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Comparison of air-displacement plethysmography and hydrodensitometry in high school football linemen

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**Comparison of air-displacement plethysmography and hydrodensitometry
in high school football linemen**

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Timothy Egan Moran

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Program of Study Committee:
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Abstract

Recently, there has been concern about obesity and its co-morbidities among football linemen from the youth to professional level. The purpose of this study was two-fold: 1) to examine the association between body mass index (BMI) and percentage fat determined by air-displacement plethysmography (ADP) and hydrodensitometry (HW) in high school football linemen and 2) to compare ADP with HW in high school football linemen to determine the feasibility and accuracy of ADP compared with HW in this group. Thirty-one high school football linemen were recruited from local high schools and were measured for height, body mass, and percentage fat estimated from ADP and HW. BMI (kg/m^2) was calculated from the measured height and body mass.

A majority of subjects were at-risk of being overweight (32%) or overweight (55%), and 6.5% had BMI $\geq$ 35 kg/m^2. The mean percentage fat approximated 20% for both ADP and HW measures. BMI was significantly correlated with percentage body fat for ADP (r=0.68) and HW (r=0.76). BMI was significantly correlated with fat mass (FM) and fat-free mass (FFM) for both ADP (FM r=0.83, FFM r=0.49) and HW (FM r=0.88, FFM r=0.57). When analyzed by weight status (non-overweight or overweight), HW was significantly correlated with BMI for the non-overweight group (r=0.72) and overweight group (r=0.54). FM was significantly correlated with BMI for both ADP and HW, respectively, in the non-overweight (r=0.60 and r=0.75) and overweight (r=0.64 and r=0.78) groups. Significant correlations were also noted between FFM and BMI for both ADP (r=0.68) and HW (r=0.56) but only in the overweight group. Percentage fat based upon ADP and HW were significantly correlated (r=0.68) and the mean difference between HW and ADP was -1.4%. Group analysis revealed a significant correlation in body fat percentage between ADP and

HW (r=0.78) only in the non-overweight group. BMI showed a high sensitivity (1.0) for identifying subjects with high body fat as overweight and a moderately high specificity (0.6-0.7) for identifying subjects with lower body fat as normal weight, i.e. suggesting some tendency to misclassify subjects with lower body fat as overweight.

In conclusion, although the BMI correlated reasonably well with fatness in this group and can be used as a first step in the screening process for overweight and obesity, caution should be used due to the tendency that individuals with lower body fat values may be misclassified as overweight about half the time. These two methods of body composition analysis showed that ADP tended to overestimate percentage body fat by ~1.4% compared to HW; however, there was considerable variation in the error among the sample. Furthermore, ADP showed a slightly greater tendency to overestimate body fat percentage as the body size of subjects increased. Although there are several limitations to both procedures, the advantage of ADP in this group was its greater ease of measurement and acceptability compared with HW.

Chapter 1 - Introduction

Obesity is an increasing health and medical issue in several nations of the world (1, 2, 3, 4) and especially in the United States (3). Current estimates for adults in the United States indicate that 65% are either overweight or obese (body mass index (BMI) >25 kg/m^2), with 30% of the total population being obese (BMI >30 kg/m^2) (5). The epidemic of obesity is not limited to adults as prevalence rates are also increasing drastically in children and adolescents (4, 6, 7). Currently, approximately 16% of children and adolescents in the United States are overweight (BMI >95th percentile of age-sex-specific reference values) (5). Given the current prevalence rates and the continuing trend in childhood obesity, it is apparent that obesity could become an even greater problem in the future.

Besides the general population of youth, obesity is particularly a concern among various sporting groups which emphasize large body size (e.g., high school football linemen). In a recent study, Laurson and Eisenmann (8) reported that 28% of high school varsity football linemen in the state of Iowa were at-risk of being overweight (BMI in the 85th - 95th age-specific percentile), 45% of the players were overweight (BMI $\geq$ 95th age-specific percentile), and ~10% had a BMI of 35 kg/m^2 or greater (e.g., adult class II obesity). Another recent report by Malina et al. (9) reported that 19.9% and 25.1% of 9-14 year old players were at-risk of overweight and overweight, respectively, based upon the Center for Disease Control and Prevention (CDC) age-gender-specific growth charts. These investigators also reported that 78% of the offensive and 50% of the defensive linemen were at-risk of overweight or overweight. Given these recent reports, obesity is a problem in young football linemen that may be influenced by increased pressure from coaches and parents to be "bigger" for competitive or performance reasons. However, an important

question is whether an increase in pressure to be bigger is a problem that will result in greater health problems associated with being overweight and obese. With the increase in adolescent obesity and pressure in high school football linemen to increase body size, a feasible and practical technique to assess body composition is needed. This would provide the ability to monitor body composition to ensure proper weight gain of no more than 1.5% of body weight per week as recommended by the American Academy of Pediatrics (10) and accurately assess obesity as a risk factor for health problems in this group. Guidelines may need to be established for appropriate weight gain to assist coaches and parents. The sport of wrestling has established weight loss guidelines and similar weight targets may be needed for football. Before this can be done more work is needed to develop effective measurement techniques.

Although BMI is widely used for assessing obesity, it does not provide an indication of fat-free mass (FFM) or fat mass (FM). Garn et al. (11) reported that BMI is limited for three reasons: 1) it is stature-dependent during adolescence, 2) it may be affected by body proportions such as leg length, and 3) FM and FFM are equally reflected in the BMI. These three limitations demonstrate why BMI alone is not a good indicator of body composition especially during adolescence. Therefore, direct assessment of body composition may be useful to further distinguish the obese state.

Some common techniques for assessing body composition are hydrostatic weighing (HW), skinfold thickness via calipers, bioelectrical impedance (BIA), and air-displacement plethysmography (ADP). Hydrostatic weighing was originally referred to as the "gold standard" to assess body composition (12) until the recent development of imaging techniques. Although HW is often considered the "gold standard," it has many limitations

including the cost of operation, high technical skills required of the operator, high subject compliance for accurate assessment, and the cumbersome and costly equipment needed for the procedure. Despite the limitations of HW, it is still considered by some to be a good means of assessing body composition and is used as the criterion standard by which other methods are compared (13, 14).

Among currently available techniques, ADP shows promise in a variety of different populations including children, the elderly, and individuals with spinal cord injury (12, 14-24). ADP and HW both rely upon Archimedes principle with only a slight difference in how the volume of the body is measured. While HW relies on the use of water to estimate body volume and calculate density, ADP relies on air as the medium to estimate body volume. The basis of Archimedes principle is that an object submerged in a fluid will displace a volume equal to the weight lost by the object (25). Archimedes principle works for both techniques because the type of fluid does not make a difference when estimating the volume of the object. However, the use of air instead of water makes the technique easier to perform and allows for greater compliance on the part of the subject. Several studies indicate that percentage body fat values are comparable between ADP and HW (1-2% differences) (12, 13, 26). However, ADP has not been used specifically in high school football linemen for comparison of its reliability and feasibility.

The purpose of this thesis was two-fold: 1) to examine the association between BMI and body composition determined by ADP and HW in high school football linemen, and 2) to compare ADP with HW in high school football linemen. It was hypothesized that BMI would be moderately correlated to body fat percentage using ADP and HW. It was also

hypothesized that the estimates of body fat percentage using ADP would show no significant

difference from those obtained using HW.

