

**BODY COMPOSITION COMPARISON:  
BIOELECTRIC IMPEDANCE ANALYSIS WITH DXA  
IN ADULT ATHLETES**

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**By  
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**The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled**

**BODY COMPOSITION COMPARISON:  
BIOELECTRIC IMPEDANCE ANALYSIS WITH DXA  
IN ADULT ATHLETES**

**presented by Joe Company,**

**a candidate for the degree of master of arts, and hereby certify that, in their opinion, it is worthy of acceptance.**

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# **BODY COMPOSITION COMPARISON: BIOELECTRIC IMPEDANCE ANALYSIS WITH DXA IN ADULT ATHLETES**

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## **ABSTRACT**

**Introduction.** Body composition of athletes is an important tool to evaluate the health of the athlete, monitor the effects of a training program, and to determine optimal competitive body weight. Coaches and athletes need a practical, easy, and accurate method to determine body fat percent (%BF). Dual Energy X-Ray Absorptiometry (DXA) is a laboratory method that has gained acceptance as the “practical gold standard” of body composition assessment. Bioelectrical impedance analysis (BIA) is a simple, inexpensive, noninvasive, reproducible alternative for estimating body composition that is widely used in both laboratories and field setting. BIA has gained acceptance as an accurate method of estimating %BF in clinics, sports medicine, weight reduction programs, hospitals, and laboratories. Due to the focus on healthy adults, non-athletes, obese individuals, and children, the fine-tuning of the BIA equations are more advanced in these populations, therefore there is more accuracy in these populations. There is a need for athletic population-specific BIA trials compared to established laboratory methods to test the validity of BIA.

**Purpose.** The primary purpose of this study was to investigate the accuracy of the DF50 BIA device using DXA as the criterion in two groups: elite endurance athletes and power athletes. The secondary purpose was to develop accurate %BF prediction equations for each group based on BIA data and/or the combination of BIA and anthropometric data.

**Methods.** 80 male athletes (40 elite endurance athletes and 40 were power athletes), age 18-45 were recruited. Anthropometric measurements were taken (height, weight, waist and hip circumference, and seven-site skinfolds [chest, midaxilla, abdomen, suprailium, subscapula, triceps, and thigh]). Body composition was assessed by DXA and BIA. An athlete-specific BIA prediction equation was developed by stepwise regression analysis using DXA as the criterion and BIA data and anthropometric measurements as variables.

**Results.** The DF50 BIA significantly overestimated %BF by  $6.4 \pm 0.5$  in the entire group ( $p < 0.001$ ) and in both the endurance group ( $6.1 \pm 0.6$ ,  $p < 0.001$ ) and the power group ( $6.7 \pm 0.7$ ,  $p < 0.001$ ). The endurance and power group showed no significant difference in the error of estimation by BIA ( $p = 0.554$ ), indicating that BIA has the same error in both groups. Two new equations were developed. The final prediction equation incorporates both anthropometric variables (umbilical circumference, hip circumference, and waist-to-hip ratio) as well as BIA variables (impedance quotient and reactance). The prediction equation produced an adjusted  $r^2$  of 0.98 and SEE of 1.98 for the entire group. This BIA prediction equation is able to predict %BF in both endurance and power athletes of varying BMIs and activity levels. In addition, this prediction equation can be



used with any BIA machine. The final correction equation uses the initial DF50 BIA %BF estimate and additional anthropometric (umbilical circumference and hip circumference) and BIA variables (impedance quotient, reactance, and extracellular water) to correct the %BF estimate. The final DF50 correction equation produced an adjusted  $r^2$  of 0.98 and SEE of 1.95 in the entire group. This DF50 BIA correction equation is able to predict %BF in both endurance and power athletes of varying BMIs and activity levels. The DF50 correction equation is a DF50 BIA-specific equation and cannot be used on other BIA models. Finally, we concluded that the addition of skinfold sums eliminated all BIA variables from the regression equation, thus making skinfold sums an inappropriate variable to use in a BIA prediction equation.

**Conclusion.** In an athletic population, the DF50 BIA device significantly overestimates %BF compared with DXA. The degree of overestimation is the same in both endurance athletes and power athletes. This study used DXA as the criterion to produce two athlete-specific BIA equations that can predict %BF in healthy males, 19-49 y, with BMIs ranging from 18.9 to 37.4. These equations use BIA measurements and anthropometric measurements, specifically trunk measurements to account for trunk size, a common source of error in BIA equations. Follow-up validation studies are necessary to further validate the equations produced in both groups.

## **INTRODUCTION**

The study of body composition seeks to divide and estimate body weight into basic compartments. Body composition models are classified by the number of compartments that are measured (7, 12, 35). In general, the more compartments, the greater the prediction accuracy. The two-compartment model divides the body mass into fat mass and fat-free mass (FFM). Three- and four-compartment models subdivide FFM into additional categories like total body water, fat free dry mass, bone mineral mass (12). In each model, total body mass is the sum of each compartment. Due to the direct effects on health and physical performance, all of the compartment models include fat mass (7).

Body composition of athletes is an important tool to evaluate the health of the athlete, monitor the effects of a training program, and to determine optimal competitive body weight and body composition (48). Knowing and understanding the effect of training and competition on body composition can help athletes control weight and alter body composition safely. Seasonal variations in body composition can be studied and used to find optimal body composition levels for health, recovery, training, and competing. Following body composition trends in specific sports enables coaches and athletes to more accurately prepare athletes for specific events/positions. Because of the importance of body composition in athletic health and performance, a practical, safe, and efficient method of measuring body composition is necessary.

**Body composition in athletes.** Body composition, specifically body fat percentage (%BF), is of great interest to athletes and is often negatively associated with athletic performance (18, 35, 53). Athletes represent a unique body composition; FFM density is altered with changes in proportions of FFM components (48). Training alters

amounts of body mineral, water and protein but possibly in different proportions to that of general population (37, 48). Young, elite male athletes have greater FFM, strength, and power; lower %BF; and earlier maturation compared to their peers, while young, elite female athletes have a less “curvy” physique, lower %BF, and later maturation than their peers (35). It is obvious that athletes have different physiology and health consequences associated with body composition, which emphasizes that body composition is an important field of study.

Body composition can be a predictor of athletic performance, making it relevant to both athletes and coaches. Physical performance declines at extremes of body weight and percentage of body fat (18), but depending on the sport, a higher or lower body fat level may be beneficial. Because of this, body composition trends in different sports can help identify/categorize potential participants. In football, defensive linemen tend to have higher body fat than defensive backs, and in track and field, sprinters have lower body fat than throwers (35). In Olympic events, athletes involved in events where their body weight was supported (swimming, kayak) had higher %BF, while athletes in weight-bearing, anaerobic sports (100, 200, 400m) had much lower body fat (15). Body composition is a safety issue in weight-dependant sports, like wrestling. The National Collegiate Athletic Association set a limit of no lower than 5% body fat for wrestlers (41).

Body composition, specifically %BF, is an important factor in endurance events where the extra fat increases the cost of running, but does not give extra energy (53). Rowland et al. (51) demonstrated that there was a significant relationship between body

fat percentage and run performance in children. In contrast to running events, FFM is a better predictor of performance than fat mass in strength events (6).

**Methods of body composition.** Coaches and athletes need a practical, easy, and accurate method to determine %BF. The most accurate body composition methods require a laboratory and specialized equipment. Dual Energy X-Ray Absorptiometry (DXA) is a laboratory method that has gained acceptance as the “practical gold standard” of body composition assessment.

**DXA.** DXA has been shown to be a safe, reliable measure of body composition and has since replaced hydrodensitometry (HWW), or underwater weighing, as the criterion method (7, 28, 36, 47, 55). DXA is a three-compartment model that estimates bone mineral mass, lean tissue mass, and fat tissue mass. Although DXA was originally developed as a tool for measuring bone mineral composition, it has been accepted as a valid method for measuring body composition, specifically %BF (7, 35). DXA gives estimates of whole body and lean muscle mass with a precision of error equal to or smaller than other non-invasive methods (20, 36). Unfortunately, DXA is expensive and requires a laboratory with a trained technician. Thus, most coaches and athletes do not have access to DXA and instead are forced to use less accurate field methods such as Body Mass Index (BMI), skinfolds, and Bioelectrical Impedance Analysis (BIA).

**BMI.** BMI is widely used in clinics, sports medicine, and in weight reduction programs. It is simple, inexpensive, and noninvasive (38). Height and weight are measured; BMI is calculated as weight (kg) divided by the square of height (m<sup>2</sup>). BMI is a good indicator of heaviness and a decent indirect indicator of body fatness (45). Although BMI is a common measure of body composition and is easy to perform, it has

been shown to be an imprecise measure of %BF (5, 9, 50). BMI does not take into account the density of an individual and can be misleading in individuals with a large amount of muscle mass. BMI has drawbacks in the athletic population due to athletes' relatively large stature and lean body compared to the general population (35).

**Skinfold thickness.** Skinfold thickness (SF) is a common and usually more accurate alternative to BMI. It is inexpensive and easily performed in the field making it a popular choice among practitioners. SF estimates of %BF are based on the assumptions that subcutaneous adipose tissue is representative of total body fat and that body fat is normally distributed (7). SF measurements are taken with a caliper at various sites on the body. The sum of the skinfold measure is plugged into a regression equation to predict density, which is then converted to %BF, usually by using the Siri equation (7). Over 100 fat prediction equations have been developed based on data collected from the non-athletic, general population (7, 35, 54), many of which are aimed at specific population characteristics such as race, age, sex, and activity level (7). Over the past thirty years, research has shown general agreement between SF and older criterion methods, mainly HWW (7, 14, 25). However, more recent research indicates that the most popular equations inaccurately predict fatness compared to the most current criterion measure, DXA (2).

Despite the fact that some prediction equations may have been derived for and from specific populations, like athletes, many SF do not accurately estimate body composition. Nindl et al. (39) investigated the accuracy of five skinfold prediction equations on black male college athletes. Compared to HWW, body density was significantly different ( $1.075 \pm 0.007$  vs.  $1.0817 \pm 0.009$ ). The Siri equation produced

significantly lower estimates of %BF compared to HWW in all five prediction equations for the black athletes, while the Schutte equation (another density-to-%BF equation) overestimated %BF in all five equations. Nindl concluded that prediction equations produced from the general population were not accurate for athletic populations.

Williams et al. (57) also found SF to inaccurately estimate %BF in athletes. Williams compared SF to HWW on 117 male university athletes. SF overestimated %BF by 0.8 +/-2.0% with as much as a 3.2% overestimation and 3.6% underestimation of %BF.

Although several other equations have been developed for athletic populations that appear to be more accurate (35), it is important to point out that they were all created from outdated technology, HWW. Percent body fat via HWW is based on densitometry, a two-compartment model (14). Density of FFM is based on the assumption that relative proportions and densities of water, mineral, and protein remain constant among individuals (35). High-level training alters the proportions of water and mineral composition of the FFM and, consequently, introduces error into the assessment of body composition (37, 48). Currently, no equations have been developed for athletes from the most current technology (DXA), which is more accurate than HWW because it can measure differences in bone mineral.

DXA is the new standard in which population-specific prediction equations must be developed in order to have acceptable accuracy. Ball et al. (2) recently created a %BF equation from DXA for 18-62 year-old men, but it has not been tested on an athletic population.

Additionally, SF suffers from other sources of measurement error (7) leading to a lack of accuracy reproducibility (50). Possible sources of error for skinfolds include:

difficulty palpating the fat/muscle interface, compression of fatty tissue during measurement, inexperience of tester, subject's hydration state, and fat prediction equation error (7, 54). For SF to be an accurate measure of body composition, care must be taken in measurement as well as in choosing the appropriate regression equation for the population. Although SF might be an acceptable method of %BF prediction for athletes, there are no DXA-created equations, and the likelihood of measurement error suggests that other field methods must be considered.

**BIA.** BIA is a simple, inexpensive, noninvasive, reproducible alternative for estimating body composition that is widely used in both laboratories and field setting. BIA has gained acceptance as an accurate method of estimating %BF in clinics, sports medicine, weight reduction programs, hospitals, and laboratories (38, 49, 50, 56). BIA is based on the principle that lean tissue has greater electrolyte and water content than fat, and as a result, has less impedance (7). Briefly, BIA sends an alternating electrical current via electrodes placed on the skin (usually on the wrist and ankle) to measure resistance. The current passes through the body, from the ankle to the wrist, and the voltage is measured. Fat mass has high impedance, while FFM has low impedance (35). Resistance, which is a component of impedance, is converted to total body water (TBW), which is used to estimate FFM (35). Since BIA body composition prediction relies on TBW, hydration changes can affect BIA estimates (29). Many prediction equations have been developed; care must be taken to select the most appropriate equation (29, 30). Selecting inappropriate equations can lead to significant error (7). Additional limitations and sources of error include body segment variations (i.e. trunk and leg have different areas), body position, hydration status, recent food consumption, recent physical activity,

conductance of the examining table, and skin temperature (29, 30). The majority of these are easily controllable and there is much less technician error compared to skinfolds.

BIA results are reproducible on the same machine (32, 50) but differ in machines from various manufacturers and in different models from the same manufacturer (40).

**Validity of BIA in healthy adults.** BIA is a useful technique for body composition analysis in a variety of individuals where water distribution is not an issue (29, 50). Reliable prediction equations have been developed in adults (31, 52), and BIA has been shown to be an effective method of estimating body composition in healthy, diabetic, and mild-to-moderately obese individuals. FFM predictions for the very lean and very obese are less accurate, with overestimation of fat mass in lean and underestimation of fat mass in obese (7, 49). Errors in height and weight, errors in BIA measurement, and errors in prediction equation all contribute to the FFM error of 4% or less (7, 11, 28). A possible reason for this problem is that the ratio of the intracellular water (ICW) to extracellular (ECW) is constant. ECW increases with advancing obesity and ECW decreases and ICW increases relative to increasing FFM (11). Sun et al. (56) measured %BF in 591 healthy adults using BIA compared to DXA as the criterion and concluded that BIA provided an accurate estimate of %BF in subjects within a normal body fat range. Sun found that BIA overestimated %BF in lean subjects and underestimated %BF in obese subjects. Patteyjohns et al. (43) found similar results in a study of overweight to obese subjects. Bolanowski et al. (4) conducted a similar study on 100 healthy adults and found that, when compared to DXA, BIA was an adequate method for body composition studies. Ersenlcan et al. (13) found that BIA and skinfolds were both adequate measures of body composition in non-obese subjects. Stewart et al. (55)



found that in 28 healthy adults, BIA was comparable to DXA for assessing body composition. Contrary to these findings, Lukaski et al. (33), in a study of 110 healthy adults, found that BIA lacked precision and accuracy when compared to DXA.

**Validity of BIA in the athlete.** Although body composition has been studied in athletes, limited data is available on BIA accuracy in the athletic population; the accuracy of BIA in determining %BF for an athletic population is currently equivocal. Moreover, there are few studies validating BIA with DXA in the athletic population; there are none in a male, endurance population or male, power lifting population.

Two previous studies succeeded in developing a DXA dependant BIA prediction equation for athletes. Fornetti et al. (16) investigated the reliability and validity of BIA in 132 female athletes participating in a variety of Division I varsity sports. DXA was used as the criterion for developing a BIA prediction equation. Compared to DXA, their BIA equation predicted FFM with 1.1 kg standard of error. Fornetti found that BIA was a reliable and valid estimate for body composition and also that single trial measurements are reliable and only a single trial is necessary. Yannakoulia et al. (59) also developed a DXA derived BIA equation for young female dancers. Yannakoulia concluded that the new BIA equation accurately assessed body composition in this group, but further validation studies were needed for cross-validation in various groups of dancers.

Few other studies have sought to validate BIA against DXA in the athletic population. Prichard et al. (44) compared %BF from BIA with DXA on seventeen elite, female distance runners using twelve different BIA formulas. While some equations worked better than others, Prichard concluded that BIA may be an accurate predictor of %BF in this population when the correct equation is used. Prichard also concluded that BIA

formulas that do not include weight are less accurate, and more research is necessary to validate BIA prediction formulas in other athletic populations. DeLorenzo et al. (10) investigated the validity of BIA against DXA in a group of 43, highly trained, male athletes. DeLorenzo found significant differences between BIA and DXA and concluded that these two methods should not be used interchangeably. Houtkoop et al. (22) studied 19 heptathlete's body composition using BIA compared to DXA as criterion. Contrary to the findings of Fornetti and Yannakoulia, Houtkoop found BIA not to be an accurate estimate of body composition, although no specific equation was developed in this study. Huygens et al. (23) investigated body composition in 34 male body builders and 15 power lifters using BIA and skinfolds. Huygens found that BIA was not as accurate as anthropometric equations in estimating %BF.

