

A COMPARISON OF BIOELECTRICAL IMPEDANCE AND
SKINFOLD MEASUREMENTS IN DETERMINING MINIMAL
WRESTLING WEIGHT IN HAWAI'I'S HIGH SCHOOL WRESTLERS

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PART 1

INTRODUCTION

In 1989 Wisconsin was the first state to institute a minimal wrestling weight program for high schools. The intent of the program was to prevent the dangerous weight cutting behaviors of wrestlers (Oppliger 1995). The importance of preventing inappropriate weight cutting practices was re-enforced with the deaths of three collegiate wrestlers during the 1997-98 collegiate wrestling season (Morbidity and Mortality Weekly Report {MMWR} 1998). Following the deaths of these wrestlers, the National Federation of State High School Associations (NFHS) mandated that every state institute a minimal wrestling weight program in place by 2005 (NFHS 2003-04). Additionally, the American College of Sports Medicine (ACSM) advocated the importance of a minimal wrestling weight program (ACSM 1996). To comply with the NFHS mandate, the Hawaii High School Athletic Association (HHSAA) instituted a minimal wrestling weight program in 1999 and recruited the Hawaii Athletic Trainers Association (HATA) to implement the program. The resulting program was required to accommodate body composition measurements for 500 plus wrestlers in a short time frame; assuring equitable, accurate and reliable measurements, at a reasonable cost and use of man power (Hawaii Wrestling Weight Monitoring Program [HWWMP], 2004).

Currently the NFHS mandates that body fat must be measured in a hydrated state; however, it does not specify which method must be used to determine the percentage of body fat (NFHS 2003-04). The HHSAA determined, through the

examination of prior minimal wrestling weight programs (Wisconsin [Oppliger 1995], Iowa [Oppliger 1988], and other mid-western states [Thorland 1991]), that skinfold measurements and urine specific gravity measured via refractometry were the appropriate methods to evaluate the wrestlers body composition in order to determine minimal wrestling weights (MWW) (HWWMP 2004). Minimal body fat percentages (%BF) were set at 7% for males and 14% for females based on the NFHS criteria (NFHS 2003-04, HWWMP 2004). In an effort to ensure accurate and equitable results, all of the wrestlers on the island of Oahu are tested on the same day by a team of experienced and National Athletic Training Association-Board of Certification certified athletic trainers (ATCs) who annually attend a workshop on skinfold analysis. Coaches that are required to travel with their teams to have this assessment done have requested that they be able to substitute bioelectrical impedance (BIA) measurements for skinfold (SF) measurements. Substitution of BIA for SF to determine MWW, has some possible advantages: BIA requires minimal training and subject preparation, the technique is less embarrassing and intrusive than SF for this age group, and BIA instruments (Tanita leg-to-leg analyzers) are readily available.

Prior studies have demonstrated the BIA is a reliable and valid method of determining MWW using BIA as a measuring tool (Oppliger 1991, Oppliger 1991S). Other researchers have concluded that there were disagreements between BIA and other methods of body composition measurements (Diboll 2003, Eckerson 1992, Clark 1993). Recently Clark et al. (2004) investigated minimum weight prediction methods (hydrostatic weighing [HW], SF, BIA, and dual energy x-ray absorption

[DEXA]) which they cross-validated using a four-compartment model. The best precision was found using the SF and HW methods, and the error was significantly greater using BIA than SF. They concluded that the use of the Lohman (1981) SF equation and HW were the most accurate methods to determine MWWs. Use of the Tanita leg-to-leg analyzer (which has a proprietary prediction equation) was not supported by the data. However, a number of other equations to determine body composition using BIA exist. The RJL Quantum II analyzer provides the impedance measurements required to use these equations. If the use of these BIA equations resulted in MWWs that are in good agreement with MWWs established using SF equations, then it is plausible that BIA could be substituted for the SF method at remote sites. Therefore, the purpose of this study was to compare the MWW from SF measurements with those derived from a variety of BIA equations, to determine if the two methods could be used interchangeably for Hawaii's high school wrestlers. It was hypothesized that BIA equations would result in MWWs that are not significantly different than those obtained by SF analysis.

METHODS

Subjects

Two hundred eight male and female high school wrestlers from the island of Oahu, Hawaii, aged 13-18 years, volunteered to participate in this study from a pool of 512 subjects. Data were collected during the mandatory preseason determination of MWWs conducted by the HHSAA. The wrestlers and their parents/guardians completed an informed assent and consent form approved by the University of Hawaii at Manoa Committee on Human Studies prior to participation in this study.

(Appendix A)

Design of Research

The BIA study was conducted in conjunction with the HHSAA minimum wrestling weight protocol administered annually by ATC's, from area high schools in the HHSAA. This study consisted of measuring the wrestler's weights on a scale to the nearest 0.25 pounds. Weights were then converted to kilograms for analysis. A refractometer was used for urinalysis to determine the state of hydration. A score of 1.020 or less indicated an euhydrated state. Wrestlers who scored a 1.020 or greater on the urinalysis test were re-tested on a subsequent date to establish MWW. Body composition of the wrestlers was measured via Lange SF caliper at each of the designated sites by three different ATCs. The male wrestlers were measured at sites in accordance with the Lohman equation (1981). The females were measured at the

sites in accordance with the Jackson, Pollock, and Ward equation (1980). Body density was calculated and converted to % BF using Brozek's equation(1963). The results were used to calculate the MWW based on 7.0 % minimum body fat for males and 14.0 % minimal body fat for females (HWWMP 2004).

Upon completion of HHSAA body composition measurements, the wrestlers who had completed the signed consent form were escorted to the BIA testing area. Height was then measured by a standard tape measure to the nearest 0.5-inch, and later converted to centimeters. Wrestlers were randomly assigned to one of four teams of ATCs who performed the BIA. Each of the research teams had participated in a minimum of two training sessions using the BIA instrument and were thoroughly instructed in the proper electrode placement prior to administering the tests. All wrestlers received the same verbal instructions prior to participating in the BIA test. (Appendix B)

Each wrestler was required to remove their right shoe and sock, as well as all of their jewelry, as recommended by the manufacturer (RJL systems). The wrestler was then instructed to lay supine on the testing table (non-conductive treatment tables) with their arms and legs thirty degrees from the midline of their body (this was measured prior to the participation and tape was laid on the table at the appropriate angles for reference). The two hand and two foot electrode sites were cleaned with alcohol, then (in accordance with the manufacturer's recommendations) electrodes were attached at the following sites: 1) at the imaginary line bisecting the ulnar head, 2) at the 3rd metacarpal phalangeal joint, 3) at the imaginary line bisecting the medial and lateral malleoli, and 4) at the 3rd metatarsal phalangeal joint. The leads to the

BIA were attached in the appropriate manner (red cords to the hand, with the red clip on the wrist, and the black clip on the hand and the black cords to the foot with the red clip on the ankle joint and the black clip on the foot). Resistance and reactance were measured using new RJL Quantum II instrument, which had been checked for calibration against a 500-ohm resistor. The wrestler was excused after having the electrodes removed. New sets of electrodes were used for each wrestler.

The resistance and reactance values were then used in four different equations for each gender to compare the SF method and the BIA equations for determining MWW. Equations by Lukaski et al. (1990), RJL and Houtkooper et al. (1992) were used on all subjects. The Lukaski et al. (1990) equation (Luk.) was developed using male and female collegiate athletes, and the RJL equation (RJL) is a generalized equation for both genders. The Houtkooper et al. (1992) equation (Hout.) was developed using subjects no older than 19 years of age, for both genders. The Oppliger et al. (1991S) equation (Opp.) was developed to estimate body composition in male high school wrestlers, and thus was only applied to the male subjects. An equation developed for body composition in collegiate female athletes by Fornetti et al. (1999)(Forn.) was used to estimate body composition on the female athletes. Table 1 provides the BIA equations that were used for the present study. Fat free mass (FFM) was divided by 0.93 and 0.86, for males and females respectively, to determine MWWs.

Table 1. BIA equations used to determine MWW.

Lukaski et al.	$\text{FFM} = 0.734 * [\text{ht}^2 / \text{resistance}] + [0.116 * \text{wt}] + [0.96 * \text{reactance}]$ $+ [0.878 * \text{gender} \{ \text{males} = 1, \text{females} = 0 \}] - 4.03$
RJL	$\text{FFM} = 0.5 [\text{ht}^{1.48} / \text{impedance}^{0.55} * 1.0 / 1.12] + [0.42 * \text{wt}] + 0.49$
Houtkooper et al.	$\text{FFM} = 0.61 * [\text{ht}^2 / \text{resistance}] + [0.25 * \text{wt}] + 1.31$
Oppliger et al.	$\text{FFM} = 1.949 + [0.701 * \text{wt}] + [0.186 * \{ \text{ht}^2 / \text{resistance} \}]$
Fornetti et al.	$\text{FFM} = [0.282 * \text{ht}] + [0.415 * \text{wt}] - [0.037 * \text{resistance}] =$ $[0.96 * \text{reactance}] - 9.734$

FFM = fat free mass

Statistical Analysis

Descriptive statistics were generated using SAS. Total Error was calculated as previously described by Lohman (1981). An ANOVA was used to test for differences between genders. A subsequent ANOVA for repeated measures with contrast comparisons was used to test for differences between the skinfold method and the five BIA equations used to determine MWW. The alpha level was set at 0.05.

RESULTS

The ANOVA revealed a significant gender by equation interaction ($p < 0.0001$). Therefore, in subsequent analyses the genders were assessed independently. Descriptive data by gender are presented in Table 2.

Table 2. Descriptive data by gender (Mean \pm STD, Range)

<u>Gender</u>	<u>N</u>	<u>Age (yrs)</u>	<u>Height (cm)</u>	<u>Weight (kg)</u>
Males	151	15.4 \pm 1.2	168.6 \pm 6.3	70.4 \pm 17.8
<u>Range</u>		<u>13 - 18</u>	<u>153.7 – 186.7</u>	<u>41.6 – 133.3</u>
Females	57	15.7 \pm 1.06	157.6 \pm 5.3	57.9 \pm 10.7
<u>Range</u>		<u>14 – 17</u>	<u>144.8 – 167.6</u>	<u>42.6 – 92.8</u>

Minimum wrestling weights were determined using SF and BIA. Five separate equations were used to determine MWW for males [a SF equation by Lohman (1981) to determine body density, and equations to determine FFM from BIA data by RJL, Opp., Luk., and Hout.]. Five equations were also used to determine MWW for females [a SF equation by Jackson et al. (1980) to determine body density, and equations to determine FFM from BIA data by RJL, Luk., Forn., and Hout.]. Body densities were converted to %BF using the equations of Brozek et al. (1963). Results of MWW determined by each equation are presented in Table 3.

Table 3. MWW by gender (Mean \pm STD, Range)

<u>Equations</u>	<u>Males</u>	<u>Females</u>
Lohman (kg) Range	62.3 \pm 10.1 40.8 – 93.0	
Jackson et al. (kg) Range		51.3 \pm 6.8 39.5 – 70.1
RJL (kg) Range	64.6 \pm 10.8 44.4 – 98.9	47.8 \pm 4.8 39.9 – 61.1
Oppliger (kg) Range	64.5 \pm 14.3 39.9 – 111.8	
Lukaski (kg) Range	59.3 \pm 9.4 38.5 – 86.4	42.2 \pm 5.8 33.6 – 59.1
Houtkooper (kg) Range	63.8 \pm 11.3 41.3 – 97.8	51.6 \pm 7.7 40.6 – 75.3
Fornetti (kg) Range		51.8 \pm 7.8 40.7 – 75.1

MWW = minimal wrestling weights (kg)

Correlations between the SF and BIA methods were calculated by gender.

The correlations between the Lohman (1981) equation and the BIA equations were:

RJL $r = 0.96$, Opp. $r = 0.95$, Luk. $r = 0.93$, and Hout. $r = 0.95$. The correlations

between the Jackson et al.(1980) equation and the BIA equations were: RJL $r = 0.95$,

Luk. $r = 0.91$, Forn. $r = 0.96$, Hout. $r = 0.94$.

An ANOVA for repeated measures was conducted to test for differences between the MWW equations for males and females. Included in the ANOVA were contrast comparisons for each of the equations. A significant difference was demonstrated between the MWW equations for males ($F = 106.06$, $p < 0.0001$). The

SF equation by Lohman (1981) calculated MWWs that were significantly different than each of the MWW derived from the BIA equations for the male subjects ($p < 0.0001$). The equations of RJL and Opp. were not significantly different from each other ($p = 0.8497$).

A significant difference was demonstrated between the MWW equations for females ($F = 321.54$, $p < 0.0001$). The SF equation by Jackson et al. (1980) calculated MWWs that were significantly different than the MWW derived from the BIA equations of RJL and Luk. ($p < 0.0001$), but no differences were revealed between MWWs established using the equations of Jackson et al.(1980) and Forn. ($p = 0.1185$) or Hout. ($p = 0.4520$). The contrast comparisons for each of the BIA equations revealed that the mean MWWs were all significantly different from each other ($p < 0.0001$).

Total error (TE), calculated as described by Lohman (1981), was used to compare the criterion value (SF) with the predicted values (BIA equations) to determine the precision of the techniques. Mean TE of MWWs predicted for all the male equations were as follows, RJL = 2.34 kg, Opp. = 2.27 kg, Luk. = 3.66 kg and Hout. = 1.51 kg. The TE for females was calculated as RJL = 3.53 kg, Luk. = 9.16 kg, Forn. = 0.49 kg, and Hout. = 0.27 kg.

DISCUSSION

The major finding of this study was that BIA could not be reasonably substituted for SF analysis to determine MWWs for high school wrestlers. Without a criterion measure for comparison, no judgments concerning the validity of BIA or SF analyses could be made in the present study. Male SF MWWs were significantly

different from the MWWs obtained from the RJL, Luk., Opp., and Hout. equations ($p < 0.0001$). Additionally, female SF MWWs were significantly different from the RJL and Luk. equation ($p < 0.0001$), but not different than the Forn. equation ($p = 0.1185$) or the Hout. equation ($p = 0.4520$). A number of authors have questioned the validity of BIA to determine MWW (Clark et al., 1993; Clark et al. 2004; Diboll and Moffit, 2003). Other authors have supported the use of BIA as a valid and reliable method to determine body composition and MWWs (Lukaski et al., 1986; Lukaski et al. 1990, Oppliger et al., 1991S, Oppliger et al, 1991, Utter, 2001). However, based on the results of the present study, if SF analyses is being used to determine the MWW of the majority of the participants in a high school wrestling program, use of BIA at remote sites would likely result in MWWs that would be statistically significantly different than the results obtained by SF analyses for the male subjects. Thus to maintain a level playing field it is important to use a single method to determine MWWs. Nevertheless, it may be possible to substitute either the Forn. or Hout. BIA equations to determine MWWs for females; and Bland Altman Plots were used below to investigate this possibility.

The above recommendations seem justified based on analysis of the data using a variety of statistics. The correlations between the MWW SF and the BIA equations ranged from $r = 0.93$ to $r = 0.96$ for the males and $r = 0.91$ to $r = 0.96$ for the females. These correlations demonstrate that there was a strong relationship between the MWW BIA equations and MWW SF equations for both genders. Many studies have demonstrated similar correlations between BIA equations and SF equations ranging from $r = 0.92$ to $r = 0.98$ (Diboll 2003); as well as between BIA

equations and HW (Clark 1993, Clark 2004, Jackson 1988, Lukaski 1990, Lukaski 1986, Oppliger 1991S, Thompson 1991, Pajmans 1992). Results of the BIA equations used in the present study were plotted against the appropriate SF equation with the line of identity included for comparison (see figures 1- 8).

However, as pointed out above, the statistical analysis via ANOVA with contrast comparisons for each equation showed that despite the high correlations (with the exception of the Forn. and Hout. equations for females), the MWW established with the BIA equations were significantly different than the SF equation in determining MWW ($p < 0.0001$). Thus, the use of correlations can be misleading. Bland and Altman (1986) suggested a better way to compare if one technique can be substituted for another that involves using what has become known as Bland Altman plots.

Bland and Altman (1986) stated that if the true value is not known than the appropriate way to plot the data is to compare the difference between methods against the mean of the two methods; thus avoiding statistical artifact. Therefore, when constructing Bland Altman Plots in the present study, the x-axis was the mean of the MWW determined by the appropriate SF and BIA equations and the y-axis is the difference between the MWWs for the same SF and BIA equations. The solid line on the graph is the mean difference in the MWWs for SF and the chosen BIA equations, and the dashed lines indicate the limits of agreement (± 2 SD)(see figures 9-16).

Perfect agreement would have been a difference of ± 0.0 SD. Diboll and Moffit (2003) used Bland Altman plots to compare SF and BIA to determine MWW in collegiate wrestlers and suggested that the maximal acceptable limits of agreement would be the range of body weights within the NCAA weight classes.

Figure 1
Skinfold vs RJL MWW with Line of Unity
(Males Only)

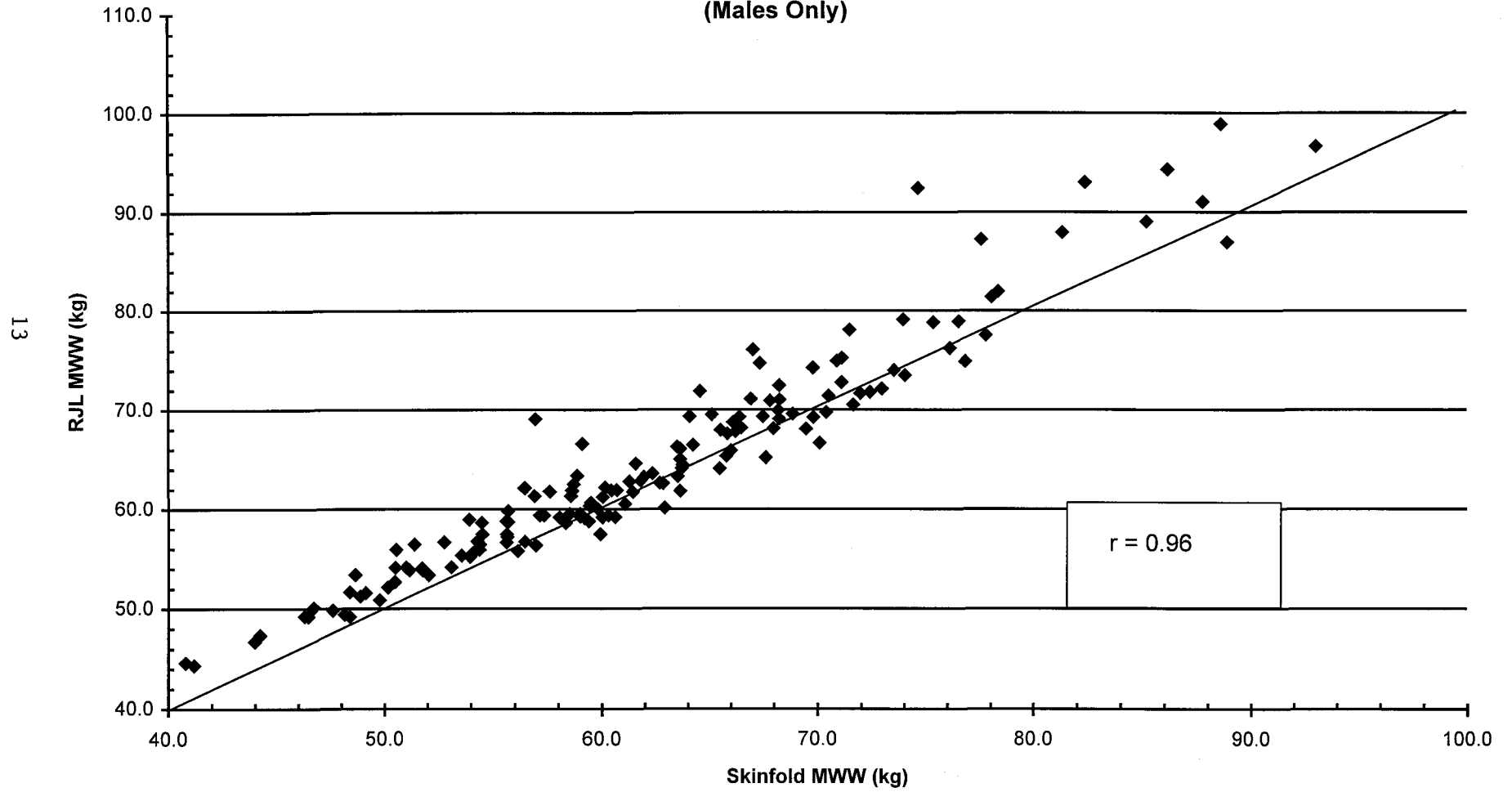


Figure 2
Skinfold vs RJL MWW with Line of Unity
(Females Only)

