A COMPARISION OF BODY ADIPOSITY INDEX AND BODY MASS INDEX TO BODY FAT PERCENTAGE IN YOUNG ADULT NON-ATHLETES AND ATHLETES

By

BLAKE BARTHOLOMEW

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE

UNIVERSITY OF FLORIDA

2013

To everyone that has helped and guided me along this long winding road that has been my college career

ACKNOWLEDGMENTS

I thank my parents for all the love and support they have given me. Thank you Dr. Shelnutt, you have treated me like a son and I wouldn’t have made it this far without your guidance. Thank you, Sweet pea, for being by my side for these past two years.

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LIST OF ABBREVIATIONS

ADP	Air displacement plethysmography
BAI	Body adiposity index
BIA	Bioelectrical impedance analysis
BF%	Body fat percentage
BMI	Body mass index
CT	Computed tomography
DEXA	Dual-energy x-ray absorptiometry
IRB	University of Florida Institutional Review Board 02
MONICA	Monitoring Trends and Determinants in Cardiovascular Disease Augsburg study
MRI	Magnetic resonance imaging
NHANES	National Health and Nutrition Examination Survey
NHANES III	The third National Health and Nutrition Examination Survey
NHANES 99-04	National Health and Nutrition Examination Survey from 1999 to 2004
NHLBI	National Heart, Lung, and Blood Institute
SAD	Sagittal abdominal diameter
TARA	Triglyceride and Cardiovascular Risk in African American study
UAA	University Athletic Association
WC	Waist circumference
WHO	World Health Organization
WHR	Waist to hip ratio

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Blake Bartholomew

May 2013

Chair: Karla Shelnutt
Major: Food Science and Human Nutrition

In this study we wanted to determine whether body adiposity index (BAI) more strongly correlated to body fat percentage (BF%) than body mass index (BMI) in young adult athletes and non-athletes. University of Florida athletes (N=53; 29 men and 24 women) and non-athletes (N=195; 64 men and 131 women) aged 18-24 participated in physical assessments (height, weight, hip circumference and BF% measured by air displacement plethysmography) in a clinical lab. The relationship between BF% and BAI and BMI was examined using Pearson's correlation and corresponding 95% confidence intervals. Bland-Altman limits of agreement plots were used to visually compare the existence of any differences between BAI and BF%. For all participants BAI was more strongly correlated to BF% than BMI was correlated to BF% [r=0.73; (0.67, 0.79) vs. r=0.31; (0.19, 0.41)]. When separated by sex BAI and BMI correlated similarly to BF% with no significant difference between the two measures. When separated by athletic status, BAI correlated more strongly with BF% than BMI in non-athletes [r=0.76; (0.70, 0.81) vs. 0.38; (0.25, 0.49)], but not in athletes [BAI–BF% r=0.41; (0.16, 0.61) vs. BMI-BF% r=0.29; (0.02, 0.52)]. When separated by sex and the combination of sex and

athletic status, BAI and BMI correlated similarly to BF% with no significant difference between the two measures. These results suggest that BAI is a better measure of adiposity than BMI in young adult non-athletes.

CHAPTER 1
LITERATURE REVIEW AND RESEARCH RATIONALE

Trends-in Obesity

The most recent National Health and Nutrition Examination Survey (NHANES) data from 2009-2010 indicate that 35.7% of adult men and women in the U.S, are obese (1). Obesity is defined as excess adiposity and with this excess body adiposity there is an increased risk of mortality and medical comorbidities such as type 2 diabetes, some cancers, and cardiovascular disease (2-4). Obese adults also experience a lower quality of life, increased medical expenses, and they miss more work than non-obese adults (5-6). Young adults are at a particularly high risk of weight gain. Many young adults leave home without the proper knowledge to prepare healthy food and do not exercise on a regular basis (7-9). In addition, young adults may adopt unhealthy behaviors once they leave home, such as becoming more sedentary, developing unhealthy eating and sleeping habits (9-11), and drinking excessively (12), which may lead to weight gain. Trends in body weight of young adults from ages 18-30 reflect this and are marked by weight increases and an increased prevalence of overweight and obesity (13, 14)

Health Consequences of Obesity

Obesity has health-related consequences. The excess fat mass in obesity is associated with multiple comorbidities (15) such as coronary heart disease, cardiovascular disease (16), liver and gallbladder disease, osteoarthritis and muscle skeletal problems, respiratory problems (17), insulin resistance, and increased mortality (18). Subjects with a BF% classified as obese had higher levels of cardio-metabolic risk factors (inflammatory markers, insulin resistance, dyslipidemia, systolic blood pressure, low HDL cholesterol) than subjects with a BF% classified as lean (19). An increase in fat mass accumulation can further be linked with an increased occurrence of metabolic syndrome (19,20). Metabolic syndrome is a name for a cluster of risk factors that occur together and increase the risk for coronary artery disease, stroke, and type 2 diabetes. The two most important risk factors for metabolic syndrome are increased abdominal adiposity (i.e. "apple-shaped") and insulin resistance. Other risk factors include aging, hormone changes, and lack of exercise. According to the American Heart Association and the National Heart, Lung, and Blood Institute (NHLBI), metabolic syndrome can be diagnosed if three or more of the following signs are present in the patient: high blood pressure (130/85 mmHg), elevated blood sugar (≥100 mg/dL), large waist circumference (men ≥40 inches, women ≥35) ,low HDL cholesterol (men <40 mg/dL, women <50 mg/dL), and elevated serum triglyceride level(≥150 mg/dL). (21).

Measuring Adiposity

A variety of methods have been developed to assess body adiposity, each varying by ease of use and cost. The gold standards are those methods that produce the most accurate measure of adiposity, but this increased accuracy comes at a price. These techniques are limited by their cost, inconvenience of use, and degree of training required to use them. Anthropometric measures use body measurements such as height, weight, and circumferences or ratios of body measurements to estimate body adiposity. These measures have their strengths such as minimal cost, convenience for the patient, and portability but are not as accurate as the gold standards. This section will describe the various measures of adiposity and their strengths and weaknesses.

The Gold Standards

Hydrostatic weighing, dual energy x-ray absorptiometry (DEXA), air displacement plethysmography (ADP), and imaging techniques are considered the gold standards for body composition analysis.

Hydrostatic weighing

Hydrostatic weighing also known as underwater weighing is the oldest of the gold standards, and relies on Archimedes principle to calculate BF%. The first step in underwater weighing is determining body density. To determine body density, the subject is first weighed outside of the water. Next the subject is weighed while submerged. From these two weights the specific gravity of the subject is determined by dividing the weight of the subject outside of water by the loss in weight of the subject when submerged in water (weight outside of the water minus weight while submerged). Once the specific gravity of the subject has been determined, it is multiplied by the density of water (1g/cm3). This yields the subject's body density. Human body densities vary between approximately 1.08 g/cm3 (very lean) and 1.00 g/cm3 (severely obese). Roughly sixty percent of the human body is composed of water, which explains why body density is very close to the density of water (22). Because adipose tissue is less dense than water, lower body density equals a greater BF%. After body density is calculated, BF% is estimated using a standard formula based on a two compartment model. In a two compartment model the body is divided into two parts. One is composed of body fat and the other is composed of all other fat free mass. The most commonly used two compartment model was developed by Siri (23). Other two compartment models have been proposed to account for body composition differences of fat-free mass (muscle and bone) associated with age, sex, ethnicity and race. (24)

Underwater weighing has been a gold standard for a multitude of years but the measurement involves distinct requirements from subjects being measured. Subjects must entirely submerge their body underwater, exhale maximally, then hold their breath and maintain their body position until a weight measurement is acquired. The subject must exhale maximally to minimize the buoyant effect of air in the lungs (23). Young children, older adults, and individuals with cardio-pulmonary diseases may not be able to perform this part of the measurement sufficiently. Special procedures may be required when performing underwater weighing of obese subjects. Obese subjects have a tendency to float, so it may be difficult for these subjects to fully submerge their bodies. A weight belt may be necessary to completely submerge the subject. The weights must then be measured and subtracted from the recorded underwater weight to obtain a true underwater weight (23).