Chapter 2 – Review of Literature

This literature review addresses the general area of human body composition and includes a brief overview of densitometry and how it relates to the assessment of body composition. Topics that are covered include special populations that have been studied, confounding factors, including scalp and facial hair, body temperature, presence of moisture, body size, and measured versus predicted lung volumes.

Overweight in young athletes. Recently, there has been considerable attention on obesity and body composition among children and adolescents. Laurson and Eisenmann (8) examined obesity in high school football linemen. In their study, BMI was calculated for all varsity football linemen in the state of Iowa and 28% were at-risk of being overweight and 45% were overweight based upon BMI (8). Ode et al. (27) used ADP to determine body fat percentage and compared it with BMI among male college athletes and non-athletes. They calculated the sensitivity (proportion of subjects over 20% body fat identified as overweight (BMI $\geq$ 25 kg/m^2)) and specificity (proportion of subjects less than 20% body fat identified as normal weight (BMI < 25 kg/m^2)) of BMI in determining adiposity, with results indicating that BMI was very good at classifying overfat individuals as overweight and not very good at classifying normal weight individuals as normal weight (tendency to classify normal fat individuals as overweight) (27). Based upon their results, they recommended that BMI not be used to classify overweight and obesity in athletes and non-athletes due to the low agreement between BMI and percent fat (27).

What is densitometry? Densitometry is the general means of determining the density of a substance relative to a reference standard. Density is calculated by dividing the mass of an object by its volume (density=mass/volume). Archimedes principle states that the buoyant

force exerted on a submerged object is equal to the weight of the fluid displaced by the object. The weight of the fluid displaced is proportional to the volume of the displaced fluid. Densitometry, or more specifically dual-energy x-ray absorptiometry (DXA), is most commonly used to determine bone mineral density. It is also used to assess body composition and is based upon x-ray images that distinguish between fat and lean (bone plus bone-free lean) mass. Densitometry is also used in HW to determine the density of the body relative to water and provides the basis of HW. ADP uses densitometry to determine body composition based upon the body density calculated from the body mass and body volume calculated from the displacement of air.

Hydrodensitometry. Hydrodensitometry was first developed by examining the weight of cadavers in air, in water, and then directly measuring the fat and fat-free masses to calculate FM and FFM percentages. The study of body composition was developed by Jindrich Matiegka in the 1920s (28). He first proposed a four compartment model that based total gross weight on the weight of bones, skin and adipose tissue, muscles, and remaining tissues (visceral organs) (28). Later scientists employed this model when cadavers were used to create the basis of hydrodensitometry. Scientists dissected the cadavers after measuring their weight/density in water and then compared the weight of the bone, adipose tissue, skin, and muscle to the total weight. From this information, equations were created to calculate body composition for the HW procedure. Hydrodensitometry or HW has been considered the best method to assess body composition in humans since about 1940 (15). Hence, HW has been termed the "gold standard" for body composition analysis, although not everyone agrees with this label. However, as technology and new techniques emerge, we must compare the new with the old techniques.

Air-displacement plethysmography. Among the newer techniques, ADP has received considerable attention. The most common name associated with ADP is Bod Pod, which is manufactured by Life Measurement, Inc. of Concord, California (16). The Bod Pod is a two-chamber unit with a diaphragm between the chambers that is electronically controlled and produces perturbations for the pressurization of the chamber for volumetric measurement. The Bod Pod involves the subject sitting motionless in the front chamber of the unit wearing minimal clothing while breathing normally. The unit then pressurizes the chamber to measure the volume of the subject using Pascal's principle. The computer attached to the unit provides the calculations of body density and body fat from the subject's body mass and measured body volume. The advantages of ADP are that it is very user friendly, requires little subject involvement, is very readily acceptable by most subjects, and is very quick. The disadvantages of ADP are that the unit is very expensive, some subjects experience claustrophobia, body and facial hair can cause measurement error, it requires complete compliance for accurate results, and bases lung volume on estimates or requires a very difficult technique for lung volume measurement.

Since the mid-1990s ADP has gained popularity as a body composition technique because it is easily performed with minimal subject involvement (16). An advantage of ADP is that the participant does not have to exhale or hold their breath underwater and should help to lower error associated with subject involvement.

While ADP has some advantage, there are also unique types of error that influence measurements with this technique. Special considerations include scalp hair, type of swim suit, whether thoracic gas volume is either predicted or measured, presence of body moisture

or heat, and facial or body hair. The impact these factors have on ADP measurements is described below:

Scalp and facial hair. One factor that may confound the ADP measurement is scalp or facial hair. In a study by Higgins et al. (29) the presence of scalp and facial hair was shown to cause an underestimation of body fat by ~3.3% with ~1% due to facial hair and ~2.3% due to scalp hair. This effect is most likely due to the trapping of air in the hair, resulting in isothermal air, which is more compressible than adiabatic air (constantly changing temperature) and can cause variation in the pressure-volume relationship (29), which in turn results in an underestimation of body volume and hence an underestimation of body fat. The effect of scalp hair is minimized by the use of a swim cap and is included as part of the directions for performing the assessment. The effect of facial hair either can be prevented by requiring subjects to be clean shaven or can be ignored and accepted as part of the measurement error (29). In addition, other sources of hair on the body can result in a further underestimation of body fat by about 3% (29). In an attempt to standardize testing, a protocol was established to limit error that includes the use of a swim cap to cover the scalp hair and the use of a tight fitting swim suit.

Body temperature and moisture. Body temperature, moisture present on the skin, and moisture in clothing have also been shown to confound the results of ADP. A study by Fields et al. (30) showed a decrease in the body fat percentage (~1.8%), raw body volume (0.2L), and corrected body volume (0.2L) when ADP was obtained after HW compared to the values obtained before HW. They also found a significant increase in body temperature and body weight when ADP was obtained after HW compared to before HW (30). In further explaining their results, Fields et al. (30) found that the increase in body temperature and

body weight did not have an effect on the change in body fat percentage when body surface area and moisture gain were controlled. The results of their study demonstrated that water and other moisture on the skin and in the clothing during ADP measurement following HW tends to cause an underestimation of body fat percentage. It can be inferred from these results that sweat would most likely play the same role as the water from the HW in causing an underestimation of the body fat percentage. There is also a possibility that although Fields et al. (30) found no effect due to an increase in body temperature, there could be an effect of isothermal air when the body temperature change is associated with exercise and sweat due to the more compressible nature of the isothermal air than adiabatic air. Thus, exercising, especially very intense exercise, swimming, or showering would be contraindicated immediately prior to ADP testing.

Body size. Body size can possibly be a problem with ADP, in the event that the measurements are adversely affected by too large or too small body size for the machine. Wells and Fuller (31) found no significant effect of body size, as determined by body volume, on the precision of density measurement for repeated trials. There was a slight impact of body size when body density was converted to percentage body fat. These researchers suggested that body size might exert an overestimation effect of body size upon results when the subject is less than 35 kg. This was likely due to the amount of air that is needed to fill the chamber when the subject occupied less space. Buchholz et al. (16) also recommended that caution also be taken when interpreting results in subjects less than 35 kg. Collins and McCarthy (22) examined plastic containers of known volumes containing fixed amounts water ranging in size from 10-150 liters (L). They found that ADP measured volumes compared to the known volumes only showed increased variation when the known

volumes were less than 40 L. Collins and colleagues (24) also found that ADP

underestimated percentage body fat in leaner subjects and suggested that the differences may

be due to high body volume in addition to the higher muscularity in larger subjects. Ginde et

al. (32) provides a contrasting view from examining overweight and obese adults. They

found no significant differences between percentage fat from ADP and HW when 77% of

their subjects had BMIs $\geq$ 25 kg/m^2. Since there is some conflicting evidence on the effect of

body size, it is impossible to eliminate body size as a potential confounding factor to ADP.