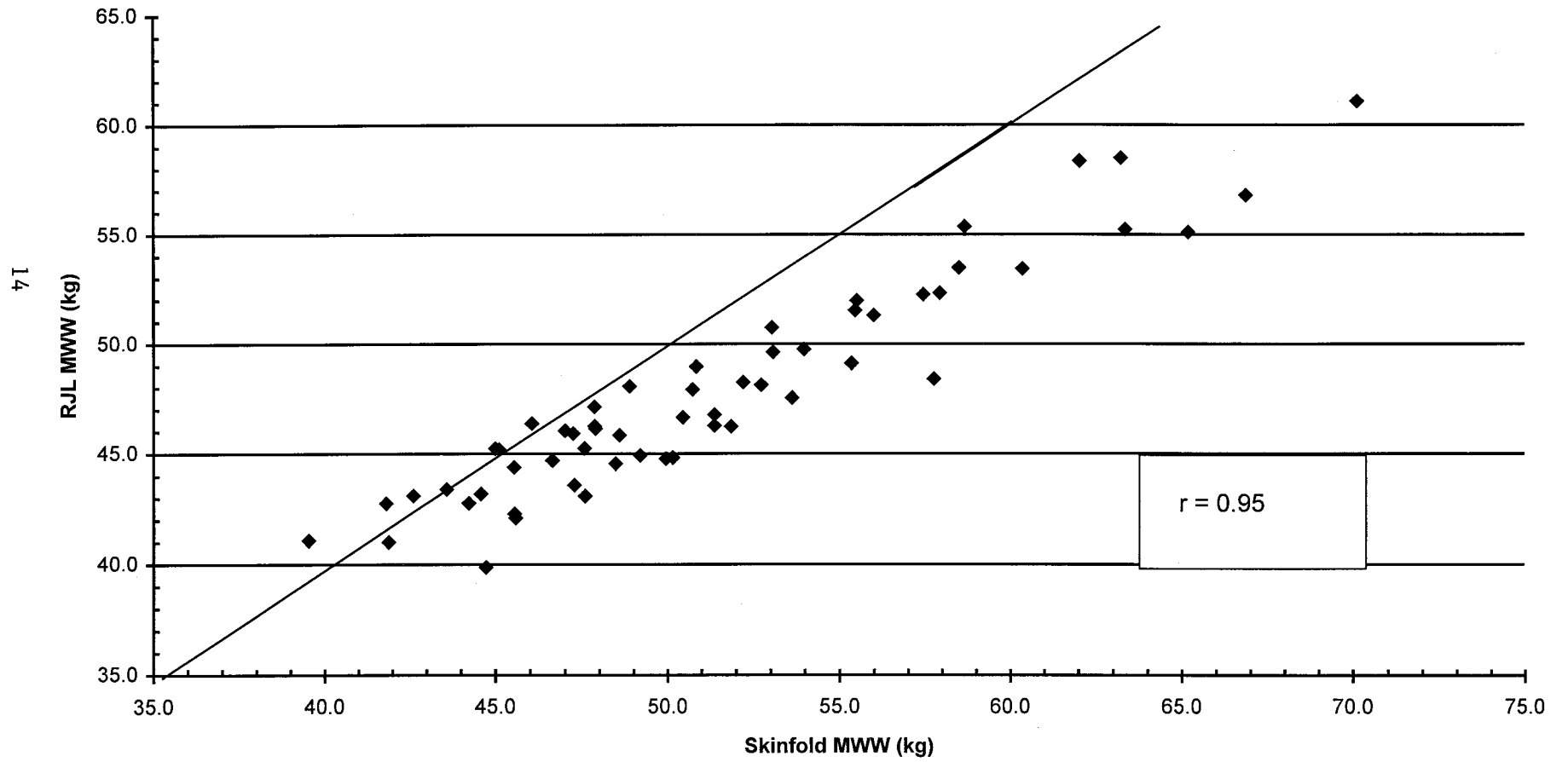


Figure 3
Skinfold vs Oppliger MWW with Line of Unity
(Males Only)

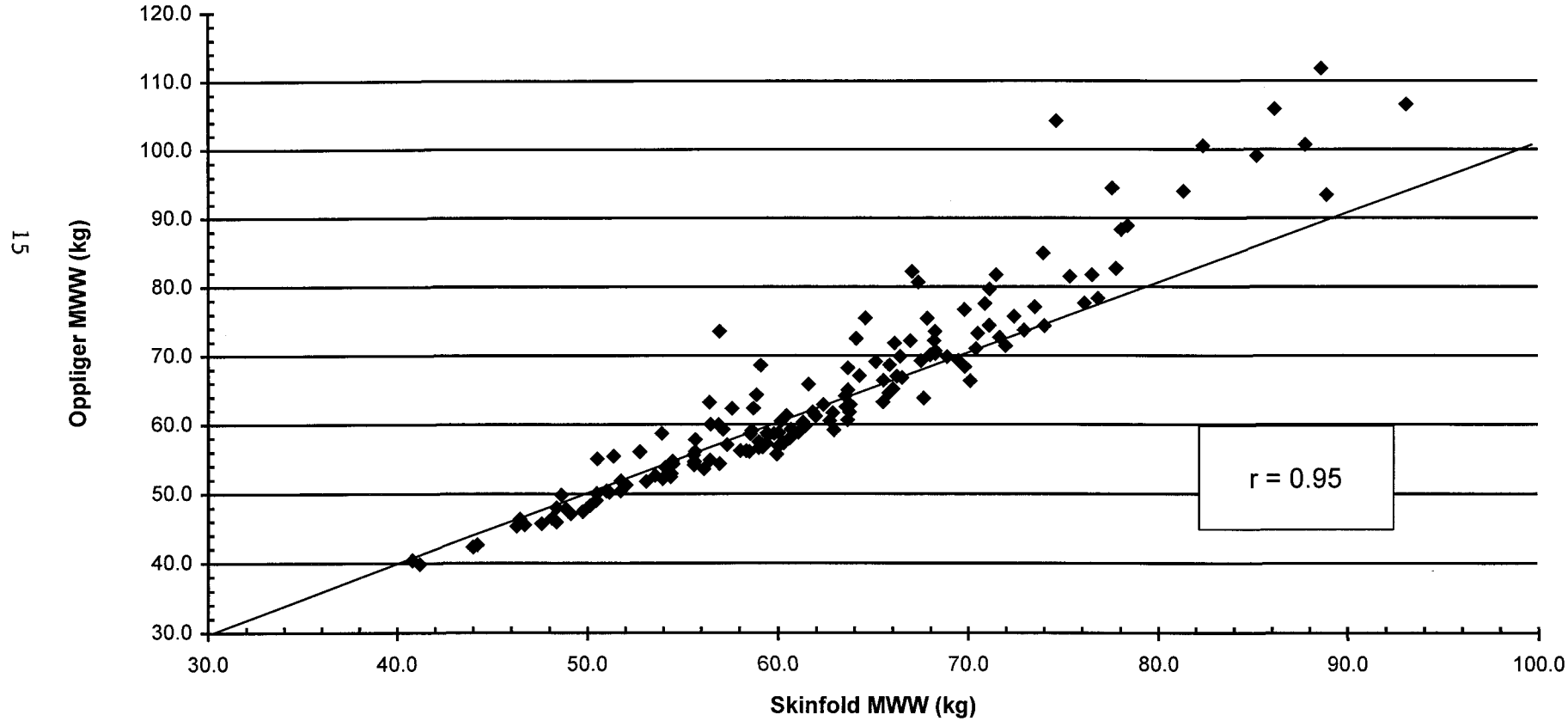


Figure 4
Skinfold vs Lukaski MWW with Line of Unity
(Males Only)

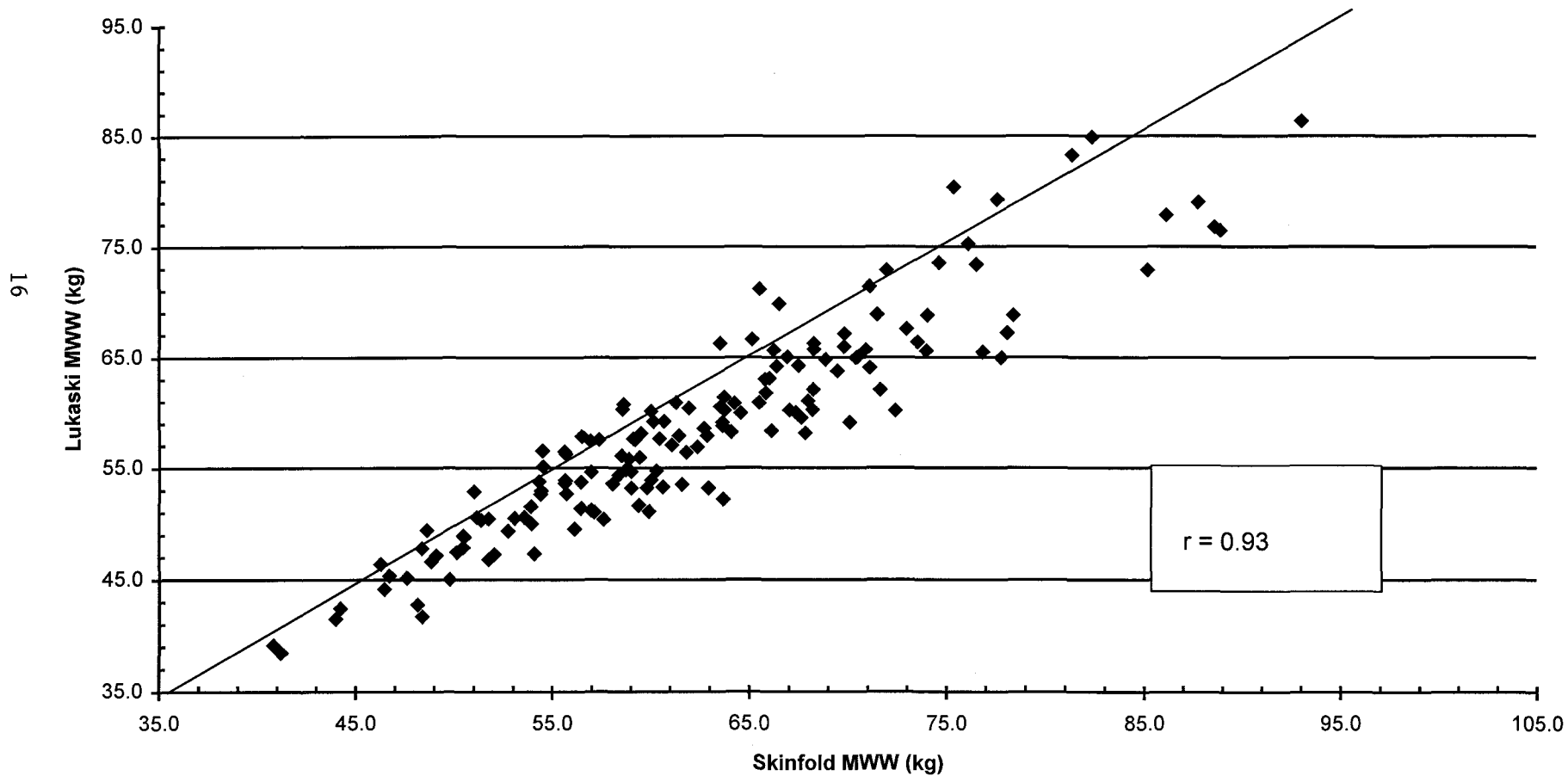


Figure 5
Skinfold vs Lukaski MWW with Line of Unity
(Females Only)

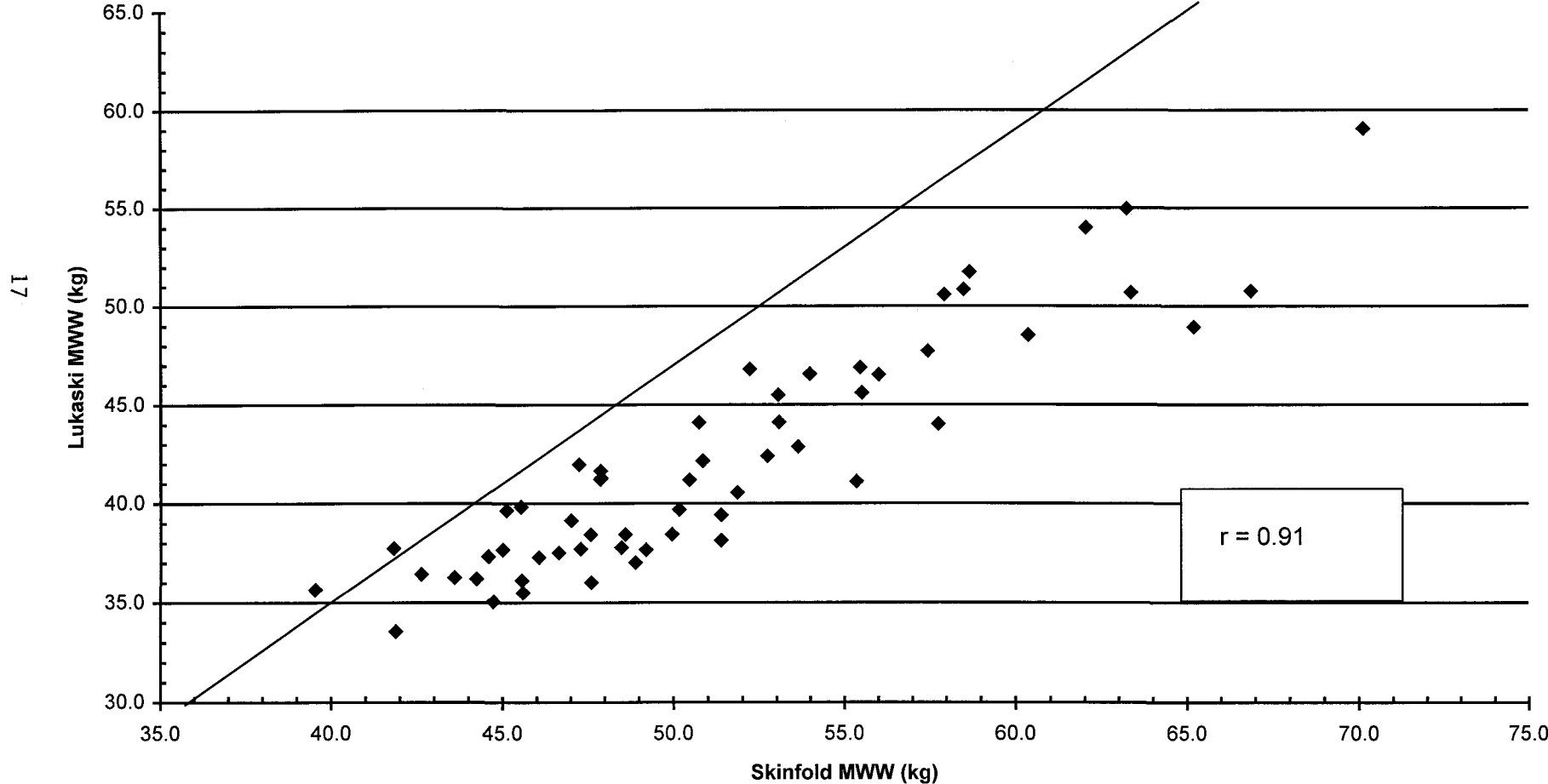


Figure 6
Skinfold vs Fornetti MWW with Line of Unity
(Females Only)

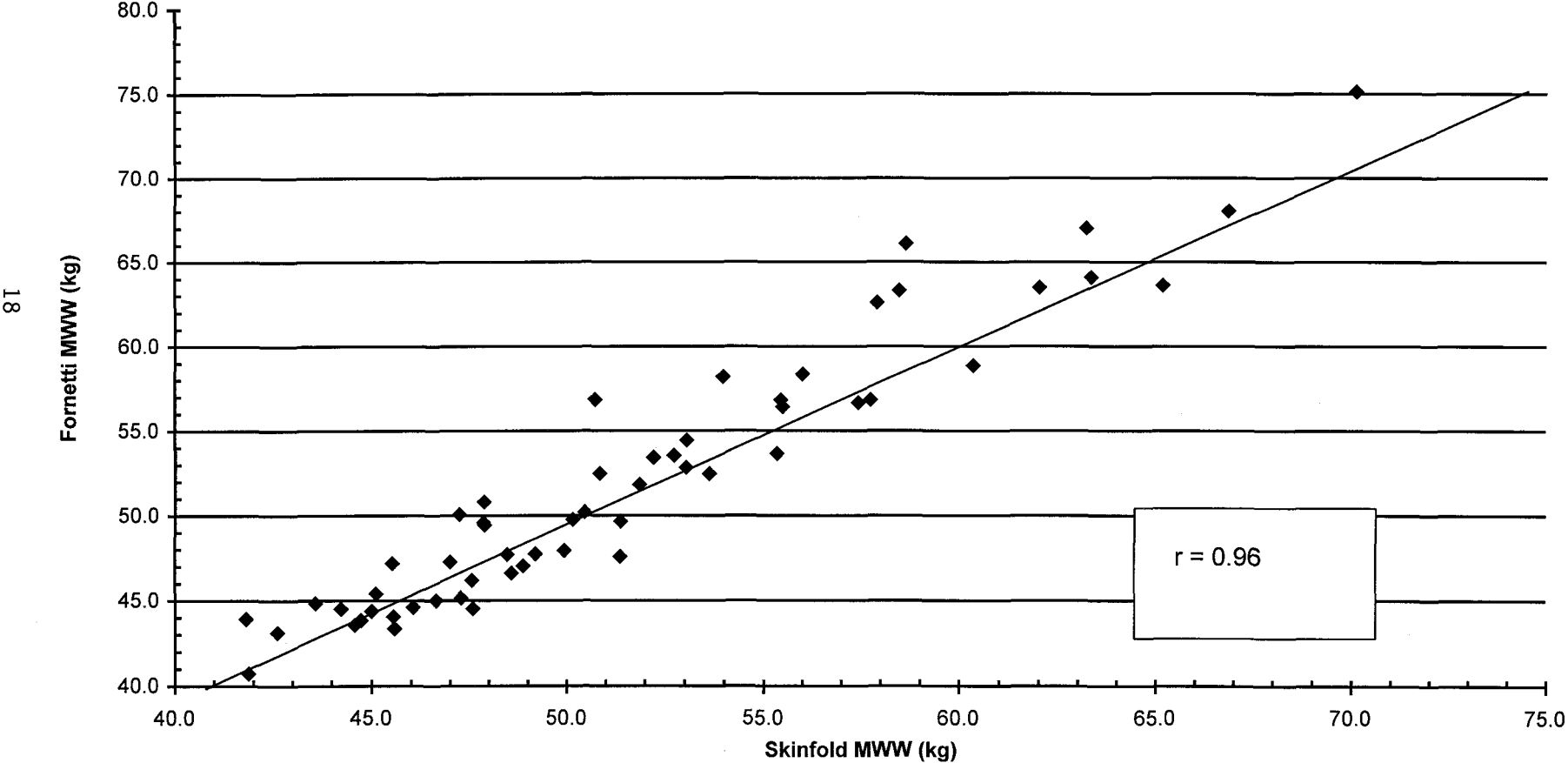


Figure 7
Skinfold vs Houtkooper MWW with Line of Unity
(Males Only)