It is clear from the studies by Fornetti and Yannakoulia that BIA has the potential to be a valid, accurate method for measuring body composition in the athlete when athlete-specific equations are created from DXA. Due to the focus on healthy adults, non-athletes, obese individuals, and children, the fine-tuning of the BIA equations are more advanced in these populations; therefore there is more accuracy in these populations. There is a need for athletic population-specific BIA trials compared to established laboratory methods to test the validity of BIA. Body segment variations, hydration, and body geometry are possible reasons why BIA equations can only be applied to a specific population. The ratio of ECW to ICW also limits the BIA equations in populations with an altered hydration status. BIA measurements need to be standardized for reproducible results to be obtained (29). Foster and Lukaski suggest that anthropometric measurements be added into BIA prediction equations (17). Due to the differences in

body diameter, abdominal circumference can help standardize equations. Foster and Lukaski suggest that further research be performed to determine if one or more anthropometric variables are needed to improve the accuracy of BIA measurements. Segal et al. investigated anthropometric measurements on BIA equation (52). Segal found that anthropometry was useful in constructing BIA prediction equations and used anthropometrically determined %BF as a criterion for choosing a BIA equation. Separate equations were developed for men below and above 20% body fat and for women below and above 30% body fat.

**DF50 BIA.** The DF50 BIA (ImpediMed Ltd, Australia) is a new, portable, whole-body, tetrapolar conductance, 50Khz, single frequency bioimpedance plethysmograph. The DF50 calculates FFM, fat mass, TBW, intracellular water, and extracellular water.

Several new features make the DF50 unique when compared to other BIA models. The DF50 has a digital board rather than an analog board, which enhances reproducibility. Previous models relied on analog-to-digital converters, which added another possible source of error. The DF50 is the first BIA instrument to use this digital technology. The DF50 is smaller than other BIA devices, which makes it portable and easy to transport. The DF50's software also allows the user to track and manage patients. Finally, the DF50 comes with a test cell to validate calibration. In an analysis of BIA quality control measures, Pichard et al. (45) stated that electrical calibration of the BIA instrument should be required. The DF50 is the first model to include this self-calibration tool. These factors make it an attractive BIA model for coaches interested in body fat testing. Unfortunately, the DF50 only has three algorithms (equations) to select

from: general (33), children (8), and obese (52). There is not a prediction equation designed for athletes.

In the only published research article on the DF50 BIA, Pateyjohns et al. (43) compared the DF50 BIA model with DXA in forty-three healthy to obese male adults. They found that the DF50 provided good relative agreement with DXA (FM:  $r^2 = 0.65$ , FFM:  $r^2 = 0.76$ , %BF:  $r^2 = 0.40$ ; all  $p < 0.001$ ). They also found that the DF50 provided good absolute agreement with DXA; the DF50 under predicted fat mass by 1.1 kg and %BF by 1.74% and over predicted FFM by 2.50 kg. The differences between DXA- and DF50- predicted fat mass and FFM decreased as FFM increased and %BF decreased, indicating that the DF50 underestimated %BF more as %BF increased. Pateyjohns concluded that the DF50 may be practical for group comparison, but should not be used in place of DXA in clinical settings.

No data has been previously collected on the DF50 in either elite endurance athletes or power athletes. The novelty of this study is several fold: (a) it will be the first study to investigate the accuracy of BIA for elite endurance athletes and power athletes compared to DXA; (b) it will be the first study to investigate new BIA technology (DF50) compared to DXA for these populations; (c) it will be the first study to attempt to create a new BIA prediction equation for two distinct athletic populations from DXA; and (d) it will be the first to attempt to create a prediction equation for athletes that includes both BIA and anthropometric data using DXA as the criterion.

**Purpose.** The primary purpose of this study was to investigate the accuracy of the DF50 BIA device using DXA as the criterion in two groups: endurance athletes and power athletes. The secondary purpose was to attempt to develop accurate %BF

prediction equations for each group based on BIA data and/or the combination of BIA and anthropometric data. We also sought to develop a DF50-specific correction equation that corrects the DF50 “General” algorithm for an athletic population. We hypothesized that the current DF50 BIA equations would not produce accurate estimates of %BF compared to DXA for these distinct athletic populations.

## **METHODS**

**Subjects.** Eighty male athletes, age 19-48 were recruited. Of these athletes, 40 were endurance athletes (aerobic athletes) and 40 were power athletes (anaerobic athletes). An endurance athlete was defined as an actively training endurance athlete who participates in at least six endurance-training sessions per week. A power athlete was defined as an athlete who solely uses resistance training as the mode of exercise for the purpose of developing power for competition (i.e. shot put or lifting competitions). All subjects were healthy and had been engaged in a training program for the past 12 months.

**Subject preparation.** Subjects were informed of the study and procedures prior to visiting the lab for measurement. Subjects abstained from exercise four hours prior to testing, abstained from eating two hours prior to testing, maintained normal hydration, and used the restroom prior to testing as to minimize possible sources of error (11). Subjects wore comfortable, workout clothing with no metal or plastic (buttons, rivets) and removed all jewelry (earrings, bracelets, etc.). Upon arrival, subjects were presented with a consent form that outlined the rationale for the study, the participant description, the procedure, the possible risks of the study, the benefits of the study, and their rights as a participant. All measurements were performed on the same day, during one visit to the laboratory.

**Body Mass Index.** Body weight was measured to the nearest 0.1 kg and height to the nearest 1 cm and were used to calculate body mass index (BMI). BMI was calculated as the weight (kg) divided by the square of the height (m<sup>2</sup>).

**Anthropometric measurements.** The American College of Sports Medicine procedures for anthropometric measurements were followed (1). Subjects wore minimal clothing (shorts only). The waist circumference, determined by the narrowest point between the umbilicus and rib cage, the hip circumference, determined by the largest extension of the buttock, and the umbilical circumference, determined by the level of the umbilicus, were measured twice to the nearest 0.5 cm using a Gullick tension retractable tape measure. Skinfolds were taken with a calibrated Lange caliper (Cambridge Scientific Industries, Inc., Cambridge, MD, USA) at seven-sites: chest, midaxilla, abdomen, suprailium, subscapula, triceps, and thigh (26). These sites were measured to the nearest 0.5 mm in a rotational order (7). Repeated trials were performed until two measures within 1 mm were obtained. The mean of these two measures were used in summing skinfolds.

**Anthropometric reliability.** A highly trained technician performed all measurements. Intratester reliability was conducted on 10 subjects by repeating the measurements after a brief break. A correlation between the trials was performed to determine reliability. Reproducibilities for the sum of seven site skinfolds were  $r = 1.000$  for measurements taken in the same subject on the same day ( $n = 10$ ). The technician was compared to another highly trained technician to investigate objectivity.

**Dual energy X-ray absorptiometry.** Body composition was assessed by DXA (QDR 4500A, Hologic, Inc., Bedford, MA, USA) using fan beam technology. The

subjects wore minimal clothing and had no metal objects on or near their body (i.e. jewelry). The subject laid supine on the DXA scanning table, was positioned by the technician as recommended by the manufacturer, and was scanned once. Body composition was estimated by computer software (QDR Software for Windows XP, version 12.4, Hologic, Inc., Bedford, MA). Bone mass fat mass, and lean tissue mass will be represented in grams; %BF were calculated by the software and represented as fat mass (g)/total mass (g) x 100.

**DXA reliability.** All DXA scans were analyzed by the same technician. Normal and standard DXA quality control measures, equipment checks, and calibrations as recommended by the manufacturer were performed prior to testing. Reliability of DXA was conducted by measuring 10 subjects twice on the same day. Subjects were removed from the examining table and repositioned between trials. A correlation between the trials was performed to determine reliability. Reproducibilities were  $r = 0.999$  for measurements taken in the same subject on the same day ( $n = 10$ ).

**Bioelectrical Impedance.** Resistance and reactance were measured with a single frequency (50 kHz), four-terminal impedance plethysmograph (DF50, ImpediMed Ltd, Eight Mile Plains, Queensland, Australia), with the subject lying in a supine position. Four electrode sites were cleaned with an alcohol swab to ensure adherence and limit possible error. Four electrodes were attached to the subject's left side, two at the wrist, two at the ankle. The electrodes were connected to the DF50 BIA unit. %BF was calculated using the "General" equation given for healthy adults (33).

**BIA reliability.** The same technician performed all BIA scans. BIA quality control measures as suggested by the manufacturer were performed prior to testing.

Reliability of BIA was conducted by measuring 10 subjects twice on the same day. The electrodes were removed from the subject's body and the subject was removed from the examining table between trials. A correlation between the trials was performed to determine reliability. Reproducibilities were  $r = 0.999$  for measurements taken in the same subject on the same day ( $n = 10$ ).

**Statistical Analyses.** SPSS for Windows, version 15.1 was used for statistical analysis. The accuracy of the DF50 BIA device was determined by a T-Test, using an alpha level of 0.05, to determine if the DF50 provided an accurate estimate of %BF compared to DXA. A T-Test was also used to determine if there was any significant difference between DF50 %BF error between the two groups (endurance and power).

The BIA prediction equation specific to athletes was developed by stepwise regression analysis. The subjects were randomly divided into two groups, a prediction group of 60 subjects, and a cross-reference group of 20 subjects. Descriptive statistics were calculated for age, weight, height, waist circumference, umbilical circumference, hip circumference, BMI, waist-to-hip ratio, impedance, phase angle, resistance, reactance, and the impedance quotient ( $Ht^2/R$ ) and were expressed as mean  $\pm$  standard deviation. Simple regression was calculated to correlate %BF between DXA and BIA. Predictor variables (the same variables calculated in the descriptive statistics) were entered into a BIA model in a stepwise fashion with the highest correlated variables entered first. The stepwise regression was ended when an entered variable showed no significance (31). This equation was validated using the group of 20 subjects. This process was repeated with another random group of 60 subjects and validated on the remaining 20 subjects. These equations were compared, and the common variables used



in these equations were then entered into a regression equation using all 80 subjects to determine the final equation.

Regression analysis was used to develop a DXA criterion “correction equation” specific to athletes. The DF50 healthy subject algorithm was used normally without any corrections. All DF50 BIA variables were collected from this test (impedance, phase angle, resistance, reactance, and the impedance quotient along with DF50 body composition results (DF50 predicted %BF, total body water, intracellular water, and extracellular water). Descriptive statistics were collected for all variables and were entered into the BIA model in a stepwise fashion like above. This equation is meant to be used in conjunction with the DF50 “General” algorithm; the DF50 “General” algorithm’s %BF estimate will be used as an independent variable in the regression equation to more accurately represent %BF.

## **RESULTS**

A total of 80 subjects, 40 endurance subjects and 40 power subjects, aged 19-48 completed the study. Table 1 shows the subject characteristics. All subject characteristics were significantly different between the endurance group and power group ( $p < 0.05$ ) except height ( $p = 0.06$ ). All body composition results are shown in Table 2. JP3, JP3b, and JP7 are equations developed by Jackson and Pollock and are the most commonly-used SF equations (25, 26). DC and DC2 are DXA criterion SF equations developed by Ball et al. (2).

Table 1. Subject characteristics

	group		
	combined	endurance	power
<i>n</i>	80	40	40
age (y)	26.73 ± 0.84	30.40 ± 1.28	23.05 ± 0.72
Height (cm)	181.16 ± 0.94	179.39 ± 1.23	182.93 ± 1.39
Weight (kg)	85.90 ± 2.37	72.20 ± 1.00	99.60 ± 3.47
BMI (kg/m <sup>2</sup> )	26.13 ± 0.56	22.35 ± 0.25	29.91 ± 0.70
Waist circumference (cm)	82.69 ± 1.10	76.16 ± 0.58	89.21 ± 1.54
Umbilical Circumference (cm)	84.62 ± 1.29	77.29 ± 0.60	91.95 ± 1.89
Hip Circumference (cm)	97.78 ± 1.03	91.55 ± 0.51	104.01 ± 1.44
WHR	0.84 ± 0.00	0.83 ± 0.00	0.86 ± 0.01
DXA %BF	14.02 ± 0.52	11.51 ± 0.32	16.53 ± 0.81

Values are means ± SE.

BMI, body mass index; WHR, waist-to-hip ratio.

Table 2. Skinfold, BIA %BF and variables, and DXA results

	group		
	all	endurance	power
<i>n</i>	80	40	40
JP3a	11.56 ± 0.72	8.29 ± 0.47 **	14.85 ± 1.16 **
JP3b	12.63 ± 0.71	9.23 ± 0.46 **	16.03 ± 1.10 **
JP7	13.11 ± 0.79	9.22 ± 0.53 **	16.99 ± 1.22 **
DC	16.62 ± 0.73	12.87 ± 0.48 **	20.37 ± 1.10 **
DC2	15.22 ± 0.59	12.23 ± 0.44 **	18.20 ± 0.89 **
BIA %BF	20.43 ± 0.76	17.63 ± 0.71 **	23.22 ± 1.21 **
Z (Ω)	439.17 ± 7.16	482.19 ± 7.48 **	396.15 ± 7.55 **
Ph (Ω)	7.76 ± 0.09	7.30 ± 0.10 **	8.21 ± 0.10 **
R (Ω)	435.18 ± 7.16	478.28 ± 7.46 **	392.09 ± 7.52 **
Xc (Ω)	58.51 ± 0.77	61.03 ± 0.97 *	55.97 ± 1.08 *
Ht <sup>2</sup> /R	77.38 ± 1.6	67.99 ± 1.31 **	86.76 ± 2.12 **
TBW	57.23 ± 0.55	59.14 ± 0.55 *	55.43 ± 0.87 *
ICW	58.66 ± 0.34	59.33 ± 0.38	57.98 ± 0.56
ECW	41.34 ± 0.34	40.67 ± 0.38	42.02 ± 0.56
DXA %BF	14.02 ± 0.52	11.51 ± 0.32 **	16.53 ± 0.81 **
BIA %BF - DXA %BF	6.40 ± 0.47	6.12 ± 0.60	6.69 ± 0.73

\*  $p < .05$ , \*\*  $p < .001$  endurance and power group are significantly different from each other.

JP3a & JP3b, Jackson-Pollock 3-site equations, JP7, Jackson-Pollock 7-site equation;

DC & DC2, DXA Criterion 7-site equation (see appendix D).

Z, impedance; Ph, phase angle; R, resistance; Xc, reactance; Ht<sup>2</sup>/R, Height squared/resistance

TBW, total body water; ICW, intracellular water; ECW, extracellular water;

BIA %BF - DXA %BF, difference between DXA and BIA results

## Body Composition Methods Compared with DXA

Body composition methods compared to DXA are shown in Table 3. All results were significantly correlated with DXA ( $p < 0.001$ ), but most were significantly different from DXA. The DF50 BIA device was highly correlated with DXA ( $r = 0.796$ ,  $p < 0.001$ ) for all subjects ( $n = 80$ ), the endurance group ( $n = 40$ ,  $r = 0.520$ ,  $p < 0.01$ ), and the power group ( $n = 40$ ,  $r = 0.812$ ,  $p < 0.001$ ) but significantly underestimated %BF in the entire group ( $6.40 \pm 0.47$ ) and in both the endurance ( $n = 40$ ,  $6.12 \pm 0.60$ ,  $p < 0.001$ ) and power ( $n = 40$ ,  $6.69 \pm 0.73$ ,  $p < 0.001$ ). A T-Test confirmed that there was no significant difference in the error of estimation by BIA in the endurance and power group ( $p = 0.554$ ), indicating that BIA has the same error in both groups.

Table 3. Comparison between body composition methods

	method vs. DXA		
	all	endurance	power
<i>n</i>	80	40	40
<b>SF</b>			
<b>JP3a</b>	-2.46 ± 0.29 **	-3.24 ± 0.28 **	-1.68 ± 0.47 *
<b>JP3b</b>	-1.39 ± 0.29 **	-2.28 ± 0.28 **	0.51 ± 0.48
<b>JP7</b>	-0.91 ± 0.33 *	-2.29 ± 1.96 **	0.46 ± 0.50
<b>DC</b>	2.60 ± 0.28 **	1.36 ± 0.27 **	3.84 ± 0.40 **
<b>DC<sub>2</sub></b>	1.19 ± 0.21 **	0.72 ± 0.26 *	1.67 ± -0.30 **
<b>BIA</b>	6.40 ± 0.47**	6.12 ± 0.60 **	6.69 ± 0.73 **

Values are: estimated %BF minus DXA%BF ± SE.

a negative number indicates an underestimation relative to DXA

\*  $p < 0.01$ ; \*\*  $p < 0.001$  significantly different from DXA

## Development of the Prediction Equation

Table 4 shows prediction equations for two random samples of 60 subjects with the cross validation in the remaining 20 subjects. It is apparent from Table 4 that the independent variables and their coefficients are similar. Thus, these five common variables were entered into a regression equation for the entire group. Table 5 shows the prediction equation developed from all subjects ( $n = 80$ ) using the predictor variables derived in Table 4.

Table 4. Prediction equations using two randomly picked groups of 60, cross-validated by 20.

<b>Group 1 (n = 60)</b>	
<b>DXA %BF</b>	13.86 ± 0.53
<b>%BF equation</b>	0.276(umb) + 0.323(hip) - 15.217(WHR) - 0.156(Xc) - 0.245(Ht <sup>2</sup> /R)
<b>Predicted %BF</b>	13.73 ± 0.47, $r^2_{adj} = 0.983$ SEE = 1.878
<b>Cross Validation (n = 20)</b>	14.84 ± 0.98, $r^2_{adj} = 0.985$ SEE = 1.900
<b>Group 2 (n = 60)</b>	
<b>DXA %BF</b>	13.78 ± 0.58
<b>%BF equation</b>	0.245(umb) + 0.431(hip) - 13.959(WHR) - 0.248(Xc) - 0.291(Ht <sup>2</sup> /R)
<b>Predicted %BF</b>	14.54 ± 0.56, $r^2_{adj} = 0.998$ SEE = 1.61
<b>Cross Validation (n = 20)</b>	15.66 ± 1.05, $r^2_{adj} = 0.976$ SEE = 2.38

umb, umbilical circumference (cm); hip, hip circumference (cm); WHR, waist-to-hip ratio; Xc, reactance; Ht<sup>2</sup>/R, height squared divided by resistance.

