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Comparison Of Air Displacement Plethysmography And Dual-Energy X-Ray Absorptiometry For Estimation Of Body Fat Percentage In National Collegiate Athletic Association Division I Athletes

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COMPARISON OF AIR DISPLACEMENT PLETHYSMOGRAPHY AND DUAL-ENERGY X-RAY ABSORPTIOMETRY FOR ESTIMATION OF BODY FAT PERCENTAGE IN NATIONAL COLLEGIATE ATHLETIC ASSOCIATION DIVISION I ATHLETES

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ABSTRACT

Body composition, or the proportion of fat, muscle, and bone of an individual's body, is an important indication of health status. Numerous techniques can be used to assess body composition, producing varied results and measurements. For individuals with insufficient or excessive amounts of body fat, accurate assessment of body composition is crucial. Two commonly used techniques for measuring body composition are air displacement plethysmography (ADP) and dual-energy x-ray absorptiometry (DXA). Past research has been conducted, comparing ADP and DXA, but the results are inconsistent. The majority of past studies found that, when compared to DXA, ADP underestimated body fat percentage, but a few studies found that ADP overestimated body fat percentage. Additionally, majority of the past studies have focused on ideal weight, overweight, and obese adults, with little research on body composition of athletes. Therefore, the purpose of this study was to determine whether body fat percentages obtained by ADP and DXA statistically differ from one another, specifically in a lean population. Ninety-three collegiate student athletes participating in Division I NCAA sports participated in the study. Subjects underwent a Bod Pod and DXA scan, measuring their body composition. Body fat measures were then analyzed using SPSS. Paired-sample t-tests were conducted, comparing body fat percentage estimates from ADP and DXA. Box plots and Bland-Altman plots were also created to display data. Results showed that body fat percentages obtained by the ADP were significantly lower than body fat percentages obtained by DXA, with the difference being greater in leaner individuals. These results are consistent with the majority of past research, which states that ADP underestimates body fat percentage when compared to

DXA. Clinicians should consider this discrepancy between ADP and DXA for deciding which equipment to use when making clinical decions regarding student athletes' health or participation status.

LIST OF ABBREVIATIONS

4C	Four-Compartment
ADP	Air Displacement Plethysmography
BF	Body Fat
BF %	Body Fat Percentage
BIA	Bioelectrical Impedance Analysis
DXA	Dual-Energy X-ray Absorptiometry
HW	Hydrostatic Weighing
NCAA	National Collegiate Athletic Association
SPSS	Statistical Package for the Social Sciences

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CHAPTER ONE

INTRODUCTION

Body composition, defined as the proportion of fat, muscle, and bone of an individual's body, is an important indication of health status (Heden, 2008). Various techniques can be used to assess body composition. Among those techniques are dual-energy x-ray absorptiometry (DXA), air displacement plethysmography (ADP), hydrostatic weighing (HW), bioelectrical impedance analysis (BIA), skinfold thickness, magnetic resonance imaging (MRI), isotope dilution, and doubly labeled water. These techniques produce varied estimates of body fat percentage, which could lead to the underestimation or overestimation of body fat and inappropriate treatment to follow (Reinert, 2012).

For the portion of the population that is generally healthy, accurate estimation of body composition may not be crucial. However, for those individuals that are at either extreme of the spectrum, accurate assessment of body fat percentage is critical. The body requires a minimal amount of fat in order for normal physiological function to occur (Brierley, 2016). This amount of recommended body fat varies based on gender. According to the American College of Sports Medicine, at minimum, males require 2-5% of body fat, and females need 10-13% of body fat. If an individual's amount of body fat drops below these ranges, physical performance can decline and severe health complications can occur. Numerous body systems may be affected, including the cardiovascular, endocrine, reproductive, skeletal, gastrointestinal, renal, and central nervous systems. Complications within these systems may lead to the development of conditions such as heart damage, gastrointestinal problems, shrinkage of internal organs, immune system abnormalities, reduced fertility, loss of muscle tissue, damage to the nervous system, abnormal growths, and ultimately death (Brierley, 2016).

Contrastingly, having too much body fat can also create serious health concerns (Brierley, 2016). Excessive body fat can negatively affect multiple body systems and increase one's risk of health issues, including high blood pressure, high cholesterol, myocardial infarction, cardiovascular disease, diabetes, sleep apnea, gallstones, osteoarthritis, and certain cancers (Brierley, 2016). Increased risk of cardiometabolic diseases and mortality are highly correlated with body fat percentage, independent of body mass index (Kim, 2013; Lee, 2016). Due to implications that body fat percentage can have on an individual's health status, accurate measurement of body fat is imperative. With multiple devices and equipment available for estimation of body fat percentage, knowing which method can provide the most reliable assessment is important.

CHAPTER TWO

LITERATURE REVIEW

Hydrostatic Weighing

Hydrostatic, or underwater, weighing was considered the gold standard for assessment of body composition for years (Dempster, 1995; McCrory, 1995). Hydrostatic weighing, however, requires maximum exhalation and complete submersion in water. This may be uncomfortable for individuals, especially if they are unable to swim or uncomfortable in water. Additionally, underwater weighing requires a qualified administrator, relies on estimation of residual lung volume, is expensive, and is not portable. For these reasons, other reliable methods of measuring body composition have been researched, developed, and incorporated.