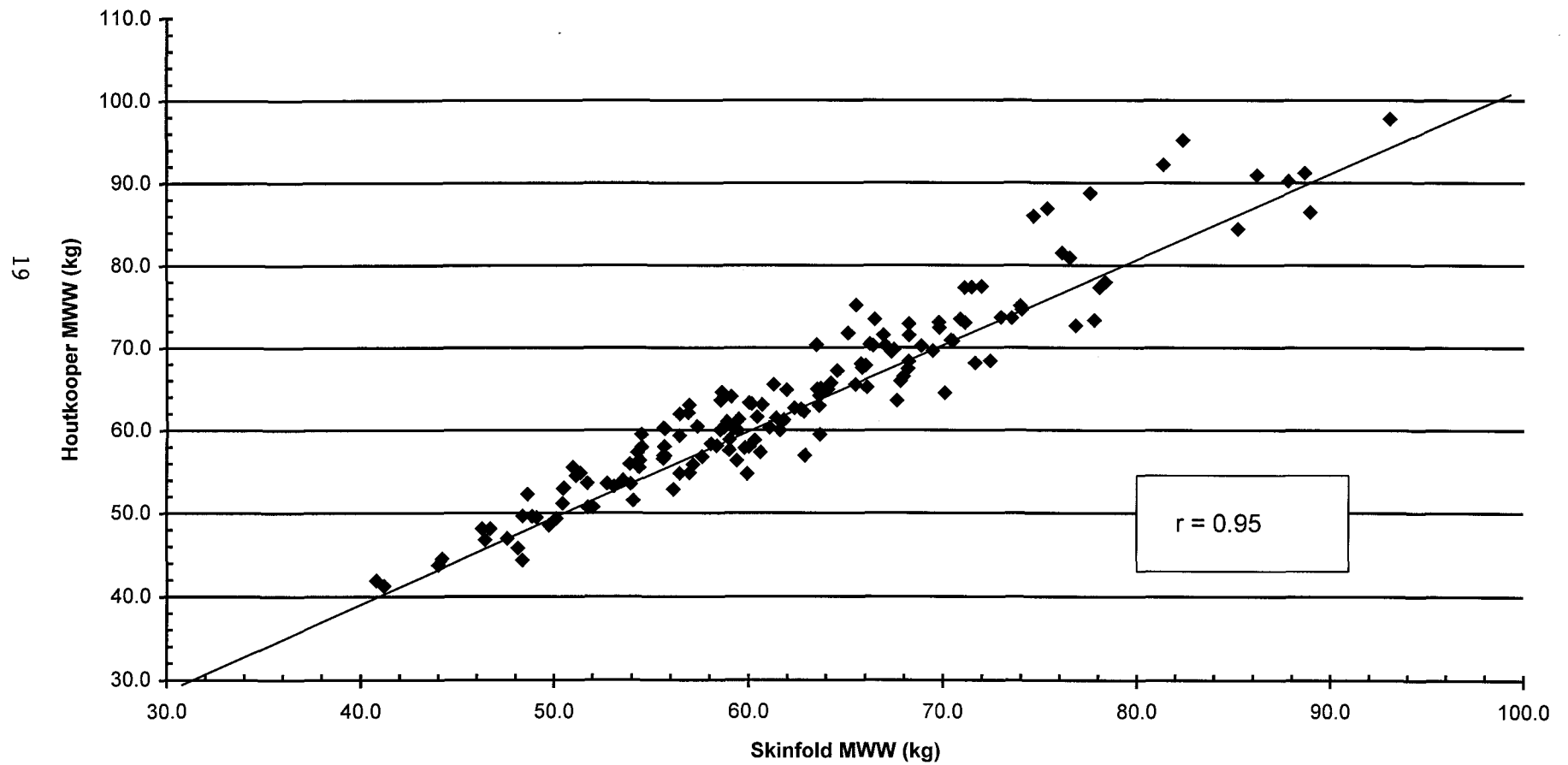


Figure 8
Skinfold vs Houtkooper MWW with Line of Unity
(Females Only)

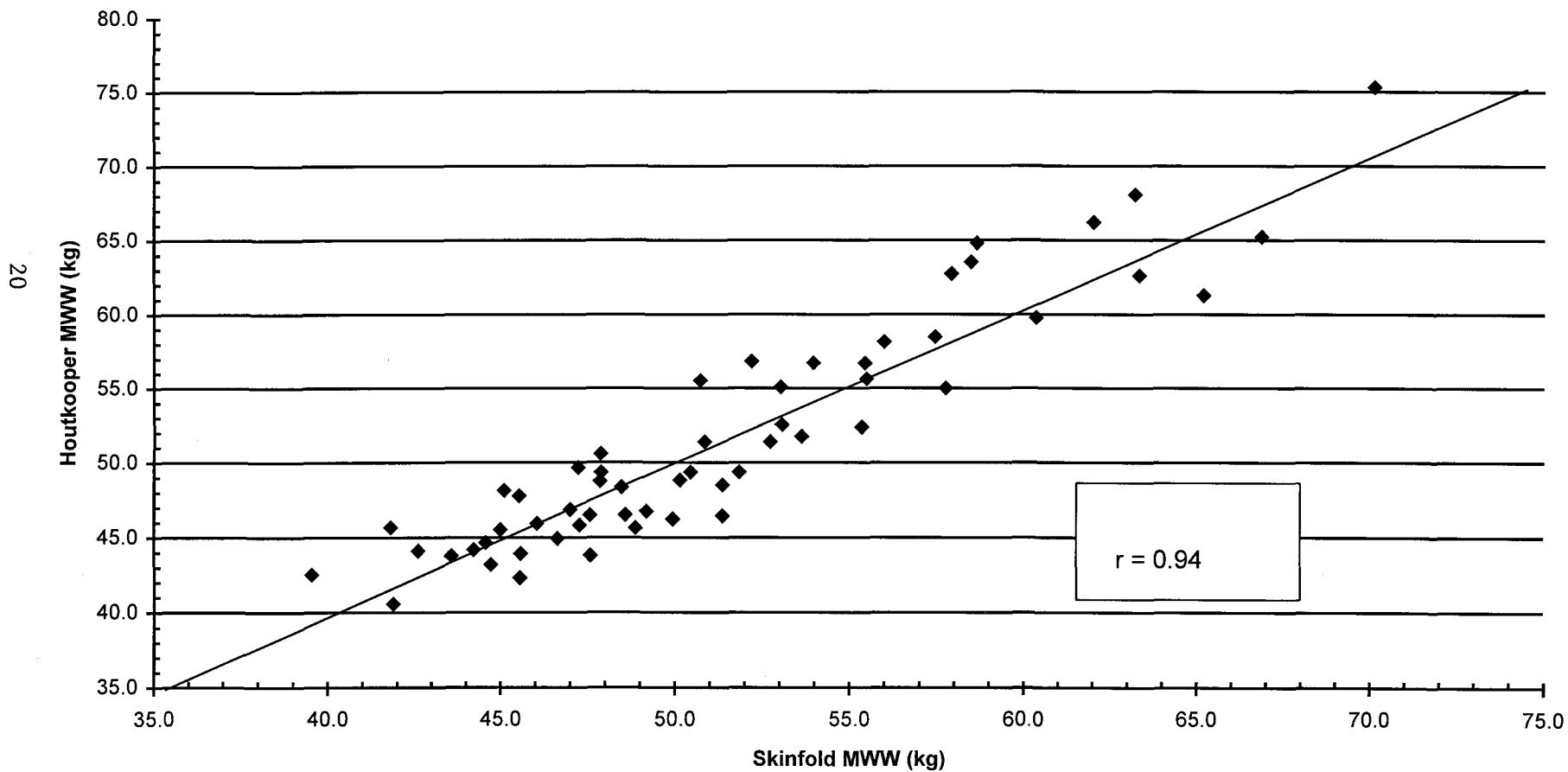


Figure 9
Bland Altman Plot Skinfold vs RJJ MWW
(Males Only)

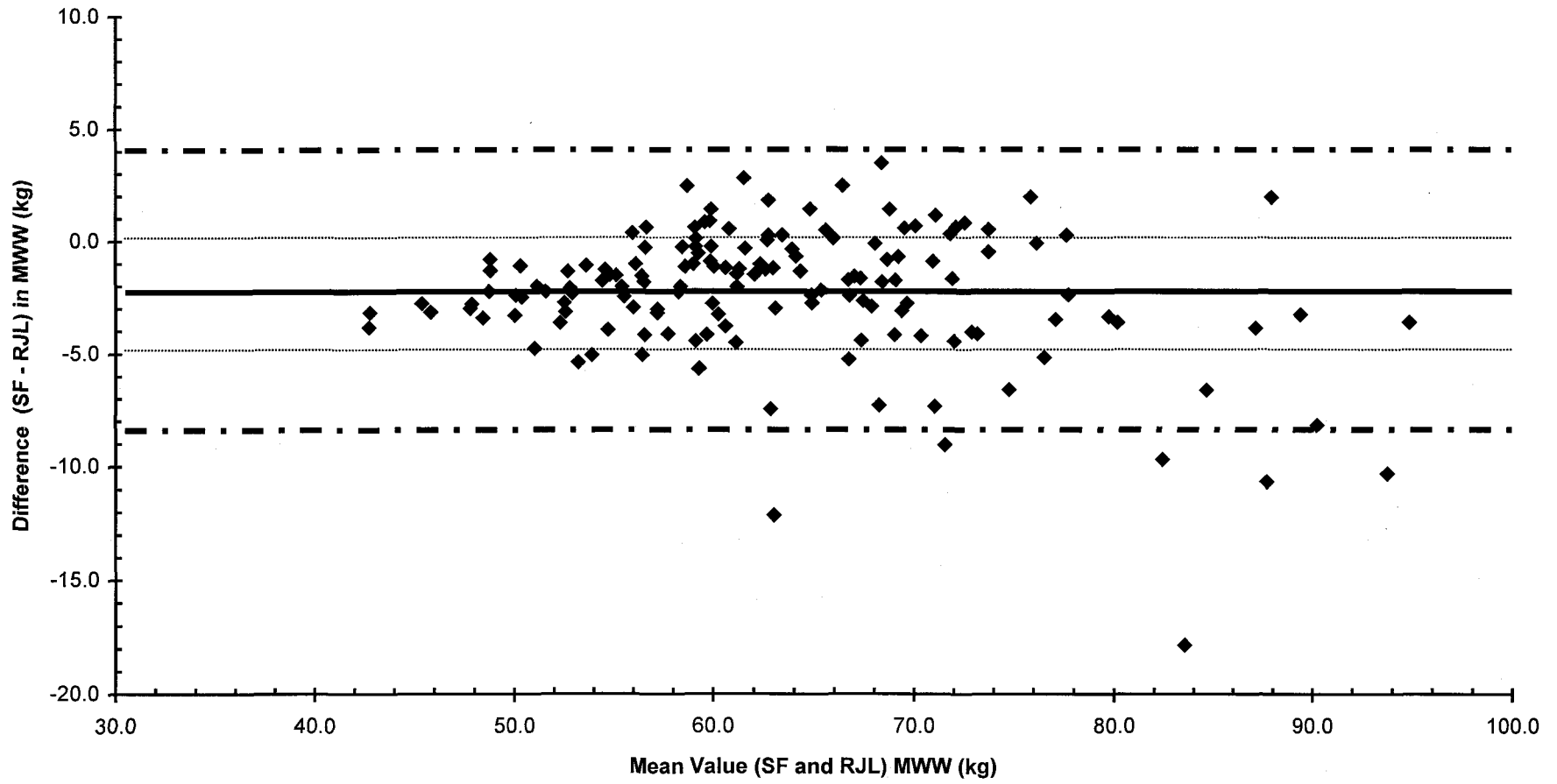


Figure 10
Bland Altman Plot Skinfold vs RJL MWW
(Females Only)

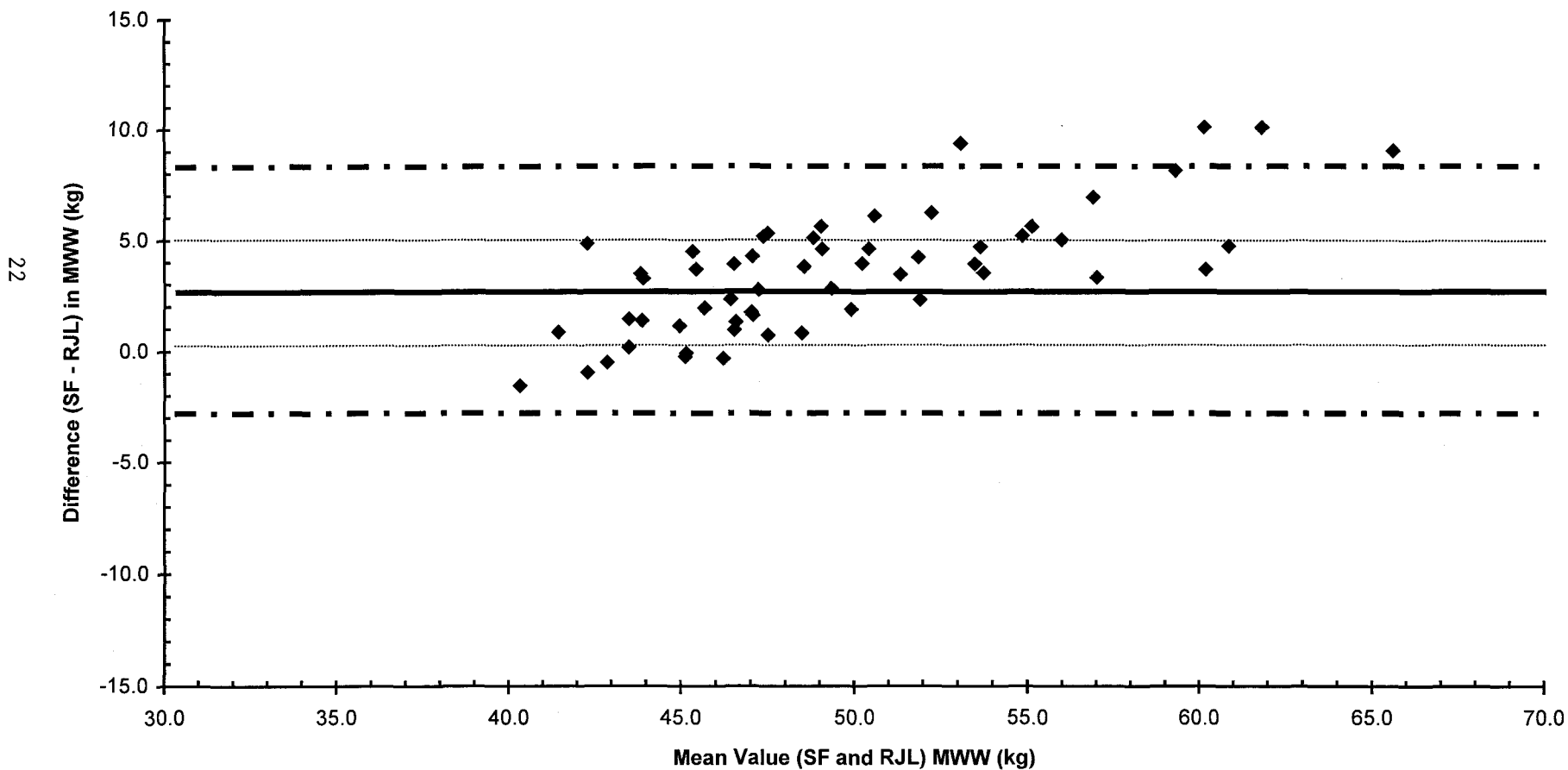


Figure 11
Bland Altman Plot Skinfold vs Oppliger MWW
(Males Only)

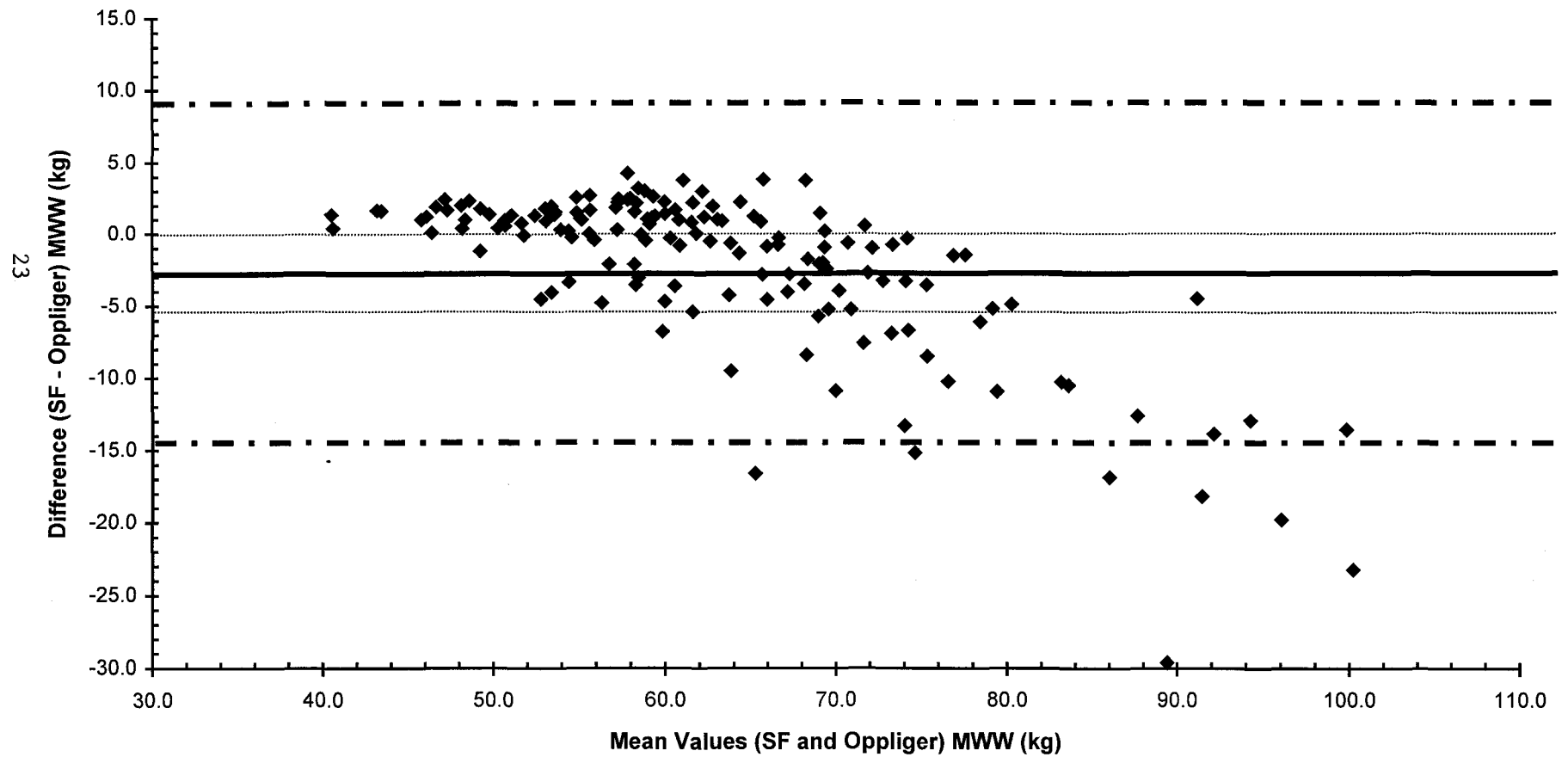


Figure 12
Bland Altman Plot Skinfold vs Lukaski MWW
(Males Only)