Table 5. Prediction equation for %BF using all subjects ( $n = 80$ )

<b>%BF equation</b>	0.360(umb) + 0.221(hip) - 17.502(WHR) - 0.136(Xc) - 0.198(Ht <sup>2</sup> /R)
<b>DXA %BF</b>	14.02 ± 0.52
<b>Predicted %BF</b>	14.01 ± 0.46, $r^2_{adj} = 0.982$ SEE = 1.98

umb, umbilical circumference (cm); hip, hip circumference (cm); WHR, waist-to-hip ratio; Xc, reactance; Ht<sup>2</sup>/R, height squared divided by resistance.

Table 6 shows the significance of the coefficients in the final prediction equation. All independent variables significantly contributed to the final regression equation.

Table 6. Coefficients for the prediction equation

variable	Unstandardized		
	Coefficients	t	Sig.
<b>umb</b>	0.360	6.072	0.000
<b>hip</b>	0.221	2.994	0.004
<b>Ht<sup>2</sup>/R</b>	-0.198	-5.623	0.000
<b>WHR</b>	-17.502	-3.562	0.001
<b>Xc</b>	-0.136	-2.972	0.004

umb, umbilical circumference (cm); hip, hip circumference (cm); WHR, waist to-hip ratio; Xc, reactance; Ht<sup>2</sup>/R, height squared divided by resistance.

Figure 1 gives a graphical representation of the %BF estimation by the prediction equation developed with DXA. The line represents a one-to-one relationship between the prediction equation %BF and DXA %BF. Figure 2 shows the prediction equation compared to DXA in a Bland-Altman plot. The Bland-Altman compares the new measurement (prediction equation) with the criterion method (DXA).

Figure 1. %BF estimated by the prediction equation vs. %BF measured by DXA.

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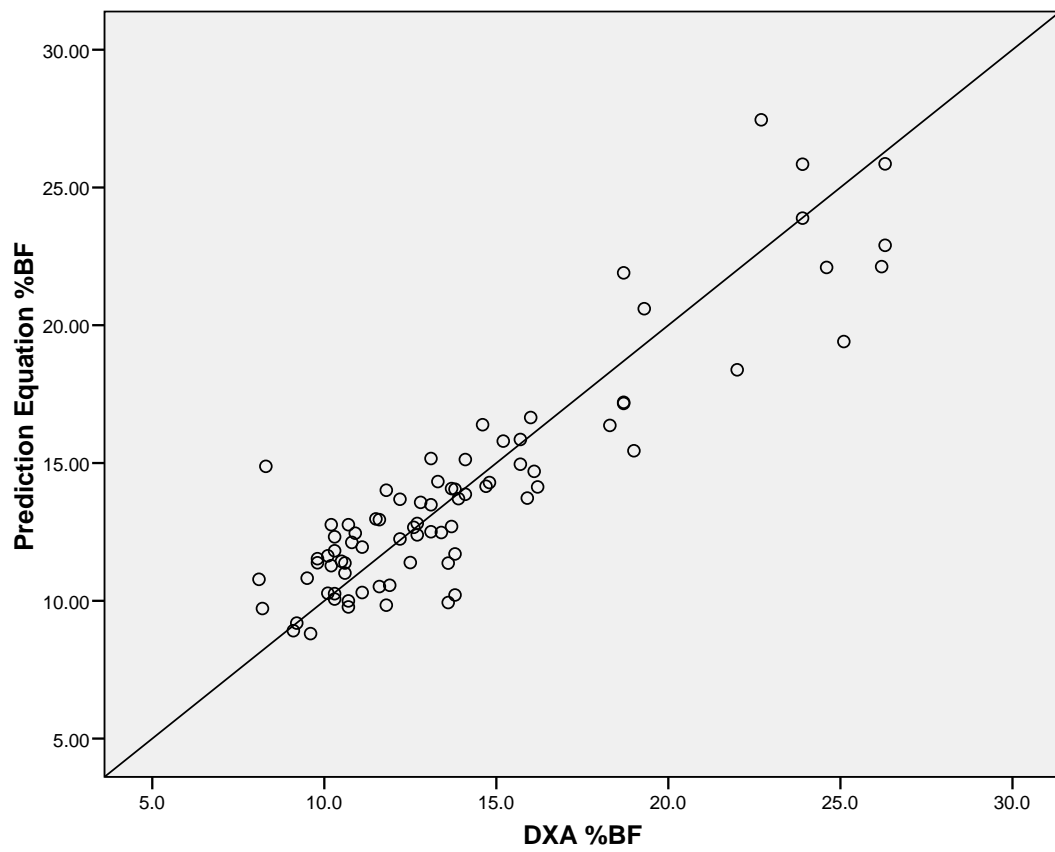
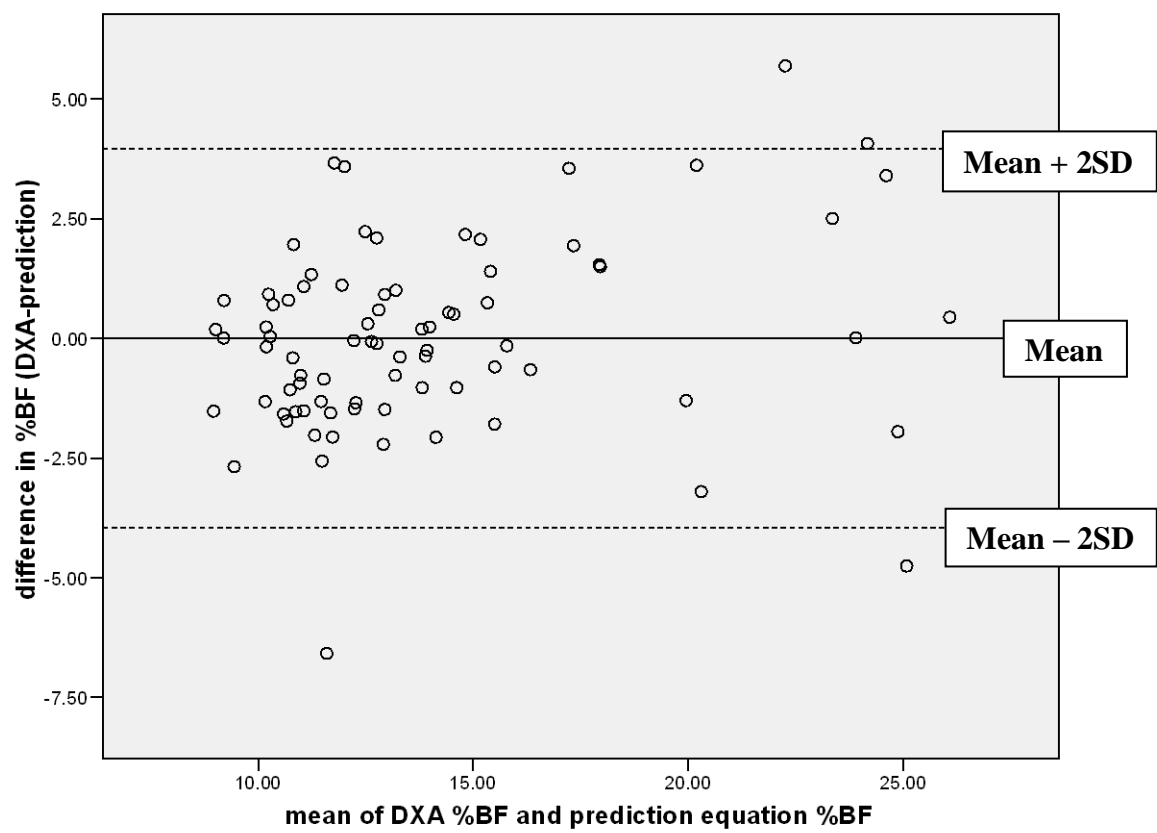


Figure 2. Difference against mean for %BF: DXA and prediction equation.



Variables, based on level of correlation to DXA %BF were entered in this order: umbilical circumference, hip circumference, waist-to-hip ratio, H<sup>2</sup>/R, and reactance (Xc) (Table 7). The three anthropometric variables (umb, hip, and WHR) accounted for 97.4% of the variance (SEE = 2.14), while H<sup>2</sup>/R and Xc together accounted for 93.3% of the variance (SEE = 3.87). Inclusion of the BIA parameters improved the prediction equation and decreased the SEE when compared to only anthropometric measurements. Table 8 shows the results of the prediction equation for the endurance group and power group.

Table 7. Contribution and order of entry into the prediction regression equation

variables	Cumulative Dependant Variables Used in Model				Dependant Variables			
	$r^2_{adj.}$	$\Delta r^2_{adj.}$	$p$	SEE	P	$r^2_{adj.}$	SEE	P
<b>umb</b>	0.955	0.000		3.14	0.001	0.955	3.14	0.001
<b>+ hip</b>	0.964	0.000		2.81	0.001	0.974	3.58	0.001
<b>+ Ht<sup>2</sup>/R</b>	0.964	0.122		2.79	0.001	0.932	3.84	0.001
<b>+ WHR</b>	0.979	0.000		2.14	0.001	0.912	4.39	0.001
<b>+ Xc</b>	0.981	0.004		2.03	0.001	0.861	5.50	0.001

umb, umbilical circumference (cm); hip, hip circumference (cm); WHR, waist-to-hip ratio; Xc, reactance; Ht<sup>2</sup>/R, height squared divided by resistance.

Table 8. Prediction equation on endurance and power groups.

<b>Endurance Group (n = 40)</b>	
<b>DXA %BF</b>	11.51 ± 0.32
<b>Predicted %BF</b>	11.73 ± 0.26, $r^2_{adj.} = 0.975$ , SEE = 1.86
<b>Power Group (n = 40)</b>	
<b>DXA %BF</b>	16.53 ± 0.81
<b>Predicted %BF</b>	16.30 ± 0.73, $r^2_{adj.} = 0.985$ , SEE = 2.09



## Development of the DF50 Correction Equation.

Table 9 shows both DF50 correction equations for two random samples of 60 subjects with cross validation in the remaining 20 subjects. The four variables plus umbilical circumference were entered stepwise into a regression equation using the entire sample. Table 10 shows the correction equation developed from all subjects using the predictor variables derived from Table 9. ECW was included in the entire group stepwise regression to optimize the adjusted  $r^2$  and SEE (Table 12). Table 11 shows the significance of the coefficients in the final DF50 correction equation.

Table 9. DF50 correction equations using two randomly picked groups of 60, cross-validated by 20.

<b>Group 1 (n = 60)</b>	
<b>DXA %BF</b>	14.42 ± 0.62
<b>%BF equation</b>	0.170(BIA) + 0.239(umb) + 0.190(hip) - .233(Xc) - 0.186(Ht <sup>2</sup> /R)
<b>Corrected %BF</b>	14.51 ± 0.58, $r^2_{adj.} = 0.985$ SEE = 1.84
<b>Cross Validation (n = 20)</b>	13.46 ± 0.85, $r^2_{adj.} = 0.980$ SEE = 1.86
<b>Group 2 (n = 60)</b>	
<b>DXA %BF</b>	13.80 ± 0.58
<b>%BF equation</b>	0.234(BIA) + 0.418(hip) - 0.290(Xc) - 0.188(Ht <sup>2</sup> /R)
<b>Corrected %BF</b>	13.87 ± 0.54, $r^2_{adj.} = 0.986$ SEE = 1.70
<b>Cross Validation (n = 20)</b>	14.95 ± 1.01, $r^2_{adj.} = 0.970$ SEE = 2.66

BIA, bioelectrical impedance %BF; umb, umbilical circumference (cm); hip, hip circumference (cm); Xc, reactance; Ht<sup>2</sup>/R, height squared divided by resistance.

Table 10. DF50 correction equation for %BF using all subjects (n = 80)

<b>%BF equation</b>	0.252(BIA) + 0.163(umb) + 0.240(hip) - 0.184(Xc) - 0.135(Ht <sup>2</sup> /R) - .175(ECW)
<b>DXA %BF</b>	14.02 ± 0.52
<b>Corrected %BF</b>	13.96 ± 0.47, $r^2_{adj.} = 0.984$ SE = 1.85

BIA, bioelectrical impedance %BF; umb, umbilical circumference (cm); hip, hip circumference (cm); Ht<sup>2</sup>/R, height squared divided by resistance; Xc, reactance; ECW, extracellular water

Table 11 shows the significance of the coefficients in the final DF50 correction equation. All independent variables significantly contributed to the final regression equation.

Table 11. Coefficients for the DF50 correction equation

(n = 80) <b>variable</b>	<b>Unstandardized Coefficients</b>	<b>t</b>	<b>Sig.</b>
<b>BIA</b>	0.252	4.481	0.000
<b>umb</b>	0.163	2.578	0.012
<b>hip</b>	0.240	2.832	0.006
<b>Ht<sup>2</sup>/R</b>	-0.135	-2.992	0.004
<b>Xc</b>	-0.184	-5.429	0.000
<b>ECW</b>	-0.175	-2.009	0.048

BIA, bioelectrical impedance %BF; umb, umbilical circumference (cm); hip, hip Circumference (cm); Ht<sup>2</sup>/R, height squared divided by resistance; Xc, reactance; ECW, extracellular water.

Figure 3 gives a graphical representation of the %BF estimation by the DF50 correction equation developed with DXA. The line represents a one-to-one relationship between the prediction equation %BF and DXA %BF. Figure 4 shows the prediction equation compared to DXA in a Bland-Altman plot.

Figure 3. %BF estimated by the DF50 correction equation vs. %BF measured by DXA.

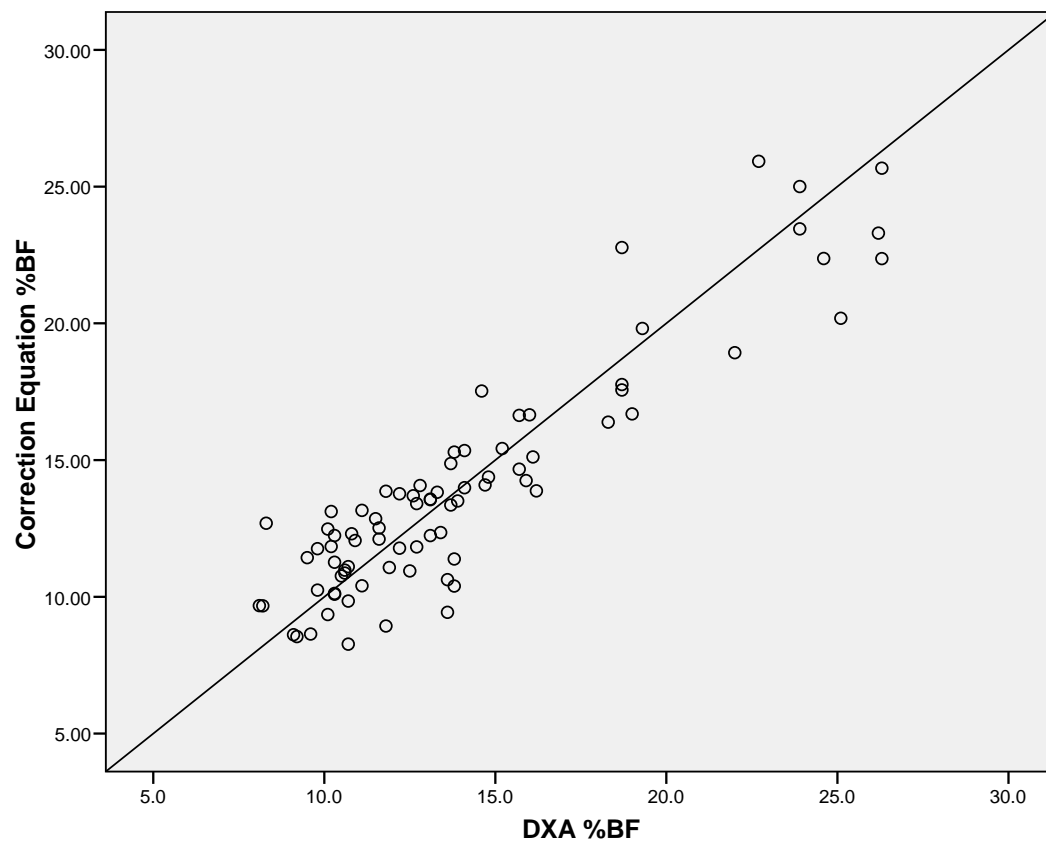
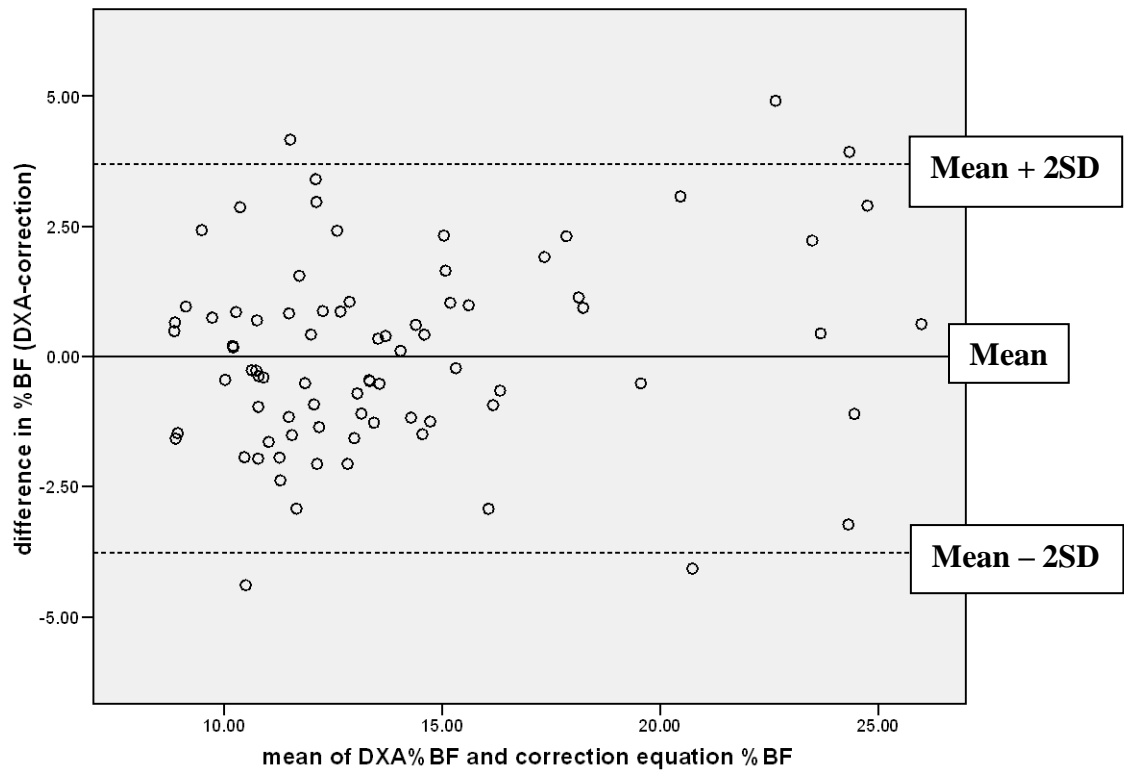