Dual-energy X-ray absorptiometry (DEXA)

Although DEXA is primarily used to measure bone density, it provides an accurate measure of body adiposity. A DEXA scan is obtained by a DEXA scanner, which is a machine with a mechanical arm that passes over the subject while they lay on a specialized table. The scan usually takes ten minutes to complete. DEXA determines body composition by using X-ray beams at two energy levels (one is high energy and the other is low energy) to differentiate between three types of tissue (bone, lean soft tissue, and fat) (25). At any one time a DEXA scan can only differentiate between two types of tissues. When bone is present, soft tissues and bone are easily distinguished from each other. When only soft tissue is present adipose and lean tissue fractions can be partitioned from each other, with the assumption that lean tissue is composed primarily of water whereas adipose tissue contains little water. The adipose and lean fractions of the soft tissue are then extrapolated to the soft tissue around the bone this produces estimates of total body fat and lean tissue mass. The algorithms used for these extrapolations are considered proprietary information and differ between DEXA scanner manufacturers (25). Validation studies have shown that body fat assessment by DEXA aligns well with the body fat measurements derived using the four compartment model (24). The four compartment model estimates body fat from measurements of underwater weighing (body density), total body water, and bone mineral values. A concern for the use of DEXA in body composition analysis is the reported differences among scanners from different manufacturers (25). These differences may arise because each manufacturer uses a different formula for calculating body composition.

Air displacement plethysmography

Air displacement plethysmography (ADP) calculates BF% by measuring body volume through air displacement and Poisson's law. The measurement of body volume involves three steps. Before ADP can be used, a calibration process is performed whereby the ADP chamber calibrated to a known volume. The subject is then weighed by the electric scale connected to the ADP chamber wearing only spandex shorts and spandex sports bra (women only). Next, the subject's volume is measured in the ADP chamber. Subjects sit in the ADP wearing spandex and a skull cap. This minimizes sources of isothermal air which could affect the calculation. The ADP chamber calculates body volume by subtracting the volume of air in the closed ADP chamber that contains the subject from the volume of air in an empty chamber. This measure is repeated twice to verify the agreement between the two volume measures. In the third step adjustments to the volume calculations are made to account for air in the lungs.

This can be done by measuring lung volume directly (while pinching their nose the subject breathes in a disposable tube connected to the machine), or it can be estimated with an equation provided by the ADP system. The predictive equation is used when the subject is unable to perform the lung volume measure. Once the system calculates body volume, body density is calculated by use of the subject's weight. Body density is then inserted into a standard formula to calculate BF% based on a two compartment model, such as Siri (same model used in underwater weighing) for the general population and Ortiz for African Americans. The Ortiz formula accounts for the higher bone density of African Americans. The reliability and validity of ADP measurements have been published at length (26).

Imaging techniques

Imaging techniques have been reserved for research purposes. The two most common imaging techniques are computed tomography (CT) and magnetic resonance imaging (MRI). Computed tomography uses X-rays in a fan shaped beam to produce two-dimensional cross sectional slices of the body. Three dimensional images are produced from a series of these two dimensional cross sections taken around a single axis of rotation. Adipose, muscle, skin, or bone tissue can be identified by their differing densities. Total body mass determined using scans along the length of the body at 10 cm intervals has been shown to be highly accurate when estimating the amount of different body tissues (22). One advantage to CT is that it can be used to separate total adipose tissue into subcutaneous and visceral components. One disadvantage of CT is the high dose of radiation required for the scan. Human cadaver studies have validated the accuracy of CT estimates of adipose tissue (27). Magnetic resonance imaging (MRI) is based on the interaction of protons in tissues and magnetic fields generated and controlled by the MRI machine. Whole-body images are created according to the rate at which protons in hydrogen atoms from various tissues, such as fat, and muscle, return to their normal state after exposure to various magnetic fields. Multiple scans along the length of the body are needed for whole body measurements, this process may require the subject to be in the MRI machine for 30 min or longer. Like CT images MRI images, allow for the separation of subcutaneous adipose tissue from visceral adipose tissue. Human cadaver studies have also validated the accuracy of MRI for estimating adiposity. An advantage of MRI over CT is the absence of radiation. Although imaging techniques like MRI and CT are the most accurate of the gold standards they are limited by their high cost, and need of a radiologist for interpretation (28).

Other Measures of Adiposity

While the gold standards discussed above provide the most accurate measurement of adiposity, cost and availability to clinicians and researchers limit their use. Instead other anthropometric methods have been developed to estimate adiposity, including waist circumference (WC), the waist to hip ratio (WHR), skin fold thickness, bioelectrical impedance analysis (BIA), sagittal abdominal diameter (SAD), body mass index (BMI), and body adiposity index (BAI). These measures are simple and inexpensive to perform but have their limitations. This section will describe these anthropometric measures.

Waist circumference (WC)

Waist circumference is used to assess central adiposity or visceral adipose tissue and has been shown to be highly associated with cardiovascular disease, metabolic syndrome, and mortality (29). The World Health Organization (WHO) recommends cutoffs for WC of >102 cm for men and >88 cm for women. These cutoffs are derived by recognizing WC values that correspond to BMI cutoffs for obesity. Waist circumference cutoffs that correspond to a BMI classification of overweight are >90 cm for men and >80 cm for women (30). Although WC cutoffs were derived from BMI cutoffs, studies have indicated that subjects with normal BMI but higher WC can be at increased risk for cardiovascular disease and mortality (31). Pischon et al. (32) examined the association of BMI, WC, and WHR with the risk of mortality in 359,387 subjects (25-70 years old) from nine European countries (Denmark, France, Germany, Greece, Italy, the Netherlands, Norway, Spain, and the United Kingdom). They reported that high BMI, WC and WHR were each associated with an increased risk of death. In addition there was positive association between high WC and increased mortality among participants with normal BMI. This highlights the importance of assessing abdominal adiposity especially among subjects with normal BMI. Even though WC has been shown to correlate strongly with cardiovascular disease, and mortality it does not provide an estimate of total fat mass. Differences in visceral adiposity within WC vary significantly by sex, age, and race (31). Compared to Caucasians, Asian populations have greater visceral adipose tissue, and African populations have less visceral and/or total BF % at a given WC (30). Ford et al.(34) examined WC trends in U.S. adults using data from the third National Health and Nutrition Examination Survey (NHANES III) and NHANES from 1999 to 2000 (NHANES 99-04). They concluded that WC increases with age across both sexes. Waist circumference measurement methods have not been standardized. There are currently eight different locations for measuring WC. Although there has not been standardization for a site measuring WC, most of the eight sites have very high reproducibility (35). The NHLBI recommends WC be measured at the top of the iliac crest whereas the WHO recommends WC measurements should be made at the midpoint between the lowest palpable rib and the top of the iliac crest (36). This is a problem because each measurement does not provide the same measurement estimate, which may affect results from one person to the next. An advantage of WC over BMI is its ability to detect changes in adiposity. Velthuis et al. (37) investigated the effect of a moderate-to-vigorous exercise program on body composition, among 189 sedentary, postmenopausal women. They measured BF% using DEXA, BMI, WC and hip before and after participation in this exercise program to determine the effect of weight loss on these measures. The authors reported that the exercise program reduced fat mass, increased lean body mass, and reduced WC, although weight and BMI were unchanged.