Bioelectrical Impedance Analysis

Bioelectrical impedance analysis (BIA) uses the passage of electrical current throughout the body to measure resistance and reactance of tissues to the current. Bioelectrical impedance is based on the principle that various body tissues react to and resist electrical currents differently. Lean tissue is largely composed of water and electrolytes; therefore, it is a good conductor to electrical current. Contrastingly, fat, skin, and bone have low conductivity and resist electrical current. After resistance and reactance are calculated, the values are put into a predictive equation, along with values for height, race, and gender, to estimate body composition (Mialich, 2014). Bioelectrical impedance analysis is simple, quick, non-invasive, portable, inexpensive, and can be used across a wide range of subjects, with regard to age and body shape. However, BIA has limitations (Valliant & Tidwell, 2007). Previous studies have found that bioelectrical impedance is not an accurate technique for measuring body fat in certain populations, including obese women (Heyward, 1992), overweight women (Varady, 2007), women with primarily abdominal body fat patterning (Swan, 1999), African American women (Gartner, 2004), Japanese women (Miyatake, 2005), collegiate wresters (Dixon, 2005), elderly subjects (Bertoli, 2008), and patients with end-stage renal disease (Flakoll, 2004). Various studies found that BIA tends to overestimate body fat percentage in athletes, lean adults, and lean children, by as much as 12% (Fors, 2002; Okasora, 1999; Segal, 1988). Contrastingly, BIA may underestimate body fat percentage as much as 8% in obese adults (Deurenburg, 1996; Gray, 1989; Newton, 2006; Sun, 2005; Verdich, 2011; Volgyi, 2008), and overweight and obese children (Azcona, 2006; Eisenkolbl, 2001; Ellis, 1996; Lazzer, 2003; Lazzer, 2008; Newton, 2005; Okasora, 1999). The accuracy of bioelectrical impedance can be altered by intense physical activity and consumption of fluid, alcohol, or food before testing, dehydration or water retention, protein malnutrition, diuretics, acute body mass changes, and the menstrual cycle (Heymsfield, 2005; Kushner, 1996).

Air Displacement Plethysmography

Air displacement plethysmography (ADP) uses whole body densitometry to measure body composition. An individual is placed inside of a chamber, and the volume of air displaced by the individual is measured. Using the individual's mass and the volume of air he or she displaced, the individual's body density is calculated. Once overall body density is determined, proportions of body fat and lean mass are calculated.

Air displacement plethysmography is a quick, noninvasive measure that can be used in young children. Some studies have found ADP to be accurate in healthy adults (Demerath, 2002; Fields, 2002) and elderly subjects (Aleman-Mateo, 2007). However, variation has also been identified. Air displacement plethysmography has been shown to underestimate body fat by 2-3% (Ackland, 2012). When compared to hydrostatic weighing, some past studies have found that ADP underestimates body fat percentage (Collins, 1999; Dewit, 2000; Iwaoka,1998; Millard-Stafford, 2001; Wagner, 2000; Wells, 2000). Other studies found that body fat percentage was higher with ADP than with hydrostatic weighing (Fields, 2000; Millard-Stafford, 2001; Wagner, 2000). One study found that, when compared to underwater weighing, ADP overestimated body fat percentage by 8% in female athletes and 16% for a leaner subset of the sample (Vescovi, 2002). Researchers have found that in comparison to HW, ADP underestimated body fat percentage in males and overestimated fat percentage in females (Biaggi, 1999; Levenhagen, 1999). This suggests a significant sex effect when comparing hydrostatic weighing to air displacement plethysmography for measuring body fat percentage.

When using ADP, accurate measurement of fat free mass is sensitive to variability in hydration status and excess fat (Waki, 1991; Wells, 1999). The accuracy of air displacement plethysmography can also be altered by excessive fluid retention (Higgins, 2001; Wells, 2006). Fluid retention decreases the density of lean mass, which leads to overestimation of body fat percentage (Wells, 2006). Presence of hair, excess heat, and moisture are additional confounding variables associated with ADP. Body fat percentage was underestimated by 1% with presence of facial hair and by an average of 2.3% with scalp hair (Higgins, 2001). Presence of excess heat and moisture within the chamber causes an underestimation of body fat percentage (Fields, 2004). Therefore, in order to achieve optimal results, facial hair should be kept to a minimum, a swim cap should always be worn, and assessment should always precede exercise.

Dual-Energy X-Ray Absorptiometry

Dual-energy x-ray absorptiometry (DXA) is used to measure bone mineral density and for the past two decades, has been the primary method used to diagnose osteoporosis. Additionally, the use of DXA for quantification of soft tissue has increased. During a DXA scan, filtered x-ray beams are passed throughout the body. Detectors within the scanner then measure the amount of radiation absorbed throughout differing tissues to determine body composition, including bone mineral density, muscle mass, and fat mass.