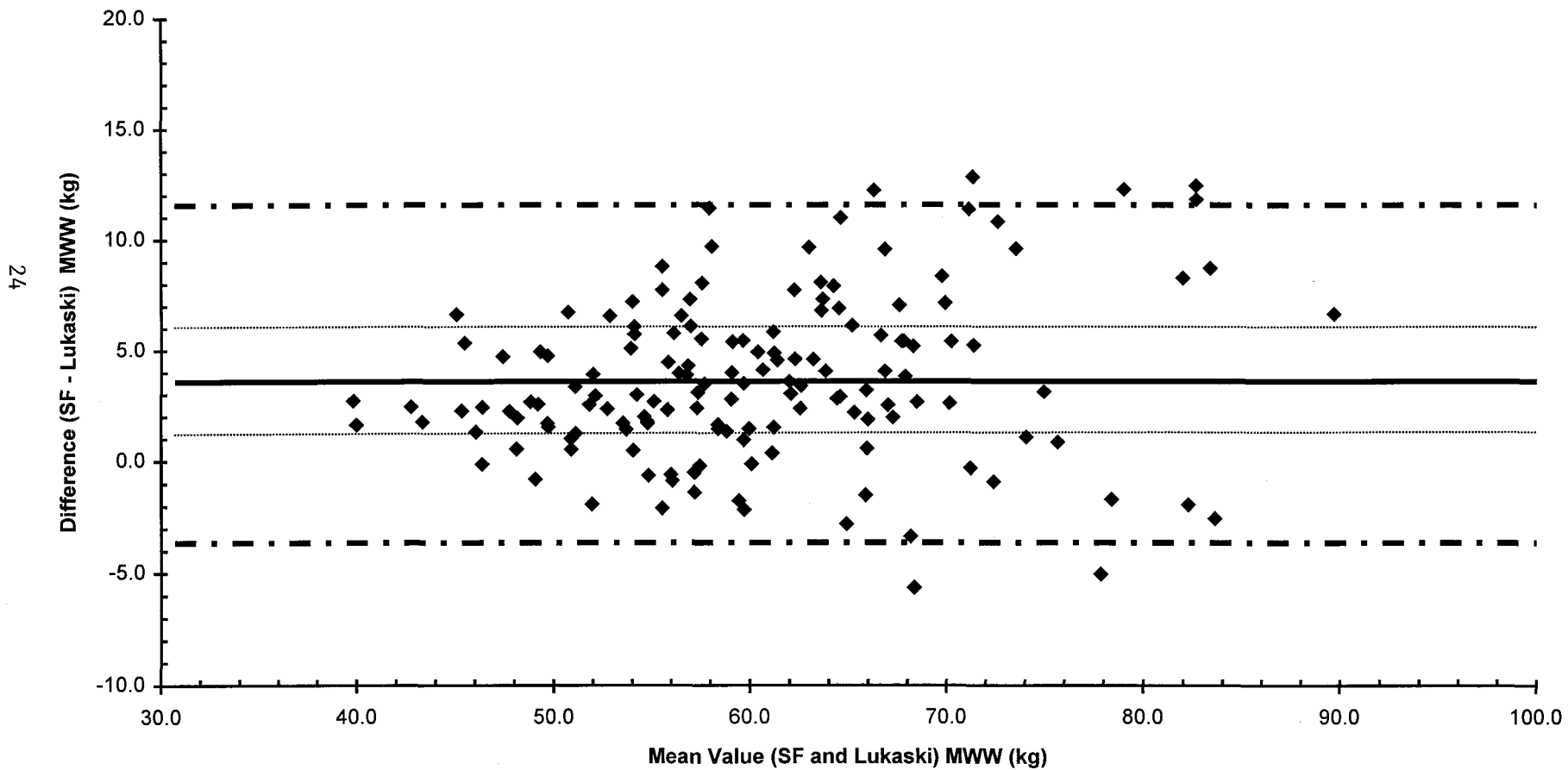


Figure 13
Bland Altman Plot Skinfold vs Lukaski MWW
(Females Only)

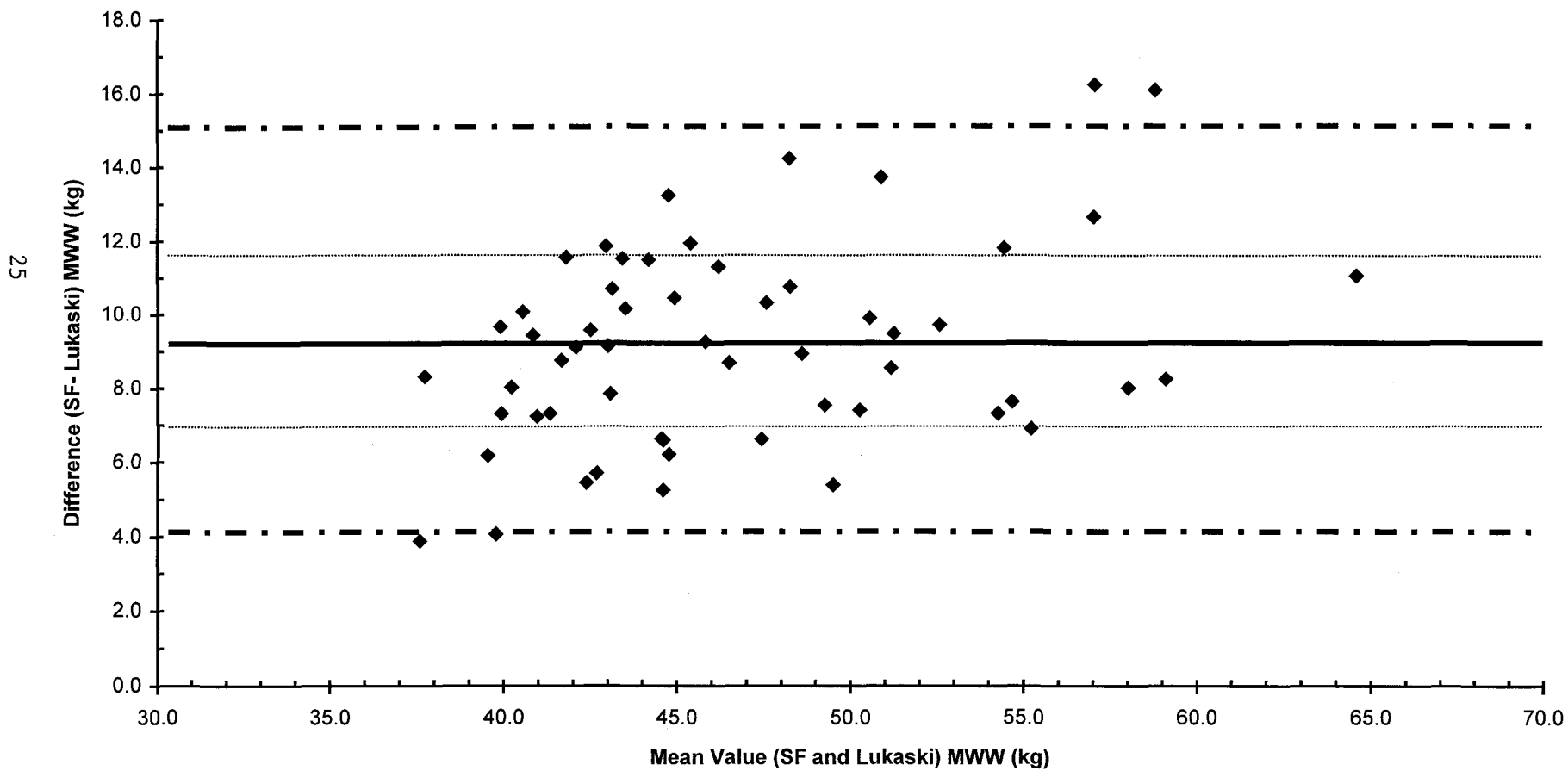


Figure 14
Bland Altman Plot Skinfold vs Fornetti MWW
(Females Only)

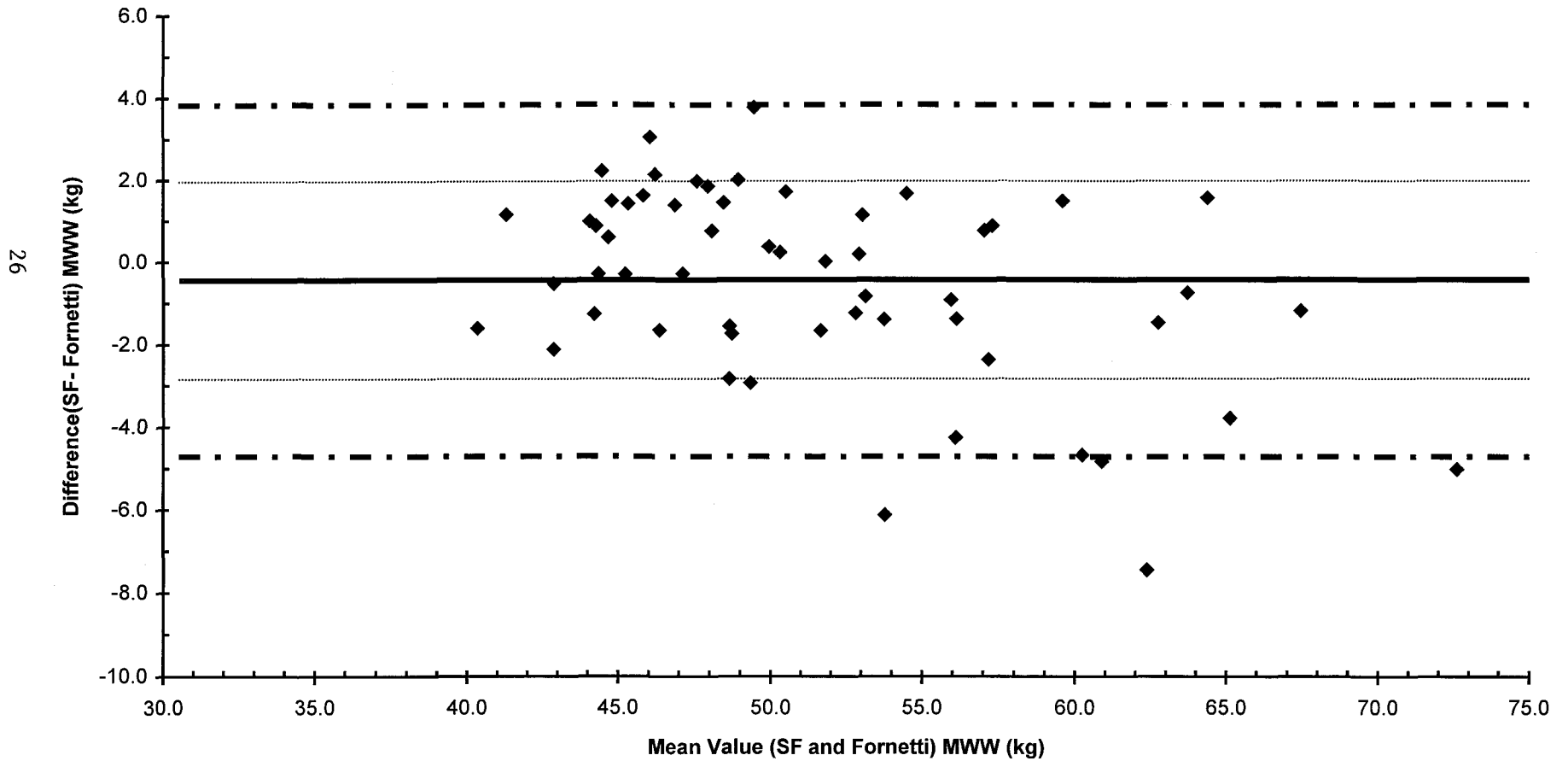


Figure 15
Bland Altman Plot Skinfold vs Houtkooper MWW
(Males Only)

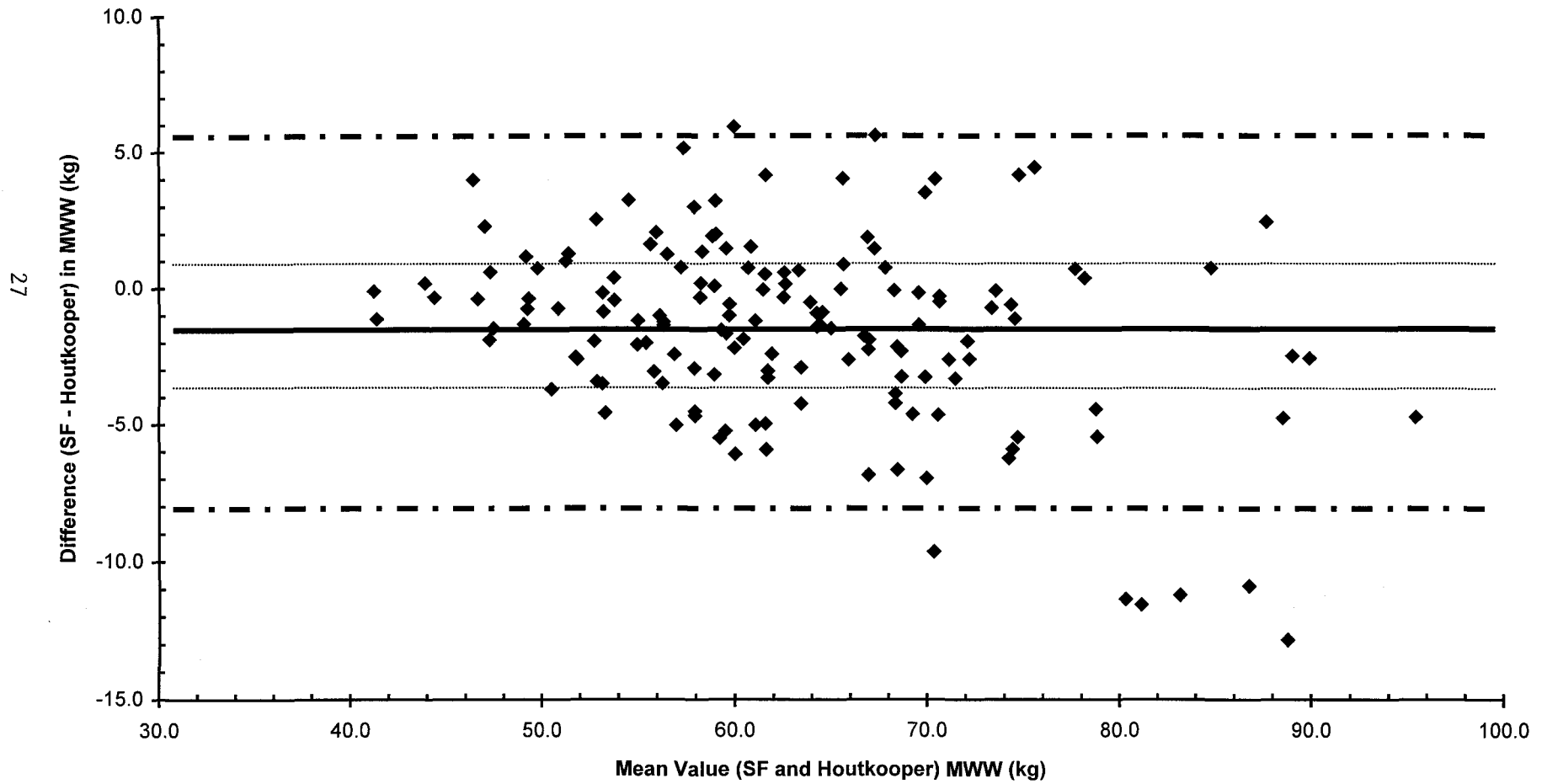
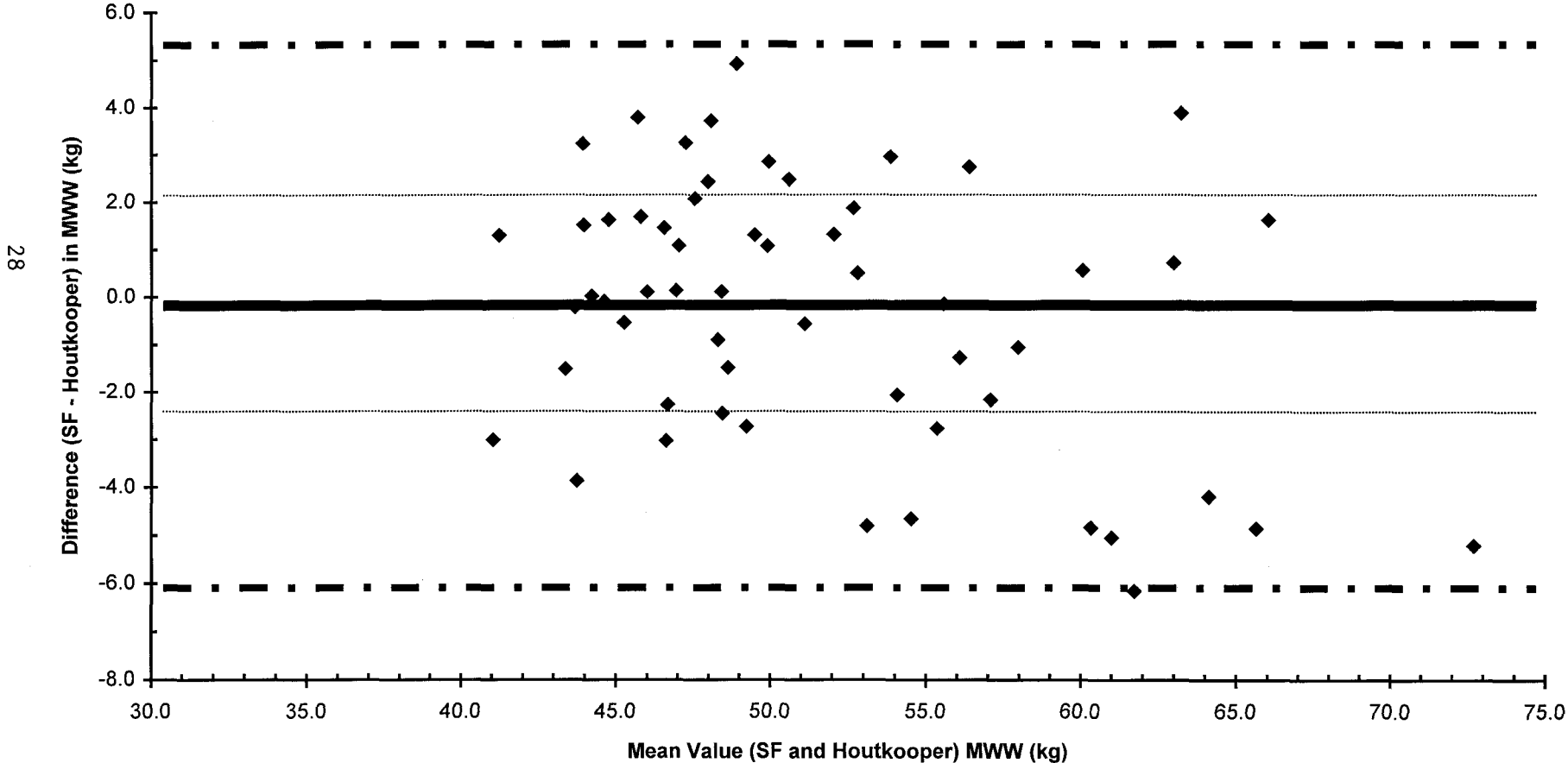


Figure 16
Bland Altman Plot Skinfold vs Houtkooper MWW
(Females Only)



The differences between weight classes for high school wrestlers are as follows: 4.1, 3.2, 2.7, 2.3, 2.3, 2.3, 3.2, 3.6, 5, 8.2, 11.8 and 27.3 kg.

Using the same rationale, the smallest and most common range between weight classes for high school wrestlers, 2.3 kg (NFHS 2003-04), was used to determine what was acceptable for substitution of BIA for SF in the present study (± 2.3 kg from the mean difference between SF and BIA). The dotted lines on the Bland Altman plots indicate ± 2.3 kg. Use of this standard resulted in 32% (RJL), 37% (Opp.), 48% (Luk.), and 40% (Hout.) of the male wrestlers falling outside of the acceptable range. Applying this same standard to the female wrestlers resulted in 35% (RJL), 37% (Luk.), 26% (Forn.), and 39% (Hout.) being more than 2.3 kg from the mean. Percentages over and under the standard, as well as the total percentages, for each equation are listed in Table 4. These results indicate the possibility that a substantial error may occur when determining the proper weight class for these wrestlers. For example, a wrestler has a calculated MWW of 55.7 kg (122.5 lbs) as determined by SF analysis. Using ± 2.3 kg (5 lbs) as the minimal error for accepting BIA to replace SF, the wrestler may be classified as having a MWW in the 54 kg (119 lb), 56.8 kg (125 lb), or 59.1 kg (130 lb) class. Using ± 2 SD (approx. 11 lbs) the wrestler could be classified as having a MWW in five different weight classes: 50.9, 54, 56.8, 59.1, or 61.4 kgs (112, 119, 125, 130 and 135 lbs, respectively). Examination of the Bland Altman plots clearly demonstrates that a large number of wrestlers may be misclassified using these criteria. These results demonstrate why use of existing BIA equations should not be substituted for SF analysis in determining MWWs for a subgroup of high school wrestlers.

Table 4. Percentages over and under the 2.3 kg acceptable range as well as total percentage outside the 2.3 kg range.