However, most variation will likely been seen when the subject is less than 35 kg or 40 L or

when the subject is larger and possibly more muscular as suggested by Collins and

colleagues (24).

Comparison studies. Many studies have been performed comparing ADP to older techniques

such as HW, DXA, and BIA in attempts to determine the reliability, reproducibility, and

feasibility in many different popultions. More specifically, several studies have examined

the comparison of body composition techniques, including ADP and HW among youth (13,

16-18, 33, 34). Nicholson et al. (33) and Buchholz et al. (16) showed no significant

difference between ADP and DXA in white and African American children when using the

Siri equation (ranging from 0.3% overestimation to ~1.9% underestimation) (16, 33). Radley

et al. (18) also compared ADP and DXA, but showed a significant difference between the

two techniques with an average of 3% underestimation in body fat percentage by ADP.

Claros et al. (34) and Dewit et al. (13) both examined ADP and HW. Claros et al. (34)

showed a significant difference between ADP and HW in body fat percentage in 10-15 year

old children, whereas Dewit et al. (13) showed no significant difference in body fat

percentage between ADP and HW in 8-12 year old children. Lockner et al. (17) went further

than the other studies and compared ADP with HW and DXA. Lockner et al. (17) showed

similar results in body fat percentage between HW and DXA, but significant differences

between ADP and both HW and DXA. In a study by Lockner et al. (17), the use of HW as a

reference technique for ADP in children was noted to not be a good comparison because of

the error that is incorporated due to the procedural problems of total body submersion while

exhaling as much air as possible from the lungs. Other problems associated with HW include

the necessity of special equipment that can be quite large and expensive, length of time

necessary for the measurements, the high technical skill, and subject participation (18). The

best technique for comparison in children was noted to be DXA (14) due to the low level of

participation that is necessary for reliable results. Lockner et al. (17) also concluded that

DXA was a better comparison technique in children than HW, but DXA also has the problem

of exposing children to some radiation (albeit minimal) to perform the scan. DXA may also

be limited due to assumptions about hydration status that can have variable effects, which in

some studies has been shown to be as low as 0.6% (35). Dewit et al. (13) were able to show

that ADP is widely acceptable among children because it is very quick and easy. Hence, the

use of ADP could be a viable option for reliable body composition assessment in children

and other populations.

Application of air-displacement plethysmography and hydrodensitometry in special

populations. Another population that is commonly studied in comparing ADP with HW is the

elderly. The elderly are commonly studied due to the tendency of body weight to increase

with age, and as body weight increases, typically decreases are noted in fat-free mass and

increases in fat mass (15). The assessment of body composition using HW in the elderly

may be difficult to perform because of physical or health limitations, making total

submersion challenging (15). The reliable assessment of body composition is important because of the association between high body fat percentages and diseases, such as atherosclerotic cardiovascular disease, diabetes, and hypertension (12). BIA is another common technique that has been compared to ADP, but is limited particularly due to hydration assumptions necessary for reliable results (12).

Summary. Due to recent trends in adolescent and childhood obesity body composition assessment has been heavily studied in recent years. Some of that research has focused on young athletes, particularly football players. The research in football players has shown trends for offensive and defensive linemen to have prevalence rates of overweight and obesity that are higher than the general population of the same age and gender. ADP has received much interest in comparing it to more established techniques. Since ADP relies upon the calculation of body density to estimate body fat percentage it is commonly compared to HW and DXA since both also rely upon densitometry. HW was based upon cadaver dissections with measurements taken of the weight of bones, skin, adipose tissue, muscles, and remaining tissues (visceral organs). The dissection equations were used to estimate body fat percentage. ADP appears to have many advantages that make it more feasible than other techniques, but several factors must be taken into account for accurate assessment. Some of these factors that need to be considered include: scalp and facial hair, body moisture, body size, and whether thoracic gas volume (TGV) is measured or estimated based upon prediction equations. Each of these factors can influence the estimates of body fat percentage, but for the most part each factor only introduces a small amount of error (~1-3% or less). From the research comparing ADP to other techniques, contrasting results have emerged, with ADP shown to over and under-estimate compared to HW, DXA, and BIA by

1-3%. However, some studies have shown these differences to be significant and other studies have shown these differences to not be significant. Additional research is needed to better understand the strengths and limitations of ADP relative to other techniques.

Chapter 3 - Methods

<u>Subjects</u>

Football players were recruited from four local high school football teams through flyers sent to coaches. "Word of mouth" recruiting was also used as permitted and arranged through the football coaches and athletic directors at the targeted schools. All subjects were in good health and excluded if they were: 1) afraid of submersion in water, 2) afraid of small spaces or claustrophobic, and/or 3) currently suffering from a cold, upper respiratory tract infection, or other lung-associated illness/disease. These exclusion criteria were used because of the protocol involved in performing the two techniques. For their participation in the study, each subject received a $10 movie theater gift certificate. The procedures were thoroughly explained to each participant and parental consent and child assent were obtained prior to testing. The study protocol was approved by the Iowa State University Institutional Review Board.

Although 31 male high school football players participated in the study, one subject was removed from the statistical analysis due to problems with compliance during HW. The remaining 30 subjects (28 Caucasian, 1 African American, and 1 Asian) ranged in age from 15.0 to 18.5 years. Subject characteristics can be found in Table 1 (Appendix A). The subjects were enrolled in schools classified as either 2A (n=12) or 4A (n=18) in the state of Iowa where schools are classified based upon enrollment ranging from A (smallest) to 4A (largest) (classifications are either A, 1A, 2A, 3A, or 4A). The subjects were all starters at their respective levels (5 freshmen, 6 sophomore, and 19 varsity).

General Procedures

Prior to arrival for testing, the subjects were asked to follow a standard protocol which included: 1) a 12-hour overnight fast with allowance to drink water, 2) no vigorous intensity exercise within 12 hours of the assessment, and 3) wear or bring a tight fitting swimsuit or compression shorts to the laboratory. Testing procedures and possible risks of the study were explained to each subject prior to assessment and voluntary written assent was obtained prior to testing in addition to a consent form signed by a parent or legal guardian.

The subjects were measured for standing height (cm) and body mass (kg) while wearing the required clothing and swim cap. The subject proceeded through the Bod Pod testing procedure. Following the completion of the Bod Pod measurements, the subjects traveled ~1 mile between testing facilities (Jacobson Athletic Building and Barbara E. Forker Building). Upon arrival to the second testing facility, the subject entered the HW tank. Each subject progressed through the HW procedure and was permitted to dry off and change clothes. Following the HW, each subject was given the movie theater gift certificate and allowed to leave.

Measurements

Height and body mass. Height was measured to the nearest 0.1 cm using a portable stadiometer. Body mass was measured using the electronic scale provided with the Bod Pod unit (see below) with the subject wearing the designated clothing (compression shorts or other tight fitting shorts and swim cap) for body composition assessment. Two measurements of body mass were taken to the nearest 0.1 kg and the average of the values was recorded. BMI was calculated using the standard formula of weight/height^2 (kg/m^2).