Dual-energy x-ray absorptiometry is quick, noninvasive, minimally affected by hydration status, and can be used in young children (Ackland, 2012). DXA has been validated against the four-compartment model (Silva, 2006; Tylavsky, 2002), underwater weighing (Tataranni, 1995), and direct chemical analysis (Mitchell, 1996; Svendsen, 1993). Numerous studies have found DXA to be a valid measure to determine body composition (Bilsborough, 2014; Chen, 2007; Ellis, 2000; Kistorp, 1997; Lohman, 1996; Mazess, 1990; Svendsen, 1993; Tataranni, 1995; Visser, 1999; Wang, 1999). If standardized protocols are followed, DXA has been determined to have the lowest standard error of estimate (Ackland, 2012). For this reason, DXA is currently considered the gold standard (Guglielmi, 2016). The equipment, however, does have limitations. DXA scans are expensive, may be difficult to access, and provide exposure to radiation

(Ackland, 2012). Bias varies with age, amount of fat, and underlying disease state of the individual being tested (Williams, 2006). DXA assumes segment constancy in tissue composition. This is an issue because water and fat content of tissues exhibit regional variation. DXA is also limited in the ability to detect small composition changes over time. One study found that DXA has a margin of error when measuring small changes in body composition amongst elite male athletes (Santos, 2010). Another limitation of DXA is that systematic variations between manufacturers, devices, and software versions have been reported (Roche, 1996; Schoeller, 2005; Tothill, 2001). Additionally, the equipment has a weight limitation. Previously, the weight limit for the DXA scanner was 300 pounds, and the width of the scanning area was 60 centimeters. Recently, the intelligent DXA (iDXA) was introduced, with a weight limit of 400 pounds and scanning area that is 66 centimeters wide. Though this development increased the limits, there remains a size limit. If an individual's body dimensions exceed the weight limit or the width of the scanning area, the accuracy is compromised. An option to overcome this weight barrier is measuring two half-body scans, rather than one total-body scan. This alternative method to measuring larger patients can accurately estimate whole-body body fat percentage (Rothney, 2009; Tataranni, 1995).

Air Displacement Plethysmography Versus Dual Energy X-Ray Absorptiometry

Currently, ADP and DXA are two commonly used techniques for measuring body composition within the collegiate setting. In these settings, the nutrition, exercise science, and kinesiology departments use DXA and the BOD POD to assess body composition (Heden, 2008).

The majority of studies investigating the accuracy of air displacement plethysmography for measuring body composition have compared ADP to hydrostatic weighing. Studies had been conducted, comparing ADP to DXA for measurement of body composition; however, research is limited, and results are varied. Previous studies have found that ADP underestimates body fat percentage when compared to DXA (Ball, 2004; Collins, 1999; Heden, 2008; Lazzer, 2008; Levenhagen, 1999; Nicholson, 2001; Sardinha, 1998; Weyers, 2002). The subjects of these studies included middle aged men, football players, children, obese Caucasian children, healthy adults, and overweight adults. Ball (2004) found a significant average difference (2.2%) in percent body fat between ADP and DXA amongst a large sample of male football players. The divergence increased as body fatness increased (Ball, 2004). One study compared body composition estimated by DXA and ADP in normal weight (BMI 17.8-24.9 kg/m2), overweight (BMI 25-29.8 kg/m2), obese (BMI 30.3-39.2 kg/m2), and extremely obese (BMI 41.1-51.5 kg/m2) adults. The researchers found that when compared to DXA, ADP estimated lower body fat percentage in normal and overweight individuals; contrastingly, ADP estimated greater fat percentage in obese and extremely obese individuals (Hames, 2014). Another study compared DXA and ADP in underweight, normal, and overweight/obese adults, ranging age 21 to 84. These researchers found that, when compared to DXA, air displacement plethysmography overestimated body fat percentage in thinner adults (up to 13.2%) and underestimated body fat percentage in heavier adults (up to -8.51%). The divergence was greater at lower body fat percentages (Lowry, 2015). A sex effect has also been identified, with a trend towards the underestimation of body fat percentage in females by ADP, when compared to DXA (Buchholz, 2004; Lazzer, 2008; Nicholson, 2001). One study, with a substantial sample size (n=721), found that, when compared to DXA, ADP estimated lower body fat percentage in females and higher fat percentage in males (Koda, 2000).

Research has also been conducted comparing ADP and DXA indirectly through comparison to a four-compartment (4C) model. An earlier study found that DXA underestimated body fat percentage in lean individuals, when compared to a 4C model (Gately, 2003). In a study of Indian adults, when compared to a 4C method, DXA had the lowest bias, with slight overestimation of body fat. ADP, however, underestimated body fat percentage compared to the 4C model (Kuriyan, 2014). Previous studies had similar findings, showing that ADP underestimated body fat percentage by up to 2-3% (Fields, 2001; Millard-Stafford, 2001).

CONCLUSION

Though past research has compared air displacement plethysmography and dual-energy x-ray absorptiometry, the results are inconsistent. Additionally, the majority of previous studies have focused on normal, overweight, and obese adults. Very little research has been done on accurate measurement of body composition on the other end of the spectrum, lean adults. Due to discrepancies identified in the literature and previously collected data, the purpose of this study is to identify the correlation between estimates of body fat percentage measured by ADP and DXA in lean collegiate athletes.

CHAPTER THREE

METHODS

Participants recruited were collegiate student athletes, ages 18-24, attending the University of Mississippi. A total of ninety-three collegiate student athletes participating in Division I National Collegiate Athletic Association sports participated in the study. Of the ninety-three student athletes that participated, twenty-five were male and sixty-eight were female. Participants reviewed and signed an informed consent (see Appendix A) prior to participation in the study. The University of Mississippi Institutional Review Board approved all procedures.

The data used for this study was a combination of previously collected data and data collected during the 2018 spring semester. At the University of Mississippi, student athletes' body composition is assessed as part of routine screening. All student athletes have their body composition measured annually by the Bod Pod, an air displacement plethysmograph. For athletes whose Bod Pod results are in the risky category (<5% for males and or <15% for females), it is often warranted for the athlete to have a DXA scan completed to more accurately analyze body fat percentage and also bone mineral density. Previously obtained concurrent ADP and DXA scan results were used for this study.