<u>Equation</u>	<u>% 2.3 kg under the mean</u>	<u>% 2.3 kg over the mean</u>	<u>% Total over or under</u>
<u>Males</u>			
RJL	19%	13%	32%
Oppliger	47%	22%	69%
Lukaski	24%	24%	48%
Houtkooper	20%	21%	40%
<u>Females</u>			
RJL	14%	21%	35%
Lukaski	18%	19%	37%
Fornetti	11%	16%	26%
Houtkooper	21%	16%	39%

Total error, as explained by Lohman (1981) has been demonstrated to be another precise method of predicting the accuracy of a predicted value with that of a criterion value (Diboll2003, Clark 1993, Thorland 1991, Lohman 1981, Eckerson 1992, Clark 2004). A TE measurement of less than 2.0 kg has been used as a standard of acceptability to compare various methods of predicting body composition in high school wrestlers to HW (Oppliger 1991, Clark1993). Although there was not a gold standard criterion variable to use for comparisons in the present study, if the same standard was applied only two equations resulted in a mean TE lower than 2.0 kg when compared to the appropriate SF methods for the female subjects (Forn., mean TE = 0.49 kg; and Hout., mean TE = 0.27 kg). For the male subjects only the

equation by Hout. had a mean TE less than 2.0 kg (TE = 1.51 kg). However, the ANOVA revealed significant differences between the SF MWW and the MWW established using the equation of Hout. for male subjects. Despite this difference, substitution of a BIA equation (Hout.) may be judged to be acceptable by some.

A similar study investigated substituting a BIA equation for the NCAA SF method in collegiate wrestlers. Clark et al. (2004) compared DEXA, leg-to-leg BIA (Tanita Scale), HW, and SF with a four-component model as criterion for predicting MWW in collegiate wrestlers. This was a significant study because it was the first study to evaluate MWW that used the modern gold standard of a four-compartment model. The TE for leg-to-leg BIA (TE = 3.08 kg) analysis using the Tanita scale was found to be significantly different than the TE for SF (TE = 1.73 kg) and HW (TE = 1.34 kg). These data suggested that the best precision for field methods to determine MWW were HW and SF analysis. The Tanita scale yielded results that were considered unacceptable due to the high TE (TE = 3.08 kg).

Results similar to those found in the present study were reported in a study conducted by Diboll and Moffit (2003) on male collegiate wrestlers. In their study, a variety of BIA equations were compared with SF as the criterion method. Total error was above 2.0 kg for every BIA equation investigated (RJL, TE = 3.4 kg; Oppliger, TE = 6.4 kg; and Lukaski, TE = 5.4 kg). The equations by RJL and Oppliger (1991S) were the same equations used in the present study. Use of the RJL equation in the present study when compared to the SF analysis produced a TE of 2.34 kg for males and 3.52 kg for females. The Oppliger (1991S) equation resulted in greater TE in their study when compared to the present study (6.4 kg vs. 2.27 kg). It should be

noted that it is expected that if a different criterion variable were substituted for SF and used for comparison (e.g. a four-compartment model) the TE results could have been much different. The point of the present study is that BIA cannot be substituted for SF in male subjects without impacting the minimal weights of the wrestlers. There were no data in the present study that could be used to suggest that the use of SF equations is more valid than BIA equations. However, the study by Clark et al. (2004) did support the use of SF over the use of leg-to-leg BIA.

In 1993 Clark et al. conducted a study on high school wrestlers comparing BIA, SF, DEXA and NIR against HW in determining MWW. Though a high correlation was demonstrated between SF and BIA ($r = 0.976$), mean TE (determined against HW) was lowest for SF (SF, mean TE = 2.25 kg; BIA, mean TE = 2.77 kg). Their study used RJL Systems Model BIA 101A and predicted a MWW value of 60.6 ± 9.1 kg that was very similar to what was determined in the present study for the males (RJL = 64.59 ± 10.79 kg, Opp. = 64.53 ± 14.25 kg, Luk. 59.28 ± 9.37 kg, Hout. 63.80 ± 11.31). The mean MWWs determined by SF measurement were similar as well (Clark's SF = 60.3 ± 8.2 kg, present study SF = 62.25 ± 10.13 kg). Thus, subjects in the present study were similar to those in Clark et al.'s study, who demonstrated that SF analysis was the more accurate method of predicting MWWs in male high school wrestlers when compared with HW.

Eckerson et al. (1992) found that in lean adult males, Oppliger et al.'s equation (1991S) better predicts fat free weight than RJL's equation when compared with HW. Total error for Opp. was 1.70 kg while RJL's TE was 4.19 kg. They concluded that BIA was of little utility for estimating fat free mass (FFM) in lean

subjects. They reported that BW was a better predictor of FFM than any of the BIA equations used.

The HWWMP was put in place to protect wrestlers from losing too much weight and negatively impacting their health. The wrestlers most at risk of losing too much weight would be the leanest athletes. Thus the substitution of BIA for SF analysis for lean individuals seems untenable given the shortcomings of existing equations.

Utter et al., (2001) compared SF and leg-to-leg BIA (Tanita Scale). They concluded that it might be possible to substitute leg-to-leg BIA for SF. Although they did not report TE, close examination of their data suggests that the TE in establishing MWW may be of the same magnitude as found in the present study. The mean %BF in their study was approximately 10%. Examination of the Bland-Altman plot showed that ± 2 SDs in % BF gave a range of $\pm \sim 5\%$. Therefore, a 68 kg (150lb) wrestler with 10% body fat measured by SF could have estimated % BFs ranging from 5% to 15% using BIA values. This would calculate a range of MMWs using the NCAA 5% standard from 61 to 68 kg (134.2 to 150 lbs). Using the 3.6 kg acceptable range proposed by Diboll and Moffit (2003), wrestlers could easily be classified in one of three different weight classes. They also showed lower correlations between SF analysis and leg-to-leg BIA ($r = 0.67$ to 0.82 at various sites) than those found for other methods of BIA in the present study ($r = 0.91$ to 0.96). Thus, it is difficult to understand their conclusion.

SUMMARY

In summary, due to the large biological error associated with BIA when compared to SF, substitution of BIA for SF analysis in a portion of the wrestlers to determine MWWs could result in a large number of wrestlers being misclassified. Data from Clark et al. (2004) emphasizes that SF and HW are more precise than leg-to-leg BIA. Data from the present study confirmed that substituting BIA for SF analysis for remote sites would not result in an acceptable number of wrestlers being assigned to the proper weight class. It should be noted that the validity of either method based on current prediction equations is questionable (Clasey et al. 1999). To ensure the health of high school wrestlers, additional studies using a four-compartment model as the gold standard to develop population specific prediction equations to determine MWWs in the field are warranted. It was concluded, based on the data from the present study, that to maintain a level playing field, SF should continue to be used to determine MWWs over BIA in high school wrestlers in the HWWMP.

PART II

REVIEW OF LITERATURE

Design of Minimal Wrestling Weight Programs

Remick et al. contributed to the MMWR (1998) study on the deaths of three collegiate athletes. During Nov. 7 – Dec. 9, 1997 three wrestlers died due to rapid weight loss to qualify for competition. The first wrestler initially lost 23 lbs in the 10 weeks prior to the competition to weigh-in at 212 lbs. The day prior to his death he lost 9 lbs using dangerous weight cutting methods. On the day of his death the wrestler continued to exercise until exhaustion and cardio respiratory failure. The autopsy demonstrated that postmortem sodium, urea nitrogen, and urine myoglobin were not conducive with what is found during a normal autopsy.

The second wrestler also dropped a considerable amount of weight prior to death. Ten weeks prior to death the wrestler had lost a total of 21 lbs. Chemistry levels ante-mortem indicated abnormal levels of sodium, urea nitrogen and serum myoglobin. The third wrestler lost 6 lbs in the 3 hours before the wrestling competition, as well as 21 lbs during the 13 weeks prior to the competition. Postmortem chemistry findings determined that sodium, urea nitrogen, creatine, and myoglobin levels were not normal when compared with average postmortem levels.

This report was the first to identify deaths in collegiate wrestling due to weight cutting practices. The NCAA recommended by that rapid weight loss due to dehydration and vigorous exercise be prohibited prior to competition.

The National Federation of State High School Associations Handbook (NFHS2003-2004) stated in section 3, article 1 that each state high school association must develop a weight control program by the year 2005. This was done to discourage weight-cutting practices. The recommended minimal body weight should be no lower than 7% for males and 12-14% for females. Each wrestler must have a certified MWW prior to January 15th. Also, the minimal wrestling weight certification programs must measure body fat in a hydrated state.

The American College of Sports Medicine (ACSM)(1996) issued a position statement on weight loss in wrestlers developed by Oppliger, Case, Horswill, Landry, and Shelter. The position statement discussed how wrestlers have been “cutting” weight for many years. College wrestlers have been shown to lose 2-2.7 kg rapidly prior to a wrestling competition. Twenty percent of high school wrestlers have been shown to cut weight as well. The position statement discussed the consequences that occur with “weight cutting”. The problems include dehydration, problems with hormonal status, impedance of normal development, and possible death. Therefore the NFHS set up a weight control program so that these negative side effects of “weight cutting” could be kept to a minimum.

The ACSM recommends that wrestlers and coaches are educated on the consequences of dehydration and fasting. The use of sauna's, laxatives, and diuretics for making weight are also strongly discouraged. A new state or national governing body should be set up so that scheduled weigh-in's can take place prior to competition. Daily weigh-in's should be done prior to and after practice to ensure replacement of fluids lost. Body composition assessments should be completed prior

to the season to ensure that the wrestlers are not losing excessive amounts of weight and dropping below a healthy body fat percentage (5-7% for males and 12-14% for females). Finally, the ACSM recommends the need for emphasis on a daily balance diet. The purpose of the position statement is to provide a safe, healthy environment for athletes to participate in.

Oppliger et al. (1995) performed a study on high school wrestlers in Wisconsin. The study entailed instituting a model for weight control to prevent weight cutting practices during the wrestling season. The initial phase of the study was to determine a proper way to assess the body fat of the wrestlers. This was done using standardized testing and certified testers. The second portion of the intervention was to educate the wrestlers in the proper nutrition by a registered dietitian (RD) or a registered dietary technician (DTR). The project extended over the course of three years; one year for a pilot study, one year as voluntary participation, and the final year as mandatory implementation of the program.

The body fat assessments of the wrestlers were taken at the sites in accordance with the Lohman (1982) equation. The modification by Thorland et al. (1991) was chosen to determine body density. Training clinics were instituted to ensure that all skin fold testers were knowledgeable and proficient in their skills. A one-day training clinic took place at various schools in the state to ensure that everyone who was a measurer was able to perform at the same level. Excellent agreement was demonstrated between the instructors of the skinfold measurements and those testers in the field (intra-class correlations of $r = 0.92$ at the 95% confidence level).

Microcomputer software was instituted that was able to utilize the skinfold measurements and the scale weight to determine percent body fat.

A committee of dietitians, coaches, educators and health professionals developed the nutrition education program. All wrestlers received a copy of *The Wrestler's Diet* for educational reading material. Surveys performed demonstrated that those coaches who were initially against the program (> 60%) changed their minds by the end of the three-year period (95% for the program). The minimal wrestling weight program is evaluated annually to ensure necessary changes are made so that the evaluation process continues to run smoothly. The project has been shown to be very effective, as is demonstrated by the amount it has been reproduced in studies and in other settings.

Oppliger and Tipton (1988) performed a cross validation study on Tcheng-Tipton (TT) minimal weight prediction formulas on Iowa's high school wrestlers. Two hundred and twenty males between the ages of 15-19yrs. were used as subjects in attempt to improve on previously developed formulas as well as test two new formulas. Hydrostatic weighing was performed using a Chatillon 9 kg scale and poolside platform. Percent body fat was determined from the density derived from the Brozek et al. equation. Minimal weight was defined as having 5% BF. Anthropometric measurements were taken at the chest (diameter and depth), bi-iliac diameter, bi-trochanteric diameter, and diameter of both wrists and ankles. Skinfold measurements were recorded at the sights recommended by Tcheng and Tipton. The Tcheng-Tipton Long Form (TTLF) equation and the Tcheng-Tipton Short Form (TTSF) equation were the equations that were assessed as valid indicators of MWW.

Correlation results produced high r-values with $r = 0.937$ (TTLF) and $r = 0.928$ (TTSF). Total error was also calculated via Lohman's recommendation.

The TTLF equation and the TTSF equation were shown to under predict and over predict, respectively, when compared with HW. Using χ^2 analysis the frequency distribution of the residuals of TTLF and TTSF were found to not differ significantly from the normal distribution. Comparison between HW and TTLF showed 2% difference while the comparison of HW and TTSF showed 2.3% difference, with the exception of the lightest weight class where the difference was 3.6%. Total error found for the TTLF was 7.7 lbs. and 8.2 lbs. for the TTSF correlation between the HW. Six variables were examined in comparison with the original TTLF, resulting in a slightly larger $r = 0.949$ and slightly smaller SEE (7.5 lbs.). When a subject's current weight was included the r-value increased even more. The subject's age was determined to have no influence on the r-value.

There were small differences between the predicted and the true minimal weight via either equation. Forced inclusion of independent variables showed a small difference in the magnitude for the regression weights. Therefore it was concluded that the measurements included in the equation were appropriate. The study suggests that all equations examined by the researchers are appropriate for determining MWW.

Thorland et al. (1991) conducted a mid-west wrestling study to better predict minimal weight for high school wrestlers. The study looked at the validity of 16 equations used to predict fat free body mass. The 860 male subjects were collected over the course of a five-year period in the states of Illinois, Iowa, Minnesota, Nebraska, and Ohio. Five human performance labs were utilized for the collection of

data; Bowling Green State University, University of Illinois, University of Iowa, University of Nebraska, and St. Cloud University. Body density (BD) was calculated based on underwater weight at residual lung volume. The measurements were collected based on the procedures of Behnke and Wilmore. Skinfold measurements were recorded by either Lange or Harpenden calipers.

Sixteen equations were chosen that would allow for determination of minimal wrestling weight. Two series of cross validations were conducted where the criterion was the FFM or the BD determined by the Brozek et al. formula or the Lohman formula. In each series constant error, SEE, TE, difference in standard deviation, and the regression coefficient were calculated. Cross validations were conducted on each random sample given (N=645 and N=215). A two-way ANOVA revealed differences that can be attributed to age and body mass for all variables. Total error was used as the main criterion to judge an equation's relative accuracy, based on 2 kg as found in a previous study.

Total Error for the previous equations when compared with HW were as follows; Lohman = 2.47, Thorland 1 = 2.52, Thorland 3 = 2.44, Katch = 2.59, Behnke = 2.54, D2 = 2.83, and D4 = 2.79. The study recommends any of the following equations, Lohman, Thorland 1 or 3, Katch 1, D2, or 4, or Behnke for MWW based on the low TE and high correlations between those studies and HW. However, MWW should be done as a preseason evaluation in a hydrated state.

The 2004 Hawaii Wrestling Weight Monitoring Program (HWWMP 2004) by the Hawaii Athletic Trainers Association (HATA) is a set of guidelines provided to all Hawaii high schools in order to promote the safety of scholastic wrestling. The

HWWMP consists of five major components. The first component encompasses rules established by the NFHS. The rules state that every high school must institute a weight control program. Each wrestler is required to weigh-in prior to the season. The NFHS recommends a minimum % BF of 7% for males and 12 –14% for females. The HWWMP chose 14% body fat for the females.

The second portion nutritional component consisted of coaches attending a nutrition education program during their first year of coaching and once every three years after. The athletes must participate in a minimum of one hour of nutrition education as well.

The third component was created to establish the MWWs. Specific gravity is recorded to determine hydration level. Skinfold measurements were taken by the HHSAA registered SF assessors. Male SF were measured in accordance with the equation by Lohman (1982) and females were measured in accordance with the equation by Jackson, Pollock, and Ward (1980).

Program procedures are the same at each site. All materials are listed in the HWWMP guidelines. Specific gravity is conducted using a refractometer with a score of 1.020 g/ml or lower indicating a state of hydration. Three separate skinfold measurements are performed on each site by three separate testers. Data analysis is performed via computer in a separate room. All results must be reported to the HWWMP.

Summary. Due to the deaths of the three collegiate wrestlers nationally recognized organizations (the ACSM 2002 and the NFHS 2004) stress the importance of determining MWWs to ensure healthy weight loss practices in wrestlers. Minimal

wrestling weight programs were demonstrated to be effective in certain states (Opp 1995, Opp 1988, Thor 1991). These MWW programs helped to establish a national standard using Lohman's (1982) SF equations as a predictor of MWW (Thor 1991). To comply with national guidelines, Hawaii instituted the HWWMP to provide a healthy environment for the high school wrestlers in Hawaii (HWWMP 2004) based on the studies that have been conducted previously and shown to be effective.

Bioelectrical Impedance as a Predictor of Body Composition for High School Aged Children

Clark et al. (1993) compared the accuracy of body fat measurements, and therefore minimal wrestling weight, in high school wrestlers via DEXA, BIA, Near-infrared Photospectrometry (NIR), and SF (Lohman). The subjects consisted of 95 Caucasian male high school wrestlers who were participating in summer wrestling camps at the University of Wisconsin. Body density as determined by HW at residual volume was the criterion measurement.

The anthropometric measurements consisted of height, weight and nine SF measurements via the Lange SF calipers. Two independent measures were done at each site, with SF thickness being determined by the average. Body density was predicted by the Lohman (1982) equation with the modified constant as suggested by Thorland et al. (1980). Near-infrared Photospectrometry measurements were done via a Futrex model 5000A, in the areas specified by the manufacturer. BIA was determined by the resistance and reactance obtained by the RJL Model BIA 101A. The subjects were measured according to the manufacturer's protocol. The BIA's

were calibrated daily and the %BF was calculated via the RJL weight management software. DEXA, by the Norland Model XR-26, was used to determine the % BF as well. This study used a rectilinear body scan.

Statistical analyses were done using paired t-test between the HW and predicted method to determine significance, mean difference, standard deviation difference to compare variability, Pearson Product Moment of correlation, SEE, TE, and regression analysis. The smallest mean difference occurred between HW and SF (0.6kg). The smallest standard deviation difference was found with BIA, with a score of 0.1. The smallest SEE was 2.12 demonstrated by the SF equation, followed closely by the 2.62 found via BIA. Total error was least for SF, with a score of 2.25. The 2.77 found by the BIA was the next closest score. The Pearson correlations between MWW predicted from HW were as follows; SF = $r = 0.972$, BIA = $r = 0.957$. The correlation between SF and BIA was $r = 0.976$. Total Error ranged from 2.25 kg to 3.45 kg, SF and NIR respectively. The study determined that SF exhibited the lowest SEE, TE, mean difference, and highest correlation when compared to all other methods. The data supports the use of SF as a predictor of MWW.

Oppliger et al (1991) conducted a study on fifty-seven male high school wrestlers. The research compared SF, BIA, two skeletal dimension equations and HW, in regards to wrestlers MWW. HW was conducted with residual volume to determine %BF. This %BF was one of the criteria in determining MWW. Anthropometric SF measures were taken with Lange calipers. Results were derived from Oppliger's equation. Three separate devices, Berkley Medical Research (BMR), RJL, and Valhalla (VAL) took BIA measures. The % BF was determined by

the most current version of the software provided by the manufacturer. Statistical analyses that were conducted include descriptive statistics, Pearson Product moment, SEE, TE, ANOVA, and paired t-tests.

The results of the study show a high correlation between HW and all other methods of computing MWW (all $r > 0.92$). The SEE ranged from 0.19 (SF) to 1.47 (Tcheng-Tipton skeletal dimensions). The study demonstrated significant differences of MWW between HW and both skeletal dimension equations, as well as between the RJL and VAL BIA's results. The TE ranged from 1.8 kg (SF) to 4.4 (RJL BIA). Testing for power found the TE for SF and BMR to be the lowest. The regression lines showed the most congruency between SF and BMR BIA as compared to the other testing methods.

The investigators concluded that the SF and BMR BIA accurately predicted MWW. They also determined that the BMR BIA produced significantly different than the other BIA systems.

Oppliger et al. (1991) assessed the fat free mass of 110 high school wrestlers comparing predictions methods of BIA and HW. The mean (standard deviation) age 15.7 ± 1.1 yr., weight 64.5 ± 12.1 kg, height 169.8 ± 10.1 cm, and percent fat $8.7 \pm 3.9\%$ of the wrestlers was determined. Body density was calculated by hydrostatic weighing with residual volume and by RJL's BIA. The BIA used reactance and resistance in combination with an already established equation to determine fat free mass (FFM). The equation was $FFM = 1.94 * 0.701 * \text{weight} + 0.186(\text{height}^2 / \text{reactance})$. Percent body fat was calculated from HW via Siri's equation. The results of this study demonstrated that SEE = 1.89 kg and $r = 0.960$) there was a high

correlation between the % BF calculated via HW and BIA, when using the previously mentioned equation.