Figure 4. Difference against mean for %BF: DXA and DF50 correction equation.



Variables, based on level of correlation to DXA %BF were entered in this order: BIA %BF, umbilical circumference, hip circumference, H<sup>2</sup>/R, reactance (Xc), and extracellular water (ECW) (Table 11). BIA accounted for 96% of the variance, but adding anthropometric (umb and hip) and other BIA parameters (Ht<sup>2</sup>/R, Xc, and ECW) increased this to 98.3%. Therefore, inclusion of the anthropometric measurements and BIA parameters improved the prediction equation's adjusted  $r^2$  and decreased the SEE when compared to only BIA. Table 13 shows the results of the correction equation for the endurance and power group.

Table 12. Contribution and order of entry into the DF50 correction regression equation.

variables	Cumulative Dependant Variables Used in Model				Dependant t Variables			
	$r^2_{adj.}$	$\Delta r^2_{adj.}$	<i>p</i>	SEE	P	$r^2_{adj.}$	SEE	P
<b>BIA</b>	0.960	0.000		2.95	0.001	0.960	2.95	0.001
+ <b>umb</b>	0.972	0.000		2.49	0.001	0.955	3.14	0.001
+ <b>hip</b>	0.975	0.001		2.33	0.001	0.941	3.58	0.001
+ <b>Ht<sup>2</sup>/R</b>	0.976	0.070		2.29	0.001	0.932	3.84	0.001
+ <b>Xc</b>	0.983	0.000		1.95	0.001	0.861	5.50	0.001
+ <b>ECW</b>	0.983	0.048		1.91	0.001	0.292	3.94	0.001

BIA, bioelectrical impedance %BF; umb, umbilical circumference (cm); hip, hip circumference (cm); Ht<sup>2</sup>/R, height squared divided by resistance; Xc, reactance; ECW, extracellular water.

Table 13. DF50 correction equation on endurance and power groups.

<b>Endurance Group (n = 40)</b>	
<b>DXA %BF</b>	11.51 ± 0.32
<b>Corrected %BF</b>	11.48 ± 0.26, $r^2_{adj.} = 0.977$ , SEE = 1.76
<b>Power Group (n = 40)</b>	
<b>DXA %BF</b>	16.53 ± 0.81
<b>Corrected %BF</b>	16.43 ± 0.72, $r^2_{adj.} = 0.987$ , SEE = 1.96

## **Inclusion of Skinfold Sums**

*Prediction equation.* When 3SF and 7SF were added as independent variables in the prediction equation, all BIA variables (impedance, phase angle, resistance, reactance, and impedance quotient) were removed from the final regression equation. The final, stepwise regression equation was:  $\%BF = -0.74(\text{weight}) + .128(\text{hip}) + 0.800(\Sigma 7SF)$ ,  $r^2_{\text{adj.}} = .992$ ,  $SEE = 1.28$ .

*DF50 correction equation.* When 3SF and 7SF were added as independent variables in the DF50 correction equation, BIA %BF was the only BIA variable included in the equation and was the least significant variable entered (appendix D). The addition of 7SF increased the adjusted  $r^2$  significantly and had the highest level of significance in the equation (appendix D). The final stepwise regression equation was:  $\%BF = -0.066(\text{weight}) + 0.133(\text{hip}) + 0.073(7SF) + 0.080(\text{BIA})$ ,  $r^2_{\text{adj.}} = .993$ ,  $SEE = 1.24$ . When BIA was excluded, the final equation was:  $\%BF = -0.74(\text{weight}) + 0.128(\text{hip}) + 0.080(7SF)$ ,  $r^2_{\text{adj.}} = .992$ ,  $SEE = 1.28$ .

## **DISCUSSION**

The ability to quickly and easily obtain an accurate assessment of body composition is beneficial to the athlete. BIA has gained acceptance as an accurate method of estimating %BF in clinics, sports medicine, weight reduction programs, hospitals, and laboratories (38, 49, 50, 56). Resistance, which is a component of impedance, is measured and is converted to total body water (TBW), which has been shown to be highly correlated with FFM (35). The accuracy of BIA estimations depends highly on population-specific prediction equations to be developed and validated from

criterion measures like DXA (30, 44). Including anthropometric variables in the BIA prediction equation has been found to increase their accuracy (17). Our study gathered BIA and anthropometric data from trained endurance and power athletes to produce a new BIA equation that can be used to estimate %BF in athletes with BMIs ranging from 18.9 to 37.4. This study also produced a correction equation specifically for athletes that can be used to make the DF50 “General” algorithm more accurate.

### **Accuracy of the DF50 BIA Device**

Despite showing good correlation  $r = 0.796$ ,  $r^2_{adj.} = 0.629$ ,  $p < .001$ , BIA significantly overestimated %BF by  $6.40 \pm 0.47$  in the entire group ( $p < 0.001$ ) and in both the endurance and power group ( $p < 0.001$ ) (Table 2). These findings agree with Demura et al. (11) who found that BIA overestimates %BF in athletes. These findings also support those of Houtkooper et al. (22) who found the BIA to be an inaccurate overestimation of the %BF of athletes. DeLorenzo et al. (10) also found BIA to be inaccurate in highly trained male athletes, but contrary to our findings, they found the BIA to underestimate %BF. None of these studies developed their own BIA equation for an athlete specific population. Table 3 shows BIA and several SF methods compared to DXA. We found that BIA was not as accurate as SF in estimating %BF. This agrees with Huygens et al. (23) who found SF equations and equations that incorporated anthropometric measures better at estimating %BF than DXA in male body builders and power lifters. Contrary to our findings, Pattenjohns et al. (43), in the only other published DF50 article, found that the DF50 underestimated %BF by 1.74%. Pattenjohns also found that the more actual %BF decreased, the more the DF50 overestimated %BF. This conclusion agrees with our findings. One possible reason for this was that our subject's

mean BMI was 26.1, while Patteyjohn's mean BMI was 34.3. Our subjects were leaner and followed the trend that leaner individuals %BF is overestimated by the DF50.

This is the first study to look at two separate athletic populations and compare BIA error. Despite a significant difference between the endurance and power groups in almost all characteristics, a T-Test confirmed that the endurance and power group showed no significant difference in the error of estimation by BIA ( $p = 0.554$ ), indicating that BIA has the same error in both groups. Because of this, subjects were combined and treated as one group when working to develop a new athlete-specific equation. One possible reason for the similarity in error between the two groups was that the "Healthy Adult" equation misrepresents subjects with higher musculoskeletal development similarly when compared to sedentary groups (24, 58). Both the endurance group and the power group subjects presented highly developed musculoskeletal development. Huygens et al. (23) suggest that BIA analysis in a muscular, athletic population is invalid and anthropometric equations are better.

### **Equation Development**

A random group of 60 subjects was chosen to develop both a prediction equation and a correction equation, which was then cross-validated by the remaining 20 subjects. This procedure was repeated with another random sample of 60 subjects. Two equations, one from each random group of 60, were developed to compare significant independent variables and their coefficients. This method follows previous methods for BIA equation development (16, 59). Numerous authors have suggested that one or more anthropometric measurements be included in BIA prediction equations (17, 52). Anthropometric measurements such as weight, height, waist circumference, umbilical



circumference, hip circumference, BMI, and WHR were treated as independent variables along with BIA variables such as impedance, phase angle, resistance, reactance and the impedance quotient in developing the equation.

### **Prediction Equation Development**

Both prediction equations from the two random samples produced the same five independent variables (umbilical circumference, hip circumference, waist-to-hip ratio, reactance, and the impedance quotient) with similar, high adjusted  $r^2$  values. In addition, the validations and cross validation produced similar %BF estimates, high adjusted  $r^2$  values, and similar SEEs (Table 4). The five variables produced from the random sample prediction equations were entered into a regression equation using the entire group of 80 subjects. The variables were entered in this order: umbilical circumference, hip circumference,  $Ht^2/R$ , WHR, and  $X_c$ .

Umbilical circumference and hip circumference accounted for 96% of the variability indicating the impact that abdominal size has on body composition estimations. One of the problems with BIA is the distorted influence of trunk volume. The trunk makes up a large proportion of total body volume (up to 46%), but due to its large cross-sectional area and short length, contributes a small amount (as little as 3%) to whole-body impedance (7, 29, 33, 40). Numerous studies encourage body build to be taken into account when developing a BIA equation (7, 21, 31, 53). Three of the variables in our equation relate to trunk size, helping our equation to limit one of the main sources of error of BIA.

The impedance quotient was included even though it did not increase the adjusted  $r^2$  because it did decrease the SEE, and it was included in both random sample,

prediction models (Table 7). The final two variables increased the model to account for 98.1% of the variability with a SEE of 2.03. Each of the variables used contributed significantly to predicting %BF (Table 6). This prediction equation is applicable to all BIA devices, not just the DF50.

The final prediction equation showed a high adjusted  $r^2$  and a low SEE in the entire group as well as in the endurance group and power group (Table 8). Therefore, this BIA prediction equation is able to accurately represent %BF in both endurance and power athletes of varying BMIs and activity levels. Our results are similar to Fornetti et al. (16) who developed a DXA dependant BIA prediction equation with an  $r^2$  of 0.96 and a SEE of 1.1 kg in 132 female varsity athletes. Yannakoulia et al. (59) also developed a DXA dependant BIA prediction equation with an  $r^2$  of 0.83 and a SEE of 1.45 kg in 42 professional female dancers. Like our equation, Yannakoulia concluded that their BIA equation accurately represented the body composition in their group, but further cross-validation studies were necessary

Kyle et al. (29, 30,) published an extensive list of BIA equations reported in the literature since 1990. The  $r^2$  values ranged from 0.65 to 0.97. For the equations that directly produced %BF (rather than FFM), the SEE values ranged from 5.45 to 6.56%. Houtkooper et al. (22) published a list of validation studies performed on BIA prediction equations. The  $r^2$  values ranged from 0.85 to 0.99. Houtkooper also published standards for FFM SEE for BIA equations. A SEE greater than 4.5 was not recommended for use. It is difficult to compare %BF SEE with FFM SEE, but %BF SEE are typically higher values than FFM SEE. Our SEE of 2.03% is clearly as low as or lower than many of the previously published BIA prediction equations. SSE is an important indicator of an

equation's ability to accurately predict fatness. An SEE of 1.0 means that there is a 67% probability that the predicted value will be  $\pm 1.0\%$  BF ( $\pm 1.0$  SEE) of the actual measure and that there is a 95% probability that the predicted value is  $\pm 2.0\%$  ( $\pm 2.0$  SEE).

One of the practical applications of a body composition procedure is to track changes over time. In this case, the validity of the %BF estimate is not as critical as the reliability. If the same device or procedure is used to track %BF changes over time, we want a procedure that is reliable.

### **Influence of Skinfolts on the Prediction Equation.**

When the mean of the sum of three-site skinfolts (3SF) and seven-site skinfolts (7SF) were included as independent variables in the prediction equation, all BIA variables (impedance, phase angle, resistance, reactance, and the impedance quotient) were excluded from the regression equation. Since the skinfold method is a well-established method of estimating body composition, it was highly correlated with DXA. Including either the 3SF or the 7SF in the stepwise regression analysis caused all BIA parameters to be not significant in the final equation, making the prediction equation unrelated to BIA. In addition, it is not practical to perform 7SF and BIA since 7SF is a well-established method by itself. Another reason SF were not included in the final equation was the practicality of performing SF as well as BIA. We wanted a procedure that was easy to perform in both the lab and in the field, and minimized potential measurement error. Yannakoulia et al. (59) produced two BIA prediction equation, one of which included a tricep skinfold included as a variable. Yannakoulia concluded that despite the improvement ( $r^2$  increased by 0.04 and SEE decreased by 0.13 kg), the risk

technician error outweighed the slight improvement in the model. In addition, not including the tricep skinfold simplified the prediction model.

One of the values of BIA is the ease of measurement. Circumference measurements are quick and easy to perform. In addition, BIA does not require a high level of technical skill and the reproducibility is good even when different technicians perform the test (40, 50). The accuracy of SF measurements is highly dependent on technician skill, and the difference between technicians is high (7, 50). Eliminating SF from the BIA measurements eliminates much of this error.

### **DF50 Correction Equation Development**

A second equation was developed to “correct” the DF50 “General” algorithm. This equation takes the %BF estimate from the DF50 “General” algorithm and uses it as an independent variable in a regression equation. This equation is specific to the DF50 BIA device and should not be used with other BIA devices. The development of the correction equation followed the same procedure as the development for the prediction equation with the addition of measured BIA variables (BIA %BF, TBW, ICW, and ECW). The hope was to take the standard DF50 measurements and use them in a correction equation to more accurately reflect DXA %BF. While there have been BIA correction equations developed for certain parameters like bone mass, hydration, and skin temperature (3, 19, 21), few, if any, BIA correction equations have been developed that take a given BIA device’s %BF estimate and adjust it for a specific population.

Both prediction equations from the two random samples produced four similar independent variables (Table 9) with similar, high correlations. In addition, the random sample prediction equation and the cross validation produced similar %BF estimates,

high correlations, and similar SEEs (Table 9). Umbilical circumference was included in the final regression equation using all 80 subjects due to its high partial correlation. The four similar variables produced from the random sample prediction equations plus umbilical circumference was entered into a regression equation in this order: BIA, umbilical circumference, hip circumference,  $Ht^2/R$ ,  $Xc$ . ECW was the final significant contributor to the entire group, and it was added last. ECW was included in the final equation for three reasons: 1. it was a significant contributor to the regression equation, 2. it decreased the SEE, and 3. it was a measured DF50 variable.

BIA %BF alone accounted for 96% of the variability, but the inclusion of anthropometric measurements (umbilical and hip circumference) increased adjusted  $r^2$  to 97.5% (Table 12). Like the prediction equation, the addition of trunk measurements improved the BIA equation. The inclusion of the final three BIA variables increased the adjusted  $r^2$  and lowered the SEE (Table 12). Each of the variables used contributed significantly to predicting %BF (Table 11). Like in the prediction equation, it was important to include at least one BIA-produced variable; this equation includes four BIA variables that contributed significantly to the DF50 correction equation.

The final DF50 correction equation showed a high adjusted  $r^2$  and a low SEE in the entire group as well as for both the endurance group and power group (Table 13). Therefore, this DF50 BIA correction equation is able to predict %BF in both endurance and power athletes of varying BMIs and activity levels. As mentioned above, our adjusted  $r^2$  and SEE are as low as or lower than many of the previously published BIA prediction equations.

