Journal of Exercise Physiologyonline
(JEPonline)

Volume 8 Number 2 April 2005

Official Research Journal of The American Society of Exercise Physiologists (ASEP)

ISSN 1097-9751

Body Composition

COMPARISON OF BODY COMPOSITION MEASURES TO DUAL-ENERGY X-RAY ABSORPTIOMETRY

RODNEY G. BOWDEN[1], BETH A. LANNING[1], EVA I. DOYLE[1], HOLLY M. JOHNSTON[1], ERIKA I. NASSAR[1], BECKY SLONAKER[1], GEORGENE SCANES[1], CHRIS RASMUSSEN[1]

[1]Department of Health, Human Performance, and Recreation; Center for Exercise, Nutrition, and Preventive Health Research, Baylor University, Waco, USA.

ABSTRACT

Bowden, RG, Lanning, BA, Doyle, EI, Johnston, HM, Nassar, EI, Slonaker, B, Scanes, G. Comparison Of Body Composition Measures To Dual-Energy X-Ray Absorptiometry. ***JEPonline***. 2005;8(1):1-9. The purpose of the study was to examine the validity of body mass index (BMI), bioelectrical impedance (BIA) and skin folds (SF) in predicting body composition when compared to dual-energy X-ray absorptiometry (DEXA). Researchers examined four accepted methods of body composition assessment: BMI, DEXA, SF and BIA. A convenience sample of sedentary college-aged students (N=108) from introductory health classes at a southern university were chosen to participate in a 12-week behavior change study. All measures were obtained by trained technicians with proficiency in each of the body composition measures. Pearson correlations for each comparison were 0.824 for DEXA and SF, 0.798 for DEXA and BIA, and 0.551 for DEXA and BMI. All correlations were significant to $p<0.001$. Stepwise multiple regression revealed SF as the greatest predictor of DEXA with 67.5% of variance explained ($r^2=0.675$) followed by BIA (12.1%) and BMI (2.6%). Total variance explained was 82.2% ($R^2=0.822$). Differences in mean body fat percentages are reported but were not significantly different. By combining the findings of the correlations, regression analyses, beta weights and scatter plots, BMI may not be an appropriate measure to assess body fat in college-aged participants.

Key Words: Body Mass Index, Bioelectrical Impedance, Skinfold

INTRODUCTION

Validity in body composition measurement is an important factor in understanding the impact body fat and obesity have on health outcomes. Dual-energy x-ray absorptiometry (DEXA) has been shown to be an effective measure of body composition and has been considered a valid and reliable reference measure (6,7,18). DEXA has the advantage of showing a three-dimensional model of body composition and taking into account bone free lean mass (3,22). Yet, access to DEXA by the general public is rather limited.

Although DEXA has been proven a better measurement of body fatness than skin fold (SF) among adults, in younger populations this difference is less pronounced and needs further study (9). Differences in measurement between DEXA and SF do exist and this discrepancy has been explained by variations in male and female visceral and subcutaneous fat contents. Nevertheless, instrument validity has been called into question in young study participants (9). Studies suggest high correlations between DEXA and SF of 0.75-0.94 in older populations (5,14,20), yet few studies have examined younger populations with none to date using sedentary college-aged participants.

Body mass index (BMI) is a routinely used indirect measure for body fatness, specifically obesity, in epidemiological research. The Centers for Disease Control and Prevention suggest BMI is more highly correlated with body fat than height and weight (2,12). A BMI of 25 or more is considered a risk factor for premature death and disability (14). Lintsi et al. (9) discovered strong correlations (0.81-0.84) between BMI and DEXA in teenagers. However, in previous studies, BMI was proven an inappropriate measure for athletes, the elderly, obese children, and children with disease states (13,16,19) and is unable to track body fat content. The authors of the present study were unable to find any studies that compared DEXA and BMI in a young sedentary college-aged population.

Bioelectrical impedance analysis (BIA) can be a useful technique for body composition analysis in healthy individuals and in those with a number of chronic conditions such as mild-to-moderate obesity, diabetes mellitus, and other medical conditions in which major disturbances of water distribution are not prominent. Researchers have published correlations between 0.84 and 0.93 between BIA and DEXA in healthy and diseased patients (5,8,17) but only in one study were participants young, yet they were under the age of nineteen, and physically active Estonian conscripts (9). The authors were unable to find any studies using college-aged participants.