Waist-to-hip ratio (WHR)

Waist-to-hip ratio is calculated by dividing waist circumference by hip circumference and is used to predict the risk of metabolic disorders and cardiovascular disease (30). Like WC, WHR is a measure of central adiposity and visceral adipose tissue and is not a measure of total BF%. The WHO recommends cutoffs for WHR of ≥ 0.90 cm for men and ≥ 0.85 cm for women but emphasize that numerous studies have suggested using cutoffs specific to ethnic groups (30). Koning et al. (29) performed a meta- analysis of fifteen prospective cohort studies and randomized clinical trials of cardiovascular disease that measured WC or WHR. They concluded that WHR and WC were significantly associated with the risk of cardiovascular disease and that these measures should be incorporated into cardiovascular disease risk assessments. In addition in the Monitoring Trends and Determinants in Cardiovascular Disease Augsburg (MONICA) study, BMI, WC, and WHR were all strongly and independently related to incident type 2 diabetes in both men and women ages 35-74 (38). Increased WHR has also been linked to increased mortality. Seidell (39) reviewed the relationship of WC and WHR to all-cause mortality in twenty prospective epidemiological studies. The author concluded that increased WC and WHR are related to increased all-cause mortality. The author also concluded that increased WC and WHR are stronger predictors of increased mortality in younger adults compared to older adults.

Skinfold measurement

The skinfold measurement involves gripping the skin in between the thumb and forefinger, pulling it away from the body slightly, and placing the fold in between specialized calipers designed to measure skinfold thickness. This measures the thickness of two layers of skin and the underlying subcutaneous fat. Skinfold measures are taken at three sites (chest, abdomen, and thigh) on the right side of the body. The skinfold measurements from all three sites are then summed and plugged into a formula to estimate body density. The most commonly used equations for estimating body density were developed by Jackson and Pollock for men and Jackson, Pollock, and Ward for women (40). Body density is then plugged into a formula to estimate BF%. Because of gender, age, racial and ethnic differences in body composition there are over 100 BF% prediction equations reported in the literature and each of these equations are restricted to the population from which the prediction equation was derived (41). The measurement of skinfolds is a popular method of estimating body composition but its inaccuracies have been described. Lohman (42) reported standard errors from skinfold measurements to be 2.6 kg for fat-free mass and 3.5% for percent body fat. Some of the potential sources of error found in the skinfolds method included variation in subcutaneous in relation to total fat, variation in skinfold thickness in relation to subcutaneous fat, and technical error in the skinfold measurement (i.e. intra and inter-observer variability, difficulty in obtaining reliable and accurate readings on older participants with loose connective tissue or obese individuals with large folds) (43).

Bioelectrical impedance analysis (BIA)

Bioelectrical impedance measures the resistance of body tissues to the flow of a small, electrical current. Different tissues conduct electricity differently based on their water and dissolved electrolyte content. Seventy-three percent of the body's fat-free mass is water and conducts the electrical current. Fat and bone are composed of a relatively small amount of water and are thus nonconductive and resist the flow of the electrical current (23). During BIA a small electrical current passes through electrodes attached to either the wrists or ankles. The resistance of the electrical current is used to estimate total body lean mass and BF% using a standardized equation. There are a multitude of population specific BF% estimation equations reported in the literature (44). The equipment needed for BIA is portable, relatively easy to use, affordable, and pose little risk to subjects (BIA is not recommended for subjects with a pacemaker). Studies have shown that body composition estimated using BIA is influenced by sex, age, disease state race and ethnicity, level of fatness, environment, and phase of menstrual cycle (23).

Sagittal abdominal diameter (SAD)

Sagittal abdominal diameter is a simple measurement that may be even better than WC for predicting metabolic syndrome (45-49), dyslipidemia, and cardiovascular disease (50-54), although this is still under investigation. Gustat et al. (55) examined the relationship between SAD and other measures of adiposity (Triceps skinfold, WC, BMI, WHR, and Coincity Index) and cardiovascular risk factors in young adults (20-38 years old). The sample was biracial and consisted of 409 African Americans and 1,011 Caucasians form Bogalusa, Louisiana. They concluded SAD correlated more strongly with the cardiovascular risk factors than other obesity measures. Sagittal abdominal diameter can be measured directly on a patient, generally in the supine position, as the distance between the examining table and the apex of the abdominal girth or the largest diameter between the bottom of the sternum and the umbilicus. Although SAD may be a promising measure of abdominal adiposity, the measure needs to be standardized and normal thresholds identified. Risérus (47) suggested a SAD cutoff for increased cardiometabolic risk to be 22cm in men and 20cm in women. These cutoffs were developed from 4032 subjects (1936 men and 2096 women) older (60 years old) Europeans and may not generalize well to other populations. Sampaio et al. (50) evaluated the validity of SAD as a predictor of visceral adipose tissue and identified SAD cutoffs for increased cardiovascular disease risk in 92 subjects (57 women and 35 men ages 20-83 years old). They concluded there was a high correlation between SAD and visceral adipose tissue and recommended SAD cutoffs for increased cardiometabolic risk to be 20.5 cm in men and 19.3 cm in women. These cutoffs were based on a small sample of subjects that included a large age range. Age-specific standards are needed due to changes in body composition with age.

Body mass index (BMI)

Currently clinicians and researchers commonly use body mass index (BMI) as an indicator of adiposity. Body mass index is calculated as weight in kilograms divided by height in meters squared. This measure was first proposed by Adolphus Quetelet in 1832 based on the observation that body weight was proportional to the square of the height in adults with normal body frames. When developing the index that would bear his name, Quetelet had no interest in obesity. His concern was defining the characteristics of 'normal man' and fitting the distribution into a Gaussian curve (56). A Gaussian curve is often referred to as a bell or normal curve. It is a symmetrical curve that represents the normal distribution of a trait in a population. In 1972 Keys et al. (57) examined how different relative weight ratios (weight to height, the Ponderal index, and the Quetelet index) correlated to obesity in 7,426 male subjects from the ages of 18-60 (the majority of the sample was aged 40-59 years old). The Ponderal index is found by dividing the cube root of weight by height (57). The subjects were composed of 12 cohorts from 5 countries (United States, Japan, South Africa, Finland and Italy). Keys et al. (57) reported that Quetelet's Index was the best indirect surrogate measure for BF% among the ratios of relative weight. Keys went on to rename Quetelet's Index BMI. In 1998 the NHLBI released the first guidelines for the assessment of obesity using BMI (58). Table 1-1 lists the different BMI categories and the corresponding weight status classification set forth by the NHLBI (59):

Table 1-1. Weight status classification within BMI ranges

BMI	Weight Status
< 18.5	Underweight
18.5-24.9	Normal
25.0-29.9	Overweight
≥30	Obese

Despite its wide spread use in obesity research, it has been debated whether BMI represents body adiposity adequately (60-63). Gómez-Ambrosi et al. (63) compared the diagnosis of obesity in 6,123 Caucasian subjects (924 lean, 1,637 overweight and 3,562 obese classified according to BMI) aged 18-80 years old, using BMI and BF %. Body fat percentage was determined using air displacement plethysmography. Gómez-Ambrosi et al. (63) reported that 29% of subjects with a normal BMI and 80% of subjects with a BMI that classified them as overweight had a BF% classified as obese. These results suggest that BMI does not reliably reflect BF% and that BF% should be considered when at all possible when estimating disease risk. Body Mass Index does not directly measure fat mass or distinguish between fat or lean mass. This limits BMI's ability to generalize among different age groups, between the sexes, different ethnic groups, and different racial groups (64,65). The Dietary Reference Intakes for Energy contains a Table 1-2 that lists typical BF% ranges (obtained from bioelectrical impendence analysis) within BMI classifications.