Additionally, data was collected during the 2018 spring semester for the purpose of this study. The researchers reviewed the routinely measured Bod Pod results obtained over the past year. Athletes in the moderately lean (males 12.1-20%; females 22.1-30%), lean (males 8.1-12%;

females 18.1-22%), ultra lean (males 5-8%; females 15-18%), or risky category (<5% for males and or <15% for females) were approached by the researchers and recruited for the study. Athletes were asked to complete an ADP and DXA scan.

Bod Pod

Participants reported to the Nutrition and Hospitality Management nutrition clinic after being instructed to fast for a period of 6 hours and refrain from physical activity for at least 2 hours prior to testing. To minimize potential error due to isothermal air trapped in clothing and hair, all participants wore tight-fitting athletic gear and an acrylic swim cap. Participants were asked to remove all metal objects, including jewelry. The BOD POD Body Composition System (Life Measurement Instruments/COSMED, Concord, CA) was used. The standard recommended Bod Pod protocols were followed. The equipment was calibrated prior to testing. After completing the calibration, subjects were weighed using the Bod Pod's electronic scale, and then entered the Bod Pod. Body fat percentage was obtained from the Bod Pod using the selected equation, based on subjects' age and ethnicity. Participants were given a hand out (see Appendix B) of their Bod Pod results, which contained percent fat (%), percent fat free mass (%), fat mass (kg), fat free mass (kg), body mass (kg), body volume (L), body density (kg/L), thoracic gas volume (L), body fat rating, resting metabolic rate estimated total energy expenditure, and daily activity level. A registered dietitian reviewed the results with the participants.

DXA

Participants reported to the Health, Exercise Science, and Recreation Management bone mineral density laboratory. All female participants completed a pregnancy test prior to testing. Subjects were instructed to remove all metal objects, including clothing containing metal. Participants were asked to remove outer clothing and change into shorts and a t-shirt or hospital gown. Height and weight were measured. Subjects were then instructed to lay supine and motionless during the scan. A whole-body scan was conducted on a Dual-Energy X-ray Absorptiometry (DXA) scanner (Hologic, Madison, WI). The scanner was calibrated prior to testing. All standard protocols were followed. Participants were given a hand out (see Appendix C) of their results, which included bone mineral count (g), fat (g), lean (g), lean + bone mineral count (g), total mass (g), percent fat, area (cm2), and bone mineral density (g/cm^2). A trained professional reviewed the results with the participants.

Statistical Analysis

Paired-sample t-tests were conducted, comparing estimates of body fat percentage from ADP and DXA. Following the recommendations of Bland and Altman for assessing agreement between two diagnostic measures, a Bland-Altman plot was also constructed (Bland & Altman, 1986). To do so, the average difference between the ADP and DXA measures were calculated, as well as the standard deviation of the difference. IBM SPSS was used to analyze data with significance set at α=.05.

CHAPTER FOUR

RESULTS

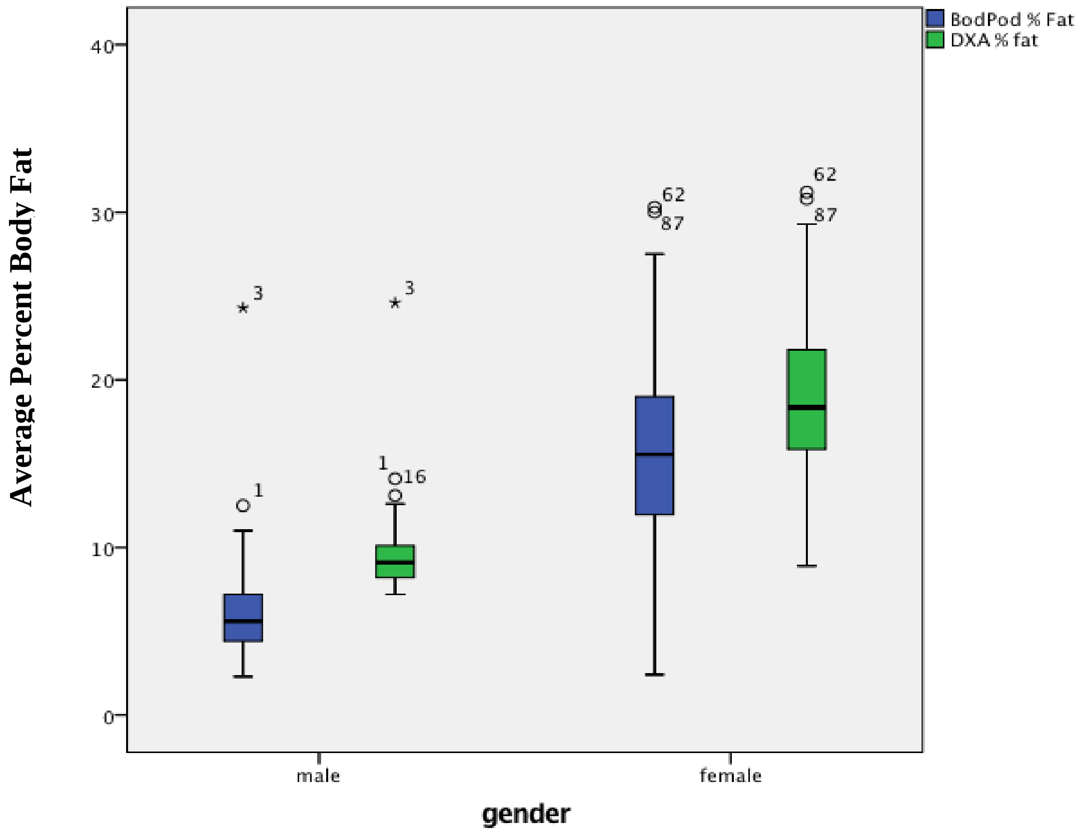
A total of ninety-three NCAA student athletes completed concurrent ADP and DXA scans, which estimated their percentage of body fat. Table 4.1 displays the averages of the participant characteristics. Body fat percentages of all participants (n=93) measured by ADP ranged from 2.30 to 30.30 (M=13.13, SD=6.91), and body fat percentages measured by DXA ranged from 7.20 to 31.20 (M=16.72, SD=6.00). Body fat percentages of males (n=25) measured by ADP ranged from 2.3 to 24.30 (M=6.75, SD=4.60), and body fat percentages measured by DXA ranged from 7.20 to 24.60 (M=10.19, SD=3.52). Body fat percentages of females (n=68) measured by ADP ranged from 2.40 to 30.30 (M=15.47, SD=6.10), and body fat percentages measured by DXA ranged from 8.90 to 31.20 (M=19.12, SD=4.82).