Wattanapenpaiboon et al. (20) suggested that DEXA, SF, BMI, and BIA not only differ in the principles of the measurements, but also in the various assumptions required for calculations. Finally, only three studies have been conducted that reviewed DEXA, BMI, BIA, and SF, but these studies used 17-18 year old Estonian conscripts, (9) elderly people (15), and dancers (21) as study participants. No studies to date have combined the aforementioned variables of DEXA, BMI, BIA, and SF, measured the same participants for each measure on the same day, and used sedentary college-aged individuals as the study population. Therefore the purpose of this study was to examine the validity of BMI, BIA and SF when compared to DEXA among a young college-aged population.

METHODS

Participants

One hundred and eight sedentary participants who self-reported they had been inactive for the previous three months volunteered for the study. To avoid major disturbances of water distribution volunteers were not allowed to participate if they had any metabolic disorder including known electrolyte abnormalities; thyroid disease, or hypogonadism; were taking thyroid, androgenic medications; or had taken ergogenic levels of nutritional supplements that may have affected muscle mass (e.g., creatine, HMB), anabolic/catabolic hormone levels (androstenedione, DHEA, etc), or weight loss (e.g., ephedra, thermogenics, etc), within three months prior to the start of the study. One-hundred and eight volunteers meeting eligibility criteria were informed of the requirements of the study and signed informed consent statements in compliance with the Human Subjects Guidelines of the university. Percent body fat was measured using DEXA, BIA, BMI, and SF within a two-hour time-span after a twelve hour fast.

Bioelectrical Impedance Analyzer

Body fat was estimated using a Xitron 4200 Bioelectrical Impedance Analyzer (*San Diego, CA*) which measures bio-resistance of water and body tissues based on a minute low energy, high frequency current (500 micro-Amps at a frequency of 50 kHz) transmitted through the body. One electrode was placed on the posterior surface of the right wrist, between the radial and ulna styloid processes; another electrode was placed on the posterior surface of the right hand at the distal base of the second metacarpal; the third electrode was placed on the anterior surface of the right foot at the distal end of the first metatarsal. Participants were in the supine position on a non-conductive table. Body fat was calculated from the fat mass percentage, reported by the Xitron 4200 Bioelectrical Impedance Analyzer, which was confirmed to be in calibration according to manufacturer instructions. All measurements were taken on the right side of the body using disposable electrodes. Water compartments were directly calculated from resistance values with extracellular water and intracellular water. The following equations used to calculate body fat were provided by the manufacturer: $FFM = 6.493 + 0.4936(ht^2/resistance) + 0.332(wt)$, and for females, $FFM = 5.091 + 0.6483(ht^2/resistance) + 0.1699\ (wt)$.

Hologic 4500W Dual-Energy X-ray Absorptiometry

Body composition/bone density was determined using a calibrated Hologic (Hologic Inc., Waltham, MA, USA) 4500W dual-energy x-ray absorptiometry device (DEXA) by qualified personnel with x-ray technology training. The DEXA body composition test required each subject lie down on their back in a standardized position wearing only a pair of shorts and t-shirt, or a gown. A low dose of radiation was used to scan the participants for approximately six minutes. The DEXA segments regions of the body (right arm, left arm, trunk, right leg, and left leg) into three compartments for determination of fat, soft tissue (muscle), and bone mass. The amount of absorbed energy from the x-ray source is used to determine body fat percentage. Additionally, body fat levels were obtained from the manufacturer’s ready report that had been adjusted for participant gender, race, and age. Body fat was determined by measuring differential attenuation of bone, fat and lean tissue between the lower and higher energy of the x-ray beam. Quality control calibration procedures were performed on a spine phantom (Hologic X-CALIBER Model DPA/QDR-1 anthropometric spine phantom) prior to the testing session. In addition, weekly calibration procedures were performed on a density step calibration phantom. The DEXA was also calibrated on-site, twice year by the manufacturer and had been calibrated four weeks prior to testing.

