00%	22.1	0.9
Averages	21.90%	21.80%	23.20%	20.80%	22.9	0.8

Table 4: Subject Data

	AGE	BMI-%	BMI	HT (m)	WT(kg)	WHr
1	14.3	45	19.5	1.715	57.4	0.84
2	13.8	68	20.9	1.632	55.6	0.78
3	13.3	97	29.4	1.676	82.6	0.91
4	14.6	87	24	1.676	67.6	0.79
5	12.7	93	24.4	1.651	66.5	0.81
6	12.7	70	20.2	1.537	47.6	0.78
7	14.7	74	22.1	1.765	68.9	0.86
Averages	13.7		22.9	1.665	63.7	0.82

WHr =	Waist to hip ratio
BMI =	Body Mass Index
HT (m) =	Height in meters
WT (kg) =	Weight in kg

Table 5: BOD POD vs. UWW Statistics

T-Test

[DataSet1] /Users/robertkaplan/Documents/UNLV_THESIS.sav

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ADP	21.9429	7	7.77064	2.93703
	UWW	21.8143	7	7.35718	2.78075

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	ADP & UWW	7	.995	.000

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	ADP - UWW	.12857	.88641	.33503	-.69122	.94836	.384	6	.714

Table 6: SKF vs. UWW Statistics

T-Test

[DataSet1] /Users/robertkaplan/Documents/UNLV THESIS.sav

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SKF	23.2000	7	7.69762	2.90943
	UWW	21.8143	7	7.35718	2.78075

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	SKF & UWW	7	.972	.000

Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	SKF - UWW	1.38571	1.81423	.68571	-.29217	3.06360	2.021	6	.090

Table 7: BIA vs. UWW Statistics

T-Test

[DataSet1] /Users/robertkaplan/Documents/UNLV_THESIS.sav

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	BIA	20.7857	7	7.58758	2.86784
	UWW	21.8143	7	7.35718	2.78075

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	BIA & UWW	7	.933	.002

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	Upper			
Pair 1	BIA - UWW	-1.02857	2.75240	1.04031	-3.57412	1.51698	-.989	6	.361

Table 8: Summary Of Studies That Compared Percentage Body Fat Measurements made with the BOD POD (ADP) or Underwater Weighing (UWW)

Reference	N	Sex	Age	BMI	ADP - UWW %BF
Nunez et al., 1999	48	M,F	19-Jun	21 +/- 4	1.2
Dewit et al., 2000	22	M,F	13-Aug	17 +/- 2	0.8 +/- 5.4
Fields and Goran, 2000	25	M,F	14-Sep	13-35	2.6 +/- 3.4
Lockner et al., 2000	54	M,F	18-Oct	NR	-2.9
Wells et al., 2000	10	NR	14-Jul	17 +/- 2	0.6 +/- 0.7

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