Table 1-2. Body fat percentages within BMI classifications*

		BF%	
BMI Range (kg/m^2)	Classification	Men	Women
18.5 - 24.99	Normal	13 – 21	23 – 31
25 – 29.99	Overweight	21 – 25	31 – 37
30 – 34.99	Obese	25 – 31	37 – 42
35 or higher	Clinically obese	> 31	> 42

*Reproduced from IOM, 2005.

These ranges were based on body composition data from the NHANES III (1). Although gender was considered when evaluating normal BF% ranges within BMI classifications and a large sample size was assessed (15,000 participants), the ranges have limitations. Theses ranges do not take into account, age, race, and ethnicity (65,66). Li et al. (64) developed BF% means that align with BMI categories stratified by sex, age, race, and ethnicity using data from NHANES 99-04. Body fat percentage was calculated using DEXA. Table 1-3. summarizes some interesting patterns, revealed in the study.

Table 1-3. Mean percentage BF% according to BMI categories among US adults from NHANES 1999-2004

		BMI (kg/m^2) Classification			
	Total BF%	< 25	25-29	30-34	≥ 35
	Mean	Mean	Mean	Mean	Mean
Men			BF%		
Crude	28.1	22.7	28.2	32.3	36.9
Adjusted	28.2	22.9	28	32.1	37
Race-ethnicity					
Non-hispanic white	28.3a	22.9a	28.3a	32.6a	37.2a
Non-hispanic black	25.8b	19.7b	26.2b	29.9b	35.8a
Mexican American	28.9a	23.6a	28.8a	32.3a	37.2a
Other	27.9a	23.6a	28.1a	32.2a	36.1a
Age					
20-39 y	26.1a	21.0a	27.0a	31.4a	36.7a
40-59 y	28.7b	23.6b	28.0b	31.8a	36.7a
60-79 y	30.9c	25.8c	30.2c	34.5b	38.0b
≥80 y	30.6c	27.5d	31.9d	35.8b	38.8a,b
Women					
Crude	40.05	34.05	40.85	44.25	48.25
Adjusted	39.95	34.15	40.65	44.15	48.35
Race-ethnicity					
Non-hispanic white	39.7a	33.8a	41.1a	44.4a	48.6a
Non-hispanic black	40.9b.c	32.4b	39.1b	43.1b	47.2b
Mexican American	41.6b	36.0c	41.1a	44.4a	47.6b
Other	39.9a,c	34.8a,c	40.7a	43.8a,b	47.8b

Table 1-3 Continued

		BMI (kg/m^2) Classification			
	Total BF%	< 25	25-29	30-34	≥ 35
	Mean	Mean	Mean	Mean	Mean
Women			BF%		
Age					
20-39 y	37.8a	32.2a	39.5a	43.5a	48.0a,b
40-59 y	40.6b	34.4b	40.8b	43.9a,c	48.1a
60-79 y	42.5c	36.9c	42.3c	45.2b	48.7b
≥80 y	40.6b	36.9c	42.0c	45.0b,c	47.7a,b

Values within categories of race-ethnicity or age groups in the same column with different superscript letters are significantly different.

Across all BMI classifications regardless of age and sex non-Hispanic blacks had a lower BF% compared to non-Hispanic whites, and Mexican Americans. Secondly BF% cutoffs were higher in women than men for any given BMI irrespective of age, race, and ethnicity. Lastly the oldest group in their study (50-84 years old) had the highest BF% ranges for the same BMI classification regardless of sex, race, and ethnicity. Li et al. (64) concluded that BF% ranges that corresponded to BMI classifications noticeably varied depending on age, sex, race and ethnicity. Gallagher et al. (66) used DEXA to measure and determine BF% ranges that align with BMI categories of 1626 subjects (ages 20-79 years old) from three ethnic groups (Caucasian, African American, and Asian) . The study also included cutoffs for a young adult (20-39 year old) sub-group. Gallagher et al. (66) proposed the following BF% cutoffs corresponding to BMI classifications in the young adults (Table 1-4).

Table 1-4. Recommended BF% cut offs by ethnicity for 20-39 year olds*

	Women			Men		
BMI	African American	Asian	White	African American	Asian	White
< 18.5	20	25	21	8	13	8
≥ 25.0	32	35	33	20	23	21
≥ 30.0	38	40	39	26	28	26

*Reproduced From Gallagher et al. (2)

Table 1-4 demonstrates and reinforces the notion of the variability of BF% within BMI classification in regards to ethnicity. Asians had higher BF% at lower BMIs, than the other two ethnic groups (Caucasians and African Americans). Table 1-4 also shows a slight difference between African Americans and Caucasian men and women. Gallagher's results slightly differed from the findings of Li et al. Li et al. (64) reported small yet significant differences in BF% between non-Hispanic whites and non-Hispanic blacks across all BMI categories. These differences may be due to the use different DEXA scanners. As stated earlier, DEXA scanners from different manufactures can produce difference in BF%. The differences in BF% ranges that corresponded to BMI classifications depending on age, sex, race and ethnicity arise because distribution of body fat for a given BMI differs by ethnicity (67). Because of BMI's inability to distinguish between fat or lean body mass it is particularly inaccurate in persons with elevated lean body mass such as athletes (68,69) and persons with normal weight but high visceral adipose tissue (70,71). This disparity occurs because the numerator in BMI is total weight and does not distinguish between fat and lean mass. Thus, individuals with higher weight due to increased lean body mass will have a higher BMI and falsely diagnosed as overweight or obese, and individuals with normal weight but excess body fat may not be diagnosed as overweight or obese when in fact they should. Ode et al. (68) used air displacement plethysmography (ADP) to explore BMI's ability to predict BF% in collegiate athletes and non-athletes. They determined that the BF% ranges within BMI classifications put forth in the Dietary Reference Intakes for Energy misclassified male college athletes with normal BF%, female college athletes with normal BF% and male non-athletes with normal BF% as having a BMI classification of overweight or obese. A significant percentage of female nonatheletes classified as having a normal BMI had a higher BF%. Ode et al. (68) concluded that BMI was not a good measure of BF% in this population.

Body adiposity index (BAI)

A new anthropometric measure, BAI has recently been developed and has been found to better reflect BF% than BMI for adult men and women of different ethnicities. Bergman et al. (60) evaluated existing data from the BetaGene study of Mexican Americans to find a trait or combination of traits most strongly correlated to DEXA measured adiposity to develop a new index of BF%. They analyzed demographic and anthropometric measures, including sex, age, weight, height, waist and hip circumference, from 1733 Mexican American adults between the ages of 18-67. They also examined the covariance among variables to select a combination of variables that independently correlated with adiposity so that each variable would contribute independent information to the prediction of BF%. Bergman et al. (60) determined that hip circumference and height correlated the strongest to BF%, and used these two measures as the basis for the new index they named BAI. The correlation between hip circumference and BF% was positive, and there was an inverse correlation between height and BF%, so they determined that the base for BAI would be hip circumference divided by height (hip/height). Quetelet (56) established that the relationship between body fat and height is nonlinear, so height in the proposed BAI had to be raised to a power term. The power term for the proposed BAI was determined by fitting the correlation between BF% and the BAI for all subjects on a parabola to a range of exponent values (1.2-1.8). Once fitted to the parabola derivation was used to find that an exponent of 1.5 in the BAI formula (hip/height$^{1.5}$) produced the maximal correlation to BF%. The authors then determined that the relationship between BF% and BAI (hip/height1.5) had a slope similar to 1 (0.934).This relationship allowed for the identification of a y intercept of 18 that maximized the correlation between BF% and BAI. The final BAI formula is Hip Circumference/(Height$^{1.5}$) – 18 and is numerically approximately equal to the percentage of body fat. Although Bergman et al.(60) concluded that BAI predicted body adiposity better than BMI, they also reported that BAI overestimated BF% at lower levels of adiposity and underestimated BF% at higher levels of adiposity.