Air-displacement plethysmography. ADP was performed using the Bod Pod (Life Measurement, Inc.; Concord, California). The Bod Pod is a two-chamber unit with a diaphragm between the chambers that is electronically controlled and produces perturbations for the pressurization of the chamber for volumetric measurement. Prior to testing, the system was calibrated using two 10-kg weights and a cylinder of known volume (49.896 L). Subject information was entered including age as reported to the nearest year and height. Each subject was measured while sitting motionless in the chamber as body volume was determined through oscillations of the diaphragm. Body volume was measured twice unless the two measurements were not within ~150 mL, in which case a third measurement was taken and the mean of the two closest measurements was used for calculating body density. Lung volume was estimated based upon age-specific prediction equations provided by the software produced by the manufacturer.

The lung volume equations used are as follows and rely upon the tidal volume (TV) constants of 1.2 L for men and 0.7 L for women (13). Functional residual capacity (FRC) was calculated using the men's equation of Crapo et al. (36):

Thoracic gas volume (TGV) = FRC + 0.5 TV

FRC = 0.0472 (height in cm) + 0.0090 (age) – 5.290

Body density was calculated from the following equations in the manufacturer's software (13):

Body Surface Area (BSA) (cm^2) = 71.84 (weight in $kg^{0.425}$)(height in $cm^{0.725}$)

Surface Area Artifact (SAA) (L) = k(L/cm^2)(BSA), where k is a negative constant
derived by the manufacturer

Body Volume (L) = Vol_{raw} + 0.4 TGV – SAA, Vol_{raw} is the raw body volume

measured by the system

Body Density (kg/L) = weight/body volume

SAA is a correction applied to the body volume to take into account differences in the

isothermal air next to the skin. Body composition was calculated from body density using

the Siri equation (% Fat = (495/body density) – 450) (37).

Hydrodensitometry. The HW procedure was administered in a partially in-ground

fiberglass tank (~7 m^3) with an autopsy scale and chair suspended in the water. Prior to

testing, water temperature (°C) and the chair weight in the water were recorded. The subject,

wearing the same minimal clothing as used for the ADP measurement, sat in the suspended

chair and removed any trapped air in his clothing. The subject exhaled maximally to residual

volume and submerged the remainder of his body. The subject's weight in water was

recorded to the nearest 0.1 kg from the autopsy scale. This was repeated 3 to 5 times and an

average used for calculation. Body density was calculated using the following equations:

Body Density = weight in air (kg)/[((weight in air – weight in water)/water density)-

(residual volume + 0.1)]

Residual Volume (L) = [0.019 x height (cm)] + [0.0115 x age] – 2.24 (males) (38)

Water density was based on values taken from a conversion chart showing water density at

corresponding water temperatures. Body composition was calculated using body density and

the Siri equation (% Fat = (495/body density) - 450) (37).

Statistical Analysis

Descriptive statistics were calculated for all variables. Pearson correlation

coefficients were computed among BMI, ADP, and HW (percentage fat). Pearson

correlations were also computed between BMI and FM and FFM based upon ADP and HW. BMI was correlated with the FFM and FM due to the equal weighting that both FM and FFM receive in calculating BMI (11). The mean difference in percentage fat between ADP and HW was analyzed using a paired t-test. Bland-Altman analysis was performed on percentage fat based upon ADP and HW to examine the distribution of error across a range of body sizes. The Bland-Altman analysis A sub-analysis was performed for all calculations based upon BMI classification as either overweight or non-overweight. An alpha level of 0.05 was used for significance testing. Statistical analysis was performed using SPSS version 15.0.

Chapter 4 – Results

Physical characteristics of the subjects are presented in Table 1 (Appendix A). The mean age was 16.8 ± 1.1 years (range, 15.0-18.5 years). The mean height and body mass approximated the 75th and 95th percentile, respectively, of the CDC growth charts (39). The mean BMI approximated the 95th percentile of the CDC growth charts and 87% were classified as at-risk of overweight (32%) or overweight (55%). Mean body fat percentage values for both ADP and HW were about 20%, with values ranging from 3.1% to 37.7% for ADP and 6.2% to 36.6% for HW.

The correlations between BMI and body composition are presented in Table 2 (Appendix A). The correlation between BMI and ADP percentage body fat was 0.68 and between BMI and HW percentage body fat was 0.76 ($p<0.0001$) (Figure 1 (Appendix A)). Classification agreement tables between BMI and ADP and HW are presented in Table 3 (Appendix A). When ADP was used for estimating body fat percentage, the sensitivity and specificity of BMI were 1.0 and 0.7, respectively. When HW was used for estimating body fat percentage, the sensitivity and specificity of BMI were 1.0 and 0.6, respectively. BMI was also significantly correlated to FM and FFM based upon both ADP and HW with the stronger correlations between BMI and FM. Further analysis of the weight category sub-groups was performed to determine any potential differences between the normal weight plus at-risk of being overweight subjects (non-overweight) (n=13) and the overweight subjects (n=17). In the non-overweight group, significant correlations were found between BMI and HW, ADP FM, and HW FM. In the overweight group, significant correlations were found between BMI and HW, ADP FM, ADP FFM, HW FM, and HW FFM.

The correlation between ADP and HW was 0.68 (Figure 2, Appendix A). Bland-Altman plots for the ADP and HW percentage fat measures are shown in Figure 3 (Appendix A). The mean difference between HW and ADP was -1.4%; however, the range of individual differences was -25.8 to +10.2%. The data showed no bias across the range of results. Sub-group analysis was also performed when comparing ADP and HW. Scatter plots of the two groups are presented in Figure 4 (Appendix A) with lines of identity represented by the dashed line. The correlation between ADP and HW percentage fat was significant in the non-overweight group (r=0.781, p<0.002) but not in the overweight group (r=0.214, p=0.410). Our results showed that ADP tended to overestimate percentage fat by 0.6% compared to HW in the non-overweight group, whereas in the overweight group ADP tended to overestimate percentage fat by 2.7% compared to HW.

The removal of five potential outliers from the analysis increased the correlation between ADP and HW to 0.89. This also slightly increased the correlations between BMI and ADP (r=0.71) and BMI and HW (r=0.79), and slightly lowered the correlation between BMI and FM for both ADP and HW (r=0.76 and r=0.84, respectively) but this did not affect the level of significance. In contrast, the correlations between BMI and FFM for ADP and HW (r=-0.30 and r=-0.38, respectively) were not significant. Bland-Altman plots without the potential outliers produced a mean difference between HW and ADP of -0.2%, with a range of individual differences from -7.6 to +9.1%. When examined by group, the non-overweight group (n=11) exhibited a higher correlation between ADP and HW (r=0.94) for percentage fat, whereas in the overweight group (n=14), the correlation increased (r=0.72) and was significant. The correlations between BMI and ADP and BMI and HW for both groups increased (non-overweight r=0.87 and r=0.80, respectively; overweight r=0.38 and r=0.56,

respectively), with all correlations being significant except between BMI and ADP in the overweight group. Correlations between BMI and FM and FFM based upon both ADP and HW increased in the non-overweight group (ADP r=0.86 and r=-0.71, respectively; HW r=0.80 and r=-0.68, respectively). The opposite was noted in the overweight group with both FM and FFM (ADP r=0.45 and r=0.004, respectively; HW r=0.63 and r=-0.12, respectively), with only BMI and FM from HW being significantly correlated.

Chapter 5 – Discussion

Given the recent interest in obesity and its complications in football linemen (8, 40),
issues related to the assessment of body composition in high school football linemen were
addressed in this study. More specifically, this study examined the association between BMI
and body composition determined by two densitometric techniques - ADP and HW, and the
measurement agreement between percentage body fat derived from ADP and HW in high
school football linemen.