Table 4.1 Participant characteristics (mean ± SD).

	All participants (n=93)	Males (n=25)	Females (n=68)
Height (in)	66.77 ± 2.89	69.96 ± 2.07	65.6 ± 2.17
Weight (lb)	141.09 ± 22.39	155.19 ± 22.73	135.91 ± 20.05
BMI	22.15 ± 2.82	22.28 ± 2.84	22.1 ± 2.83
ADP BF %	13.13 ± 6.91	6.75 ± 4.60	15.47 ± 6.10
DXA BF%	16.72 ± 6.00	10.19 ± 3.52	19.11 ± 4.82

Box plots were created to create a visual representation of the spread of the data collected. As shown in table 4.2, the average body fat percentage measured by ADP was lower than the average fat percentage measured by DXA, for both males and females.

Figure 4.2 Box plots of male & female body fat percentages measured by ADP and DXA.



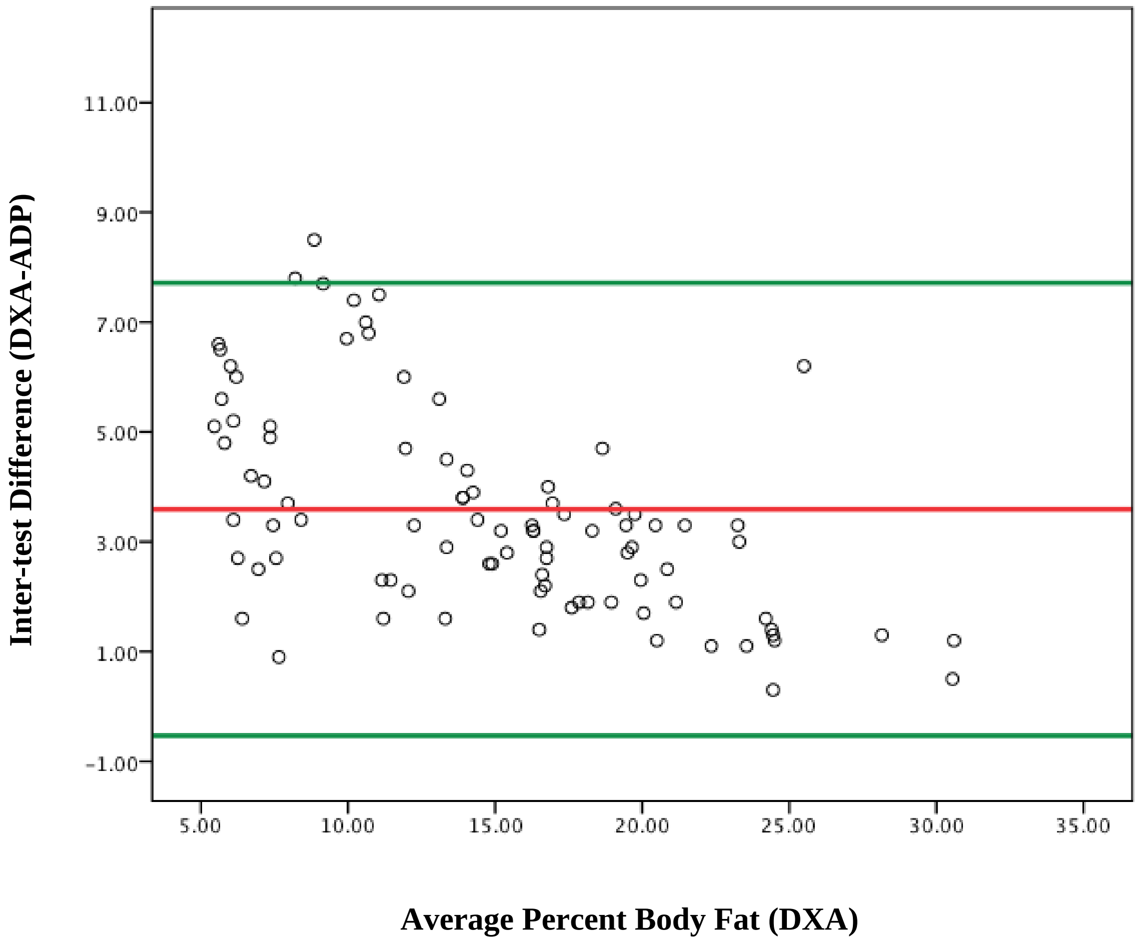
A paired sample t-test was performed to compare body fat percentages of all participants as measured by ADP and body fat percentages as measured by DXA. Based on the results (see Table 4.3), body fat percentage of all participants (n=93) measured by ADP (M=13.13, SD=6.91) was significantly lower than body fat percentage measured by DXA (M=16.72, SD=6.00); $t(92) = -16.44$, $p < 0.05$. Paired sample t-tests were also performed comparing body fat percentages measured by ADP and DXA, for males and females separately. According to the results, males' (n=25) body fat percentage measured by ADP (M=6.75, SD=4.60) was significantly lower than body fat percentage measured by DXA (M=10.19, SD=3.52); $t(24) = -10.24$, $p < 0.05$. Additionally, females' (n=68) body fat percentage measured by ADP (M=15.47, SD=6.10) was significantly lower than body fat percentage measured by DXA (M=19.12, SD=4.82); $t(67) = -13.36$, $p < 0.05$.