Skin Folds

Skinfold thickness was measured using Lange (Cambridge Instrument, Cambridge, MA, USA) calipers. The sum of three sites was used with measurements from the chest, abdomen, and thigh in males and triceps, suprailliac, and thigh for females. The chest measurement was a diagonal fold, one-half the distance between the anterior anxillary line and the nipple. The abdominal measurement was a vertical fold, 2 cm to the right side of the umbilicus. The triceps measurement was a vertical fold on the posterior midline of the upper arm, halfway between the acromion and olecranon processes with arm held freely to the side of the body. The suprailiac measurement was a diagonal fold in line with the natural angle of the iliac crest taken in the anterior axillary line immediately superior to the iliac crest. The thigh measurement was a vertical fold on the anterior midline of the thigh, midway between the proximal border of the patella and inguinal crease. All measurements were made on the right side of the body. Three measurements at each site were performed with the reported measurement being an average of three trials. A complete round of measurements was completed, followed by second trial, and then followed by a third trial. Body fat levels were determined using the formulas by Jackson and Pollock (1). Female %BF = 1.099421 – 0.0009929 (sum of 3 skinfolds) + 0.0000023 (sum of 3 skinfolds)^2 – 0.0001392 (age). Male %BF = 1.10938 – 0.0008267 (sum of 3 skinfolds) + 0.0000016 (sum of 3 skinfolds)^2 – 0.0002574 (age).

Body Mass Index

Body Mass Index was calculated using weight expressed in kilograms divided by height in meters squared was used to calculate BMI (1). Height and weight was measured in a laboratory setting with trained technicians using a balance scale to the nearest 0.1 kg. Body height was measured to the nearest 0.5 cm with the participant standing with their back to a stadiometer. Participants wore light clothes and no shoes while height and weight calculations were performed.

Statistical Analyses

The Statistical Package for the Social Sciences software for Windows (version 10.0, SPSS Inc, Chicago, IL) was used to perform the statistical analysis of the raw data. Pearson correlation coefficients were used to determine relationships between DEXA and BMI, DEXA and BIA, and DEXA and SF. Significant differences between mean body fat percentages for DEXA, BMI, BIA, and SF were calculated using ANOVA. A step-wise multiple regression was calculated to reveal the best predictors for DEXA. Descriptive statistics were used to calculate means and standard deviations for each measure of body composition. The level of significance was set a-priori at $p<0.05$. Effect size calculations were performed for ANOVA (eta^2) and regression analysis (R^2).

RESULTS

Males and females averaged 20.32±1.88 and 19.65±1.35 years of age respectively. Body fat results for all body composition methods are found in Table 1. Results from one-way ANOVA for each of male and female data sets are presented in Table 2. Correlation data for method comparisons are presented in Table 3.

Table 1: Descriptive statistics for body fat measures.

Gender	*Body Comp*	*Mean±SD*
Female	BMI	23.97±5.12
	SF	28.337.93
	BIA	38.335.84
	DEXA	31.287.26
	Age	19.651.35
Males	BMI	26.794.66
	SF	20.027.34
	BIA	30.048.08
	DEXA	24.046.67
	Age	20.321.88

Table 2: Simple one-way ANOVA for mean Body composition measures compared to DEXA.

Gender	*Body Comp*	*p-value*	*f-ratio*	*eta^2*
Female	BMI	0.067	3.3	0.963
	SF	0.051	3.79	0.954
	BIA	0.112	2.62	0.87
Male	BMI	0.076	6.35	0.976
	SF	0.495	1.26	0.921
	BIA	0.585	1.02	0.974

Table 3: Pearson correlations between DEXA and other body composition measures.

Variables	*Correlation*	*p-value*	*R2*	*SEE*
DEXA and BMI	0.551	0.01		
DEXA and SF	0.824	0.01		
DEXA and BIA	0.798	0.01		
Regression Model			0.822	3.37

A step-wise multiple regression analysis was calculated revealing SF as the greatest predictor of DEXA with 67.5% of variability explained (r^2=0.675) followed by BIA (12.1%) and BMI (2.6%). Total variability explained was 82.2% (R^2=0.822). Beta weights were calculated for BIA (0.457), SF (0.425) and BMI (0.197). Standard error of the estimate for the regression was 3.37 % body fat. Scatter plots for DEXA and SF, DEXA and BIA, and DEXA and BMI can be found in Figures 1-3.