The subjects in this study showed similar prevalence rates of overweight as those in a
recent study of Iowa high school football linemen (8). Approximately 32% of the subjects in
the current study were at-risk of being overweight, whereas Laurson and Eisenmann (8)
showed 28% were at-risk of overweight. In addition, 55% of our subjects were overweight,
with 6.5% having a BMI > 35 kg/m^2, compared to 45% and ~10%, respectively, in the
Laurson and Eisenmann study (8). Malina et al. (9) also showed similar results in younger
(9-14 years of age) football players with 78% of offensive linemen being at-risk of
overweight or overweight. Tyler et al. (41) had similar results as well with 36% of linemen
in their study at-risk of being overweight and 44% being overweight. Furthermore, the
percentage fat estimates for ADP (20.6%) and HW (19.2%) were comparable to those
reported for college football players (HW, offensive (23.5%) and defensive (19.6%) linemen)
(23). Therefore, this small sample of football linemen is probably representative of the
general population of high school football linemen.

One aspect of this study stems from concerns about the limitations of BMI as a proxy
for body fatness and obesity among "athletic" groups (28). Ode et al. (27) found BMI to
vary in its specificity and sensitivity to percentage fat among various groups of college

athletes (including football players) and non-collegiate athletes. In the present study,

significant correlations were found between BMI and body fat by both ADP and HW. In

addition, FM derived from both ADP and HW displayed moderately strong correlations with

BMI. Although the BMI is a fairly good indicator of body fatness, the correlations were not

strong enough to definitively state that a high BMI necessarily means that an individual has a

high body fat percentage, but that this is likely true. The results confirm those of Ode et al.

(27) in that sensitivity was high between BMI and percentage fat in classifying overweight,

suggesting that BMI tended to accurately classify over fat subjects as overweight (Table 3,

Appendix A). However, our results disagreed with Ode et al. (27) with respect to the

specificity of BMI. Compared to the low specificity reported by Ode et al. (27), our results

indicated moderate specificity between BMI and both ADP and HW, suggesting that BMI

tended to accurately classify normal fat subjects as not being overweight about 50% of the

time.

There were no significant differences in mean body fat percentages obtained from

ADP (20.6 ± 10%) and HW (19.2 ± 8.7%) and the correlation between the two techniques

was moderately strong (r=0.68). The Bland-Altman plot indicated a slight tendency for

overestimation of percentage fat with ADP compared to HW (1.4%). However, there was

considerable variation in the sample with ADP underestimating by as much as 25% and

overestimating by as much as 10% compared to HW. In examining both groups, a

moderately strong correlation was found between ADP and HW in the non-overweight

group, whereas a non-significant correlation between the two in the overweight group. This

suggests that although ADP and HW are moderately related and show similar results there

may be potential differences between the two techniques when larger subjects are involved

that may lead to greater overestimation of percentage fat, such as in the overweight subjects. The differences in results may have been due to some subjects experiencing difficulty with the HW procedure or due to possible error from larger subjects. These differences could also be similar to those found by Collins et al (24) in that ADP underestimated FM in leaner subjects and overestimated FM in fatter subjects, possibly due to their larger body size. In general, these results are similar to the majority of other studies comparing ADP with HW (12-14, 17, 24, 26). In particular, our results were similar to those of Dewit et al. (13) who showed slight overestimation of percentage fat by ADP in children. Several other studies (12, 17, 24, 26) found that ADP tended to underestimate percentage fat by ~1-2% compared to HW. Wagner et al. (14) found similar results that ADP tended to overestimate FM by ~2% compared to HW. Although there is some discrepancy about whether or not ADP over- or under-estimates FM compared to HW, there is some agreement that the difference is minimal. Although our results showed a tendency for ADP to overestimate percentage fat compared to HW, the results of individual subjects were quite variable.

One limitation to this study was the small sample size. Subject recruitment was difficult at the time of data collection (November-February) because many subjects were either off-season or engaged in other winter sports. Another limitation was the use of estimated rather than measured lung volumes. McCrory et al. (42) found differences of ~2% underestimation with predicted RV in HW and no significant differences between predicted and measured TGV in ADP in adults. Their results suggest that percentage fat did not differ significantly, regardless of whether predicted or measured TGVs were used for the calculations of ADP. In contrast, Claros et al. (34) found statistically significant differences between predicted and measured RV and TGV in children 10-15 years of age. Since

predicted TGV did not result in significant differences in percentage fat estimates among adults, we decided to use this prediction equation. Although it is preferable to use measured rather than predicted RV when performing HW, it is not always feasible (e.g., public school athletic training rooms, etc.). The choice of equation can also influence the results. Since our subjects were adolescents (16-18 years of age), the prediction equations used may not have been appropriate, although the equations by Crapo et al. (36) covered the range of adolescents used in this study. The TGV equations used in this study were created from data collected on subjects 15-90 years of age. Thus, since our subjects fell within this age range, there should be little concern in there use with our subjects. We chose to use predictive equations for HW as well, although it may have resulted in underestimation of fat by ~2%. Although measuring RV for HW would have been preferable to using the prediction equation, this likely added little additional error beyond what is added by body and facial hair in ADP. Lastly, the issue of using the adult or child-specific equations for converting body density to percent body fat was considered. Other studies have shown the Siri equation to be superior to the Lohman equation in converting body density in similarly aged subjects and to result in less difference between results when comparing different techniques (18). Part of the reason we chose the Siri equation over a child-specific equation was because it has been reported to be better than Lohman and because our subjects would for the most part be considered physically or biologically mature. A potential issue with the Siri equation is that it was developed at a time when the general population and subjects were much leaner, whereas it was used on mostly overweight subjects in this study. Adams et al. (43) found that the densities obtained while performing body composition assessment on professional football players were high enough that negative values were obtained for percentage fat and

suggested that the very high density measurements were due to possible increases in muscle and bone deposits caused by the heavy exercise routines of the football players compared to the general population. Skinfold measurements were used in the study to compare the HW results and indicated a larger amount of fat deposited than the body densities indicated (43). They made the suggestion that the Siri equation should be used cautiously in very large and muscular subjects due to these results. This supports the idea that caution may be needed when using the Siri equation in football linemen. Although each of these methodological limitations potentially adds more error and more possibility for variation between the two techniques, the error that is possible with any of these is similar to the potential error in ADP that can be added by facial hair (29). Facial and body hair may have introduced error, as all of the subjects had gone or were going through puberty based upon age. Since the subjects may have had facial and body hair, the results may have been affected by 2% or more. Another limitation is that there is no true criterion method. However, Lockner et al. (17) showed strong agreement among ADP, HW, and DXA in children and adolescent ages 10-18.

This study has several practical applications for health professionals (e.g., athletic trainers, strength and conditioning or athletic coaches, etc.) involved in monitoring the health of young athletes. Monitoring body composition is particularly important to ensure that an athlete gains appropriate weight (10). As previously stated, it is important to have a quick, feasible, and reliable method for assessing body fat. From the results of this study and others (23, 26), it can be suggested that ADP is an appropriate tool to assess body composition in football linemen. In fact, several universities and professional teams use the Bod Pod for assessment of athletes. Due to the high cost of purchasing a Bod Pod system, it is not

feasible for most high schools to purchase their own system unless they have funding similar to most division I colleges or universities. However, the cost of a Bod Pod system would be the same as or less than HW, depending upon the set-up. Since it is not feasible to purchase a Bod Pod system in the high school setting, the best way for a high school to utilize Bod Pod would be if the school is near a medical or fitness facility that has one available. Also, since ADP has shown such promise in children and adolescents, it can be used to help monitor body composition changes in an effort to prevent the problems associated with obesity, such as high blood pressure, diabetes, and atherosclerotic cardiovascular diseases. If these problems associated with obesity are not prevented in adolescents, they will only persist into adulthood (44).