Once they developed the formula for BAI, Bergman et al. (60) validated the measure using cross-sectional data of 223 African American adults between the ages of 18-67 who participated in the Triglyceride and Cardiovascular Risk in African American (TARA) study. Demographic and anthropometric information collected in the TARA study included sex, age, height, weight, BMI, waist and hip circumference and DEXA measured BF%. They calculated the percent difference between the BAI estimates of BF% of the BetaGene and TARA studies at specific ranges of DEXA derived BF%. They found that BAI predicted BF% similarly in both studies, only differing at the BF% range <10%. Vinknes et al. (72) compared the relationships of BMI and BAI with BF%

assessed by DEXA, in 5,193 middle aged (47-49 years old) and elderly (71-74 years old) Caucasian, European subjects. They reported that the correlation between BAI and BF% was stronger (r = 0.78) than the correlation between BMI and BF% (r = 0.56) with similar results in the middle-aged and elderly groups. When separated by sex BMI was more strongly correlated with BF% in men, (r = 0.76), and women (r = 0.81) than BAI in men, (r = 0.57) and women (r = 0.72). They also reported that BAI overestimated BF% in lean subjects (particularly in men) and underestimate it in those with higher proportions of body fat. Lopez et al. (73) compared BAI and BMI measurements to BF% using bioelectrical impedance analysis (BIA) in Spanish subjects from Mallorca, Spain (1,726 women and 1,474 men). They found that although BAI and BMI were positively correlated, BAI was more strongly correlated to BF% than BMI was correlated to BF% for all subjects. When separated by sex the correlations between BMI and BF% were higher than the ones obtained between BAI and BF% for both men and women. Lopez et al. (73) reported BAI overestimated BF% in men and slightly underestimated BF% in women. Although the researchers used BIA to assess body adiposity, which has its limitations, a strength of this study is that it included a large number of subjects.

Johnson et al. (74) evaluated whether BAI reflected adiposity better than BMI in 623 European Americans adults, using DEXA measured adiposity. Their findings were similar to Bergman et al. (60). The correlation between BAI and BF% was significantly stronger than that between BMI and BF% for all subjects. When separated by sex BAI overestimated BF% in men and underestimated BF% in women. They also reported that BAI overestimated BF% at lower levels of adiposity and underestimated BF% at higher levels of adiposity. Barreira et al. (75) investigated the sex-specific relationship between

BAI and BF% and BMI and BF% in a large (n=3851) biracial (Caucasian and African American) sample ages 18-69. They concluded that BMI and BAI correlated similarly to BF% across both sex and race groups. Freedman et al. (76) compared the relationship of BF%, as assessed by DEXA, to WC, hip circumference, BAI, and BMI, in 1151 adults ages 18-110 years old (mean age was 45), in five ethnic categories (Caucasian, African American, Hispanic, Asian and other). They reported that BF% was correlated similarly to BAI, BMI, WC, and hip circumference with BAI having the strongest correlation to BF% for all subjects. When controlled for both sex and age, BMI correlated more strongly to BF%. Additionally BAI in general underestimated BF% by 2.5% in women and overestimated BF% by 4.0% in men. This was similar to the findings of Johnson et al. (74). From these results they concluded BAI is not more accurate than BMI, waist circumference, or hip circumference when estimating BF%. BAI appears to be a promising new anthropometric measure that may more accurately assess body adiposity than BMI in a variety of populations.

The accuracy of the BAI has been evaluated in college athletes. To date only one study has reported BAI in athletes. Esco (77) evaluated whether BAI reflected DEXA-measured BF% better than BMI in 30 collegiate female athletes (age = 20.0 ± 1.3) from three sports (soccer, tennis, and basketball). The author reported that neither BAI nor BMI correlated strongly to BF%, but that BMI was more strongly correlated to BF% than BAI (rBMI-BF% =0.49, rBAI-BF% =0.28). Esco also reported that BAI underestimated BF% at higher levels of adiposity and overestimated BF% at lower levels of adiposity in these women. More research is needed in athletes to determine if BAI has the same limitations as BMI in reflecting body adiposity of athletes. The current study has one specific aim:

- To determine whether BAI more strongly correlates to BF% than BMI in undergraduate non-athletes and athletes ages 18-24 years.
- Hypothesis: BAI will correlate more strongly to BF% than BMI in undergraduate non-athletes and athletes between the ages of 18-24

CHAPTER 2
METHODS AND PROCEDURE

Study Design and Subjects

A cross-sectional observational study was conducted using a convenience sample of undergraduate students between the ages of 18-24 years. Approval for the study was granted by the University of Florida Institutional Review Board 02 (IRB) starting fall 2011 and ending fall 2012. All subjects were volunteers. Undergraduate students were recruited by visiting classes, advertising in the school newspaper, and recruiting from other studies. University athletes were recruited from a convenience sample of athletes who visited the University Athletic Association (UAA) nutrition office for BF% measurements. Students from participating Family, Youth & Community Sciences classes received five points of extra credit for participation. No compensation was given to the other participants. Non-athletes interested in the study contacted the study coordinator via email to schedule an appointment for participation in the study.

Physical Assessments

Nonathletes completed a 20 minute physical assessment in the clinical lab (Room 227) of the Food Science and Human Nutrition building. University athletes who participated in the study completed the physical assessment in the UAA nutrition office during their BF% measurement. Subjects were fasting for two hours before their scheduled appointments. Upon arrival to their appointment, informed consent was obtained (Appendix A) from each subject and the subjects were asked to change into approved clothes for the physical assessment (i.e., spandex shorts, sports bra). Physical assessment measurements were obtained by trained research staff and included height, weight, hip circumference using the NHANES protocol described below and BF% using ADP. Measures were recorded into an approved data collection form (Appendix B). Height was measured in centimeters (cm) to the nearest 0.1 cm using a wall mounted stadiometer (Heightronic 235) or a portable stadiometer (SECA 213). Subjects were measured without shoes. Height was obtained twice to ensure accuracy. If the measures varied by greater than 0.5 cm they were repeated until two values within 0.5 cm were obtained. Weight was obtained during body composition assessment using the ADP calibrated electronic scale to the nearest 0.1 kg. Hip circumference was measured in centimeters (cm) using NHANES protocol to the nearest 0.5 cm using a Gulick tape (Patterson Medical). A Gulick tape is a self-retracting measuring tape that allows the researcher to keep a constant tension when measuring body dimensions. Attached to the end of the Gulick tape is a tension indicator composed of a compression spring attached to two beads spaced slightly apart. When there is no tension on the tape measure the beads are covered by a sleeve. When taking measurements enough tension should be applied so that only one bead can be observed. This is what allows the researcher to keep constant tension. Keeping constant tension when measuring body dimensions is important because the measurement will vary if tension is changed. If tension is increased tissue compression will increase thus decreasing the measured circumference. Subjects were measured in spandex shorts or a swim suit with weight distributed on both feet. The tape was placed at the maximum extension of the buttocks (Figure 2-1).

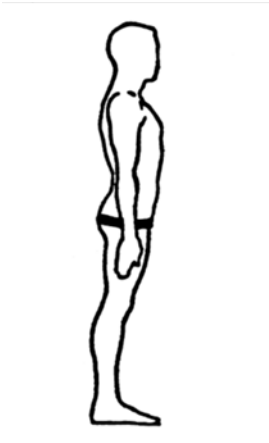

Figure 2-1. Placement of tape during measurement of hip circumference

To ensure accuracy hip circumference was obtained twice. If the measures varied by greater than 0.5 cm they were repeated until two values within 0.5 cm were obtained. Body fat percentage was measured using air displacement plethysmography (ADP, Life Measurement, Inc.). In order to obtain an accurate measurement subjects removed all jewelry, and wore a swim cap. The swim cap was used to minimize a source of isothermal air (air trapped in hair around the head) that could affect the calculation

Statistical Analysis

The agreement between BAI, BMI, and BF% was evaluated using Pearson's correlation and corresponding 95% confidence intervals. This assesses the strength of the relationship between two anthropometric measures. Comparing the confidence intervals for each correlation coefficient allows for the determination of whether a correlation coefficient is different from another correlation coefficient. Bland-Altman limits of agreement plots were used to visually compare the existence of any differences between BAI and BF% In this method the differences between the two measures for each subject were plotted against the averages of the two measures for each subject.