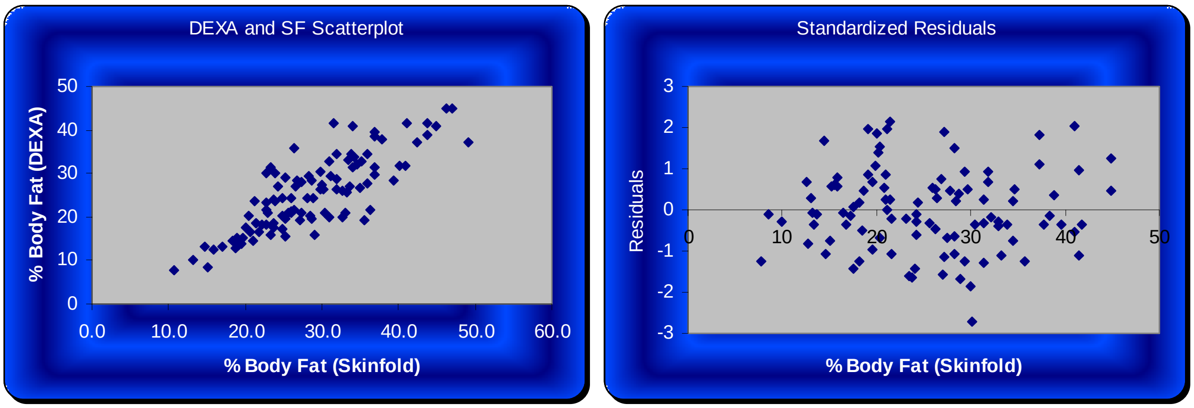

Figure 1. Scatterplot and Standardized Residuals Plot for DEXA and SF.