A study by Houtkooper et al. (1992) attempted to cross validate and/or develop the "best" prediction equations for fat free mass in children ages 10 – 19 yrs. The sample included 94 children and was cross validated against three other samples (N = 131). Fat free mass calculated via BIA using prior prediction equations was compared with HW. Statistical analysis demonstrated a SEE ranging from 1.3 kg to 3.7 kg and r^2 ranging from 0.8 to 0.95 when using the already developed prediction equations.

Four sample equations were combined to produce a recommended equation. Three regression models were created. The SEE when compared with hydrostatic weighing produced a range from 2.1 kg to 2.9 kg. The r^2 produced also demonstrated a better correlation when compared with hydrostatic weighing ($r = 0.91$ to 0.95). The study recommended that the equation $FFB-DW = 0.61(ht^2/resistance) + (0.25*weight) + 1.31$ be used when assessing fat free mass in children in comparison with HW.

Summary. Subjects of all the validation studies were high school aged children. Validity of the studies were determined via comparison of hydrostatic weighing (as the gold standard) to BIA, skinfold, DEXA, and NIR. Skinfold data was determined from the Lohman equation (Opp 1991, Opp 1991, Clark 1993). One study determined that the comparison of skinfold and bioelectrical impedance with hydrostatic weighing produced results that indicated the inaccuracy of BIA when compared with skinfold (Clark 1993). Conversely, Oppliger (1991), Oppliger (1991

sup), and Houtkooper (1992) found that equations utilizing BIA were able to predict MWW that coincided with those predicted by HW. Oppliger (1991) also determined that BMR BIA system produced data that predicted MWW more accurately than RJL and VAL BIA systems.

Bioelectrical Impedance as a Predictor of Body Composition for Collegiate

Athletes

Diboll and Moffit (2003) conducted a comparative study of MWWs using BIA, NIR and SF, in collegiate wrestlers. Twenty-five collegiate wrestlers participated in this study. Each wrestler participated in height and weight measurements as well as hydration measurements via urine specific gravity. A score of < 1.020 was considered adequately hydrated. Skinfold measurements were performed at the triceps, subscapularis and abdominal sites using Lange calipers. Calculations were performed using Lohman's (1982) equation to determine body density and the Brozek et al. equation to determine percent body fat. BIA measurements were performed via the RJL Quantum X Body Composition analyzer. All measurements were taken as the manufacturer specified. Three different equations were used to determine the fat free mass (FFM). BIA1 (equation 1) was the general equation utilized by the Cyprus software that was provided by RJL manufacturers. BIA 2 was an equation that had been derived for high school males and females by Lukaski (1990) and BIA 3 was an equation that was modified specifically for males by Oppliger (1991). NIR was performed using the Futrex system. Percent body fat and FFM were then used to calculate MWW ($FFM/0.95$).

A one-way ANOVA was performed to detect significant differences between various measurement methods. Skinfold served as the criterion for the Pearson Product of moment correlation (r), coefficients of determination, and SEE. Difference in mean and differences in standard deviation were used as comparison methods, as was TE.

The ANOVA results showed that there was no statistical difference (based on $p < 0.05$) between SF (criterion method) and all other methods of determining MWW. The Pearson product moment of correlation showed a significant relationship between SF and all other methods of determining MWW. The strongest relationship occurred between SF and BIA 1 ($r = 0.978$). The weakest relationship was between SF and BIA 3 ($r = 0.921$). The SEE ranged from 2.1 kg (BIA 1) being the closest to SF and 3.9 kg (BIA 3). The TE ranged from 3.41 kg (BIA1) to 6.4 kg (BIA 3). The Bland Altman plots indicated that BIA 1 has the best agreement with SF.

The results showed that the BIA 1 equation would be the closest to determining MWW when compared with SF. However the limits of agreement for BIA 1 are ± 4.6 kg, which falls out of the 3.6 kg weight class range. This would indicate that neither the BIA nor the NIR is an acceptable method of determining MWW when compared SF measurements.

Lukaski et al. (1990) conducted a study on the body composition assessment of athletes using BIA measurements. One hundred and four female and male athletes participated in the study. Measurements were taken under two experimental conditions, controlled and uncontrolled conditions. Uncontrolled condition measurements of BIA and HW were performed without regards to exercise or

hydration state. The controlled state consisted of measurements two hours after a light meal and no exercise.

Body composition was estimated by HW according to the procedures of Akers and Buskirk. Residual volume was determined by the N₂ wash out method. Percent body fat was calculated from Brozek et al. For those African American participants, the equation by Schutte et al. was used to calculate %BF. Bioelectrical impedance was measured by RJL Systems model 101. Fat free mass was predicted using an equation established prior to testing. Independent and dependent t tests were performed. Repeated measures ANOVA and significance were identified by Scheffe contrast. Linear regression analysis assessed the different experimental conditions. Comparisons of Pearson's product moment correlation were performed as well.

Statistical analyses showed no significant difference between the mean estimates of FFM determined by HW or by BIA regardless of experimental condition. However, in the uncontrolled condition BIA calculated lower than the average fat mass when compared with HW. In the uncontrolled state the resistance decreased ($p < 0.05$; 469.1 ± 7.6 ohms) and reactance increased ($p < 0.05$; 69.4 ± 1.7 ohms). Controlled condition's BIA FFM related more closely to HW (controlled $r = 0.988$ vs. non-controlled $r = 0.977$). Under controlled conditions the correlation coefficient was greater. This study demonstrates the validity of BIA in determining %BF. It also demonstrates the necessity of controlled measurement conditions to obtain valid and accurate results.

A study by Clark et al. (2004) compared MWWs for collegiate wrestlers derived from a four-component model (gold standard) with MWW from HW, SF, leg-

to-leg BIA, and DEXA. Statistical analyses conducted included SEE, TE, and Pearson product moment correlations. Bland Altman plots were drawn to identify the bias between the prediction and the criterion methods.

Strong correlations were produced by each method ($r = 0.92$ to 0.98).

However, TE has been considered the best single variable for evaluated differences between a prediction and a criterion. The lowest TE was demonstrated by HW (1.34 kg) and SF (1.73 kg). The highest TE was produced by BIA (3.08 kg). The study concluded that HW and SF, as used by the NCAA, were appropriate for producing MWW when compared with the four-component model.

In 1999 Fornetti et al. inspected the reliability and validity of BIA and NIR compared with DEXA in female collegiate athletes. Bioelectrical impedance and NIR were performed twice on each subject to assess the reliability. The reliabilities ranged from 0.987 to 0.997 for BIA and 0.957 to 0.980 for NIR.

Prediction equations were developed for BIA using resistance and reactance, and for NIR using optical density measures. When compared with the FFM calculated by DEXA the BIA equation produced an $r = 0.981$ and a $SEE = 1.1$ kg. NIR produced similar results when compared to DEXA ($r = 0.975$; $SEE = 1.2$ kg). Use of just height and weight produced an $r = 0.961$ and $SEE = 1.6$ kg. The study demonstrates that BIA and NIR techniques are reliable and can be used for estimation of body composition in female collegiate athletes when using the study's prediction equation.

Utter et al. (2001) conducted a study comparing leg-to-leg BIA with SF in predicting %BF in collegiate athletes. Five separate collection times were used in the

study using the Lohman equation to predict % BF via SF. The Tanita body fat analyzer was used to determine the BIA measurements for % BF. Pearson r-values and SEE were calculated to compare % BF. A Bland Altman plot was constructed to examine the systematic differences.

Significant correlations were produced between the two methods at each of the 5 sites ($r = 0.67$ to 0.83). Standard error of estimate produced by the comparison of the two methods ranged from 2.1 % to 3.5 %. Therefore this study demonstrated that leg-to-leg BIA accurately estimates % BF when compared with SF measurements in the male wrestlers collegiate population.

Summary. When BIA was compared to gold standard measures such as HW (Luk 1990) or the new gold standard the four-component model (Clark 2004) SF has been demonstrated as an appropriate substitution for assessing body composition as opposed to BIA. On the other hand, when comparing SF measures with leg-to-leg BIA (Utter), various BIA equations (Diboll 2003), or using DEXA as the criterion method (Fornetti) BIA has demonstrated a high correlation. However, one must take into consideration the population specific equations that have been used, as well as the lack of a gold standard criterion when determining the better method of predicting body composition.

Bioelectrical Impedance as a Predictor of Body Composition for the Adult

Population

Eckerson et al (1992) conducted a study on the validity of bioelectrical impedance equations on estimating fat-free weight (FFW) in lean males. Sixty-eight

Caucasian males (22 ± 3 , ranging from 19-40 yr.) participated in this research. The subjects were selected based on their lean appearance. Body density (BD) was assessed using HW techniques, with corrections for residual volume (RV). HW was measured in the shallow (1m deep) of a swimming pool with a Chatillon 9 kg scale. Percent body fat was calculated using BD and the revised formula of Brozek et al (1963). Fat free weight was determined via the following formula: $FFW = ((\%BF/100) * \text{body weight})$.

Bioelectrical impedance was measured using the RJL Systems BIA-106 Spectrum. The RJL BIA was administered according to the manufacturer's guidelines. Body composition was determined via each method after a 12-hour fast and 12 hours, minimum, of no exercise. The study examined eight separate equations for determining FFW.

The validity of FFW was assessed first by the constant error, which was the estimated FFW minus the actual FFW (as calculated by HW). The SEE, r, TE, and the similarity between the standard deviations also assessed the validity. Simple linear regression was performed to compare the accuracy of body weight alone and $\text{weight} * \text{resistance}/\text{height}^2$, as supplied by RJL Systems. Multiple regression was also conducted to determine the contribution of body weight, WR/Ht^2 , ht^2/R , resistance, body mass index, Ht^2 , and Ht to predict FFW.

The statistical significance of constant error (CE) was determined by dependent t-tests. The CE values ranged from -0.02kg (EQ3) to -8.06kg (EQ6). The validity of the coefficients ranged from $r = 0.81$ (EQ4) to $r = 0.98$ (EQ3 and EQ5). The TE, which accounts for the effects of both CE and SEE, ranged from 1.70kg

(EQ3) to 8.92 (EQ6). Body weight ($r = 0.98$) was determined to be a significant predictor via simple linear regression. WR/Ht^2 , as provided by RJL Systems, demonstrated a much lower significance ($r = 0.15$). Multiple regression analysis indicated that body weight is responsible for the majority of variance ($R^2 = 0.96$).

The study concluded that EQ3 was the most accurate predictor of FFW when compared to the FFW determined by HW. The cross validation analyses for EQ1 and EQ2 determined that the equations provided by RJL Systems are unacceptable when compared with HW. Also the results showed that body weight alone was as accurate as EQ3.

A study conducted by Thompson et al. (1991) compared BIA and HW in the measurements of body composition in states of hydration and dehydration. Ten Caucasian males (18-44yr) volunteered to participate in the study. The subjects were randomly assigned to be measured by BIA (BCA model MC-2217, Bio-Analysis, Inc.) or by HW. Subject's preparation for BIA was in accordance with the manufacturer's specifications. HW preparation involved determining residual volume (RV) and measurements underwater via a Chatillon 15 kg scale. Criteria for measurements were determined by the recommendations of Behnke and Wilmore. Body density was calculated using the Goldman and Buskirk's formula. Percent body fat was determined using Siri's formula.

After %BF was calculated in the control state, each subject hydrated by ingesting 0.5 L of distilled water. After 30 minutes passed body composition measurements were repeated. To dehydrate, the subjects combined exercise and a steam room, until the subject lost 2-4% of their weight. This was monitored by

periodical weigh-ins. Upon obtaining this goal, the subject again repeated the body composition measurements.

Statistical analysis by two-way ANOVA showed no significant differences between BIA and HW. However, a significant difference was determined among the three various conditions. Post hoc analysis showed that the differences existed in the varied states of hydration.

The predictions of BIA and HW were significantly altered in the dehydrated state only. The SD of %BF determined by the BIA in the control state was 16.05 ± 3.54 , in the hydrated state the SD was 16.44 ± 3.22 , and in the dehydrated state the SD was 14.37 ± 3.53 . This demonstrates the large degree of difference between the controlled, hydrated, and dehydrated states. The same is demonstrated via HW with SD's of 17.37 ± 4.28 , 17.12 ± 4.57 , and 15.89 ± 4.68 , respectively.

The hydration state of the subject, as determined by this study, influences the %BF, as well as the body weight of the subjects who participated in this study. The study recommends that when body composition is to be determined that a state of hydration be recorded to allow understanding of the hydration level.

Pajmans et al (1992) examined the use of BF and BIA for body composition after rapid weight reduction. Fourteen obese but healthy individuals agreed to participate in this study (10 women and 4 men). Fourteen non-obese subjects were used as control subjects. The obese subjects participated in a very low calorie diet for thirteen weeks (the diet was nutritionally sound).

Hydrostatic weighing, SF, and BIA assessed body composition. Hydrostatic weighing was done with a minimal of ten trials to get a reading. Body fat was

estimated via the Siri's equation. Bioelectrical impedance was determined by the Valhalla BIA and used the Valhalla 1990B equation to determine %BF. Skinfold measurements were taken using a Harpenden caliper, in accordance with Behnke and Wilmore's protocol. Body composition assessments were also estimated using Durnin and Rahaman, Durnin and Womersly, Jackson and Pollock, Jackson, Pollock, and Ward, Sloan, and Sloan, Burt and Blyth equations.

Statistical analyses consisted of paired t-tests to assess the significant differences in body composition, repeated ANOVA to determine the differences in the means of the various methods. Prediction equations and hydrostatic weighing were compared using Pearson's product-moment correlation and SEE.

The obese subjects lost a wide range of weight (mean 34.4 ± 11.4 -kg range of 15.7 – 55.0 kg) over a varying period of time (mean 33.1 ± 11.8 weeks, range 13-56 weeks). The results demonstrated that BIA, Jackson and Pollock's, and Sloan's equations underestimate the %BF of the obese group (when compared with the hydrostatic weighing). However, %BF was overestimated in the non-obese group when using the Durnin and Rahaman and the Durnin and Womersly equations. However, in the non-obese group the Sloan and the Sloan, Burt, and Blyth equations underestimate the %BF. The Jackson and Pollock equation and the BIA were not significantly different from the HW control group.

Skinfold equations by Jackson and Pollock, Jackson, Pollock, and Ward, and BIA were the most highly correlated with HW. In the control group Jackson and Pollock, Durnin and Rahaman, and the BIA provided the highest correlation with a low SEE when compared with HW. The majority of the equations derived for body

fat assessment were derived from small, specific groups. This could contribute to the large over/under estimation of %BF. The BIA resulted in substantial differences when compared to HW in the obese group. The SEE for the SF equations were $\pm 3.3\%$, while BIA equations were $\pm 2.7\%$. The authors recommended that further research needs to be done in the area of SF and BIA.

Lukaski et al (1986) conducted a study on the validation of tetra polar BIA to assess human body composition. The study looked at the relationship between bioelectrical conductance (Ht^2/R) and HW predictions of fat free mass, as well as compared the accuracy of body fatness gathered from SF measurements, BIA and HW. One hundred and fourteen subjects agreed to participate in this study (both male and female, 19-50 yrs.) Each female participated in the study seven to eight days after the start of her period. Each subject completed all tests on the same day, after a light breakfast (2 hours prior). Hydrostatic weighing was performed using systems and procedures provided by Akers and Buskirk. Residual volume was measured by the open circuit technique for N_2 . Percent body fat was calculated from body density according to Brozek et al. Fat free mass was determined from the difference between body mass and fat mass. Bioelectrical impedance was measured using the RJL Systems model 101. Electrodes were applied according to manufacturers recommendations. Height was measured to the nearest 0.1mm and weight was measured with in $\pm 0.2kg$. Skin fold measurements were taken at the triceps, biceps, supra iliac, and scapular sites with Tanner-Whitehouse calipers. Body density was calculated using Durnin and Womersley's equation. Percent body fat was calculated using the equation by Brozek et al (1963).

Statistical analyses consisted of a double cross validation of the prediction of fat free mass. Multiple regression analyses were applied to the best predictors of FFM. Multiple regression and ANOVA determined the relationships between FFM of the present study and of previous studies. Pearson product moment of correlation was also used.

The men, as a group, weighed more, were taller, and were leaner than the women participants. Mean resistance values were lower in males when compared with the females. The cross validation between the studies demonstrated that the male subjects of this study were similar to those of previous studies. Percent body fat, derived from FFM data emphasized the similarities between the two male groups. No significant differences were found between slopes or intercepts of the individual regression lines, which indicated the validity and reliability of Ht^2/R as a predictor of FFM.

The study on the women was then compared with prior studies done on men. Fat free masses were similar between the male and female samples. Correlation coefficients between observed and predicted FFM were shown to be similar. The similarity of the regression coefficient proves the validity of this relationship. The comparison of HW and BIA in females shows no difference in the slope ($F= 0.04$, $P = 0.85$). This demonstrates the validity of Ht^2/R of females as a predictor of FFM. Stepwise regression analysis showed that Ht^2/R was the best predictor of FFM. The correlation coefficients between HW and SF were lower than those BIA and HW. The study confirms the validity and reliability of conductance as a predictor of FFM. In comparison to HW, BIA has an error of $\sim 2.7\%$ while SF measurements have an

error of ~3.9%. Due to the variety of the population, the similarity of the results shows promise between BIA and HW. The results of this study demonstrate that tetrapolar BIA is a valid and reliable method of body composition measurement.

Jackson et al (1988) performed a study on the reliability and validity of BIA in determining body composition. Participants in the study included forty-four women and twenty-four men. Each subject participated in a twenty-four hour diet, activity, and medical history prior to participation. The order of testing began with BIA, then SF, and then HW. Two separate testers measured each subject on two different days.

Bioelectrical impedance measurements were taken via RJL Systems 103B and were applied according to manufacturer's recommendations. Skinfold measurements were taken with a Lange SF caliper and %BF was determined via gender specific equations developed by Jackson and Pollock. Hydrostatic weighing was measured via a Chatillon 15 kg scale with residual volume being determined by the N₂ washout technique with a Gould model 110-V pulmonary function analyzer. Body density was determined by Goldman and Buskirk and percent body fat was determined by Brozek et al's equation.

The largest mean differences were obtained with the male BIA equation. This equation underestimated %BF by 2.4% when compared with HW. Therefore FFM was overestimated by 2.2 kg. The women's BIA overestimated the percent of body fat by 2.6%. In turn, the FFM was underestimated by 1.2 kg. The largest difference in SF was with the male sample, where %BF was underestimated by 1.4%, meaning FFM was over estimated by 2.2 kg.

The general reliability for all methods were high ($R_{xx} \geq 0.957$). Bioelectrical impedance analysis (>3%) showed more random error than HW (~ 2%). The highest cross validation occurred between the $\Sigma 7$ SF equation and the HW. The comparison of BIA as an independent variable shows that it has no significant impact when compared with no BIA involvement. Multiple correlations showed that validity was not increased when other models were used when compared with SF measurements. The study determined that BIA is not as accurate as SF assessments when compared with HW. Neither BIA FFM nor body density was found to be more accurate than SF equations. The results state that weight/height² is the major source³ of variance in BIA prediction models.

Diaz (1989) performed a study of the ability of BIA compared with SF measurements in predicting %BF and FFM. Ninety-nine women, belonging to three separate groups, and forty-nine men participated in this study. Every subject participated in height and weight measurements as well as BIA via RJL systems BIA 103 and HW. Bioelectrical impedance measurements were done in accordance with the manufacturer's guidelines. Hydrostatic weighing was measured using a Detecto scale, while lung volume was measured using a Collins spirometer. Body fat was calculated from HW via Siri's equation. Body fat for the BIA was calculated using the RJL software.

Statistical analyses were made using the SPSSX statistical package. Descriptive analysis, Pearson correlation, and step wise multiple regression were the types of statistical analyses that were performed. Densitometry was used as the dependent variable for the linear regression.

The variables that were used in the BIA equation (resistance, reactance, Ht^2/r , height and weight) were assessed for their importance in determining FFM and body fat. The resistance and reactance when compared with height and weight explained very low variance of FFM. For example, group two of the women showed 0% variance with resistance and only 1% FFM variance with resistance and reactance as variables. Height squared divided by resistance demonstrated a lower percentage of variance through out all the groups compared with variance from just weight, demonstrating weight as a more important variable in determining FFM and %BF. The same analyses were performed with %BF. The variable of Ht^2/r explained 0%-40% of the variance in %BF where as weight accounted for 37%- 82% of the variance, again indicating weight as a more powerful variable. Stepwise multiple regression showed that weight, height, and then Ht^2/r were the variables that contributed the most to determining FFM and %BF.