### **Influence of Skinfolds on the Correction Equation.**

When the mean of the sum of three-site skinfolds (3SF) and seven-site skinfolds (7SF) were included as independent variables in the correction equation, the only BIA variable included in the regression equation was BIA%BF, and it was the least significant variable in the equation (Table 14). When BIA %BF was entered last, it only accounted for an additional 0.1% of the variability and decreased the SEE by only 0.04. The 7SF was the last entry in the stepwise regression equation, but significantly increased the  $r^2$  by 0.017 and decreased the SEE by 1.07 (Table 15). Although the adjusted  $r^2$  is higher and the SEE is lower for the SF-DF50 correction equation that includes SF ( $r^2_{\text{adj.}} = .993$ , SEE = 1.24) than for the DF50 correction equation that does not ( $r^2_{\text{adj.}} = 0.983$ , SEE = 1.91), the practicality of performing SF outweighs the increase in accuracy; the introduction of skinfolds introduces an additional source of error: technician training.

### **Limitations of the Study**

All subjects in this study were healthy men; therefore the equation developed in this study is intended for healthy men, 19-49 years of age. Despite notifying the subjects about abstaining from exercise and eating 2 hours prior to coming in, there was no guarantee that the subjects followed these guidelines. Also, since the data collection was collected during warm months, hydration levels may have not been maintained. Hydration status was not measured in this study. Subjects were tested at a time convenient for them, and some subjects were measured in the morning, some in the evening.

The prediction equation can possibly be used with any BIA device that produces resistance and reactance measures, while the DF50 correction equation is to be used with the DF50 BIA device and “General” algorithm only.

### **Summary of the Results**

To Summarize:

1. Our first purpose was to investigate the accuracy of BIA for elite endurance athletes and power athletes compared to DXA. We hypothesized that the current DF50 BIA equations will not produce accurate estimates of %BF compared to DXA for these distinct athletic populations. We found that the DF50 BIA significantly overestimated %BF by  $6.40 \pm 0.47$  in the entire group ( $p < 0.001$ ) and in both the endurance group ( $6.12 \pm 0.60$ ,  $p < 0.001$ ) and the power group ( $6.69 \pm 0.73$ ,  $p < 0.001$ ). Despite a significant difference between the endurance and power groups in almost all characteristics, a T-Test confirmed that the endurance and power group showed no significant difference in the error of estimation by BIA ( $p = 0.554$ ), indicating that BIA has the same error in both groups.
2. Our second purpose was to develop accurate %BF prediction equations for each group based on BIA data and/or the combination of BIA and anthropometric data. Since both groups had the same error, the endurance athletes and power athletes were combined into one athletic group. We developed two new equations. The final prediction equation uses measured variables to produce an accurate estimate of %BF. The prediction equation showed a high adjusted  $r^2$  and a low SEE in the entire group and was appropriate for both the endurance

group and power group. Therefore, this BIA prediction equation is able to predict %BF in both endurance and power athletes of varying BMIs and activity levels. This prediction equation can be used with any BIA machine. The final correction equation uses the initial DF50 BIA %BF estimate and additional anthropometric and BIA variables to correct the %BF estimate. The final DF50 correction equation showed a high adjusted  $r^2$  and a low SEE in the entire group and worked well for the endurance group and power group both. Therefore, this DF50 BIA correction equation is able to predict %BF in both endurance and power athletes of varying BMIs and activity levels. The DF50 correction equation is a DF50 BIA-specific equation and cannot be used on other BIA models.

3. Our third purpose was to seek to investigate adding SF variables in a BIA prediction equation. We found that the addition of SF eliminated all BIA variables from the regression equation, thus making SF an inappropriate variable to use in a BIA prediction equation. However, we did find that incorporating 7SF into a correction equation produced an equation with a high adjusted  $r^2$  and low SEE, better than both the prediction equation and the DF50 correction equation. The drawback of this equation is the time needed to measure seven skinfold sites as well as perform the BIA measurement. The accuracy of SF measurements is highly dependent on technician skill, and the difference between technicians is high (7, 50). Eliminating SF from the BIA measurements eliminates much of this err



## **Conclusion**

In conclusion, in an athletic population, the DF50 BIA device significantly overestimates %BF compared with DXA. The degree of overestimation is the same in both endurance athletes and power athletes. This study used DXA as the criterion to produce two athlete-specific BIA equations that can predict %BF in healthy males, 19-48 y, with BMIs ranging from 18.9 to 37.4. These BIA equations are one of the first equations to use anthropometric measurements, specifically trunk measurements. Follow-up validation studies are necessary to further validate the equations produced in both groups.

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**APPENDIX A:  
EXTENDED LITERATURE REVIEW**



**UNDERSTANDING BIA  
AND  
DENSITY'S ROLE IN ESTIMATING BODY COMPOSITION OF AN ATHLETE**

**BIOELECTRICAL IMPEDANCE**

It has been known for over 100 years that the body tissues are able to conduct an electric current, but it has been in the last two decades that bioelectrical impedance has improved enough to be considered a valid method to evaluate body composition. In the early 1960s, Thomasset et al. established a relationship between the impedance of an electrical current passed through a body and total body water (TBW) by using two stainless steel needles inserted subcutaneously in the hand and foot (15). The relationship between conductor volume and impedance was later defined by Hoffer et al. in 1969 as  $TBW = \text{conductor cross sectional area} \times \text{height}^2 / \text{impedance}$ . (15). In addition, conductivity of the human body has been shown to be closely related to lean body tissue; body fat and bone are poor conductors, while lean body tissue is a good conductor (8, 22). In 1992, Matthie et al. validated that BIA could describe TBW and its components intracellular water (ICW) and extracellular water (ECW) compared to total body potassium (5). The improvement in BIA technology and the relative low cost of BIA devices has allowed the commercial availability of BIA devices to grow rapidly and become one of the most frequently used methods of estimating body composition (8).

BIA is a simple, inexpensive, noninvasive, reproducible alternative for estimating body composition that is widely used in both laboratories and field setting. BIA has gained acceptance as an accurate method of estimating body fat percentage (%BF) in clinics, sports medicine, weight reduction programs, hospitals, and laboratories (25, 28, 29, 35). When the proper equations and procedures are used, BIA has been

found to be reliable in determining the fat-free mass (FFM) and TBW in subjects with normal fluid and electrolyte levels (18, 25). BIA has also been found to be a highly reliable method for determining hydration status in healthy individuals (25, 32). BIA is based on the principle that lean tissue has greater electrolyte and water content than fat, and as a result, has less impedance, but the underlying science behind how BIA works is more complicated (3). The principles of BIA, assumptions associated with BIA measurement, sources of error, and appropriate formula selection will be discussed in detail.

**Principles of BIA.** BIA measures an electrical current that is passed through the entire body, from one electrode (normally placed on the wrist) to another electrode (normally placed on the ankle). BIA measurements take into account the volume, length, components, and impedance of the subject (3). Each body component contains a different level of charged ions, and the current passes through some components more easily than others. The impedance the current faces allows for an estimation of the composition of the body component. ICW and ECW act as electrical conductors in the body, while cell membranes act as electrical condensers (22). Relatively new advances enable a differentiation to be made between ICW and ECW (9). The differentiation between ICW and ECW is important because a greater variability in the ECW:ICW ratio hinders the accuracy of BIA predictive equations (18, 19).

Electrical circuits and the impedance they face are used as a model to examine body components *in vivo*. The body's fluids and electrolytes carry the electrical current (conduction). Circuits can be aligned either in parallel or in series, and a range of frequencies can be passed through the body to estimate ICW and ECW (3, 8). It is

assumed that intra- and extra-cellular pathways are aligned in parallel (13). When the circuit is aligned in parallel, ECW has properties independent of the ICW compartment (9). At a very low frequency (1 kHz or 5 kHz), the electrical current cannot pass through the cell membrane and will travel solely through the ECW. At a very high frequency (>100 kHz), the current is able to pass through the cell membrane and reflects both ICW and ECW and is representative of TBW (9, 25, 32). Since measurements are not performed at zero or infinite kHz, mathematical formulas are used to describe ICW and ECW from the impedance of the current.

Different body components consist of different amounts of fluid. Blood and urine have high conductivity (low impedance), muscle has intermediate conductivity, and fat and bone have low conductivity (high impedance). Impedance refers to the resistance of an electrical current and is composed of resistive (R) and reactive capacitance (Xc) components (3).

*Resistance* can be illustrated by examining a perfect cylinder. If we look at a perfect cylinder consisting of uniform components, resistance is proportional to the length of the cylinder and inversely related to the cross sectional area (18). In other words, the longer the cylinder, the more resistance the current will encounter. The greater the cross sectional area, the less resistance the current will encounter. This approach establishes a relationship between water and current; an experimental relationship between a known volume of water in a cylinder and the impedance quotient ( $\text{length}^2/\text{R}$ ) can be defined. Lean body mass is estimated to consist of 73% water, referred to as total body water (TBW), so the relationship between lean body mass and the impedance quotient is used,  $\text{TBW} = \text{length}^2/\text{R}$  (30). This TBW estimate is used to

estimate FFM. TBW estimates for FFM are based on isotope dilution ( $^2\text{H}$  deuterium),  $^3\text{H}$  tritium), and  $^{18}\text{O}$ -labeled water and have been used to validate BIA ( $\text{height}^2/\text{R}$ ) estimates of TBW (23). The correlation between FFM and TBW is 0.95 in normal, healthy subjects ranging from infants to adults (25).

DeLorenzo et al. (5) concluded that in healthy subjects, BIA was valid in estimating ICW and ECW volume by total body potassium and by bromide dilution respectively. Simmons et al. (33) found that in both normal- and underweight cancer patients, BIA accurately reflected changes in TBW assessed by deuterium dilution. Since resistance is a component of impedance and is determined by the size, volume, length and shape of the body, body shape is a factor in the application of BIA and is discussed later as a possible source of error (3, 23).

*Reactive capacitance* is the ratio of an impressed charge on a conductor to the corresponding change in potential. Reactive components relate to the portion of the current that shifts the voltage and current out of phase as it passes through the cell membranes (8). Phase angle is another variable that is included in estimating body composition. In healthy adults, the phase angle ranges from 8-15 degrees. Wide variations in the phase angle occur at high frequencies and in disease patients. An abnormally low phase angle may indicate an increase in ECW and a reduction of ICW (8). As mentioned previously, impedance ( $Z$ ) is a function of both  $R$  and  $X_c$  components and is defined as the sum of the squares of resistance and reactance ( $Z^2 = R^2 + X_c^2$ ) (3). This will be addressed again when sources of error are discussed.

Both single-frequency (SF-BIA) and multi-frequency (MF-BIA) BIA methods are used to estimate body composition. SF-BIA devices use either four or eight electrodes

and pass a 50 kHz current between electrodes placed on the skin. SF-BIA relies on the principle that a constant, low-voltage, high frequency current that is passed through the body is nearly completely conducted throughout the FFM fluid (33). Usually the electrodes are placed on the hand and foot, but foot-to-foot and hand-to-hand methods are also used. SF-BIA is able to estimate FFM and TBW, but due to using one constant frequency, SF-BIA cannot differentiate between ICW and ECW (18). MF-BIA allows multiple frequencies from 0 to 500 kHz to be used. FFM, TBW, ICW, and ECW can be estimated from MF-BIA. At low frequencies (less than 5 kHz) and high frequencies (greater than 200 kHz), MF-BIA shows poor reproducibility, but when compared to SF-BIA, MF-BIA predicted TBW better and is recommended for at-risk subjects where hydration status is critical (3). Demura et al. (6) compared three BIA devices, a four electrode SF-BIA, an eight electrode SF-BIA, and an eight electrode MF-BIA, using DXA as the criterion. The MF-BIA device produced the highest correlation to DXA and the least estimation error compared the both SF-BIA methods. Gudivaka et al. (13) found that MF-BIA, when performed in a parallel circuit, could accurately measure changes in TBW, but could not accurately assess ECW and ICW when compared to deuterium isotope dilution.

In 1994, the National Institutes of Health (NIH) Technology Conference on BIA found that BIA provided reliable estimates of TBW under normal conditions, and is a useful technique for healthy subjects and those with certain chronic diseases (diseases in which there are no water disturbances). They also concluded that BIA does not accurately predict %BF in severely obese subjects and should not be used in subjects who had conditions that altered ICW and ECW compartments (25).

Other BIA methods include: bioelectrical spectroscopy, which uses mathematical equations to illustrate relationships between resistance and body fluid (4); segmental-BIA, which involves placing additional electrodes on the wrist and foot of the opposite side (26, 36); localized BIA, which uses specific body segments; and BIA vector analysis, which eliminates equations and relies solely on the impedance vector.

**Assumptions associated with BIA measurement.** Despite the known properties of electrical currents, application to the human body requires various assumptions. Three of these assumptions are: 1. the body is composed of five, perfect cylinders with uniform cross-sectional areas, 2. the body has homogeneous conductivity making the reactance equal to zero, and 3. a 50 kHz is able to pass through cell membranes and all body fluids.

*5 cylinders.* One of the assumptions is that the conductor (body) consists of five perfect cylinders (upper and lower arm, upper and lower leg, and the trunk), each with a length proportional to subject's height, and each with a uniform component (3, 16, 18). The volume of the conductor can be calculated from the length and resistance of the cylinder. BIA calculations are based on the volume of a body from length and resistance measurements of these assumed cylinders (3). The human body is actually five irregular cylinders plus a head, with each cylinder consisting of various cross-sectional areas and components. Variations in the structure and composition of the cylinder affect the current. Fluid volume, temperature, and electrolyte concentration of the cylinder may alter resistance measurements. Therefore, the BIA does not directly measure any biological component (i.e. fat), but uses resistance to determine TBW to describe a subject.

The variation in cylinder composition and length leads to different resistance measurements, which means that body proportion variations can possibly magnify the body composition measurement error (3). The human body is poorly represented by the cylinder model, and BIA measurements are disproportionately sensitive to limb versus trunk water content since the principal part of the measured wrist-to-ankle impedance is due to the limbs (12). The largest contributors to whole-body resistance are the forearm (28%) and lower leg (33%), but only contribute < 2% of FFM and < 3% respectively of body weight compared to the trunk (22). This is further illustrated when examining the trunk region. The trunk makes up a large proportion of total body volume (up to 46%), but due to its large cross-sectional area and short length, contributes a small amount (as little as 3%) to whole-body impedance (3, 18, 26).

Despite these problems, BIA relates the impedance quotient ( $\text{length}/R^2$ ) to TBW by modeling the human body as a cylinder of uniform resistivity (26). The association between TBW and the impedance quotient is used in regression analysis to produce equations to predict FFM from TBW or TBW plus body weight (16). In SF-BIA, it is necessary to know the length of the conductor to estimate body composition. Height or a value based on sex and age is used as the conductor length. Due to SF-BIA's inability to measure both ICW and ECW, FFM is estimated from regression equations rather than directly measuring TBW.

*Homogeneous conductivity.* The second assumption is that the body has homogeneous conductivity, which makes the reactance (change in potential as the current passes through the body) zero. As mentioned above, impedance is a function of both resistance and reactance ( $Z^2 = R^2 + Xc^2$ ), but when the reactance is assumed to be very

small (zero), impedance and resistance are used interchangeably (3, 9). The human body does not have a uniform cross-sectional area and does not have homogeneous conductivity (25). Therefore the reactance is not zero, and assuming the Z and R are equal leads to incorrect %BF estimates.

By combining the first two assumptions (the body represented by perfect cylinders and reactance is equal to zero), the subject's volume can be quantified as  $\text{height}^2/\text{resistance}$ , referred to as the impedance index. Since the impedance index is based on a perfect cylinder, coefficients must be added to describe the actual geometry of the subject and account for the reactance (18). As a result, errors result from a number of factors: variation of the subject's body shape, variation of the segment shape, variations in the ratio of height to length, and the composition of the segment.

*50 kHz.* The third assumption is that a 50 kHz current will pass through all cell membranes and all body fluids. In fact, a 50 kHz current does not penetrate all body fluids; this frequency passes through ECW and only some ICW. Foster and Lukaski (11) demonstrated this and showed that resistance decreased as the frequency increased above 50 kHz. As a result, there are differences between BIA TBW estimates and isotopic dilution TBW estimates in subjects that an altered distribution of ECW:ICW (25). Gudivaka et al. (13) studied 27 healthy adult subjects before and after a water compartment alteration intervention. They found that SF-BIA at 50 kHz did not predict changes in TBW, but a parallel model 50 kHz SF-BIA did accurately measure changes. Gudivaka also found that the MF-BIA zero-to-infinity kHz model was the only model to accurately predict changes in both ICW and ECW.



**Sources of error.** Apart from the assumptions described above, there are other potential sources of error associated with BIA. Some other sources of error include hydration/electrolyte status, extreme leanness or obesity, and procedure (electrode placement, recent food intake, exercise, menstrual cycle, skin temperature, medication, and body position) (3, 16). If these variables are controlled, prediction errors can be kept to a minimum (3-5 %BF) (16).

*Hydration/electrolyte status.* The greatest source of error comes from hydration and electrolyte status. Equations assume that the subject is properly hydrated and are not accurate for subjects that are either hypo- or hyper-hydrated. In addition, electrolyte balance influences BIA measurements independently from fluid levels (18). Both hydration status and electrolyte balance effects the ratio of extra- to extra-cellular fluid. This ratio is critical to the reliability of BIA equations (18, 19). At 50 kHz, SF-BIA gives an estimate of extra-cellular water, which is related to TBW in a normally hydrated, healthy subject. If edema or malnutrition is present, there may be an increase in extra-cellular water or an alteration in the extra- to intra-cellular water ratio (9). In significantly altered hydration states (edema, kidney disease), the differences are too great to develop equations that fit the population (19).