Table 4.3 Results of paired samples t-test for the difference between ADP and DXA body fat percentages. Pair 1 included all participants, male and female (n=93). Pair 2 included males only (n=25). Pair 3 included females only (n=68).

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
1	All participants: ADP % Fat – DXA % Fat	-3.59	2.11	0.22	-4.02	-3.16	-16.44	92	0.00
2	Males: ADP % Fat – DXA % Fat	-3.44	1.68	0.34	-4.13	-2.75	-10.24	24	0.00
3	Females: ADP % Fat – DXA % Fat	-3.65	2.25	0.27	-4.19	-3.10	-13.36	67	0.00

A Bland-Altman plot was constructed to display the differences between the ADP and DXA measures against the averages of the two measures. The plot shows (see Table 4.4) that there is a greater difference between DXA and ADP measures at lower body fat percentages. As body fat percentage increased, there was less of a difference between the two measures, but the difference was still significant. Cohen's d value was 0.5548, which implies a medium effect size.

Figure 4.4 Bland-Altman plot for all participants (n=93).



CHAPTER FIVE

DISCUSSION

Discrepancies Between ADP And DXA

The results revealed a significant difference in body fat percentages estimated by ADP versus body fat percentages estimated by DXA. When compared to DXA measures, body fat percentages measured by ADP were significantly lower. This was found to be true for males and females alike. These findings were consistent with much of the past research, which also found that ADP underestimated body fat percentage when compared to DXA in normal to overweight individuals (Ball, 2004; Collins, 1999; Hames, 2014; Heden, 2008; Lazzer, 2008; Levenhagen, 1999; Nicholson, 2001; Sardinha, 1998; Weyers, 2002). There is a trend of ADP underestimating body fat percentage, when compared to DXA.

The Bland-Altman plot (Table 4.4) showed that the difference between DXA and ADP measures was greater amongst leaner individuals, or those with lower body fat percentages. This was consistent with former studies, which found that the difference between ADP and DXA measures were greater at both lower and higher body fat percentages in men (Ball, 2004) and underweight, normal weight, and obese individuals (Lowry, 2015).

Our findings are contradictory to the previous research including lean individuals. Lowry and his colleagues found that, among individuals categorized as underweight by BMI, ADP overestimated body fat percentage when compared to DXA (Lowry, 2015). However, our results showed that ADP still underestimated body fat percentage. It is important to note that, though both samples of our and Lowry's studies were considered lean or underweight, the samples were drastically different. Lowry's underweight sample (n=30) had a mean age of 54.64 years, was 75.9% male, and was recruited from the Calorie Restriction Society (Lowry, 2015). Our sample (n=93) ranged from 18-24 years, was 73.12% female, and was recruited from the University of Mississippi Athletics. Additionally, our sample was a much leaner sample, with a lower range of body fat. Our average ADP body fat percentage was 13.13%, with a minimum of 2.3% body fat. Lowry's average ADP body fat percentage was 16.15%, with a minimum of 8.1% body fat (Lowry, 2015). Considering the differences in age, gender, diet, activity level, and muscle mass between the two samples, one or more of the variables mentioned may account for the opposing findings, concerning the comparison of ADP and DXA.

This study adds to preexisting data, regarding the relationship between ADP and DXA. Our findings provide additional support to the notion that ADP underestimates body fat percentages when compared to DXA. The study also creates a new area of focus: individuals with low body fat. Since research comparing ADP and DXA in lean individuals is limited, and our results contradict previous findings, more research needs to be done to fully understand the relationship between ADP and DXA in athletes and lean individuals.

Clinical Implications

There was a significant difference in body fat percentages measured by ADP versus DXA, which is considered the gold standard (Guglielmi, 2016). For individuals in the normal to overweight category, air displacement plethysmography appears to be a suitable measure.

However, for individuals with inadequate amounts of body fat, ADP may not be an appropriate means to accurately measure body fat percentage. Since the difference between ADP and DXA is greatest among those with low body fat, ADP appears to provide a less accurate estimation of body fat percentage for those individuals. DXA would provide a more accurate estimation of body fat percentage for individuals with low amounts of body fat.