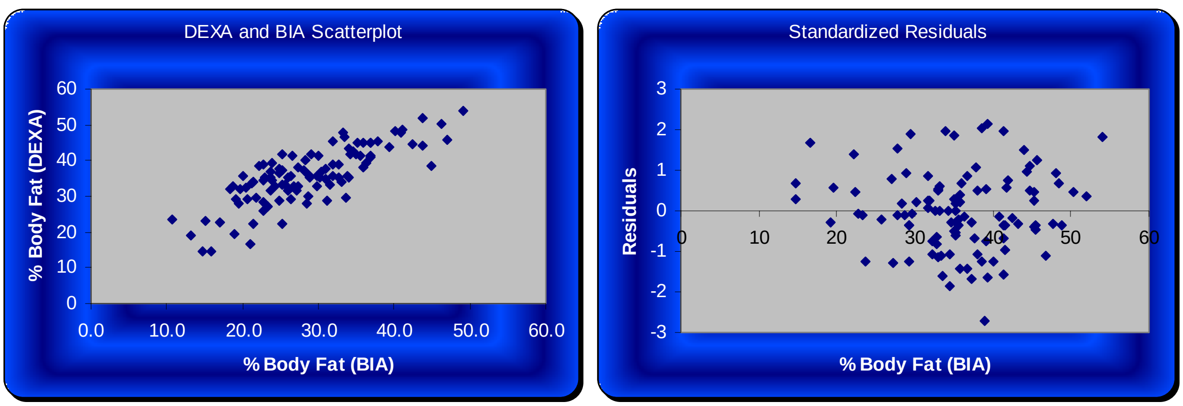

Figure 2. Scatterplot and Standardized Residuals for DEXA and BIA

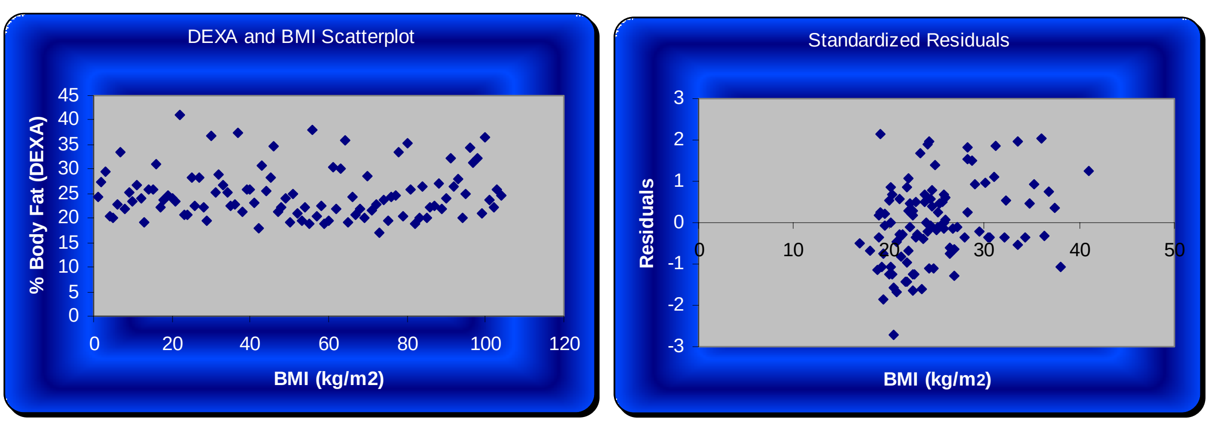

Figure 3. Scatterplot and Standardized Residuals for DEXA and BMI

Effect size calculations for ANOVA in females revealed an eta^2 of 0.963 (DEXA and BMI), 0.954 (DEXA and SF), and 0.870 (DEXA and BIA) and are displayed in Table 2. Effect size calculations for

ANOVA in males revealed and eta^2 of 0.976 (DEXA and BMI), 0.921 (DEXA and SF), and 0.974 (DEXA and BIA) and are displayed in Table 2.

DISCUSSION

DEXA has been shown to be an effective measure of body composition and has been considered a valid and reliable reference measure of fat mass percentage (6,7,10). However, DEXA is not used in many programs and universities, necessitating the need for valid, reliable, and cost effective means of body composition measurement. Consequently the researchers in the present study compared SF, BIA, and BMI to DEXA to compare the strength of correlation between these measures and DEXA. Additionally, the authors attempted to identify which variables were more likely to predict DEXA body fat levels among a college-aged population using regression analysis. The study authors found more agreement between SF and BIA with DEXA and less agreement between BMI and DEXA.

Skin fold thickness is a well-established, simple and inexpensive technique for determining body fat in a diversity of subjects and settings. Researchers have published correlations between SF and DEXA to be 0.75-0.94 in older populations (8,9,14). The present study has demonstrated the validity of SF when compared to DEXA with college-aged participants finding a correlation of 0.824. The present study adds to the literature, finding that SF with highly trained technicians can be a valid measure of body fat in a college-aged population. Some discrepancies, however, did exist, but appear to be minimal. The SF technique was found to underestimate body fat percentage when compared to DEXA in the present study, but the differences were not statistically significant. Though SF underestimated body fat levels compared to DEXA, the lack of significant differences in mean body fat levels adds to the validity of SF as a reliable measure of body fat in a college-aged population.

Bioelectrical impedance is another measure of body composition that has been used successfully to monitor body composition in clinical settings (8). However, no studies were found that demonstrated validity in college-aged populations. Additionally, hydration status has been demonstrated to affect the validity of the body composition measure (23). The present study participants were properly hydrated when BIA was calculated revealing a correlation with DEXA of 0.798. The present study agrees with the literature that in disease-free and hydrated participants, BIA is a valid means of measuring body fat, but also demonstrates new findings suggesting it is appropriate for use in college-aged populations. Bioelectrical impedance was found to overestimate fat mass percentage compared to DEXA in the present study, but the differences were not found to be statistically different. Though differences in levels existed, their lack of statistical significance and strong correlation supports the validity of this method in college-aged populations.

Lintsi et al. (9) reported a correlation of 0.81-0.84 between BMI and DEXA in 17-18 year old Estonian conscripts. The correlation of 0.551 found between BMI and DEXA in this study does not support the finds of Lintsi et al. and Svendsen et al. (15). The NIH has reported BMI as an acceptable measure of adiposity in healthy populations, cautioning against the use in athletic populations (13,16,19). Additionally, the NIH supports BMI as a valid measure of body fat percentage or adiposity in sedentary populations (11). The present study does not support these findings. Secondly, the step-wise multiple regression revealed that very little variability was explained by BMI (2.6%), suggesting that BMI is not a good predictor of DEXA in this study population. Secondly, the beta weight calculations (0.197) revealed BMI is this study to be poor predictor of DEXA. Finally, figure 3 also demonstrates that BMI in this study was not a good predictor of DEXA. Though the participants of this study were sedentary for at least three months and were not an athletic population, the validity of

BMI was still not demonstrated. By combining the findings of the correlation, regression analysis, beta weights and scatter plot reveal a measure that may not be appropriate for college-aged participants. The results may suggest a need to study further the validity of BMI as compared to DEXA in sedentary college-aged populations.