Statistical analysis was carried out using SAS 9.0 (SAS Institute, Cary, North Carolina) and GraphPad Prism 6m (GraphPad Inc., La Jolla, California) statistical software.

CHAPTER 3
RESULTS

Subject Characteristics

Overall subject characteristics are presented in Table 3-1. Nonathlete and athlete subject characteristics are presented in Table 3-2 and Table 3-3, respectively.

Table 3-1. Overall subject characteristics. All values are mean ± SD

	Total	Men	Women
Total (n)	249	94	155
Height (m)	1.7 ± 0.1	1.8 ± 0.1	1.6 ± 0.7
Weight (kg)	68.1 ± 15.8	78.8 ± 15.0	61.8 ± 14.4
BMI(kg/m^2)	23.4 ± 4.2	24.8 ± 4.2	22.5 ± 3.8
Hip Circumference (cm)	97.5 ± 8.3	98.3 ± 8.1	96.9 ± 8.0
BAI, mean	26.2 ± 4.6	23.2 ± 3.3	27.9 ± 4.1
BF%, mean	22.9 ± 9.2	15.6 ± 6.4	27.1 ± 7.5
Race-ethnicity			
Non-Hispanic white	127	51	76
Non-Hispanic African American	23	5	18
Hispanic white	23	10	13
Hispanic African American	0	0	0
Asian	14	10	4
Other	5	1	4
Not reported	57	17	40

In the overall sample women substantially outnumbered men. Two-thirds of the population was composed of women. The majority of the overall sample was composed of non-Hispanic whites (n=127). The rest of the sample identified themselves as non-Hispanic African American (n=23), Hispanic whites (n=23), Asian (n=14), other (n=5) or did not report their race-ethnicity (n=57). Weight, height, hip circumference, and BMI were higher in men compared to women. When comparing average BAI and BF%

between the sexes in the overall population, both BAI and BF% were higher in women compared to men.

Subject characteristics for non-athletes are presented in Table 3-2.

Table 3-2. Nonathlete subject characteristics. All values are mean ± SD

	Total	Men	Women
Total (n)	195	64	131
Height (m)	1.7 ± 0.1	1.8 ± 0.1	1.6 ± 0.1
Weight (kg)	65.6 ± 14.7	76.5 ± 14.2	60.3 ± 11.7
BMI(kg/m^2)	23.1 ± 4.2	24.5 ± 4.4	22.4 ± 3.9
Hip Circumference (cm)	70.0 ± 8.2	96.7 ± 8.2	97.1 ± 28.4
BAI	26.7 ± 4.6	23.2 ± 3.6	28.4 ± 4.1
BF%	24.4 ± 8.9	16.3 ± 6.4	28.6 ± 7.1
Race-ethnicity			
Non-Hispanic white	88	27	61
Non-Hispanic African American	18	4	14
Hispanic white	19	8	11
Hispanic African American	0	0	0
Asian	13	10	3
Other	3	0	3
Not reported	54	15	39

The sex and racial-ethnic make-up of the nonathlete sample was similar to the overall sample in that women substantially outnumbered men, and it was primarily composed of non-Hispanic whites. When comparing average BMI across all the non-athlete sample population men had higher BMI's compared to women. Men also on were taller and weighed more than women. When comparing average hip circumference across sex women had slightly larger hip circumferences compared to men. BAI and BF% were lower in men compared to women.

Athlete subject characteristics are presented in Table 3-3

Table 3-3. Athlete subject characteristics. All values are mean± SD

	Total	Men	Women
Total (n)	54	30	24
Height (m)	1.8 ± 0.1	1.8 ± 0.1	1.7 ± 0.1
Weight (kg)	76.4 ± 16.6	84.1 ± 15.7	65.6 ± 10.2
BMI(kg/m^2)	28.4 ± 11.4	25.3 ± 3.5	22.8 ± 2.9
Hip Circumference (cm)	99.0 ± 7.3	101.7 ± 6.9	95.6 ± 6.1
BAI, mean	24.1 ± 3.2	23.1 ± 2.8	25.4 ± 3.2
BF%, mean	17.0 ± 6.5	14.0 ± 6.2	20.0 ± 5.8
Race-ethnicity			
Non-Hispanic white	39	24	15
Non-Hispanic African American	5	1	4
Hispanic white	4	2	2
Hispanic African American	0	0	0
Asian	1	0	1
Other	2	1	1
Not reported	3	2	1
Sport			
Baseball	12	12	0
Basketball	4	1	3
Crew	7	4	3
Football	1	1	0

Table 3-3. Continued

	Total	Men	Women
Sport			
Golf	2	1	1
Gymnastics	3	0	3
Lacrosse	1	0	1
Tennis	7	7	0
Soccer	4	0	4
Softball	1	0	1
Swimming	1	1	1
Track	6	1	6
Volleyball	1	0	1
Cross country/track	2	2	0

The majority of the athlete sample was composed of non-Hispanic whites (n=39). The rest of the sample identified themselves as non-Hispanic African American (n=5), Hispanic whites (n=4), Asian (n=1), other (n=2) or did not report their race-ethnicity (n=3).

All athletes, male athletes, and female athletes were taller, heavier and had a higher BMI than nonathletes. All athletes, female athletes, and male athletes had lower BAI and BF% than non-athletes. All athletes, female athletes, and male athletes had larger hip circumferences than their non-athletes counterparts. Female athletes had smaller hip circumferences than female nonathletes. The athletes that participated in this study represented a wide gamut of sports, the majority coming from baseball (n=12), track/cross country (n=8), crew (n=7), and tennis (n=7).

Pearson's Correlations

All Subjects

Pearson's correlation coefficients and corresponding 95% confidence intervals for all subjects are presented in Table 3-4.

Table 3-4. Pearson's correlation coefficients for BAI to BF% and, BMI to BF% in all subjects

	BMI	BAI
Men	0.62 (0.52, 0.71)	0.65 (0.55, 0.73)
Women	0.62 (0.48, 0.73)	0.55 (0.39, 0.68)
Total	0.31 (0.19, 0.41)	0.73 (0.67, 0.79)

The correlations between BAI to BF% and BMI to BF% were not different for men [$r_{BAI\text{-}BF\%}$ =0.65; (0.55, 0.73), $r_{BMI\text{-}BF\%}$ =0.62; (0.52, 0.71)] and women [$r_{BAI\text{-}BF\%}$ =0.55; (0.39, 0.68), $r_{BMI\text{-}BF\%}$ =0.62; (0.48, 0.73)]. These relationships for men and women are illustrated in Figures 3-1 and 3-2 respectively.