*Extreme leanness or obesity.* FFM predictions for the very lean and very obese are less accurate, with overestimation of fat mass in lean and underestimation of fat mass in obese (3, 30). Errors in height and weight, errors in BIA measurement, and errors in prediction equation all contribute to the FFM error of 4% or less (3, 17). SF-BIA tends to overestimate the FFM of the obese and to underestimate that of athletes (6). A possible reason for this problem is the assumption that the ratio of the ICW to ECW is constant.

ECW increases with advancing obesity (leading to an overestimation) and ECW decreases and ICW increases relative to increasing FFM (leading to an underestimation) (6). Foster and Lukaski suggest that anthropometric measurements be added into BIA prediction equations. Due to the differences in body diameter, abdominal circumference can help standardize equations. Foster and Lukaski suggest that further research be performed to determine if one or more anthropometric variables are needed to improve the accuracy of BIA measurements (11). Segal et al. investigated anthropometric measurements on BIA equation. Segal found that anthropometry was useful in constructing BIA prediction equations and used anthropometrically determined %BF as a criterion for choosing a BIA equation. Separate equations were developed for men below and above 20% body fat and for women below and above 30% body fat. (30).

*Procedure.* The BIA device used and the procedure performed also are important in eliminating sources of error. Deurenberg et al. found a difference in 1.5 kg of estimated FFM when using two different BIA instruments of the same model and under the same conditions. Lohman found differences between eight different BIA instruments from the same company in two subjects (16).

Along with the device used, the procedure followed affects BIA accuracy. Evans et al. (10) found that impedance increased the longer the subject was supine, possibly due to a redistribution of body fluid as well as temperature and blood flow changes. Within the first ten minutes of lying supine, impedance increases and continues to increase for up to four hours (25). Cleaning the skin with alcohol also produced a significant increase in impedance. Variations in electrode position and number of electrodes used in the procedure make it difficult to validate data from various devices.

Different placement of electrodes (alternate combinations of arms and legs) produced a 6% change in impedance (10). A 1 cm movement of electrodes can account for as much as a 2% change in resistance (25). Ingesting 1 liter of water had no significant effect, but ingesting a large meal increased impedance (10). Skin temperature and ambient temperature, especially cold, affects resistance and reactance measurements (20). Position of the body and limb position can alter the electrical path and lower impedance (25). A height overestimation of 2.5 cm can alter the TBW measurement by up to 1 liter (25). A 1 kg over- or under-estimation of body weight can alter the TBW measurement by 0.2 liters (25). Regular calibration is critical for accurate and reliable measurements. Ideally, calibration checks should be made on standardized resistors over a range of resistance values, which could help to establish a standard for measurement (16). The NIH recommends that instrument standards and procedural methods be established (25). Other factors that affect the accuracy of BIA include: leg and arm position, consumption of food and beverages, recent physical activity, and conductance of examining table (25).

**Choosing an appropriate formula.** Since Hoffer et al. (15) published the correlation between TBW and  $\text{length}^2/R$ , many studies have sought to develop BIA algorithms that accurately represent body composition. The earliest published BIA equations showed wide variations across different ethnic groups and ages (18). It was soon determined that BIA equations should be specific to the population being studied, and all BIA equations should be verified against a reference method specific to the population being studied (18). Numerous BIA equations have been developed in both healthy and disease populations. Kyle et al. has published an extended list of BIA equations (18, 19).

There are numerous BIA equations that have been developed and validated, most on healthy, Caucasian subjects (25). As a result, there are many BIA equations in the literature, most of which are population-specific. Because of this, great care must be taken in choosing the correct BIA equation for the both the BIA device being used and the population being measured. Equations are developed on populations with similar characteristics (children, obese males, Asian, etc.). As a result, equations may only be useful for describing subjects who fit the equation's reference population. General prediction equations across different races should not be used without prior testing due to differences among ethnic groups (7).

The association between TBW and  $\text{height}^2/\text{R}$  are used in regression analysis to produce equations to predict FFM. Some BIA prediction equations predict FFM directly from  $\text{height}^2/\text{R}$ , while other equations include additional anthropometric variables like weight and circumferences as well as sex and age (16). Once an equation has been established, cross-validation is necessary to test the accuracy of the equation when applied to independent samples. Isotope dilution TBW and underwater weighing are the most common criterion methods for validation BIA equations. Due to changes in sex, age, and race, population-specific studies are necessary to most accurately describe body composition. It is important to standardize procedures (similar electrode placement, electrode number, SF v MF, protocols, algorithms). Additional anthropometric parameters, besides height and weight, have begun to be included in BIA equations (9). When looking for an appropriate, valid equation for FFM estimation Houtkooper suggests, a high  $R^2$ , a SEE less than 3.5 kg for men and 2.8 kg for women, and an actual error less than 2.9 kg for men and 2.4 for women when compared to criterion (16).

Houtkooper et al. have published an extended list of equations and their cross-validation results (16).

Some of the limitations of the BIA equations are due to the assumptions and sources of error (see above). Body segment variations, hydration, and body geometry are possible reasons why BIA equations can only be applied to a specific population. The ratio of ECW:ICW also limits the BIA equations in populations with an altered hydration status. BIA measurements need to be standardized for reproducible results to be obtained (18). No matter if SF-BIA or MF-BIA is chosen, the estimates obtained need to be validated with a more direct method of body composition. Originally, densitometry and hydrometry were used as the criterion, but more recently DXA has been used as a criterion method (1, 16).

In summary, BIA equation should be validated in the population studied. This includes age-, gender-, and ethnic-specific equations (9). Caution must be used when using BIA on subjects with abnormal body builds (very tall, very short, amputation) (19).

## **THE ROLE OF DENSITY IN THE BODY COMPOSITION OF ATHLETE**

Due to the differences in the athlete's physiology, body composition procedures used in healthy populations may not be suitable for athletes, specifically when body density is a factor. Many body composition procedures rely on density when calculating %BF; hydrostatic or underwater weighing (UWW), air displacement, and skinfolds (SF) are three of the most common methods that use density in calculating %BF. UWW requires the subject to be submerged underwater. The volume of water displaced and the subject's weight are used to determine density (3, 8). Air displacement measures the

volume of the body, which is used to calculate density. SF estimation often requires equations that use density; density is calculated from the skinfold sum, then %BF is calculated from density. There are wide variation in body density due to race, activity level, and age (31). Most athletes are more musculoskeletally developed, and as a result, FFM density is altered. It is possible that methods of body composition analysis that eliminate density from the equation may be more suitable for the athlete. Below is an overview of body density and its role in body composition analysis and how it relates to the athletic population.

**Body Density.** Density is defined as mass per unit volume. The density of water is  $1 \text{ g/cm}^3$ . Cadaver studies have shown lean tissue to be approximately  $1.100 \text{ g/cm}^3$ , while fat tissue is  $0.09007 \text{ g/cm}^3$  (23). The exact density of lean tissues varies, but is assumed to be  $1.1 \text{ g/cm}^3$ . Body density can be converted to a percentage of body fat (%BF) based on the assumption that there are two homogenous compartments in the body, fat and fat-free tissue, and each has a constant density (3). Density and body fat are inversely related; the higher percentage of fat, the lower the density.

**Body Density Assumptions.** %BF estimates are based on the assumption that fat- and fat-free component densities are known and are constant, and, apart from different percentages of fat, all adults have identical composition (23). Fat consists of a mixture of glycerides, sterols, phospholipids, and glycolipids. These variations are typically ignored in %BF calculations from density (3). Variations in the fat density exist between individuals and within the same individual at different times (3). Due to the changes in growth, maturation, and physical activity, these assumptions lead to wide variations in the composition of FFM (14). It is widely accepted that, even though there

may be differences in the composition and density of FFM, it is very difficult to accurately predict. The two-component model, which divides the body components into fat mass and fat-free mass (FFM), will be inaccurate if the fat-free body density (dFFM) differs from the assumed value of  $1.10 \text{ g/cm}^3$ , like in the highly developed musculoskeletal system of the athlete (3, 34).

**Body Density Equations.** Formulas that convert density to %BF have been derived from numerous studies on healthy adults. Two of the most commonly used formulas were derived by Brozek et al.  $\%BF = [(4.57/\text{density}) - 4.142] \times 100$  and Siri  $\%BF = [(4.950/\text{density}) - 4.5] \times 100$  (23). Each of these equations was produced from studying healthy adults. Both equations give similar %BF estimations in the healthy population but differ when measuring very lean, very obese, and hyper-hydrated subjects (2, 7, 27). The Brozek equation was based on the chemical composition of cadaver chemical analysis and was intended to be used in young, healthy, non-athletic populations, but it has been used in populations varying from children to elderly to women (3). The Siri equation worked well in providing accurate estimates of %BF in healthy adults, but was less accurate in young, very lean, very obese, high musculoskeletal development, and athletic individuals (24, 38). Alternatives to the Siri equation have been suggested (like the modified Siri equation) for use in athletic populations (27).

**Body Density in Studies.** The altered FFM density can lead to inaccurate body composition estimates. The two components of FFM, muscle and bone, have densities of  $1.066 \text{ g/cm}^3$  and  $3.317 \text{ g/cm}^3$  respectively (24). Alterations from “normal” would change the FFM density. Increases in musculoskeletal development would decrease the density

of FFM, while increases in bone density should increase the density of FFM. If muscle density and bone density increase in proportion, the density of FFM will be greater (greater influence from bone density). This is not always the case. Modlesky et al. (24) found that, when calculating %BF from density using the Siri equation, the FFM density was  $1.0989 \pm 0.005 \text{ g/cm}^3$ , and %BF was overestimated in young white men with high musculoskeletal development. The reason for this is that in high musculoskeletal development, there is a greater percentage of muscle in FFM (density =  $1.066 \text{ g/cm}^3$ ), lowering the density below  $1.1 \text{ g/cm}^3$ . Withers et al. (37) found that %BF was overestimated when using hydrodensitometric measurement in body builders. Withers compared hydrodensitometric measurement to a four-compartment mode that was able to determine percentages of water and bone mineral in the FFM. The differentiation between the components of FFM eliminated the error associated with body density. Prior et al. (27) studied whether the density of FFM was affected by musculoskeletal development in male and female collegiate athletes and nonathletes. FFM density ranged from  $1.075 \text{ g/cm}^3$  to  $1.127 \text{ g/cm}^3$  and was highly related to the water and protein content of the FFM and moderately related to the bone mineral content of the FFM. Prior concluded that athletes might have deviations in the density of FFM that are assumed in the Siri equation, which can lead to 2-5%BF errors. Prior also concluded that these deviations are not solely related to differences in musculoskeletal development.



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**APPENDIX B:  
INFORMED CONSENT**

## CONSENT FORM TO PARTICIPATE IN A RESEARCH STUDY

PRIMARY INVESTIGATOR: STEPHEN D. BALL  
STUDENT INVESTIGATORS:  
PROJECT # 1088057  
DATE OF PROJECT APPROVAL: JULY 11, 2007

FOR HS IRB USE ONLY	
APPROVED	
	7-23-07
HS IRB Authorized Representative	Date
EXPIRATION DATE:	7-11-2008

**STUDY TITLE:** COMPARISON OF SEVERAL BODY COMPOSITION ANALYSIS  
**TECHNIQUES:** SKINFOLD ANTHROPOMETRY, ~~BOB-POB~~, BIA, AND DXA

### INTRODUCTION

**This consent may contain words that you do not understand. Please ask the investigator or the study staff to explain any words or information that you do not clearly understand.**

This is a research study. Research studies include only people who choose to participate. You have the right to know about the procedures that will be used in this research study so that you can make the decision whether or not to participate. The information presented here is simply an effort to make you better informed so that you may give or withhold your consent to participate in this research study.

Please take your time to make your decision and discuss it with your family and friends.

*In order to participate in this study, it will be necessary to give your written consent.*

### WHY IS THIS STUDY BEING DONE?

The purpose of the study is to compare the accuracy of several available body composition measurement techniques by testing each one on a large group of volunteers. Results will be compared to the current standard (Dual X-Ray Absorptiometry, commonly known as a DXA scan) to determine the validity of currently used equations and possibly lead to updated and more accurate testing equations.

### **HOW MANY PEOPLE WILL TAKE PART IN THE STUDY?**

About 200 people will take part in this study at this institution only.

### **WHAT IS INVOLVED IN THE STUDY?**

If you take part in this study, your participation will involve having <sup>three</sup> ~~four~~ different body composition tests performed on the same day. These tests take about ~~90~~ <sup>30</sup> minutes total. You will need to come to the Exercise Physiology Laboratory (McKee Gymnasium) to complete these tests.

#### Prior to Testing:

To ensure the accuracy of the tests administered, you should NOT have exercised within 4 hours or eaten within 2 hours prior to testing.

#### Body Composition Tests:

When you arrive at the Exercise Physiology Laboratory an experienced technician will measure your body height, weight, skin fold thickness (arm, chest, side, stomach, hip, and thigh) and body circumferences (waist, hip, ~~arm~~, and ~~thigh~~). This will take approximately ~~10-20~~ minutes.

~~Next, analysis using the Bod Pod apparatus will take place, requiring that you be dressed in a swim-suit and swimming cap and sit in an egg-shaped chamber for 5 minutes while breathing normally.~~

Upon completion of the Bod Pod analysis, body composition will be measured with a Dual Energy X-Ray Absorptiometry (DXA) technique. The apparatus requires the removal of all jewelry, and you will be asked to lie still on a table for approximately 5 minutes while your body is scanned with low-intensity x-rays.

Finally, the last body composition technique utilized will be the bioelectrical impedance analysis (BIA), which passes an undetectable electrical stimulus through your body in order to test overall electrical impedance and predict your body composition.

A qualified lab technician will complete all measurements in order to minimize risk or discomfort during the testing process.

### **HOW LONG WILL I BE IN THE STUDY?**

We think you will be in the study for only the ~~90~~ <sup>30</sup> minutes required for testing.

**You can stop participating at any time. Your decision to withdraw from the study will not affect in any way your status on your respective athletic team, your medical care and/or your benefits. Your participation is entirely voluntary. You are entitled to have any further inquires answered regarding this research project.**

## **WHAT ARE THE RISKS OF THE STUDY?**

While in the study, you are at risk for the side effects described below. You should discuss these with the investigator and/or your doctor or coach. There may also be other side effects that we cannot predict.

Risks and side effects related to the procedures we are studying include:

- a) The skin fold thickness measurement by the calipers may cause a slight pinching sensation and in some rare cases minor redness or bruising.
- b) You may feel uncomfortable being touched during anthropometric analysis or being seen in a swimsuit.
- c) ~~You may experience claustrophobia while sitting in the Bod Pod during body composition analysis.~~
- d) DXA uses small levels of radiation. The radiation dose and risk from this procedure typically is judged to be negligible. The amount of radiation from a DXA scan is about 1/10<sup>th</sup> of the amount you will receive from a chest X-ray.

**You should not have the DXA scan if there is any possibility of your being pregnant.**

- e) The BIA sends a weak electrical current through the body during analysis.

**You should not participate in the study if you have an artificial cardiac pacemaker, as the electrical signal may cause the device to malfunction.**

For the reasons stated above we will observe you closely while performing the procedures described, and if you have any worrisome symptoms or symptoms that my associates or I have described to you, we will stop the tests. Please notify Dr. Stephen Ball immediately if you have any other side effects after leaving the lab. Dr. Ball's telephone number is 573-882-2334.

## **ARE THERE BENEFITS TO TAKING PART IN THE STUDY?**

You may benefit from participating in this study by receiving an accurate measure of your body composition at the time of testing for understanding the impact of your percent body fat on your health and exercise planning. Data from this research may eventually lead to improved prediction equations and procedures for the composition techniques, making body composition analysis more accurate using techniques more commonly available.



### **WHAT OTHER OPTIONS ARE THERE?**

An alternative is to not participate in this research study.

### **WHAT ABOUT CONFIDENTIALITY?**

Information produced by this study will be stored in the investigator's file and identified by a code number only. The code key connecting your name to specific information about you will be kept in a separate, secure location. Information contained in your records may not be given to anyone unaffiliated with the study in a form that could identify you without your written consent except as described in this consent form or as required by law.

It is possible that your medical and/or research record, including sensitive information and/or identifying information, may be inspected and/or copied by the study sponsor (and/or its agent), the Food and Drug Administration (FDA), federal or state government agencies, or hospital accrediting agencies, in the course of carrying out their duties. If your record is inspected or copied by the study sponsor (and/or its agents), or by any of these agencies, the University of Missouri will use reasonable efforts to protect your privacy and the confidentiality of your information.

The results of this study may be published in a medical book or journal or used for teaching purposes. However, your name or other identifiers will not be used in any publication or teaching materials without your specific permission.

### **WHAT ARE THE COSTS?**

You will not be charged for your participation in this research study.

### **WILL I BE PAID FOR PARTICIPATING IN THE STUDY?**

You will receive no payment for taking part in this study.