The results of the step-wise multiple regression, small standard error of the estimate revealing high precision in the regression model, and scatter plots demonstrated better prediction strength with SF and BIA. Skin folds contributed the most to the explained variance for DEXA (67.5%) followed by BIA (12.1%) and BMI (2.6%). Figures 1-3 demonstrate the variability in each comparison, revealing BMI as the least valid method in this study.

CONCLUSIONS

Several limitations existed in the study. First, a convenience sample of college students enrolled in introductory health courses was used and therefore the results should not be generalized beyond traditional college-aged people. Second, the participants were young (males and females averaged 20.32 and 19.65 years of age respectively) and fairly healthy. Lastly, the sample group consisted of predominately white (non-Hispanic) individuals. Further studies examining body composition measurements in other ethnic groups would expand the data needed to recommend the most cost-efficient and accurate method to assess body fatness in the general public.

DEXA has been identified as a valid measure for body fat percentage with SF, BIA, and BMI identified as acceptable measures of fat mass percentage in older populations. The authors of the present study discovered that SF and BIA are valid measures of fat mass percentage when compared to DEXA in a college-aged population. Both measures could be used when attempting to measure body fat percentage in a non-invasive and less inexpensive modality, especially when DEXA is not available. Body mass index in the present study was not found to be as valid a measure when compared to DEXA in a college-aged population. Though BMI has been identified as a measure that is inappropriate for athletic populations, the researchers found that BMI was a poor predictor in a college-aged, sedentary population.

ACKNOWLEDGEMENTS

The *Faculty Research Investment Program* at Baylor University provided funding for this study
The *Exercise and Sports Nutrition Lab* at Baylor University provided body fat assessments for the study. Anthony L. Almada, MSc and Imaginutrition provided the DEXA scans for this study
The study authors wish to express their gratitude for tireless efforts of the technicians in the *Exercise and Sports Nutrition Lab* at Baylor University

Address for correspondence: Bowden, RG, PhD., Department Health, Human Performance, and Recreation, Center for Exercise, Nutrition, and Preventive Health Research, Baylor University, Waco, Texas, USA, 76798-7313. Phone: (254)710-4020; FAX: (254)710-3527; Email: Rodney_Bowden@baylor.edu.

REFERENCES

1. Hansen NJ, Lohman TG, Going SB, Hall MC, Pamenter RW, Bare LA, Prediction of body composition in premenopausal females from dual-energy X-ray absorptiometry. ***J Appl Physiol*** 1993;75:1637-1641.

2. Houtkooper LB, Going SB, Sproul J, Blow RM, Lohman TG Comparison of methods for estimating body-composition changes over 1 y in postmenopausal women. ***Am J Clin Nutr*** 2000;72(2):401-406.

3. Wang, W, Wang, Z, Faith, S, Kotler, D, Shih, R, Heymsfield, SB. Regional skeletal muscle measurement: Evaluation of new dual-energy X-ray absorptiometry model. ***J Appl Physiol*** 1999;87:1163 – 1171.

4. Clasey, JL, Kanaley, LJA, Wideman, SB, Heymsfield, SB, Teates, CD, Gutgesell, ME, et al. Validity of methods of body composition assessment in young and older men and women. ***J Appl Physiol*** 1999;86:1728 – 1738.

5. Withers, RT, LaForgia, RK, Pillans, NJ, Shipp, BE, Chatterton, CG, Schultz, F. Comparison of two-, three-, and four-compartment models of body composition analysis in men and women. ***J Appl Physiol*** 1998;85:238 – 245.

6. Lintsi, M, Kaarma, H, Kull, L. Comparison of hand-to-hand bioimpedance and anthropometry equations versus dual-energy X-ray absorptiometry for the assessment of body fat percentage in 17-18-year-old conscripts. ***Clin Physiol Funct Imaging*** 2004;24(2):85-90.