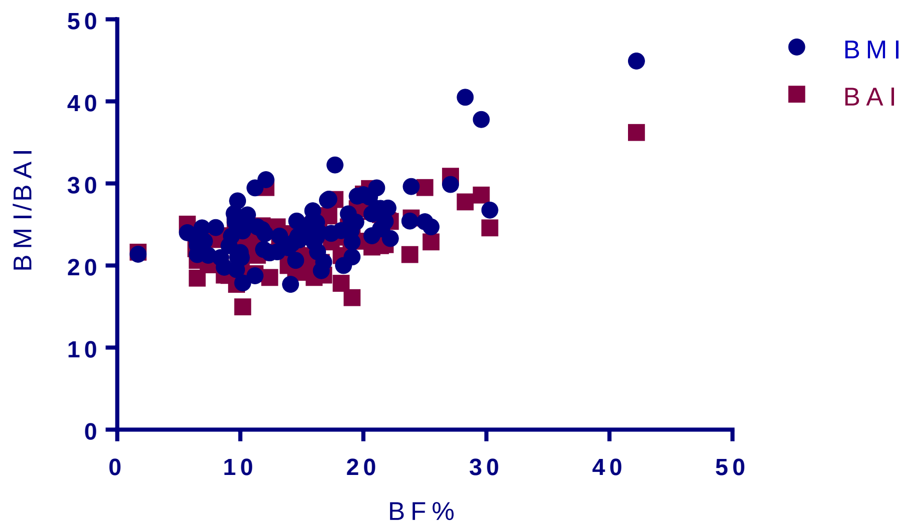

Figure 3-1. Correlation of BMI and BAI to BF% in all male subjects

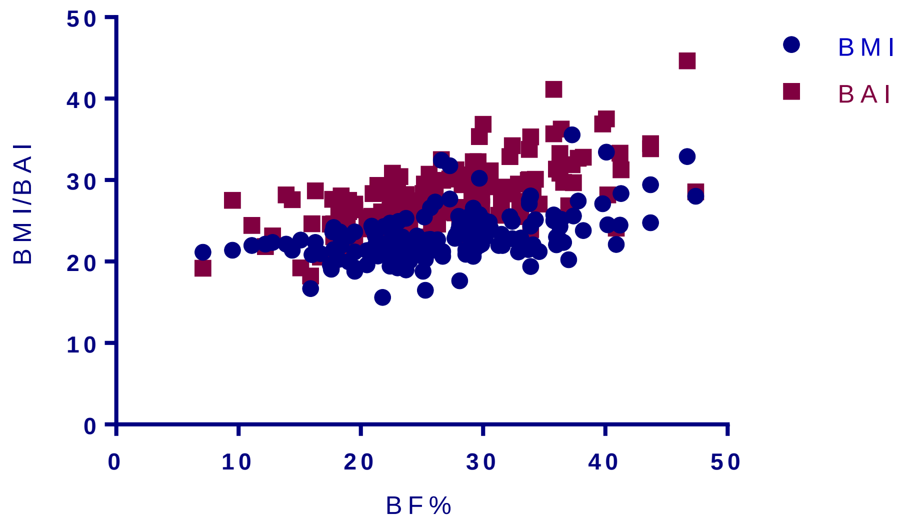

Figure 3-2. Correlation of BMI and BAI to BF% in all female subjects

For all participants BAI was more strongly correlated to BF% than BMI was correlated to BF% [r $_{\text{BAI-BF\%}}$ =0.73; (0.67, 0.79) vs. r $_{\text{BMI-BF\%}}$ =0.31; (0.19, 0.41)]. The confidence intervals for all subjects do not overlap, which indicates that the correlations are different. This relationship is illustrated in Figure 3-3.

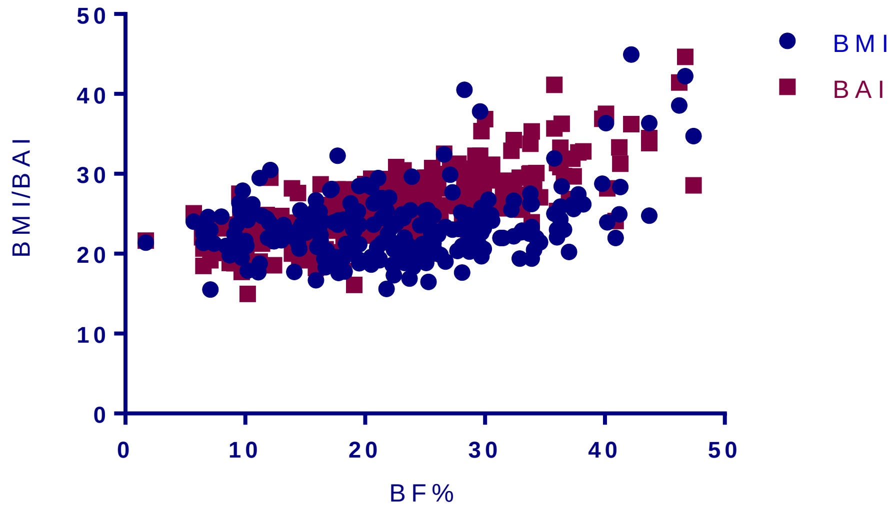

Figure 3-3. Correlation of BMI and BAI to BF% in all subjects

A Bland-Altman limits of agreement between BAI and BF% for all subjects is presented in Figure 3-4.

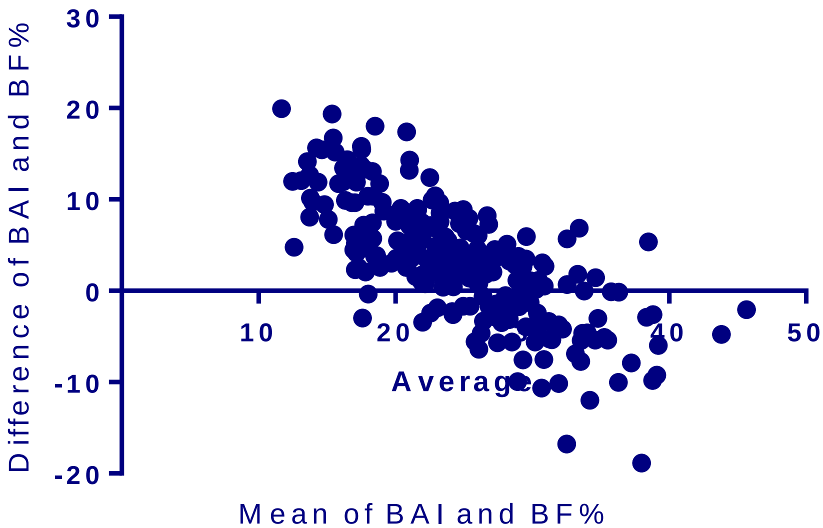

Figure 3-4. Bland-Altman limits of agreement plot between BAI and BF% in all subjects.

The limits of agreement (95% confidence intervals) between the BAI and BF% ranged between -9.5 and 16.2 Body adiposity index underestimated BF% at lower body fat percentages and overestimated BF% at higher BF%. The plot also showed that BAI predicted BF% well for those whose BF% was in the 20-30% range

Non-athletes

Pearson’s correlation coefficients and 95% confidence intervals for BAI, BMI and BF% for non-athletes are presented in Table 3-5.

Table 3-5. Pearson's correlation coefficients for BAI to BF% and BMI to BF% in nonathletes

	BMI	BAI
Men	0.66 (0.50, 0.78)	0.63 (0.45, 0.76)
Women	0.72 (0.63,0.80)	0.66 (0.55, 0.74)
Total	0.38 (0.25, 0.49)	0.76 (0.70, 0.81)

In nonathletes, the correlations between BAI to BF% and BMI and BF% were not different for men [$r_{BAI-BF\%}$ =0.63; (0.45, 0.76), $r_{BMI-BF\%}$ =0.66; (0.50, 0.78)] and women [$r_{BAI-BF\%}$ =0.66; (0.55, 0.74), $r_{BMI-BF\%}$ =0.72; (0.63, 0.80)]. The correlations are for men and women are illustrated in Figures 3-5 and 3-6 respectively.