Since air displacement plethysmography is less expensive and does not use radiation, it would be the better option for routine screening purposes or providing an assessment of change in body composition over time. However, for individuals identified as ultra lean or risky, a DXA scan may want to be considered for a more accurate assessment of body fat.

It is essential that professionals working with athletes understand the differences between ADP and DXA. They must be properly educated and realize that the two measures are not interchangeable. Though ADP may be useful in quantifying changes in body composition over time, it should not be used when making clinical decisions. For such decisions regarding student athletes' health or participation status, DXA, would be the preferred tool of assessment.

Limitations

One of the major limitations of this study was the timing of concurrent ADP and DXA measures. Ideally, measures would have been taken within the same day, back to back. Due to the athletes' hectic and conflicting schedules, most of the measures were taken within one week. Body composition likely did not change significantly during the period between the two measures. However, due to training and competition, it is possible that the athletes' body fat percentages fluctuated some from the initial ADP measure to the follow up DXA measure.

Another potential limitation was the unequal gender ratio. Ideally, the distribution of males and females would have been equal. For this study, out of the ninety-three total participants, only 25 were males. The majority, 73%, were females.

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LIST OF APPENDICES

Appendix A: Informed Consent Form

The University of Mississippi
Institutional Review Board
Protocol # 18-059
Approval Date 02-13-18
Expiration date 02-12-19
Signature

Consent to Participate in Research

Study Title: Bod Pod Versus DXA for Measuring Body Fat Percentage

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☐ By checking this box I certify that I am 18 years of age or older.

The purpose of this study
We want to determine whether body fat percentage, as measured by the Bod Pod and DEXA scan, differ significantly from one another.

What you will do for this study
Bod Pod Procedure
1. You will come to Lenoir Hall Room 116.
2. You will remove any loose fitting garments. Women will wear a sports bra and fitted tights. Men will wear fitted tights.
3. You will remove all metal objects, including jewelry.
4. Your height and weight will be measured.
5. You will sit in a chamber
6. You will sit still for about 42 seconds during each of two measures.
7. You will receive body composition results and discuss them with a registered dietician.

DXA Scan Procedure
1. You will report to Turner Center Body Composition Lab.
2. You will remove all metal objects, including clothing containing metal.
3. You will remove at least your outer clothes and change into shorts and a t-shirt or wear a hospital gown.
4. Your height and weight will be measured.
5. You will lie on the DXA padded table.
6. A research clinician will position your body on the table.
7. You will lie still for about 30 seconds during each of two scans (hip and spine).

8. You will receive DXA results (and an opportunity to release results to team physician).

Time required for this study
The Bod Pod measurement will take approximately 10 minutes. The DEXA scan will take approximately 20 minutes, for a total of 30 minutes.

Possible risks from your participation
The DXA device exposes you (and any unborn fetus) to a low dose of X-ray radiation - about 1/10 of the radiation from a chest x-ray and about as much radiation as you get from the sun from flying coast to coast. Some people experience anxiety during this test, just like any medical test.

Benefits from your participation
You will receive knowledge of body composition, including lean mass, fat mass, and body fat percentage. You will find out if your bone mineral density (a contributor to bone strength) is within normal limits.

Confidentiality
Research team members will have access to your records. We will protect confidentiality by removing your name from your results.

Members of the Institutional Review Board (IRB) – the committee responsible for reviewing the ethics of, approving, and monitoring all research with humans – have authority to access all records. However, the IRB will request identifiers only when necessary. We will not release identifiable results of the study to anyone else without your written consent unless required by law.

Right to Withdraw
You do not have to take part in this study, and there is no penalty if you refuse. If you start the study and decide that you do not want to finish, just tell Dr. Bass or Dr. Valliant. Whether or not you participate or withdraw will not affect your current or future relationship with the Nutrition and Hospitality Department, Athletics Health and Sports Performance, or with the University, and it will not cause you to lose any benefits to which you are entitled.

IRB Approval
This study has been reviewed by The University of Mississippi's Institutional Review Board (IRB). The IRB has determined that this study fulfills the human research subject protections obligations required by state and federal law and University policies. If you have any questions or concerns regarding your rights as a research participant, please contact the IRB at (662) 915-7482 or irb@olemiss.edu.

Please ask the researcher if there is anything that is not clear or if you need more information. When all your questions have been answered, then decide if you want to be in the study or not.

Statement of Consent
I have read the above information. I have been given an unsigned copy of this form. I have had an opportunity to ask questions, and I have received answers. I consent to participate in the study.

Furthermore, I also affirm that the experimenter explained the study to me and told me about the study's risks as well as my right to refuse to participate and to withdraw.

Signature of Participant ______________________________ Date __________

Printed name of Participant ______________________________

NOTE TO PARTICIPANTS: DO <u>NOT</u> SIGN THIS FORM
IF THE IRB APPROVAL STAMP ON THE FIRST PAGE HAS EXPIRED

Because I did not fully tell you in the consent form about some of the procedures in this study, the IRB requires that I get your consent in order to use the information I collected from you.

- If you do not give your consent, there will be no penalty from me, your instructor, the department, or the School – this is completely your choice.

- If you do consent to the use of the information collected, please sign below and date it.

"Following debriefing, I approve that the information collected from me in the *[Title]* study can be used by Mr. Student & Dr. Faculty."