### **WHAT IF I AM INJURED?**

It is not the policy of the University of Missouri to compensate human subjects in the event the research results in injury. The University of Missouri, in fulfilling its public responsibility, has provided medical, professional and general liability insurance coverage for any injury in the event such injury is caused by the negligence of the University of Missouri, its faculty and staff. The University of Missouri also will provide, within the limitations of the laws of the State of Missouri, facilities and medical attention to subjects who suffer injuries while participating in the research projects of the

University of Missouri. In the event you have suffered injury as the result of participation in this research program, you are to contact the Risk Management Officer, telephone number (573) 882-1181, at the Health Sciences Center, who can review the matter and provide further information. This statement is not to be construed as an admission of liability.

#### **WHAT ARE MY RIGHTS AS A PARTICIPANT?**

**Participation in this study is voluntary. You do not have to participate in this study. Your present or future care or status on your team will not be affected should you choose not to participate.** If you decide to participate, you can change your mind and drop out of the study at any time without affecting your present or future status at the University of Missouri. Leaving the study will not result in any penalty or loss of benefits to which you are entitled. In addition, the investigator of this study may decide to end your participation in this study at any time after he/she has explained the reasons for doing so. You will be informed of any significant new findings discovered during the course of this study that might influence your health, welfare, or willingness to continue participation in this study.

#### **WHOM DO I CALL IF I HAVE QUESTIONS OR PROBLEMS?**

If you have any questions regarding your rights as a subject in this research and/or concerns about the study, or if you feel under any pressure to enroll or to continue to participate in this study, you may contact the University of Missouri Health Sciences Institutional Review Board (which is a group of people who review the research studies to protect participants' rights) at (573) 882-3181.

You may ask more questions about the study at any time. For questions about the study or a research-related injury, contact Dr. Stephen D. Ball at 573-882-2334.

A copy of this consent form will be given to you to keep.

**SIGNATURE**

I confirm that the purpose of the research, the study procedures, the possible risks and discomforts as well as potential benefits that I may experience have been explained to me. Alternatives to my participation in the study also have been discussed. I have read this consent form and my questions have been answered. My signature below indicates my willingness to participate in this study.

\_\_\_\_\_  
Subject/Patient\* \_\_\_\_\_  
Date

\_\_\_\_\_  
Legal Guardian/Advocate/Witness (if required)\*\* \_\_\_\_\_  
Date

\_\_\_\_\_  
Additional Signature (if required) (identify relationship to subject) \_\_\_\_\_  
Date

\*A minor's signature on this line indicates his/her assent to participate in this study. A minor's signature is not required if he/she is under 7 years old. Use the "Legal Guardian/Advocate/Witness" line for the parent's signature, and you may use the "Additional Signature" line for the second parent's signature if applicable.

\*\*The presence and signature of an impartial witness is required during the entire informed consent discussion if the patient or patient's legally authorized representative is unable to read.

**SIGNATURE OF STUDY REPRESENTATIVE**

I have explained the purpose of the research, the study procedures, identifying those that are investigational, the possible risks and discomforts as well as potential benefits and have answered questions regarding the study to the best of my ability.

\_\_\_\_\_  
Study Representative\*\*\* \_\_\_\_\_  
Date

\*\*\*Study Representative is a person authorized to obtain consent. Per the policies of the University of Missouri Health Care, for any 'significant risk/treatment' study, the study representative must be a physician who is either the Principal or Co-Investigator. If the study is deemed either 'significant risk/non-treatment' or 'minimal risk,' the study representative may be a non-physician study investigator.

**APPENDIX C:  
DATA SHEETS**

## BODY COMPOSITION COMPARISON STUDY

Subject Number: \_\_\_\_\_ Date: \_\_\_\_\_ Operator: \_\_\_\_\_

Birth date: \_\_\_\_\_ Age: \_\_\_\_\_ (years)

Weight: \_\_\_\_\_ (kg) \_\_\_\_\_ (lbs) Height: \_\_\_\_\_ (cm) \_\_\_\_\_ (inches)

cm	Trial 1	Trial 2	Trial 3	mean
Waist				
Umb.				
Hip				

BMI:  kg/m<sup>2</sup>

WHR:

### SKIN FOLDS

Use mean of two closest values within 1 mm.

Skinfold site	Trial 1	Trial 2	Trial 3	Mean
Chest				*
Midaxillary				
Tricep				
Subscapular				
Abdomen				*
Suprailiac				
Thigh				*

Sum of 3 SF: \_\_\_\_\_

Sum of 7 SF: \_\_\_\_\_

Skinfold result:

Equation	%BF
JP3a	
JP3b	
JP7	
DC	
DC <sub>2</sub>	

### BIA

Z = \_\_\_\_\_

Ph = \_\_\_\_\_

R = \_\_\_\_\_

Xc = \_\_\_\_\_

BIA result (from computer):  %

TBW: \_\_\_\_\_ ICW: \_\_\_\_\_ ECW: \_\_\_\_\_

### DXA

DXA result:  %

**APPENDIX D:  
STATISTICAL RESULTS**

**SF reliability, BIA reliability, DXA reliability**

**Reliability of body composition methods,  $n = 10$  repeated twice on same day**

method	correlation		Paired T-Test			
	$r$	P	mean diff.	SEM	t	P
<b>BIA</b>	0.999	< .001	0.010	0.2233	0.142	0.891
<b>DXA</b>	0.999	< .001	0.030	0.3653	0.260	0.801
<b>JP3a</b>	1	< .001	0.057	0.1528	1.179	0.268
<b>JP3b</b>	1	< .001	0.003	0.1236	0.077	0.940
<b>JP7</b>	1	< .001	0.030	0.0949	1.000	0.343
<b>DC</b>	1	< .001	0.030	0.1229	0.514	0.619

Accept null hypothesis for all (means are equal).

**Recommended generalizable anthropometric equations for men**

Equation	Sites	Formula
<b>3 site equations:</b>		
<b>JP3a:</b>	<b>Chest, abdomen, thigh</b>	$[1.10938 - 0.0008267(\sum 3SF) + 0.0000016(\sum 3SF)^2 - 0.0002574(\text{age})]$
<b>JP3b:</b>	<b>Chest, tricep, subscapular</b>	$[1.1125025 - 0.0013125(\sum 3SF) + 0.0000055(\sum 3SF)^2 - 0.000244(\text{age})]$
<b>7 site equations:</b>		
<b>JP7:</b>	<b>Chest, midaxillary, tricep, thigh, subscapular, suprailiac, abdomen</b>	$[1.112 - 0.00043499(\sum 7SF) + 0.00000055(\sum 7SF)^2 - 0.00028826(\text{age})]$
<b>DC:</b>	<b>Chest, midaxillary, tricep, thigh, subscapular, suprailiac, abdomen</b>	$[\%BF = 0.465 + 0.180(\sum 7SF) - 0.0002406(\sum 7SF)^2 + 0.06619(\text{age})]$
<b>DC<sub>2</sub>:</b>	<b>Chest, midaxillary, tricep, thigh, subscapular, suprailiac, abdomen</b>	$[\%BF = -7.57531 + 0.16523(\sum 7SF) - 0.00025244(\sum 7SF)^2 + 0.03726(\text{age}) + 0.25708(\text{waist in cm}) - 0.06480(\text{mass in lbs})]$

**JP3a equation developed by Jackson and Pollock (25)**

**JP3b equation developed by Jackson and Pollock (26)**

**JP7 equation developed by Jackson and Pollock (25)**

**DC and DC<sub>2</sub> equations developed by Ball et al. (2)**

**All variable correlations with DXA**

**Correlations of all variables**

<b>n = 80</b>	<b>Age</b>	<b>Weight (kg)</b>	<b>Height (cm)</b>	<b>Waist (cm)</b>	<b>Umb (cm)</b>
<b>Age</b>	1	-.358**	-.113	-.343**	-.321**
<b>Weight (kg)</b>		1	.588**	.942**	.939**
<b>Height (cm)</b>			1	.503**	.542**
<b>Waist (cm)</b>				1	.983**
<b>Umbilical (cm)</b>					1
<b>Hip (cm)</b>					
<b>BMI</b>					
<b>WHR</b>					
<b>3SFa</b>					
<b>3SFb</b>					
<b>7SF</b>					
<b>BIA</b>					
<b>Z (Ω)</b>					
<b>Ph (Ω)</b>					
<b>R (Ω)</b>					
<b>Xc (Ω)</b>					
<b>Ht2/R</b>					
<b>TBW</b>					
<b>ICW</b>					
<b>ECW</b>					
<b>DXA</b>					

\* p < .05, \*\* p < .01



<b>n = 80</b>	<b>Hip (cm)</b>	<b>BMI</b>	<b>WHR</b>	<b>3SFa</b>	<b>3SFb</b>
<b>Age</b>	-.333**	-.414**	-.220*	-.258*	-.320**
<b>Weight (kg)</b>	.955**	.888**	.500**	.846**	.851**
<b>Height (cm)</b>	.561**	.279**	.136	.434**	.401**
<b>Waist (cm)</b>	.952**	.907**	.681**	.879**	.869**
<b>Umbilical (cm)</b>	.944**	.879**	.644**	.907**	.884**
<b>Hip (cm)</b>	1	.898**	.427**	.879**	.861**
<b>BMI</b>		1	.542**	.831**	.832**
<b>WHR</b>			1	.493**	.508**
<b>3SFa</b>				1	.955**
<b>3SFb</b>					1
<b>7SF</b>					
<b>BIA</b>					
<b>Z</b>					
<b>Ph</b>					
<b>R</b>					
<b>Xc</b>					
<b>Ht2/R</b>					
<b>TBW</b>					
<b>ICW</b>					
<b>ECW</b>					
<b>DXA</b>					

n = 80	<b>7SF</b>	<b>BIA</b>	<b>Z (Ω)</b>	<b>Ph (Ω)</b>	<b>R (Ω)</b>
<b>Age</b>	-.309**	-.292**	.275*	-.389**	.277*
<b>Weight (kg)</b>	.859**	.643**	-.679**	.348**	-.678**
<b>Height (cm)</b>	.426**	.418**	-.124	-.064	-.122
<b>Waist (cm)</b>	.888**	.685**	-.681**	.386**	-.680**
<b>Umbilical (cm)</b>	.912**	.709**	-.620**	.314**	-.619**
<b>Hip (cm)</b>	.886**	.684**	-.660**	.368**	-.659**
<b>BMI</b>	.840**	.636**	-.785**	.496**	-.758**
<b>WHR</b>	.504**	.382**	-.455**	.285**	-.455**
<b>3SFa</b>	.989**	.784**	-.471**	.176	-.469**
<b>3SFb</b>	.978**	.736**	-.509**	.176	-.507**
<b>7SF</b>	1	.777**	-.493**	.197**	-.491**
<b>BIA</b>		1	-.047	-.003	-.047
<b>Z</b>			1	-.636**	1.000**
<b>Ph</b>				1	-.643**
<b>R</b>					1
<b>Xc</b>					
<b>Ht2/R</b>					
<b>TBW</b>					
<b>ICW</b>					
<b>ECW</b>					
<b>DXA</b>					

<b>n = 80</b>	<b>Xc (Ω)</b>	<b>Ht2/R</b>	<b>TBW</b>	<b>ICW</b>	<b>ECW</b>	<b>DXA</b>
<b>Age</b>	.034	-.294**	.288**	.080	-.080	-.240*
<b>Weight (kg)</b>	-.577**	.871**	-.632**	-.629**	.629**	.782**
<b>Height (cm)</b>	-.208	.596**	-.427**	-.581**	.581**	.392**
<b>Waist (cm)</b>	-.536**	.823**	-.674**	-.613**	.613**	.821**
<b>Umbilical (cm)</b>	-.522*	.795**	-.689**	-.664**	.664**	.849**
<b>Hip (cm)</b>	-.530**	.838**	-.669**	-.634**	.634**	.828**
<b>BMI</b>	-.549**	.782**	-.617**	-.486**	.486**	.775**
<b>WHR</b>	-.322**	.437**	-.380**	-.279**	.279**	.449**
<b>3SFa</b>	-.469**	.620**	-.753**	-.719**	.719**	.952**
<b>3SFb</b>	-.522**	.647**	-.700**	-.687**	.687**	.935**
<b>7SF</b>	-.480**	.639**	-.744**	-.705**	.705**	.958**
<b>BIA</b>	-.058	.277**	-.976**	-.782**	.782**	.796**
<b>Z</b>	.725**	-.853**	.043	.059	-.059	-.412**
<b>Ph</b>	.027	.463**	-.007	.429**	-.429**	.136
<b>R</b>	.719**	-.852**	.043	.054	-.054	-.411**
<b>Xc</b>	1	-.701**	.044	.437**	-.437**	-.423**
<b>Ht2/R</b>		1	-.277**	-.366**	.366**	.552**
<b>TBW</b>			1	.758**	-.758**	-.752**
<b>ICW</b>				1	-1.000**	-.705**
<b>ECW</b>					1	.705**
<b>DXA</b>						1

Coefficients for the SF DF50 correction equation

(*n* = 80) **Unstandardized**

<b>variable</b>	<b>Coefficients</b>	<b>t</b>	<b>Sig.</b>
<b>weight</b>	-0.066	-4.037	0.000
<b>BIA</b>	0.080	2.436	0.017
<b>hip</b>	0.113	8.575	0.000
<b>7SF</b>	0.073	13.856	0.000

BIA, bioelectrical impedance %BF; hip, hip circumference; 7SF, sum of Seven skin folds.

Contribution and order of entry into the SF DF50 prediction regression equation

<b>variables</b>	<b>Cumulative Dependant Variables Used in Model</b>			<b>Dependant Variables</b>		
	$r^2_{adj.}$	<b>SEE</b>	<b>P</b>	$r^2_{adj.}$	<b>SEE</b>	<b>P</b>
<b>weight</b>	0.962	2.88	0.001	0.962	2.88	0.001
<b>+ BIA</b>	0.975	2.31	0.001	0.960	2.95	0.001
<b>+ hip</b>	0.976	2.31	0.001	0.941	3.58	0.001
<b>+ 7SF</b>	0.993	1.24	0.001	0.936	3.72	0.001

BIA, bioelectrical impedance %BF; hip, hip circumference; 7SF, sum of seven skin folds.

**APPENDIX E:  
RAW DATA**

**Endurance group – anthropometric data**

subj #	age	weight (kg)	height (cm)	Waist circ. (cm)	Umb. Circ. (cm)	Hip Circ.(cm)	BMI	WHR
2	39	69	180.6	72.5	74	91.5	21.16	0.792
5	40	66.6	168.6	75	76.5	91.5	23.43	0.82
6	21	68.6	174	77	78.5	93	22.66	0.828
9	44	76.6	179	79	78	94	23.91	0.8404
10	34	70.2	180	73	74	91	21.67	0.8022
12	22	61.8	168.5	74	74.5	87	21.77	0.8506
3	20	72	179	72	72.5	91	22.47	0.791
15	48	84.4	186	80.5	80	97	24.4	0.8299
17	21	67.9	176.5	75.5	75.5	89	21.8	0.8483
18	32	68.4	188	73	73.5	90	19.35	0.8111
20	43	78.6	175	80	82	93	25.67	0.86
21	21	73.6	180	75.5	75.5	91	22.72	0.8297
24	24	81	177.5	80	79	94	25.71	0.8511
25	30	72.5	177.5	78	79	91	23.01	0.8667
26	41	84.2	193	77	81	95	22.6	0.8105
30	38	68.5	151	75	75	90	21.14	0.8333
31	27	74.4	176.4	83	83	90	23.9	0.9222
34	38	81.4	182.6	82	85	94	24.41	0.8723
42	23	74.9	180	80	78	92	23	0.8696
43	31	71.6	180	77	80	89.5	22	0.8603
44	26	85	185.4	83	81	96	24.7	0.8646
45	20	71	181.5	74.5	75	88	21.55	0.8466
46	24	71.5	177.5	78	78	91	22.69	0.8571
47	27	68.7	190.5	69	72	89	18.93	0.7753
48	29	77	180	77	78	98	23.7	0.7857
49	41	78	183	80.5	79.5	96	23.29	0.8385
51	46	59.6	188	77	79	91	20.3	0.8461
54	33	77.6	190.5	75.5	80	96	21.38	0.7865
56	29	63.9	175	73	73.5	87	20.8	0.8391
57	27	75.8	190.5	78	83.5	95	20.9	0.8211
58	35	67.2	174	73	74	88	22.2	0.8295
59	26	67.6	181.5	73	75	91	20.52	0.8022
60	21	62.8	174	70	70	88	20.8	0.7955
61	36	67	173.8	74.5	77	90	22.18	0.8278
62	21	70.2	181.4	73.5	74	89	21.33	0.8258
63	30	64.6	165	72	73	85	23.73	0.8471
64	30	71.1	185.5	74.5	77	90	20.66	0.8278
66	22	67	177.5	70.5	72	87	21.3	0.8103
86	23	79.5	185.4	82	86.5	95.5	23.1	0.8586
88	33	76.6	182.5	79	79	97	22.99	0.8144