In conclusion, BMI is best used as a first step in screening for overweight and obesity and as an indicator of whether or not further assessment of body composition is necessary. When BMI is used in football linemen, caution needs to be exercised when classifying the individuals as normal weight, at-risk of overweight, or overweight in subjects due to the lower specificity of BMI in classifying leaner subjects as normal weight. As for the use of body composition assessment, there was no significant difference in mean percentage fat between ADP and HW with a mean error of 1.4%. Based upon our results and results from other studies in adolescents of similar ages, ADP is an acceptable technique to use in high school football linemen (17). Although there are limitations, there are several advantages of ADP, including minimal assessment time and subject comfort; thus, ADP is more feasible than HW. From a practical standpoint, ADP can be a good means of estimating percent body fat and could be a good alternative to other methods for assessing body composition in other groups of athletes.

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Appendix A—Tables and Graphs

Table 1. Descriptive statistics of subjects. All variables were normally distributed. (n=30) (28 Caucasian, 1 Asian, 1 African American)

	Mean (SD)	Range
Age (yr)	16.8 (1.1)	15.0 - 18.5
Height (cm)	181.1 (5.4)	173.1 - 195.1
Body Mass (kg)	94.8 (15.7)	71.3 - 143.2
BMI (kg/m^2)	28.8 (4.1)	23.2 - 42.5
ADP % Fat (%)	20.6 (10.0)	3.1 - 37.7
HW % Fat (%)	19.2 (8.7)	6.2 - 36.3

Table 2. Pearson correlation coefficients of BMI versus ADP and HW in two BMI groups.

	Total Subjects	Non-Overweight (n=13)	Overweight (n=17)
ADP			
% Fat	0.68**	0.55	0.29
FM	0.83**	0.60*	0.64**
FFM	0.49**	-0.03	0.68**
HW			
% Fat	0.76**	0.72**	0.54*
FM	0.88**	0.75**	0.78**
FFM	0.57**	-0.04	0.56*

* Correlation is significant at 0.05 level (2-tailed)

** Correlation is significant at 0.01 level (2-tailed)

Table 3. Classification agreement tables between BMI and ADP and HW. Panel A is agreement between BMI and percentage fat from ADP with sensitivity and specificity calculations. Panel B is agreement between BMI and percentage fat from HW with sensitivity and specificity calculations. Overweight classification is based upon BMI $\geq 95^{th}$ percentile of age-sex-specific reference values. Non-overweight is based upon $< 95^{th}$ percentile of age-sex-specific references values.

A

ADP

	<25% BF	>25% BF
Non-Overweight	13	0
Overweight	6	11

Sensitivity = 1.0
Specificity = 0.7

B

HW

	<25% BF	>25% BF
Non-Overweight	13	0
Overweight	10	7

Sensitivity = 1.0
Specificity = 0.6

Figure 1. Scatter plots of percentage fat of HW and ADP compared to BMI. Panel A is HW percentage fat. The panel B is ADP percentage fat.
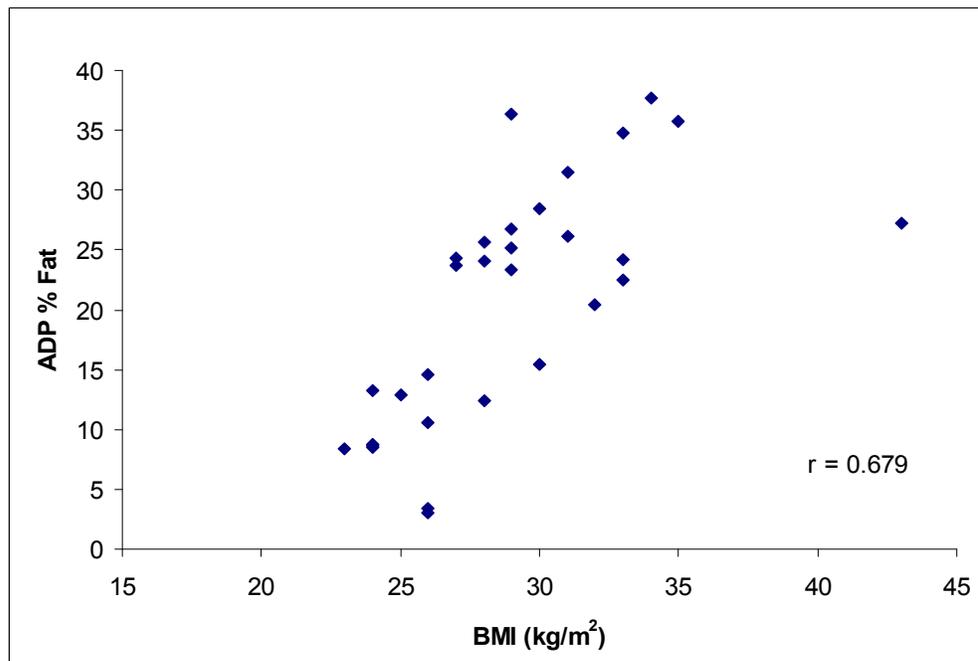
A
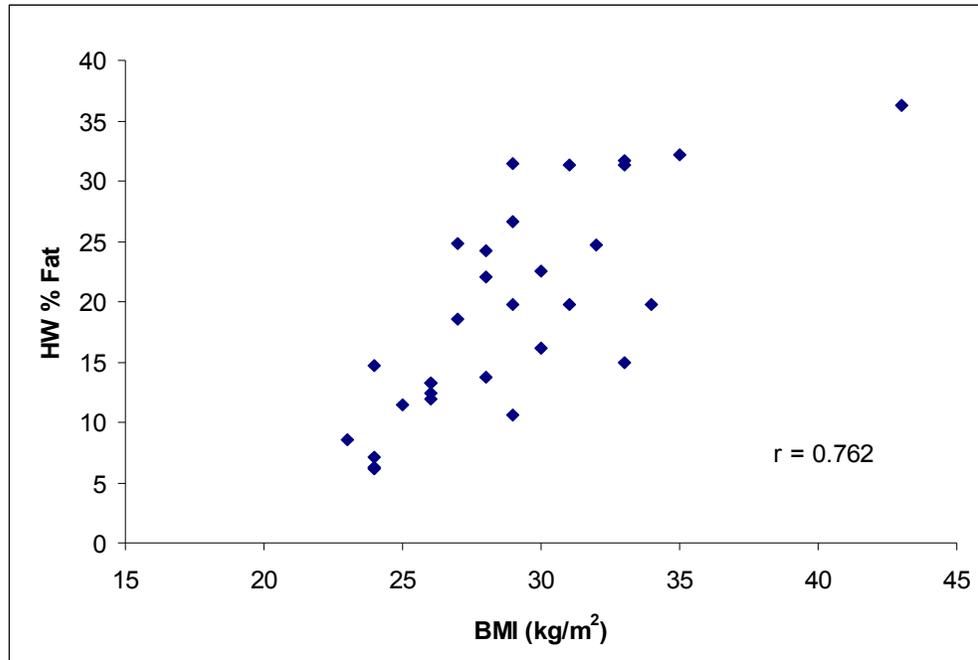
B