Signature of Participant ______________________________ Date __________

Printed name of Participant ______________________________

Appendix B: Bod Pod Results Hand Out

BOD POD® Body Composition Tracking System Analysis

SUBJECT INFORMATION	
NAME	
AGE	
GENDER	
HEIGHT	
ID_1	
ID_2	
ETHNICITY	General Population
OPERATOR	melinda
TEST DATE	
TEST NUMBER	

BODY COMPOSITION RESULT	
% FAT	%
% FAT FREE MASS	%
FAT MASS	kg
FAT FREE MASS	kg
BODY MASS	kg
BODY VOLUME	L
BODY DENSITY	kg/L
THORACIC GAS VOLUME	L

TEST PROFILE	
DENSITY MODEL	Siri
THORACIC GAS VOLUME MODEL	Predicted

OPERATOR COMMENTS

Body Fat: A certain amount of fat is absolutely necessary for good health. Fat plays an important role in protecting internal organs, providing energy, and regulating hormones. The minimal amount of "essential fat" is approximately 3-5% for men, and 12-15% for women. If too much fat accumulates over time, health may be compromised (see table below).

Fat Free Mass: Fat free mass is everything except fat. It includes muscle, water, bone, and internal organs. Muscle is the "metabolic engine" of the body that burns calories (fat) and plays an important role in maintaining strength and energy. Healthy levels of fat-free mass contribute to physical fitness and may prevent conditions such as osteoporosis.

BOD POD Body Fat Rating Table*

**Applies to adults ages 18 and older. Based on information from the American College of Sports Medicine, the American Council on Exercise, Exercise Physiology (4th Ed.) by McArdle, Katch, and Katch, and various scientific and epidemiological studies.*

	BODY FAT RATING	MALE	EXPLANATION
☐	Risky (high body fat)	> 30%	Ask your health care professional about how to safely modify your body composition.
☐	Excess Fat	20.1 - 30%	Indicates an excess accumulation of fat over time.
☐	Moderately Lean	12.1 - 20%	Fat level is generally acceptable for good health.
☐	Lean	8.1 - 12%	Lower body fat levels than many people. This range is generally excellent for health and longevity.
☐	Ultra Lean	5 - 8%	Fat levels often found in elite athletes.
☐	Risky (low body fat)	< 5%	**Ask your health care professional about how to safely modify your body composition.**

ENERGY EXPENDITURE RESULTS

Est. Resting Metabolic Rate (RMR) kcal/day	*Est. Total Energy Expenditure (TEE) kcal/day	Daily Activity Level
	2454	Sedentary
	2895	Low Active
	3336	Active
	3987	Very Active
(See RMR Info Sheet for additional info)	*Est. TEE = Est. RMR x Daily Activity Level	

Applies to adults ages 18 and older. Based on information from the Institute of Medicine (2002), Dietary Reference Intakes For Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, And Amino Acids, Part I, pp93-206. Washington, D.C., National Academy of Sciences.

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Appendix C: DXA Results Hand Out

The University of Mississippi-Bone Mineral Density Laboratory

248A Turner Center
University, MS 38677

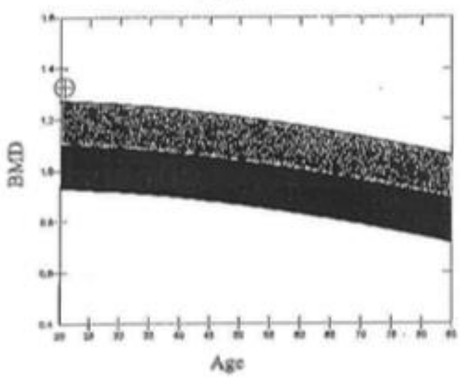
Telephone: 662-915-6770 | E-Mail: ford@olemiss.edu | Fax: 662-915-5525

Name:	Sex:	Height:
Patient ID:	Ethnicity:	Weight:
DOB:		Age:

Referring Physician:

Image not for diagnostic use
k = 1.190, d0 = 46.9
318 x 150

Total



T-score vs. White Female; Z-score vs. White Female. Source:BMDCS/Hologic

Scan Information:

Scan Date: ID:
Scan Type: a Whole Body
Analysis: 12:28 Version 12.7.3.1:7
Auto Whole Body
Operator: mb
Model: Discovery W (S/N 84291)
Comment:

DXA Results Summary:

Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T-score	Z-score
L Arm					
R Arm					
L Ribs					
R Ribs					
T Spine					
L Spine					
Pelvis					
L Leg					
R Leg					
Subtotal					
Head					
Total					

Total BMD CV 1.0%, ACF = 1.033, BCF = 1.003

Physician's Comment:

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The University of Mississippi-Bone Mineral Density Laboratory

248A Turner Center
University, MS 38677

Telephone: 662-915-6770 E-Mail: ford@olemiss.edu Fax: 662-915-5525

Name: Patient ID: DOB:	Sex: Ethnicity:	Height: Weight: Age:

Scan Information:

Scan Date: ID:
Scan Type: a Whole Body
Analysis: 12:28 Version 12.7.3.1
Auto Whole Body
Operator: mb
Model. Discovery W (S/N 84291)
Comment:

DXA Results Summary:

Region	BMC (g)	Fat (g)	Lean (g)	Lean+BMC (g)	Total Mass (g)	% Fat
L Arm						
R Arm						
Trunk						
L Leg						
R Leg						
Subtotal						
Head						
Total						

TBAR353

HOLOGIC®

VITA

Caitlyn Chenevert received her Bachelor of Science in Athletic Training from Louisiana State University in May 2016.