**Endurance Group – skinfold data**

subj #	chest	midax	tricep	subscap	abd	suprailiac	thigh	3SF sum	7SF sum
2	4	5.5	6	8	9.5	6	5.5	19	44.5
5	9	16.5	8	17	19	25.5	14	42	109
6	6.5	8	12	11	17	17	8.5	32	79.5
9	6.5	6	8.5	11	10	9	6	22.5	56.5
10	7	12	8	13	12	21	7	26	79.5
12	5	5	4.5	9	10	11.5	7	22	52
3	8	9	11	13	17	29	10	34.5	96
15	8.5	6	9.5	8	10	6.5	16	34.5	64.5
17	4	6	8	10	9	16	12	25	65
18	5	5	5	6	7	6	6	18	40
20	7	10	7	17	31	22	9	47	103
21	5	5	6	11	8	8.5	10	23	53.5
24	5	5.5	5.5	9	8	12.5	9	22	54.5
25	7	7	8	13	16	16	7.5	30.5	74
26	6	6	7	10	15	15	16	37	75
30	4.5	4.5	4	6	6	5	8	18.5	38
31	5	7	8	12	10	13	10	25	65
34	8	10.5	7	11	17	14.5	9	33.5	76.5
42	6	5	6	9	8	10	11	25	55
43	4	4	4	6	8	5	5	17	36
44	6	7	6	7	9	11	10	25	56
45	4.5	5	4	8	8	9	6	18.5	44.5
46	6.5	5.5	6	6	6.5	8	8	21	46.5
47	3.5	4	5.5	6.5	8	8.5	9	20.5	45
48	6	12	9.5	14	23	16	13	41.5	93
49	7	6.5	8	9	9	8.5	7.5	23.5	55.5
51	8	7	10.5	9.5	18	11.5	13	39	77.5
54	6	5	11	9	9	11	17	32	68
56	4	5	5	6	6.5	6.5	12	22.5	45
57	11	11.5	9	9	21	16	7	39	84.5
58	5	6	9	8	16	15	12	33	71
59	8	10	13	15	14	17	13	35	90
60	4	6	13	7	12	12	10	26	64
61	4	5	10	8	14	8	10	28	59
62	4	4	6	7	7	8	6	17	42
63	5	6	6	8.5	7.5	5	6	18.5	44
64	5	5	7	9	8	7	6	19	57
66	4	4	5	6.5	6	6	7	17	38.5
86	10	13	13	12	20	21.5	12	41	101
88	6.5	6	6	6	11	7	8	25.5	50.5

**Endurance Group – BIA and DXA data**

subj #	BIA	BIA FFM	Z	Ph	R	Xc	Ht2/R	TBW	ICW	ECW	DXA	DXA FFM
2	7.8	63.618	440.3	7.9	436.2	60.3	74.773	66.5	62.7	37.3	10.7	61.617
5	25	49.95	513.5	7.1	509.5	63.5	55.791	54.1	58.5	41.5	15.9	56.0106
6	18.8	55.7032	483.6	7.7	479.2	65.2	63.180	58.5	61.1	38.9	11.6	60.6424
9	11.7	67.6378	403.5	7.2	400.3	50.8	80.042	63.6	59.3	40.7	12.5	67.025
10	12.2	61.6356	461.4	8.1	456.8	64.9	70.922	63.3	62.7	37.3	11.8	61.9164
12	17.8	50.7996	497.5	7.4	493.3	64.4	57.555	58.1	60.5	39.5	10.6	55.2492
3	12.9	62.712	442.2	7.6	438.3	58.5	73.102	62.8	60.9	39.1	13.6	62.208
15	20.1	67.4356	421	6.5	418.3	48	82.706	57.6	54.4	45.6	12.7	73.6812
17	21.2	53.5052	528.4	7.7	523.6	71	59.496	56.8	60.9	39.1	11.9	59.8199
18	13.8	58.9608	522.5	6.8	518.9	61.7	68.113	62.1	59.1	40.9	10.1	61.4916
20	12.1	69.0894	376.5	7.2	373.5	47	81.994	63.4	58.9	41.1	12.7	68.6178
21	14.7	62.7808	450.6	7.6	446.6	59.9	72.548	61.5	60.5	39.5	10.3	66.0192
24	18.9	65.691	420	7.8	416.2	56.6	75.699	58.5	59.5	40.5	10.1	72.819
25	12.1	63.7275	424.7	7.2	421.4	53	74.765	63.3	59.7	40.3	10.6	64.815
26	23	64.834	503.3	6.3	500.3	55.3	74.453	55.5	53.9	46.1	13.9	72.4962
30	12.6	59.869	483.1	7	479.5	58.9	47.551	63	59.7	40.3	8.3	62.8145
31	17.5	61.38	446.4	8	442.1	61.9	70.384	59.5	61.1	38.9	10.2	66.8112
34	21	64.306	458.2	7.5	454.4	59.5	73.377	57	58.4	41.6	13.1	70.7366
42	16.2	62.7662	447.4	7	444.2	54.2	72.940	60.4	58.3	41.7	9.8	67.5598
43	11.2	63.5808	442.3	7.7	438.3	59.6	73.921	64	61.6	38.4	8.1	65.8004
44	17.3	70.295	430.1	8.3	425.6	62	80.764	50.6	60.8	39.2	9.5	76.925
45	14.8	60.492	474.8	7.2	471.1	59.3	69.926	61.5	59.7	40.3	8.2	65.178
46	20.3	56.9855	482.4	6.5	479.3	54.5	65.733	57.5	56.3	43.7	10.2	64.207
47	15.9	57.7767	539.1	5.6	536.5	52.2	67.642	60.6	53.6	46.4	9.8	61.9674
48	21.1	60.753	472.2	7.3	468.4	60	69.171	56.9	58.3	41.7	16.2	64.526
49	20.8	61.776	494.9	8.1	489.9	69.9	68.358	57.1	60.9	39.1	10.8	69.576
51	20.4	47.4416	557.8	7.1	553.5	69.1	63.855	57.4	59.2	40.8	13.8	51.3752
54	14.7	66.1928	478.2	7.4	474.2	61.3	76.529	61.5	59.6	40.4	10.7	69.2968
56	17.6	52.6536	521.9	7.5	517.5	67.8	59.178	59.4	61.5	38.5	10.3	57.3183
57	18.5	61.777	508.2	6.1	505.4	53.7	71.805	58.7	54.6	45.4	13.1	65.8702
58	17.9	55.1712	488	7.8	483.5	65.9	62.618	59.2	61.6	38.4	13.8	57.9264
59	29.5	47.658	636.5	6.1	632.9	67.6	52.049	50.9	54.5	45.5	12.8	58.9472
60	18.8	50.9936	529.1	7.2	524.9	66.2	57.679	58.6	60.6	39.4	11.1	55.8292
61	19.3	54.069	495.3	7.2	491.4	62.1	61.470	58.2	59.7	40.3	13.1	58.223
62	17.7	57.7746	507.4	7.6	503	67.1	65.419	59.4	60.8	39.2	10.7	62.6886
63	25.3	48.2562	513.7	7.5	509.3	67.2	53.455	53.9	60.1	39.9	11.6	57.1064
64	16.3	59.5107	503.7	6.8	500.2	59.3	68.792	60.3	58.3	41.7	10.5	63.6345
66	15	56.95	488.9	7.9	484.2	67.4	65.068	61.3	62.3	37.7	9.1	60.903
86	24.9	59.7045	519.7	7.4	515.4	66.6	66.6922	54.2	57.9	42.1	15.7	67.0185
88	18.6	62.3524	479.1	8.2	474.2	68.1	70.236	58.7	61.3	38.7	10.9	68.2506



**Power Group – anthropometric data**

subj #	age	wt (kg)	ht (cm)	waist(cm)	umb.(cm)	hip(cm)	BMI	WHR
4	34	103	188	93.5	96	105	29.14	0.89
8	20	89	180	85	84.5	101	27.56	0.842
14	19	103	180	93	92.5	106	31.64	0.8815
16	29	94	180	89	90	106	29.01	0.8436
19	19	64	165	73	73	86	23.38	0.8488
28	22	101	183	90	91	100	30.1	0.9
29	22	79	170	80	80	96	37.3	0.8333
32	21	92	173	82	82	104	31	0.7885
33	21	78	184	77	79	95	23.1	0.8105
36	25	93	188	84	88.5	98	26.26	0.8571
38	23	83	183	82	85	95	24.8	0.8632
39	22	74	181	74.5	78	92	22.5	0.8098
41	24	129	188	103	110	123	36.5	0.8349
50	22	74	170	76	75	92	25.74	0.8261
52	19	106	180	95	100	107	32.72	0.9159
53	25	80	165	82.5	81.5	99	29.53	0.8333
55	21	137	193	102	110	119	36	0.8571
65	23	105	176	98.5	106	107	33.86	0.9122
67	22	108	194	92	94	109	28.8	0.844
68	21	138	192	106	119	121	37.4	0.876
69	20	114	187	94	95	110	32.7	0.8545
70	21	135	191	104	108	115	37.2	0.9043
71	22	103	182	93.5	94	103	31	0.898
72	22	93	184	81	80	100	27.55	0.81
73	22	94	182	84.5	83	101	28.23	0.8366
74	19	100	188	85	88	100	28.23	0.85
75	28	74	164	79.5	82	93	27.5	0.8548
76	19	129	191	97	102	118	35.6	0.822
77	20	84	182	78.5	80	98	25.38	0.801
78	20	63	185	89	90	103	27.96	0.8641
79	21	129	188	108	112	120	34.1	0.9
80	23	102	191	90	94	103	28.1	0.8738
81	19	103	188	90	93	104	29.12	0.8653
82	20	112	196	93.5	97.5	107	29.1	0.8738
83	22	149	201	106	110	120	37.1	0.8833
84	20	136	192	108	117	116	36.9	0.931
85	29	82	170	84	83.5	98	28.45	0.8571
87	37	90	188	83.5	87	99	25.54	0.8434
89	28	74	175	80	82	93	23.99	0.8602
90	36	90	184	82	86	100	26.5	0.82

**Power group – skinfold data**

subj #	chest	midax	tricep	subscap	abd	suprailiac	thigh	3SF sum	7SF sum
4	9.5	16	17.5	27	30	24	13	52.5	137
8	5	7	6	10	12	12	9	26	61
14	6	12	10	22	24	20	8	38	102
16	11	11	13	15	38	41	22	71	151
19	4	5	9	8	6	5.5	6	16	43.5
28	11	22	15	20	24	20	11	46	123
29	9	13	13	13	23	12	15	47	98
32	9	15	13	13	16	15	13	38	94
33	5	5	7	12	8.5	13	7	20.5	57
36	6	10	9.5	12	14	18	11	30.5	79.5
38	6	11	5.5	13	18	12	8	31.5	73
39	7	12	7	14	19	19	9	35	87
41	25	30.5	22.5	30	50	63	28	102	248
50	4	5	4.5	11	7	6	6	17	43
52	15	30	23	33	44	40	23	81.5	207
53	11	22	10	25	24	28	11	46	131
55	12	20	19	23	30	31	15	57	150
65	20	29.5	24.5	35	37	43	43	99	231
67	9	20	7	16	29	34	14	52	129
68	17	32	21	43	60	62	38	115	273
69	14	18	22	27	30	28	24	68	163
70	15	24	14	25	52	43	12	79	185
71	12	17	16.5	23	22	30	12	46	131
72	5	8	5	15	12	9.5	11	28	66
73	7.5	7	12	12	13	12	19	39	81.5
74	7	9.5	8.5	14	16	21	12	35	87.5
75	8.5	12	10	17	25	17.5	13	46	102
76	16	30	31	36	49	47	23	87	231
77	5	7	6	11	10	11	11	26	60.5
78	7	11.5	6.5	12	24	17.5	13	43.5	101
79	21	28.5	24	35	47	59	28	95.5	242
80	9.5	15.5	19.5	21	31	27	16	56	139
81	9	12.5	14	14	16	20.5	19	43.5	104
82	14	27.5	13.5	25	35	33.5	25	72.5	172
83	21	42	27	44	56	47	29	106	266
84	24	40	11	35	55	47	14	93	226
85	5.5	13	5	12	13	16.5	11	29	74
87	9.5	13	8	12	20	24	15	44.5	102
89	10	16	12	13	21	25	8	39	105
90	5	9	5	7	16	16.5	9	30	67.5

**Power group – BIA and DXA data**

subj#	BIA	BIA FFM	Z	Ph	R	Xc	Ht2/R	TBW	ICW	ECW	DXA	DXA FFM
4	17.2	85.284	355.1	7.7	351.8	47.8	100.466	59.7	57.7	42.3	15.2	87.344
8	15.4	75.5478	377.3	9.5	372.2	62.1	87.049	61	63	37	10.3	80.1021
14	13.7	88.4575	315.4	9.2	311.3	50.7	104.079	62.2	61.7	38.3	12.2	89.995
16	26.6	68.996	422.6	8.4	418.1	61.8	77.493	52.9	58.3	41.7	18.7	76.422
19	11.4	56.3496	424.4	8.7	419.5	64.5	64.898	63.9	64.9	35.1	9.6	57.4944
28	16.5	84.001	342	8.4	338.3	50.1	98.992	60.2	59.7	40.3	13.7	86.8178
29	26.5	58.065	448.1	8	443.7	62.4	65.134	53	58.9	41.1	13.8	68.098
32	15.9	77.7084	330.5	8.7	326.6	50	91.109	60.6	60.9	39.1	14.1	79.3716
33	21	61.936	482.9	7.2	479	60.9	70.680	57	57.9	42.1	11.5	69.384
36	20.1	74.1472	415.4	7.6	411.7	55.2	85.848	57.6	57.7	42.3	11.8	81.8496
38	13.3	72.0477	405.2	8.9	400.3	62.9	83.659	62.5	62.8	37.2	13.6	71.7984
39	22.4	57.424	513.9	7.4	509.6	66.4	64.287	55.9	58.9	41.1	13.4	64.084
41	32.9	86.4248	365.1	7.7	361.8	49.2	97.689	48.4	52.6	47.4	23.9	98.0168
50	6.3	69.7128	353.5	8.7	349.4	53.7	82.713	67.5	64	36	9.2	67.5552
52	29.9	74.306	392.3	8.3	388.2	56.5	83.462	53.6	56.2	43.8	25.1	79.394
53	25.7	59.7372	404.8	8.1	400.8	56.9	67.926	53.6	58.9	41.1	19	65.124
55	22.5	106.02	310.8	8.3	307.5	45.1	121.135	55.8	56.5	43.5	19.3	110.3976
65	29.6	73.8496	371.1	7.1	368.2	46.2	84.128	50.7	53.2	46.8	26.3	77.3113
67	23.1	83.052	397.8	8.2	393.9	56.5	95.055	55.4	57.6	42.4	16	90.72
68	37.5	85.9375	394.8	8.7	390.2	59.9	94.179	45.1	53	47	22.7	106.2875
69	23	87.78	343.4	7.6	340.4	45.3	102.180	55.5	55.5	44.5	18.7	92.682
70	34.1	88.965	366.4	7.8	363	49.8	99.973	47.5	52.2	47.8	18.7	109.755
71	27.8	74.2216	400.5	8.4	396.2	58.4	83.604	52	57.2	42.8	14.6	87.7912
72	24.1	70.8147	430.9	8.9	425.8	66.4	79.511	54.7	60	40	11.1	82.9437
73	21.7	73.2105	401.9	8.8	397.1	61.6	83.414	56.5	60.3	39.7	12.6	81.719
74	25.4	74.4508	425.1	8.1	420.8	60.3	83.992	53.8	57.5	42.5	13.7	86.1274
75	14.1	63.2224	368.1	8.8	363.8	46.1	73.480	61.9	63.1	36.9	14.8	62.7072
76	32.5	87.2775	371.1	7.7	367.7	49.8	98.695	48.7	52.7	47.3	24.6	97.4922
77	14.4	71.9896	401.1	8.5	396.7	59.5	83.498	61.7	61.7	38.3	10.3	75.4377
78	28.6	45.1962	455	8.5	450	67.1	76.055	51.5	58	42	15.7	53.3619
79	36.2	81.983	394.3	7.8	390.6	53.5	90.679	46	51.9	48.1	26.3	94.7045
80	23.5	78.1065	404.7	7.2	401.4	51.8	90.409	55.2	55.2	44.8	18.3	83.4157
81	22.5	79.9025	393.5	8.8	388.9	60	91.075	55.9	59.4	40.6	14.1	88.5629
82	33.9	73.8337	481.3	8	476.6	67	80.604	47.6	54.4	45.6	22	87.126
83	31.7	101.903	353.1	8.3	349.4	42.3	115.05	49.2	53.7	46.3	26.2	110.1096
84	32.2	92.0046	358.2	8.4	354.4	52.1	103.477	48.9	54.2	45.8	23.9	103.2677
85	10.3	73.2849	335.9	9.2	331.6	53.8	86.641	64.7	63.7	36.3	12.2	71.7326
87	22	70.434	444	8	439.7	61.5	80.382	56.3	58.7	41.3	14.7	77.0259
89	24.6	55.419	491.7	6.8	488.3	58.1	62.717	54.3	56.5	43.5	16.1	61.6665
90	18.6	73.1786	402.8	7.9	398.9	55.7	84.874	58.7	59	41	13.3	77.9433