The study demonstrated that body fat and fat free mass variations are explained mostly by the body weight of the subject and not by the resistance and reactance. It was concluded, based on the results, that BIA is a poor predictor of body composition when compared with height and weight. The authors suggested that the reason there was a high correlation between BIA and other body composition measurements in other studies was due to the inclusion of height and weight, as well as other variables.

Clasey et al (1999) conducted a study on the validity of body composition assessments in young and older men and women. Seventy-eight subjects consented to participate in the study. The study compared % BF calculated by Baumgartner's

four-component model, Siri's three-component model, DEXA's three-component model, Siri's two-component model, SF by Williams, Jackson and Pollock, and Tran-Weltman with the criterion of %BF by Heymsfield's four-component model. An ANOVA with repeated measures was conducted to compare %BF calculated by the criterion method with %BF calculated via all other methods. Bland Altman plots were also drawn to examine the strength of the relationships between the criterion and all other methods.

The TE Ranged from 0.30% to 5.71%, with Baumgartner's four-component model (TE = 0.30%) and Siri's three-compartment model (TE = 0.72%) having the lowest TE. When comparing the criterion with all other methods of predicting %BF using the Bland Altman plot Baumgartner's four-component model produced a very low mean \pm 2 SD (\pm 0.29%). However, methods that are used commonly, such as Jackson-Pollock's SF equations produced large mean \pm 2 SD (\pm 5.9%) The study concluded that the Siri's three-component model provided accurate %BF when compared with the criterion method. However, the data also suggested that use of SF BF% calculations should be viewed with caution due to the large mean differences and considerable amount of inter-individual variability.

Summary. The majority of the studies done on the general population found that BIA cannot be substituted for HW in body composition measurements. Some studies found that BIA was as reliable as body weight (Diaz 1989, Eckerson 1992) or body mass index (BMI) (Jackson 1988) when compared with HW. However, some research found that there was no significant difference between BIA and HW

(Thompson 1991, Lukaski 1986). Overall more research needs to be done in order to accurately assess the relationship between BIA, SF, and HW in predicting body composition (Paijmans 1992). All methods should be looked at with caution, when not compared with the gold standard four-component model (Clasey 1999)

Skinfold Equations Used in Determining MWW

Oshiro (2001) conducted a study on the state of Hawaii's certified athletic trainers in reliability of skinfold measurements. Lange skinfold calipers were used to measure skinfold sites as indicated by the Lohman and Jackson, Pollock and equations. The participants in the study were compared against two certified athletic trainers who had been practicing skinfold measurements for over twenty years. Measurements were recorded twice at each site. The results were compared with each measurements taken by experienced certified athletic trainers (the criterion). The results indicated that both the intra and inter – reliability of the certified athletic trainers were high (correlations ranging from $r = 0.95$ to $r = 0.99$). This indicated that Hawaii athletic trainers are proficient in their skinfold measurement skills.

Lohman (1982) reviewed over 40 studies to compare the regression analyses that were used to develop prediction equations for body composition, evaluate statistical considerations, and define a better approach to the resolution of body fatness via skinfolds. Past studies demonstrated that the population that had been used in the majority of the literature consisted of young adults, both male and female, and were lacking in elderly, children, and athletes. This study determined that SF measurements were fairly accurate in predicting %BF (TE = 3.3 % body fat).

However, the error that did occur was most often attributed to intra-tester reliability, inter-tester reliability, specific populations, and biological fat distribution variations.

To better statistically evaluate body density equations Lohman recommended: SEE; an equation used to predict body density on one sample would be compared with the actual density measurements, if the first equation coincides with the other equation then the means should be comparable; Total Error ($TE = \Sigma (Y - Y_i)^2 / N$); Use large samples; Use of subjects similar to the population that the equation was derived from. Lohman also recommended the use of body densities rather than the use of %BF, FFM, or lean body mass when developing equations as well as the establishment of standard measurement procedures.

Jackson, Pollock and Ward (1980) conducted a study that attempted to derive equations for women differing in age and body composition. Hydrostatic weights and SF data were gathered on 331 females over a six-year period at three separate laboratories. Seven SF sites were used to obtain the skinfold data; chest, axilla, triceps, subscapula, abdomen, suprailiac, and thigh. Multiple regression analysis was used to develop the generalized regression equations. Skinfold and HW data correlations ranged from 0.867 to 0.838. Standard errors produced ranged from 4.0 % to 3.7 % BF. The study demonstrated that those equations that used a sum of four SF sites ($r = 0.37$) produced a higher correlation than the other equations using seven ($r = 0.33$) and three SF sites ($r = 0.32$). A cross validation sample of 82 females produced high correlations ($r = 0.799$ to $r = 0.827$) and low standard errors (3.7 to 4.0 % BF). The researchers determined that the equations were valid when applied to

adult females of various body builds. However, they recommended that care be taken with women over the age of forty.

Summary. The literature demonstrated the most reliable equations for conducting body composition. The Lohman (1981) SF equation was determined to be an accurate way of determining %BF for males when compared with HW. The same comparison was made between the Jackson et al. (1980) equation and HW for females. The study by Oshiro (2001) demonstrated the reliability of the SF assessors who were used in the present study, the HATA ATCs.

Statistic Analysis

Bland and Altman (1986) provided an alternate statistical approach to assessing agreement between two methods of clinical measurement. The authors discussed the difficulties of finding appropriate statistics to determine if a new method of measurement is as good as or better than a previous method used. Many studies have used product moment correlations coefficients r as an indicator of agreement between results. However, it has not been proven to be efficient.

Bland and Altman (1986) provided sample data to demonstrate the new statistical approach. The data consisted of peak expiratory flow rate measured between a Wright peak flow meter and with a mini-Wright flow meter. The data was initially plotted as if the two devices produced exactly the same results. The regression line enables a person to visualize the agreement between the two measures. The next portion of the statistical analysis would be to calculate the correlation

coefficient. The data provided a high correlation ($r = 0.94$). However the r , in actuality, measures the strength of relation between the two methods of measurement. Therefore there is a strong relationship between the two variables but not an agreement between them. The sample size, as well as the scale of the measurements can also affect correlation.

Bland and Altman (1986) suggest that after plotting a regression line the researcher should plot the difference between the methods against their mean. This would allow the researcher to see discrepancies between the two variables that could not be seen in a regression line. Also this method would allow the researcher to investigate any relationships between the measurement error and the true value (the mean of the two values is the closest measurement to the true value, therefore is considered the true value). To establish if bias is present in the study the researcher can adjust by subtracting the mean difference of the original variable by the mean difference of the new variable. This would demonstrate where the normal distribution lies and therefore indicates what falls outside of the normal distribution. Use of SEE and confidence intervals, after determining if the distribution is normal; will help determine how precise the data is.

Summary. Bland and Altman (1986) suggested a new method of determining the agreement of data by plotting the mean of the data gathered against the difference between the criterion and the predictor. This would allow for better assessment of the prediction method.

AGREEMENT TO PARTICIPATE IN

Comparison of Two Methods of Hydration and Body Composition Assessment in High School Wrestlers

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I. Introduction

This research study is being conducted by athletic trainers from the University of Hawaii departments of Kinesiology and Leisure Science and Intercollegiate Athletics. The purpose of this research study is to compare data from the existing wrestling weight monitoring program to Bioelectrical Impedance Analysis data. Since 1999 all high school wrestlers in Hawaii have been required to have hydration and body composition assessed one month prior to official wrestling competition in order to establish minimal wrestling weight. Hydration is currently assessed using urinalysis, while body composition is analyzed with skinfold techniques. This study will compare the results of these assessments with those of another technique known as bioelectrical impedance analysis (BIA). Wrestlers who hereby give consent will act as subjects of this research study and will have measurements taken using BIA.

II. Procedures

You will report to the Castle High School gymnasium on December 8, 15, or January 12 to undergo the required wrestling weight monitoring program. Following this complete program, you will be assessed using BIA. Disposable electrodes will be placed on your right wrist, ankle, finger, and toe. You will then be asked to lie down on your back while a reading is recorded with BIA. Standing height will then be measured and recorded. The entire BIA process takes no more than three minutes to complete.

III. Confidentiality

Bioelectrical impedance analysis data carry no significance until entered into a computerized program. No inferences can be drawn from the presence of this data alone. Data will be used for research purposes only and will have no affect on minimum wrestling weight or your wrestling season.

IV. Right to Withdraw or Removal from the Study

Assessment with BIA requires less than three minutes to complete. Nonetheless, if at any time pain, discomfort, anxiety, or discontent of any kind in expressed, or detected, the procedure will be terminated. It is important to emphasize

that the BIA section of the assessment protocol is not required by the Hawaii High School Athletic Association, but is strictly voluntary. Therefore, you may withdraw without prejudice at any time.

V. Benefits

Although you may receive no direct benefit, the data collected from this research study will allow the comparison of another method of hydration and body composition assessment to the current methods, which may not necessarily be the most accurate assessments in determining minimum weight. As a result, the data may help to improve the accuracy of hydration and/or body composition assessment. More accurate body composition assessment yields more accurate minimum wrestling weight classification. In turn, accurate minimum weight classifications create a level environment for athletic competition, as well as emphasize safety by discouraging dangerous weight loss practices. In addition, the data collected from this study may also enable the development of more specific equations that better address the body composition of the diverse population that makes Hawaii unique.

V. Risks

Bioelectrical impedance analysis is powered by one 9 volt battery and sends a safe, unfelt, and harmless impulse through the body. The disposable electrodes that are used are self-adhesive and leave no residue upon the skin. In the event of any physical injury from the research procedure, only immediate and essential medical treatment is available. You should understand that if the you are injured in the course of this research procedure that you alone may be responsible for the cost of treating your injuries.

VI. Certification

I certify that I have read and I understand the foregoing, that I have been given satisfactory answers to my inquiries concerning project procedures and other matters and that I have been advised that I am free to withdraw my assent and to discontinue participation in the projects or activity at any time without prejudice.

I herewith give my consent to participate in this project with the understanding that such consent does not waive any rights, nor does it release the principal investigator or the University of Hawaii or any employee or agent thereof from liability for negligence.

Signature of Participant: _____ Date: _____

If you cannot obtain satisfactory answers to your questions or have comments or complaints about your treatment in this study, contact: Committee on Human Studies, University of Hawaii, 2540 Maile Way, Honolulu, Hawaii 96822.

Phone: 808-956-5007

APPENDIX B

Instructions read to each participant.

Hello and welcome to the Bioelectrical Impedance study. My name is _____, and I am a graduate student at the University of Hawaii at Manoa. You will be participating in the BIA study by a graduate student at the university. If you have any questions feel free to ask. If you could please remove your right sock, shoe and any jewelry that you might have on, we would appreciate it greatly. If you would please climb up on to the table and lay down on your back, placing your arms and legs on the tape. We are now going to clean off the place where we will be putting electrodes on you. After cleaning off the spots with rubbing alcohol we are going to place the sticky electrodes on those same spots. We will then hook up the wires that run from the BIA machine to the electrodes. Once you are hooked up please do not move until you are told that you are finished. With this test you should not be able to feel anything, so if for any reason you feel anything at all please let us know. Also feel free to stop the test at any time. Once you have completed the test we will have you sit up and help you remove the electrodes.

Thank you very much for participating in this study.

Appendix C
Descriptive Characteristics of Male Subjects: Age, Height, Body Mass, Minimal Wrestling Weight via Skinfolts, and Minimal Wrestling Weight via BIA RJL, Opp, Luk & Hout

Subject	Age	Height (cm)	Body Mass (kg)	MWW Skinfolts (kg)	MWW RJL (kg)	MWW Opp (kg)	MWW Luk (kg)	MWW Hout (kg)
1	13	162.56	65.8	57.1	59.4	59.3	56.5	55.89
2	13	157.48	70.5	56.4	62.1	63.2	53.7	59.36
3	13	153.67	42.2	40.8	44.6	40.4	39.2	41.92
4	14	172.72	78.9	66.9	71.1	72.2	65.0	71.54
5	14	167.64	57.7	55.6	58.8	55.6	56.5	60.29
6	14	167.64	90.2	71.1	75.2	79.6	64.1	73.04
7	14	166.37	44.5	44.2	47.4	42.6	42.5	44.55
8	14	170.18	62.7	61.3	62.8	60.3	60.9	65.52
9	14	168.91	55.2	54.4	56.4	52.9	53.0	56.40
10	14	167.64	56.7	54.5	57.5	54.3	55.1	57.99
11	14	167.64	61.4	60.0	61.2	58.8	60.1	63.31
12	14	154.94	60.0	51.4	56.4	55.4	50.4	54.86
13	14	160.02	51.6	51.0	54.1	50.4	52.9	55.57
14	14	172.72	67.2	61.8	62.8	61.8	56.4	61.28
15	14	175.26	60.0	59.0	59.5	56.6	54.7	58.91
16	14	165.10	79.6	71.1	72.8	74.4	71.4	77.33
17	14	162.56	44.4	44.0	46.7	42.3	41.5	43.80

**APPENDIX C
CON'T**

Subject	Age	Height (cm)	Body Mass (kg)	MWW Skinfolds (kg)	MWW RJL (kg)	MWW Opp (kg)	MWW Luk (kg)	MWW Hout (kg)
18	14	160.02	57.3	55.6	57.2	54.7	53.9	58.07
19	14	173.99	59.6	58.0	59.2	56.2	53.6	58.39
20	14	170.18	115.8	87.7	91.0	100.7	79.0	90.23
21	14	157.48	41.6	41.2	44.4	39.9	38.5	41.28
22	14	170.18	61.0	58.6	61.3	58.6	60.3	63.57
23	14	173.99	95.0	77.8	77.5	82.7	65.0	73.34
24	14	158.75	55.4	52.0	53.4	51.3	47.3	50.74
25	14	168.91	61.8	59.5	60.6	58.5	58.1	61.33
26	14	168.91	70.2	57.6	61.8	62.3	50.4	56.84
27	14	175.26	67.3	63.8	64.5	62.9	60.2	64.67
28	14	162.56	93.6	67.3	74.7	80.7	60.0	69.48
29	14	156.21	60.3	50.5	55.9	55.1	48.8	53.11
30	14	176.53	80.4	68.2	72.5	73.5	66.3	72.88
31	14	170.18	61.2	58.6	61.9	59.1	60.8	64.54
32	14	170.18	80.9	68.2	69.9	72.2	60.3	67.44
33	14	161.29	62.9	55.7	58.7	57.8	52.7	56.92
34	14	173.99	62.3	60.7	61.9	59.3	59.2	63.07
35	14	176.53	64.5	62.7	62.7	60.5	58.6	62.53
36	14	176.53	91.5	71.4	78.1	81.7	68.8	77.35
37	14	161.29	85.3	56.9	69.1	73.6	54.6	63.04

**APPENDIX C
CON'T**

Subject	Age	Height (cm)	Body Mass (kg)	MWW	MWW	MWW	MWW	MWW
				Skinfolds	RJL	Opp	Luk	Hout
				(kg)	(kg)	(kg)	(kg)	(kg)
38	14	177.80	86.7	70.9	74.9	77.6	65.7	73.46
39	14	170.18	75.8	66.4	69.3	69.9	64.2	70.25
40	14	168.91	74.3	61.6	64.6	65.8	53.5	60.04
41	14	172.72	97.7	73.9	79.1	84.9	65.6	75.07
42	14	165.10	52.6	51.7	54.1	50.4	50.5	53.66
43	15	173.99	64.0	56.5	62.1	60.0	57.9	61.97
44	15	166.37	77.4	70.4	69.8	71.1	65.0	70.89
45	15	168.91	57.6	55.6	57.5	54.6	53.9	56.97
46	15	160.02	50.0	48.1	49.5	46.5	42.8	45.85
47	15	186.69	69.4	66.0	65.9	65.2	63.1	67.89
48	15	161.29	50.3	49.8	50.9	47.5	45.0	48.58
49	15	182.88	76.5	68.2	71.0	70.7	65.7	71.50
50	15	163.83	63.8	56.9	61.3	60.0	57.4	62.14
51	15	173.99	82.8	76.1	76.2	77.7	75.3	81.56
52	15	170.18	51.4	50.1	52.1	48.4	47.5	49.38
53	15	172.72	63.8	61.4	61.8	59.8	57.9	61.47
54	15	168.91	68.3	62.4	63.6	62.9	56.9	62.68
55	15	175.26	56.6	54.5	58.6	54.7	56.6	59.50

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**APPENDIX C
CON'T**

Subject	Age	Height (cm)	Body Mass (kg)	MWW Skinfolds (kg)	MWW RJL (kg)	MWW Opp (kg)	MWW Luk (kg)	MWW Hout (kg)
56	15	175.26	75.8	68.9	69.6	69.8	64.8	70.21
57	15	163.83	59.1	56.4	56.7	54.8	51.4	54.83
58	15	162.56	58.2	57.0	56.3	54.3	51.2	54.91
59	15	170.18	102.2	78.0	81.4	88.4	67.2	77.34
60	15	171.45	49.3	49.1	51.6	47.1	47.2	49.48
61	15	167.64	59.1	54.1	55.6	53.8	47.3	51.56
62	15	170.18	52.4	50.5	54.1	50.1	48.9	52.99
63	15	180.34	80.9	74.0	73.5	74.4	68.8	74.62
64	15	180.34	121.6	93.0	96.7	106.6	86.4	97.77
65	15	165.10	68.4	65.8	65.3	64.6	63.0	68.03
66	15	162.56	64.5	63.6	61.8	60.7	59.1	62.98
67	15	172.72	78.5	63.6	66.1	68.2	52.2	59.49
68	15	168.91	54.9	54.4	55.9	52.5	52.7	55.57
69	15	165.10	51.6	50.5	52.7	49.1	47.9	51.19
70	15	167.64	47.4	46.7	50.1	45.5	45.4	48.15
71	15	170.18	77.4	68.2	69.1	70.3	62.1	68.32
72	15	176.53	75.0	67.5	69.3	69.3	64.3	69.79
73	15	172.72	60.8	60.0	59.2	56.9	53.9	58.02
74	15	165.10	75.2	65.8	67.6	68.7	61.8	67.58
75	15	179.07	73.0	70.1	66.6	66.4	59.1	64.49

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**APPENDIX C
CONT**

Subject	Age	Height (cm)	Body Mass (kg)	MWW	MWW	MWW	MWW	MWW
				Skinfolds (kg)	RJL (kg)	Opp (kg)	Luk (kg)	Hout (kg)
76	15	165.10	86.2	72.4	71.8	75.7	60.2	68.40
77	15	167.64	82.7	64.1	69.3	72.5	58.2	64.97
78	15	160.02	50.5	48.9	51.3	47.9	46.6	49.60
79	15	184.15	133.3	88.6	98.9	111.8	76.8	91.17
80	15	172.72	102.7	78.4	82.0	88.9	68.8	77.99
81	15	167.64	71.0	63.6	65.0	65.0	58.8	64.16
82	15	167.64	64.1	60.2	62.2	60.5	59.2	63.17
83	15	168.91	62.0	59.0	59.3	57.5	53.2	57.64
84	16	162.56	57.1	55.6	56.6	54.2	53.6	56.61
85	16	173.99	66.5	63.5	66.3	64.2	66.3	70.34
86	16	165.10	52.3	48.6	53.4	49.8	49.4	52.32
87	16	163.83	66.2	60.4	61.9	61.3	57.6	61.62
88	16	172.72	81.0	70.5	71.4	73.2	65.1	70.79
89	16	175.26	58.6	58.5	59.5	56.1	56.1	60.03
90	16	157.48	55.0	53.1	54.2	51.8	50.5	53.25
91	16	153.67	49.4	46.4	49.2	46.4	44.2	46.83
92	16	163.83	56.0	53.6	55.3	52.7	50.6	54.00
93	16	184.15	113.1	82.3	93.0	100.5	84.9	95.18
94	16	171.45	86.4	64.6	71.9	75.5	60.0	67.19
95	16	167.64	55.5	53.9	55.2	52.2	50.0	53.55
96	16	157.48	61.7	52.7	56.7	56.1	49.4	53.60
97	16	168.91	85.8	73.5	74.0	77.1	66.4	73.60
98	16	161.29	56.3	51.8	53.8	51.9	46.8	50.74
99	16	172.72	89.7	76.5	78.9	81.7	73.4	80.96