Figure 2. Scatter plot of percentage fat determined by ADP and HW. Line of identity is represented by the dashed line. Correlation is represented by the solid line.
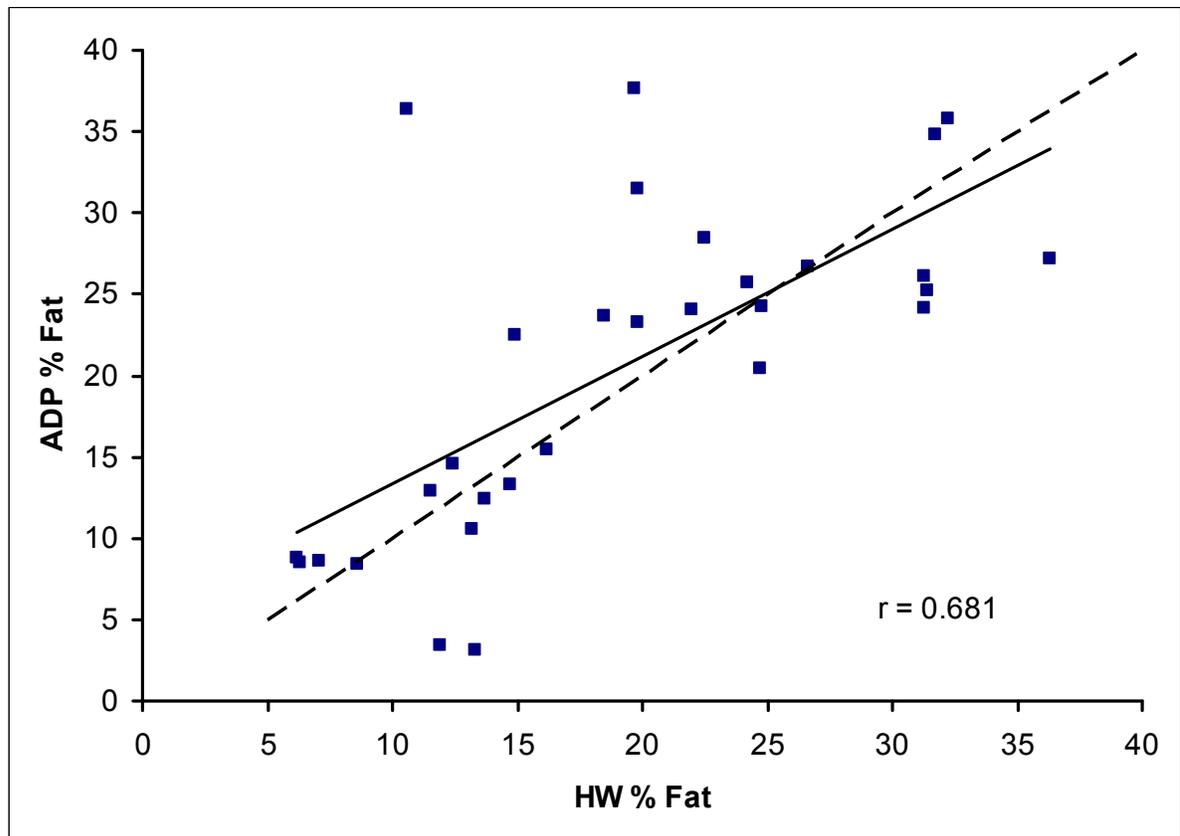
Figure 3. Bland-Altman plot of individual agreement between percent fat of HW and ADP. The squares represent the non-overweight subjects and the circles represent the overweight subjects.
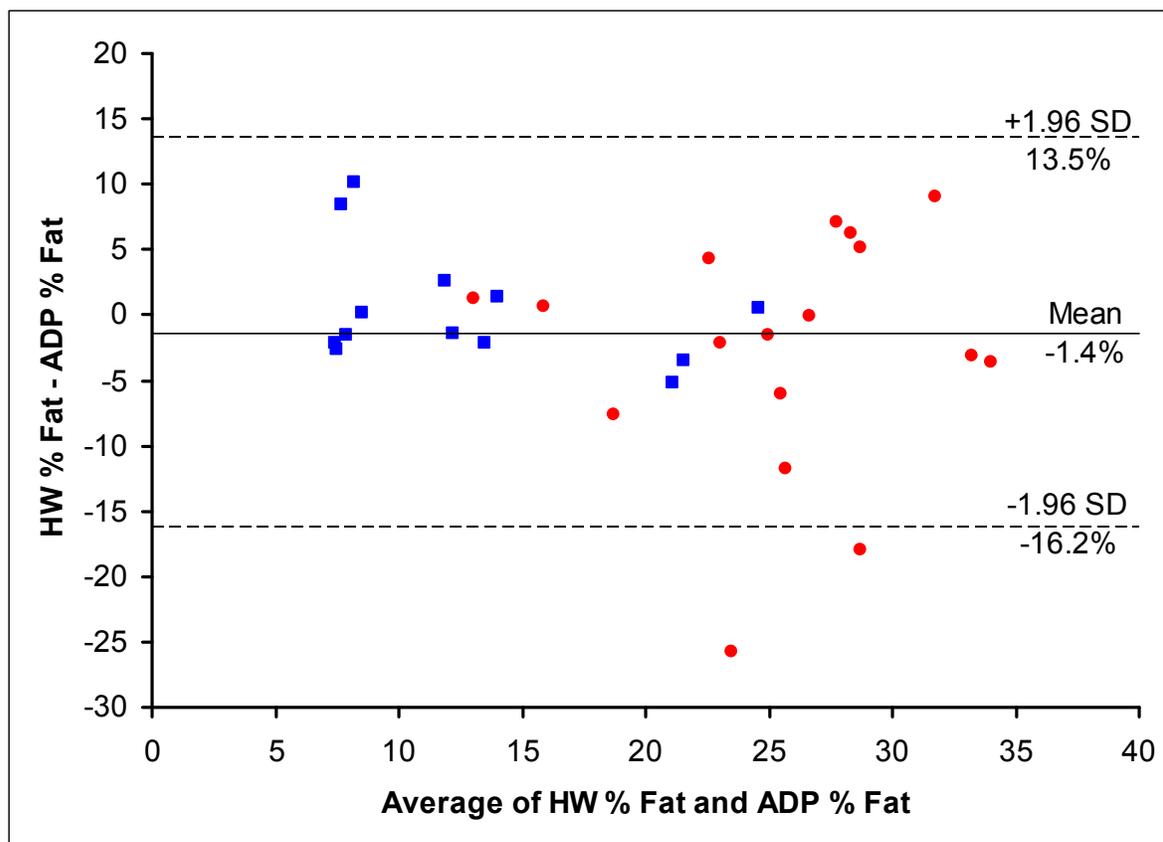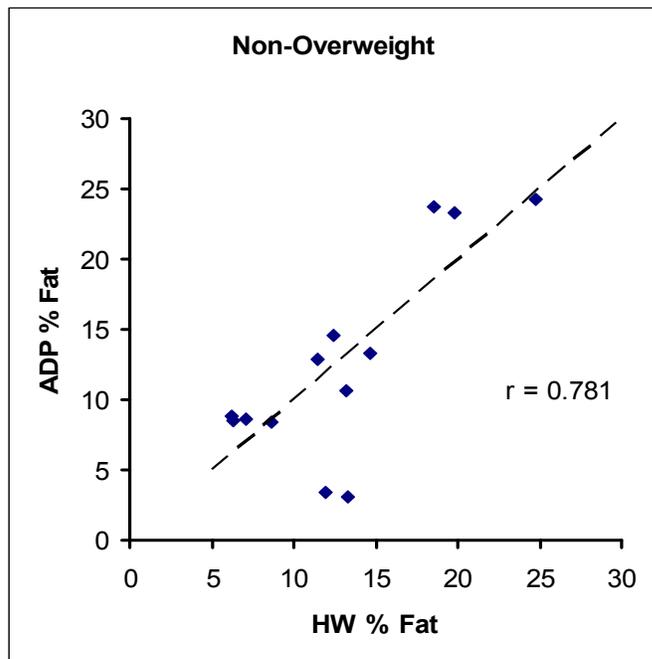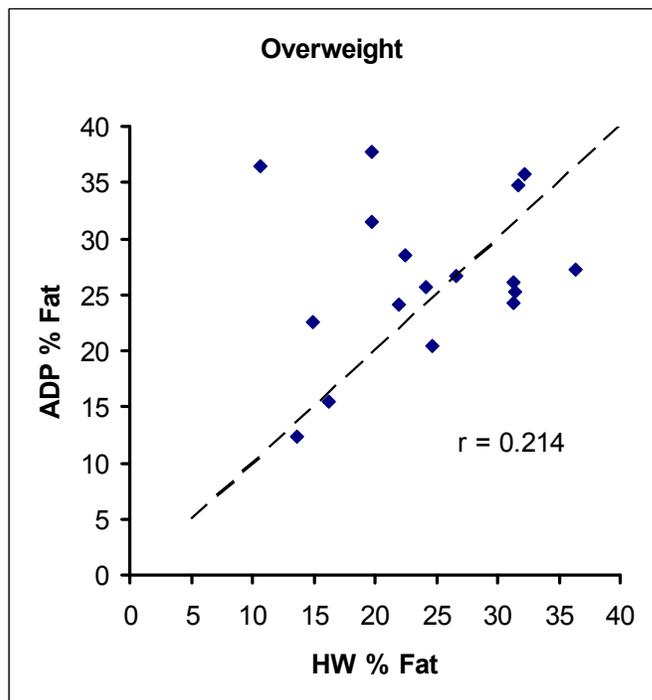
Figure 4. Scatter plots comparing HW and ADP between the two groups of comparison.
Line of identity is represented by the dashed in line each plot. Panel A is the non-overweight
group (n=13). Panel B is of the overweight group (n=17).
A