7. Erselcan, T, Ferhan, C, Saruhan, S, Tulay, A. Comparison of body composition analysis methods in clinical routine. ***Ann of Nutri and Metab*** 2000;44:243-248.

8. Stewart, SP, Bramely, PN, Heighton, R, Green, JH, Horsman, A, Losowsky, MS, Smith, MA. Estimation of body composition from bioelectrical impedance of body segments: Comparison with dual-energy X-ray absorptiometry. ***Br J Nutr*** 1993;69(3):645-655.

9. Wattanapenpaiboon, N, Lukito, W, Straus, BJG, Hsu-Hage, BHH, Wahlqvist, ML, Stroud, DB. Agreement of skinfold measurement and bioelectrical impedance analysis (BIA) methods with dual energy X-ray absorptiometry (DEXA) in estimating total body fat in Anglo-Celtic Australians. ***Inter J of Obesity*** 1998;22: 854-860.

10. Centers for Disease Control and Prevention: ***Nutrition and Physical Activity***.Washington, DC: National Center for Chronic Disease Prevention and Health Promotion. http://www.cdc.gov/nccdphp/dnpa/bmi/index.htm.

11. National Research Council. **Diet and health: implications for reducing chronic disease risk**. Washington, DC: National Academy Press, 1989.

12. Prior, BM, Cureton, KJ, Modlesky, EM, Sloniger, MA, Saunders, M, Lewis, RD. In vivo validation of whole body composition estimates from dual-energy X-ray absorptiometry. ***Am J Physiol*** 1997;83:623 – 630.

13. Tyrell, VJ, Richards, G, Hofman, P, Gillies, GF, Robinson, E, Cutfield, WS. Foot-to-foot bioelectrical impedance analysis: A valuable tool for the measurement of body composition in children. ***Int J of Obesity*** 2001;25:273-278.

14. Warner, JT, Cowan, FJ, Dunstan FD, Gregory, JW. The validity of body mass index for the assessment of adiposity in children with disease states. ***Ann Hum Biol*** 1997 May-Jun; 24(3): 209-215.

15. Kamimura, MA, Avesani, CM, Cendoroglo, M, Canziani, MEF, Draibe, SA, Cuppari, L. Comparison of skinfold thickness and bioelectrical impedance analysis with dual-energy X-ray absorptiometry for the assessment of body fat in patients on long-term haemodialysis therapy. ***Nephrol Dial Transplant*** 2003;18:101-105.

16. Van den Ham, EC, Kooman, JP, Christiaans, MH, Nieman, FH, Van Kreel, BK, Heidendal, GA, et al. Body composition in renal transplant patients: Bioimpedance analysis compared to isotope

dilution, dual energy X-ray absorptiometry, and anthropometry. ***J Am Soc Nephrol*** 1999 May; 10(5):1067-1079.

17. Svendsen, OL, Haarbo, J, Heitmann, J, Berit L, Gotfredsen, A, Christiansen, C. Measurement of body fat in elderly subjects by dual-energy x-ray absorptiometry, bioelectrical impedance, and anthropometry. ***Am J Clin Nutr*** 1991;53:1117-1123.

18. Wilmerding, MV, Gibson, AL, Mermier, CM, Bivins, KA. Body composition analysis in dancers: methods and recommendations. ***J of Dance Med and Sci*** 1993;7(1):24-31.

19. American College of Sports Medicine. **Guidelines for Exercise Testing and Prescription**. 6th Ed. Baltimore, MD: Lippincott, Williams & Wilkins, 2000.

20. Lockner, DW, Heyward, VH, Baumgartner, RN, Jenkins, KA. Comparison of air-displacement plethysmography, hydrodensitometry and dual X-ray absorptiometry for assessing body composition of children 10-18 years of age. ***Annals New York Acad Sci*** 2000 May;904:72-78.

21. Woodrow, G, Oldroyd, B, Smith, MA, Turney, JH. Measurement of body composition in chronic renal failure: Comparison of skinfold anthropometry and bioelectrical impedance with dual energy X-ray absorptiometry. ***Eur J Clin Nutr*** 1993;50:295-301.

22. National Institutes of Health. **Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults**. Washington, DC NIH Publication No. 98-4083. September, 1998.