**APPENDIX C
CON'T**

Subject	Age	Height (cm)	Body Mass (kg)	MWW	MWW	MWW	MWW	MWW
				Skinfolds	RJL	Opp	Luk	Hout
				(kg)	(kg)	(kg)	(kg)	(kg)
100	16	167.64	62.9	61.1	60.5	58.9	57.1	60.31
101	16	172.72	81.4	71.6	70.5	72.7	62.1	68.13
102	16	177.80	58.5	55.7	59.8	56.1	56.3	60.18
103	16	163.83	81.5	66.1	68.8	71.8	58.4	65.20
104	16	173.99	72.4	69.8	69.3	68.4	67.1	72.41
105	16	177.80	104.0	81.3	88.0	94.0	83.2	92.19
106	16	172.72	71.1	66.2	67.8	67.0	65.6	70.44
107	16	157.48	47.0	46.3	49.3	45.3	46.4	48.16
108	16	167.64	73.5	64.2	66.4	67.1	60.9	65.70
109	16	177.80	65.4	63.7	64.1	61.8	61.4	65.06
110	16	167.64	67.8	65.5	68.0	66.4	71.2	75.16
111	16	172.72	123.5	74.6	92.5	104.2	73.5	85.98
112	16	180.34	105.9	88.9	87.0	93.4	76.5	86.45
113	16	166.37	68.5	58.7	62.5	62.4	54.8	60.36
114	16	162.56	86.9	67.8	70.9	75.4	58.2	65.94
115	16	161.29	75.2	69.5	68.1	69.3	63.8	69.63
116	16	165.10	78.0	68.0	68.1	70.1	61.1	66.51
117	16	171.45	123.9	86.1	94.3	105.9	77.9	90.90
118	17	165.10	50.6	48.4	51.7	48.0	47.8	49.67
119	17	168.91	63.8	59.8	60.0	58.7	53.2	57.88
120	17	167.64	86.4	75.3	78.8	81.5	80.4	86.90
121	17	171.45	69.3	66.5	68.2	66.8	69.8	73.44
122	17	172.72	106.4	77.6	87.3	94.4	79.2	88.76
123	17	166.37	95.7	67.0	76.1	82.2	60.2	70.27

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**APPENDIX C
CON'T**

Subject	Age	Height (cm)	Body Mass (kg)	MWW	MWW	MWW	MWW	MWW
				Skinfolds	RJL	Opp	Luk	Hout
				(kg)	(kg)	(kg)	(kg)	(kg)
124	17	175.26	73.9	65.1	69.5	69.2	66.6	71.77
125	17	167.64	62.3	59.4	58.8	57.3	51.7	56.39
126	17	165.10	60.0	57.3	59.4	57.1	57.5	60.50
127	17	162.56	66.6	63.5	63.3	62.5	60.5	64.95
128	17	171.45	116.0	85.2	89.1	99.1	72.9	84.44
129	17	166.37	62.9	59.4	60.3	58.8	55.9	60.00
130	17	161.29	64.8	53.9	59.0	58.7	51.6	55.97
131	17	170.18	54.8	54.3	56.8	52.9	53.8	57.33
132	17	165.10	59.5	59.2	59.1	56.7	57.6	60.19
133	17	170.18	80.4	72.9	72.2	73.7	67.5	73.67
134	17	167.64	66.5	62.8	62.6	61.7	57.9	62.27
135	17	171.45	64.4	61.9	63.2	61.2	60.4	64.85
136	17	165.10	67.5	65.5	64.1	63.3	60.9	65.51
137	17	167.64	61.2	60.3	59.4	57.3	54.8	58.82
138	17	165.10	63.0	60.6	59.2	58.0	53.3	57.38
139	17	181.61	69.4	67.6	65.2	63.8	59.5	63.58
140	17	170.18	85.5	69.8	74.2	76.7	66.0	73.09
141	17	167.64	50.0	48.4	49.2	46.0	41.7	44.38
142	17	167.64	60.5	59.9	57.5	55.7	51.1	54.77
143	17	167.64	58.1	56.1	55.8	53.6	49.6	52.89
144	17	160.02	51.8	51.1	53.9	50.2	50.6	54.55
145	17	173.99	88.3	76.8	74.9	78.3	65.5	72.66
146	17	162.56	76.8	59.1	66.6	68.6	57.6	64.06
147	17	167.64	48.3	47.6	49.8	45.7	45.2	46.98

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APPENDIX C
CON'T

Subject	Age	Height (cm)	Body Mass (kg)	MWW Skinfolds (kg)	MWW RJL (kg)	MWW Opp (kg)	MWW Luk (kg)	MWW Hout (kg)
148	17	161.29	71.4	58.9	63.4	64.3	55.8	61.05
149	17	170.18	65.1	62.9	60.1	59.2	53.2	56.97
150	18	172.72	74.8	72.0	71.7	71.4	72.9	77.43
151	18	167.64	59.6	58.3	58.6	56.2	54.4	58.17
Mean	15.39	168.62	70.38	62.25	64.59	64.53	59.28	63.80
SD	1.18	6.33	17.84	10.13	10.79	14.25	9.37	11.31

Appendix D
Descriptive Characteristics of Female Subjects: Age, Height, Body Mass, Minimal Wrestling Weight via Skinfolts, and Minimal Wrestling Weight via BIA RJL, Luk, Forn & Hout

Subject	Age	Height (cm)	Body Mass (kg)	MWW	MWW	MWW	MWW	MWW
				Skinfolts	RJL	Luk	Forn	Hout
				(kg)	(kg)	(kg)	(kg)	(kg)
152	14	157.48	53.3	49.9	44.8	38.5	47.9	46.23
153	14	152.40	47.0	45.1	45.2	39.7	45.4	48.13
154	14	157.48	50.5	43.6	43.4	36.3	44.9	43.81
155	14	158.75	46.8	45.0	45.2	37.7	44.4	45.53
156	14	162.56	48.6	46.0	46.4	37.3	44.6	45.94
157	14	157.48	49.6	47.6	45.2	38.4	46.2	46.49
158	14	158.75	67.4	56.0	51.3	46.5	58.4	58.15
159	14	153.67	46.2	42.6	43.1	36.4	43.1	44.13
160	14	148.59	57.6	52.2	48.3	46.8	53.4	56.85
161	14	162.56	64.0	55.3	49.1	41.1	53.7	52.39
162	15	153.67	50.0	44.2	42.8	36.2	44.5	44.21
163	15	152.40	45.4	44.6	43.2	37.3	43.6	44.66
164	15	165.10	73.6	63.3	55.2	50.7	64.1	62.63
165	15	167.64	83.6	66.9	56.8	50.8	68.0	65.23
166	15	158.75	48.2	46.6	44.7	37.5	45.0	44.95
167	15	160.02	50.5	48.6	45.8	38.4	46.6	46.51
168	15	154.94	66.8	57.7	48.4	44.0	56.9	55.02
169	15	162.56	65.5	60.3	53.4	48.5	58.9	59.79
170	15	153.67	55.6	47.9	46.3	41.7	50.8	50.59

**APPENDIX D
CON'T**

Subject	Age	Height (cm)	Body Mass (kg)	MWW Skinfolds (kg)	MWW RJL (kg)	MWW Luk (kg)	MWW Forn (kg)	MWW Hout (kg)
171	15	162.56	78.2	58.7	55.4	51.7	66.1	64.80
172	15	160.02	51.9	47.9	47.1	41.2	49.6	48.76
173	15	152.40	54.5	48.9	48.1	37.0	47.0	45.64
174	15	151.13	49.0	45.6	42.1	35.5	43.4	43.95
175	15	165.10	92.8	70.1	61.1	59.1	75.1	75.31
176	16	160.02	55.5	53.0	50.7	45.5	52.9	55.09
177	16	162.56	58.1	50.8	49.0	42.2	52.5	51.41
178	16	161.29	61.6	55.4	51.5	46.9	56.8	56.72
179	16	148.59	46.3	41.8	42.8	37.7	43.9	45.68
180	16	160.02	50.5	47.0	46.1	39.2	47.3	46.87
181	16	166.37	76.8	63.2	58.5	55.0	67.0	68.07
182	16	157.48	54.0	50.4	46.7	41.2	50.2	49.38
183	16	156.21	65.6	54.0	49.8	46.6	58.2	56.74
184	16	152.40	56.4	48.5	44.6	37.8	47.7	48.36
185	16	157.48	74.2	58.5	53.5	50.9	63.3	63.53
186	16	152.40	56.5	50.1	44.8	39.7	49.8	48.84
187	16	157.48	59.0	51.8	46.2	40.6	51.8	49.37
188	16	154.94	46.5	41.9	41.0	33.6	40.7	40.58
189	16	154.94	72.8	57.9	52.3	50.6	62.6	62.76
190	16	156.21	57.2	53.6	47.5	42.9	52.5	51.75

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**APPENDIX D
CON'T**

Subject	Age	Height (cm)	Body Mass (kg)	MWW	MWW	MWW	MWW	MWW
				Skinfolds	RJL	Luk	Forn	Hout
				(kg)	(kg)	(kg)	(kg)	(kg)
191	16	157.48	55.3	49.2	44.9	37.7	47.7	46.76
192	16	152.40	48.8	47.3	43.6	37.7	45.2	45.83
193	16	144.78	50.7	44.7	39.9	35.1	43.8	43.21
194	17	153.67	52.5	47.2	45.9	42.0	50.1	49.68
195	17	162.56	58.5	53.1	49.6	44.1	54.5	52.56
196	17	148.59	42.6	39.5	41.1	35.6	41.1	42.55
197	17	152.40	67.5	50.7	47.9	44.1	56.8	55.52
198	17	160.02	59.8	52.7	48.1	42.4	53.6	51.40
199	17	160.02	61.9	57.4	52.3	47.7	56.7	58.50
200	17	158.75	56.4	51.4	46.3	39.4	49.7	48.53
201	17	167.64	74.6	65.2	55.1	48.9	63.6	61.30
202	17	156.21	50.4	47.6	43.1	36.0	44.5	43.81
203	17	165.10	53.6	51.4	46.8	38.1	47.6	46.45
204	17	154.94	52.4	47.9	46.2	41.3	49.4	49.37
205	17	151.13	49.9	45.5	44.4	39.8	47.2	47.80
206	17	156.21	48.2	45.5	42.3	36.1	44.1	42.32
207	17	165.10	62.1	55.5	52.0	45.6	56.4	55.64
208	17	167.64	69.9	62.0	58.4	54.0	63.5	66.21
Mean	15.67	157.59	57.94	51.34	47.81	42.18	51.83	51.62
SD	1.06	5.32	10.69	6.76	4.8	5.81	7.83	7.72

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Appendix E Descriptive Characteristics of Male Subjects: Reactance, Resistance, Body Mass Index, and Phase Angle

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SUBJECTS	RESISTANCE	REACTANCE	BODY MASS INDEX	PHASE ANGLE
1	471	59.3	24.9	7.2
2	417	56	28.4	7.6
3	531	53	17.9	5.7
4	400	48	26.5	6.8
5	425	49	20.5	6.6
6	389	42	32.1	6.2
7	582	61	16.1	6
8	402	44	21.7	6.2
9	466	53	19.3	6.5
10	446	60	20.2	7.7
11	406	59	21.8	8.3
12	422	53	25.0	7.2
13	417	55	20.2	7.5
14	468	55	22.5	6.7
15	487	51	19.5	6
16	328	48	29.2	8.3
17	569	60	16.8	6
18	407	47	22.4	6.6
19	484.9	44.8	19.7	5.3
20	329.3	46.9	40.0	8.1
21	567	52	16.8	5.2
22	415	57	21.0	7.8
23	428	57	31.4	7.6

APPENDIX E CON'T

SUBJECTS	RESISTANCE	REACTANCE	BODY MASS INDEX	PHASE ANGLE
24	480	60	22.0	7.1
25	432	62	21.7	8.2
26	512	50	24.6	5.6
27	446	55	21.9	7
28	404	48	35.4	6.8
29	451	58	24.7	7.3
30	410	48	25.8	6.7
31	407	51	21.1	7.1
32	429	50	27.9	6.6
33	442	59	24.2	7.6
34	442	54	20.6	7
35	467	58	20.7	7.1
36	398	44	29.3	6.3
37	441	51.1	32.8	6.6
38	425.3	47.1	27.4	6.3
39	392	48.3	26.2	7
40	484.1	53.3	26.0	6.3
41	412.9	48.7	32.8	6.7
42	469.1	54	19.3	6.6
43	458	56	21.1	7
44	373	52	28.0	7.9
45	467	61	20.2	7.4
46	542	60	19.5	6.3
47	478	52	19.9	6.2
48	507	52	19.3	5.9
49	443	51	22.9	6.6

APPENDIX E CON'T

SUBJECTS	RESISTANCE	REACTANCE	BODY MASS INDEX	PHASE ANGLE
50	404	49	23.8	6.9
51	343	45	27.4	7.5
52	556	70	17.7	7.2
53	456	62	21.4	7.7
54	436	46	23.9	6
55	470	57	18.4	6.9
56	416	55	24.7	7.5
57	469	62	22.0	7.5
58	458	58	22.0	7.2
59	392	48	35.3	7
60	553.8	61.9	16.8	6.4
61	538	58.4	21.0	6.2
62	506.5	45.3	18.1	5.1
63	414.5	54.8	24.9	7.5
64	335.1	46.8	37.4	8
65	370.6	47.1	25.1	8
66	392	58	24.4	8.4
67	529	54	26.3	5.8
68	475	59	19.2	7.1
69	498	54	18.9	6.2
70	542	55	16.9	5.8
71	412	52	26.7	7.2
72	424	53	24.1	7.1
73	486	55	20.4	6.5
74	389	53	27.6	7.8
75	484	57	22.8	6.7

<p style="text-align: center;">APPENDIX E CON'T</p>

SUBJECTS	RESISTANCE	REACTANCE	BODY MASS INDEX	PHASE ANGLE
76	408	48	31.6	6.7
77	446	61	29.4	7.8
78	485	57	19.7	6.7
79	412.5	46.3	39.3	6.4
80	399.6	57.5	34.4	8.2
81	422	53.3	25.2	7.2
82	414	56.1	22.8	7.7
83	473	54.2	21.7	6.5
84	435	61	21.6	8
85	389	51	22.0	7.5
86	485	58	19.2	6.8
87	415	62	24.7	8.5
88	411	61	27.2	8.4
89	470	50	19.1	6.1
90	439	64	22.2	8.3
91	482	62	20.9	7.3
92	469	58	20.9	7
93	351	45	33.3	7.3
94	453	60	29.4	7.5
95	495	56	19.7	6.5
96	457	61	24.9	7.6
97	381	51	30.1	7.6
98	499	57	21.6	6.5
99	353	46	30.1	7.4
100	439	65	22.4	8.4
101	436.3	61.5	27.3	8.4

**APPENDIX E
CON'T**

SUBJECTS	RESISTANCE	REACTANCE	BODY MASS INDEX	PHASE ANGLE
102	481.8	49.7	18.5	5.9
103	420.2	57.1	30.3	7.7
104	385.2	47	23.9	7
105	330	45	32.9	7.8
106	392	52	23.8	7.6
107	477	65	19.0	7.8
108	414	62	26.2	8.5
109	450	59	20.7	7.5
110	332	48	24.1	8.2
111	381	54	41.4	8.1
112	377	45	32.6	6.8
113	448	52	24.8	6.6
114	421	57	32.9	7.7
115	355.4	49.9	28.9	8
116	405.1	63.4	28.6	8.9
117	343.2	42.5	42.2	7.1
118	516	69	18.6	7.6
119	476	55	22.4	6.6
120	296	43	30.7	8.3
121	361	57	23.6	9
122	333	48	35.7	8.2
123	421	45	34.6	6.1
124	399	52	24.1	7.4
125	482	53	22.2	6.3
126	416	62	22.0	8.5
127	379.8	53.9	25.2	8.1

**APPENDIX E
CON'T**

SUBJECTS	RESISTANCE	REACTANCE	BODY MASS INDEX	PHASE ANGLE
128	371.9	51	39.5	7.8
129	435.6	56.8	22.7	7.4
130	459.5	61.8	24.9	7.7
131	461.2	50	18.9	6.2
132	418	65	21.8	8.8
133	375	52	27.7	7.9
134	429	58	23.7	7.7
135	418	50	21.9	6.8
136	389	53	24.8	7.8
137	450	55	21.8	7
138	458	60	23.1	7.5
139	497	65	21.0	7.5
140	390	52	29.5	7.6
141	624	66	17.8	6
142	497	63	21.5	7.2
143	514	64	20.7	7.1
144	428.3	43.4	20.2	5.8
145	417.8	57.3	29.2	7.8
146	412.7	54.1	29.1	7.5
147	565.5	68.2	17.2	6.9
148	421.8	59.4	27.4	8
149	499	67.9	22.5	7.7
150	350	53	25.1	8.6
151	452.6	55.6	21.2	7
MEAN	438.09	54.57	24.7	7.17
SD	57.68	6.22	5.5	0.81

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Appendix F
Descriptive Characteristics of Female Subjects: Resistance, Reactance, Body Mass Index, and Phase Angle

SUBJECTS	RESISTANCE	REACTANCE	BODY MASS INDEX	PHASE ANGLE
152	602	70	21.5	6.6
153	500	50	20.2	5.7
154	637	68	20.3	6.1
155	588	57	18.6	5.5
156	619	52	18.4	4.8
157	576	60	20.0	5.9
158	482.5	52.7	26.7	6.2
159	574	58	19.6	5.8
160	406	51	26.1	7.2
161	581	52	24.2	5.1
162	595	62	21.2	5.9
163	550	60	19.5	6.2
164	487	60	27.0	7
165	506	52	29.8	5.9
166	607.6	64.3	19.1	6
167	599.5	61.5	19.7	5.9
168	499.8	59.5	27.8	6.8
169	477.7	52.4	24.8	6.3
170	509.2	60.9	23.6	6.8
171	462.2	56.2	29.6	6.9
172	565	69	20.3	7
173	583	64	23.5	6.3

**APPENDIX F
CON'T**

SUBJECTS	RESISTANCE	REACTANCE	BODY MASS INDEX	PHASE ANGLE
174	574.8	55.6	21.5	5.5
175	413.1	47.4	34.1	6.5
176	485	52	21.7	6.1
177	568	62	22.0	6.2
178	495	61	23.7	7
179	510	55	21.0	6.2
180	592	65	19.7	6.3
181	444	52	27.8	6.7
182	547	66	21.8	6.9
183	479	65	26.9	7.7
184	541	46	24.3	4.9
185	435	53	29.9	6.9
186	533	61	24.3	6.5
187	573	69	23.8	6.9
188	667	67	19.4	5.7
189	425	56	30.3	7.5
190	515	64	23.4	7.1
191	603	60	22.3	5.7
192	547.1	58.1	21.0	6.1
193	551.8	62.3	24.2	6.4
194	509	68	22.2	7.6
195	551	71	22.2	7.3
196	547	60	19.3	6.3
197	479	56	29.0	6.7
198	559	68	23.4	6.9
199	466	51	24.2	6.2
200	583.7	61.3	22.4	6

**APPENDIX F
CON'T**

SUBJECTS	RESISTANCE	REACTANCE	BODY MASS INDEX	PHASE ANGLE
201	523.5	58	26.6	6.3
202	626.1	65.2	20.6	5.9
203	659	65	19.7	5.7
204	522	64	21.8	7
205	510	61	21.9	6.8
206	646	78	19.7	6.9
207	536	60	22.8	6.4
208	449.3	48.7	24.9	6.2
MEAN	538.12	59.74	23.2	6.73
SD	62.67	6.69	3.5	0.63

APPENDIX G

Example of Statistical Program Used

```
Data mww;  
STEP1 -ALL SUBJECTS ALL SEXES  
input sub sex MWW1 MWW2 MWW3 MWW4 MWW5;  
cards;  
input all cards used  
  
proc glm;  
class sex;  
model mww1-mww5 = sex/nouni;  
repeated mww 5 (1 2 3 4 5)/nom;  
run;
```

```
STEP 2 -MALES or Females ONLY  
Data mww;  
input sub sex MWW1 MWW2 MWW3 MWW4;  
cards;  
input either male or female cards used  
  
proc glm;  
model mww1-mww4 = /nouni;  
repeated mww 4(1 2 3 4)  
contrast(1)/  
nom summary;  
repeated mww 4(1 2 3 4)  
contrast(2)/  
nom summary;  
repeated mww 4(1 2 3 4)  
contrast(3)/  
nom summary;  
run;
```

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