B

Appendix B—Subject Data

Individual Subject Data

Subject ID No.	Age (yr)	Race[A]	Class	Level[B]	Height (cm)	Body Mass (kg)	BMI (kg/m^2)	CDC Child Classification
001	18.5	C	4A	V	179.2	104.4	32.5	Overweight
002	16.0	C	4A	S	176.9	89.1	28.5	Overweight
003	16.2	C	4A	S	177.1	90.4	28.8	Overweight
004	16.2	C	4A	S	173.9	71.3	23.6	Healthy
005	17.8	A	4A	V	183.2	107.9	32.1	Overweight
006	15.9	B	4A	S	180.8	80.0	24.5	At-Risk
007	16.2	C	4A	S	176.9	78.4	25.1	At-Risk
008	17.2	C	4A	V	191.3	108.8	29.7	Overweight
009	18.1	C	4A	V	181.4	86.8	26.4	At-Risk
010	17.6	C	4A	V	185.5	88.9	25.8	At-Risk
011	17.7	C	4A	V	183.0	87.7	26.2	At-Risk
012	18.4	C	4A	V	179.6	84.0	26.0	At-Risk
013	15.7	C	4A	S	176.7	74.6	23.9	At-Risk
014	17.3	C	2A	V	180.1	78.5	24.2	Healthy
015	17.0	C	2A	V	184.3	76.3	22.0	Healthy
016	15.3	C	4A	F	173.1	80.1	26.7	At-Risk
017	17.5	C	2A	V	179.6	93.4	29.0	Overweight
018	17.5	C	2A	V	186.6	117.6	33.8	Overweight
019	16.6	C	2A	V	175.7	94.6	30.6	Overweight
020	18.1	C	4A	V	183.5	143.2	42.5	Overweight
021	15.5	C	2A	F	184.8	99.1	29.0	Overweight
022	15.4	C	4A	F	185.0	91.1	26.6	At-Risk
023	16.6	C	2A	V	176.3	96.9	31.2	Overweight
024	17.5	C	2A	V	195.1	88.4	23.2	Healthy
025	15.3	C	4A	F	179.9	106.7	33.0	Overweight
026	16.9	C	2A	V	185.8	119.7	34.7	Overweight
027	15.8	C	2A	F	176.5	94.5	30.3	Overweight
028	15.0	C	2A	F	184.0	94.0	27.8	Overweight
029	18.4	C	4A	V	176.3	88.7	28.5	At-Risk
030	17.5	C	2A	V	191.2	120.1	32.9	Overweight
031	16.4	C	2A	V	175.4	85.8	27.9	Overweight

[A]C=Caucasian; B=African American; A=Asian

[B]F=Freshmen; S=Sophomore; V=Varsity

Subject ID No.	Percent Body Fat		Fat Mass (kg)		Fat-Free Mass (kg)	
	(ADP)	(HW)	(ADP)	(HW)	(ADP)	(HW)
001	22.5	14.9	23.5	15.6	80.9	88.8
002	24.1	22.0	21.5	19.6	67.6	69.5
003	25.2	31.4	22.8	28.4	67.6	62.0
004	13.3	14.7	9.5	10.5	61.9	60.8
005	20.4	24.7	22.0	26.7	85.9	81.3
006	8.6	7.1	6.9	5.7	73.1	74.3
007	12.9	11.5	10.1	9.0	68.3	69.4
008	15.5	16.2	16.9	17.6	91.9	91.2
009	10.6	13.2	9.2	11.5	77.6	75.3
010	3.1	13.3	2.8	11.8	86.1	77.1
011	3.4	11.9	3.0	10.4	84.7	77.3
012	14.6	12.4	12.3	10.4	71.7	73.6
013	8.5	6.3	6.3	4.7	68.3	69.9
014	8.8	6.2	6.9	4.9	71.6	73.6
015	15.2	2.5	11.6	1.9	64.7	74.4
016	23.7	18.5	19.0	14.8	61.1	65.3
017	36.4	10.6	34.0	9.9	59.4	83.5
018	37.7	19.7	44.3	23.2	73.3	94.4
019	31.5	19.8	29.8	18.7	64.8	75.9
020	27.2	36.3	39.0	52.0	104.3	91.2
021	26.7	26.6	26.5	26.4	72.6	72.7
022	24.3	24.8	22.1	22.6	69.0	68.5
023	26.1	31.3	25.3	30.3	71.6	66.6
024	8.4	8.6	7.4	7.6	81.0	80.8
025	34.8	31.7	37.1	33.8	69.6	72.9
026	35.8	32.2	42.9	38.5	76.9	81.2
027	28.5	22.5	26.9	21.3	67.6	73.2
028	25.7	24.2	24.2	22.8	69.8	71.3
029	23.3	19.8	20.7	17.6	68.0	71.1
030	24.2	31.3	29.1	37.6	91.0	82.5
031	12.4	13.7	10.6	11.8	75.2	74.1

Individual Subject Data (continued)