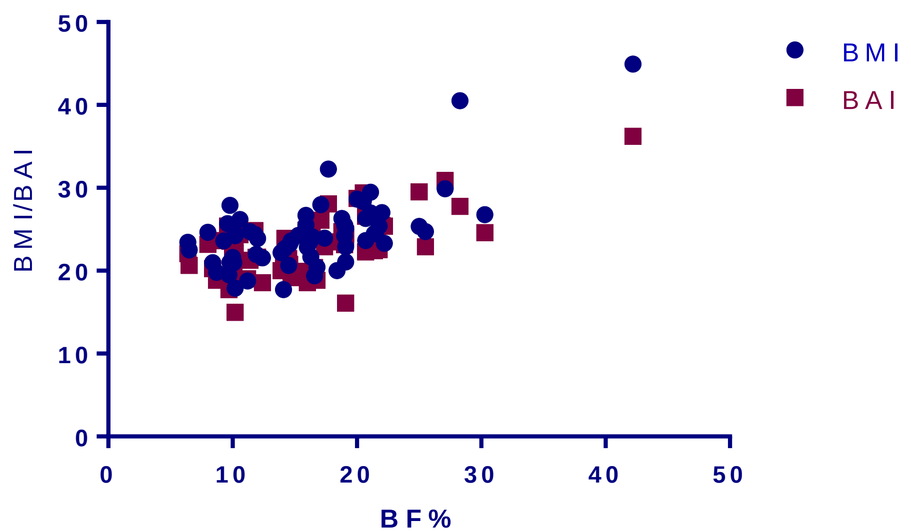

Figure 3-5. Correlation of BMI and BAI to BF% in male non-athletes

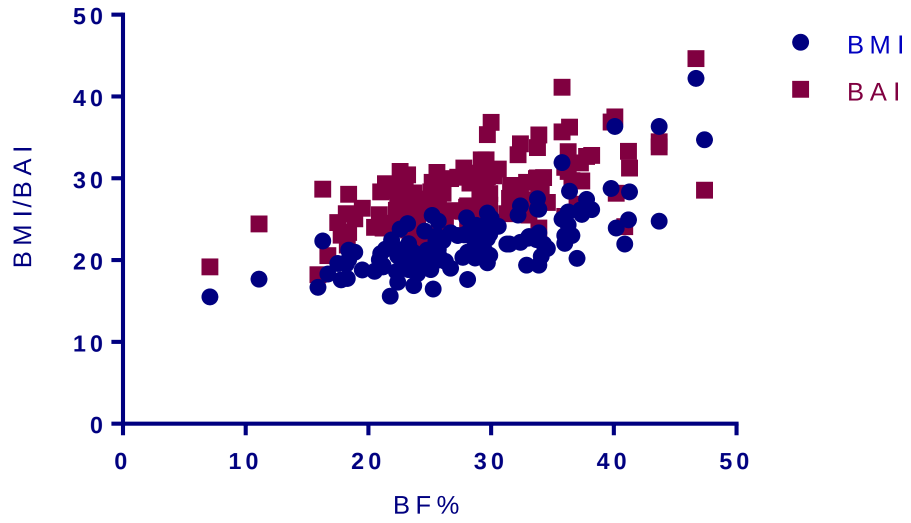

Figure 3-6. Correlation of BMI and BAI to BF% in female non-athletes

BAI correlated more strongly with BF% than BMI in non-athletes [$r_{BAI-BF\%}$ =0.76; (0.70, 0.81) vs. $r_{BMI-BF\%}$ =0.38; (0.25, 0.49)]. Since the confidence intervals do not overlap the correlations are different. The correlation of BAI to BF% and the correlation of BMI to BF% in non-athletes is illustrated in Figure 3-7.

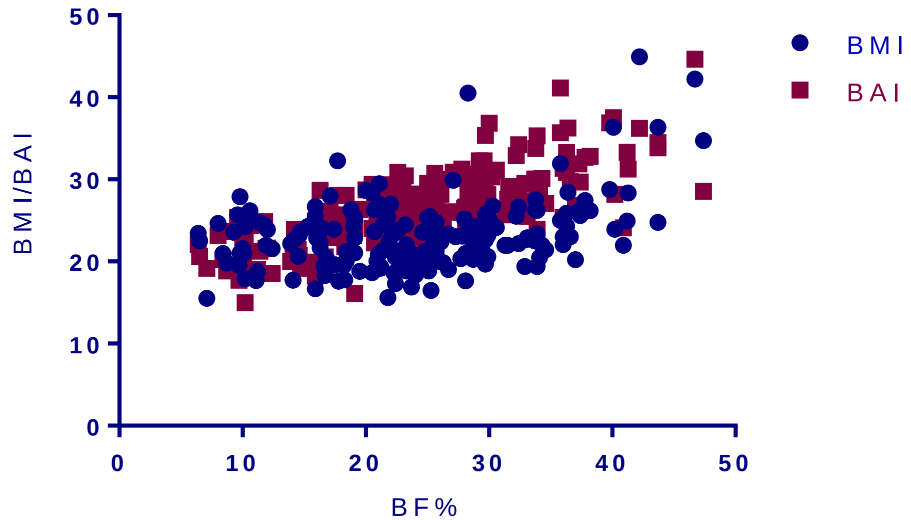

Figure 3-7. Correlation of BMI and BAI to BF% in nonathletes

The Bland-Altman limits of agreement plot in non-athletes is illustrated in Figure 3-8.

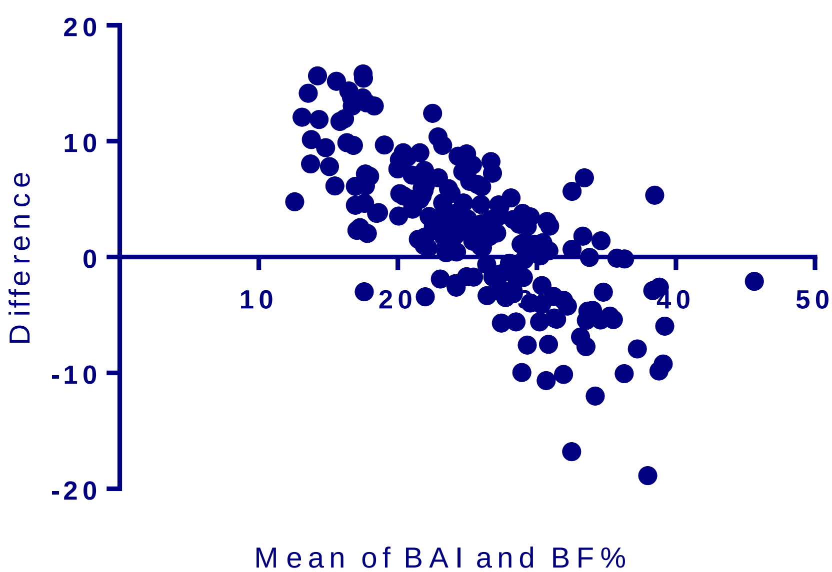

Figure 3-8. Bland-Altman limits of agreement plot between BAI and BF% in non-athletes

The limits of agreement (95% confidence intervals) between the BAI and BF% ranged between -9.8 and 14.4. According to this plot BAI overestimated BF% at lower levels of adiposity and underestimated BF% at higher levels of adiposity.

Athletes

The Pearson's correlation coefficients and 95% confidence intervals for BAI, BMI, and BF% in athletes are listed in Table 3-5.

Table 3-6. Pearson's correlation coefficients for BAI to BF% and, BMI to BF% in athletes

	BMI	BAI
Men	0.62 (0.33, 0.81)	0.35 (0.02, 0.62)
Women	0.43 (0.04, 0.71)	0.24 (0.18, 0.59)
Total	0.29 (0.02, 0.52)	0.41(0.16, 0.61)

In athletes BMI was more strongly correlated to BF% than BAI in men $r_{BAI\text{-}BF\%}$ =0.35; (0.02, 0.62), $r_{BMI\text{-}BF\%}$ =0.62; (0.33, 0.81) and women [$r_{BAI\text{-}BF\%}$ =0.24; (0.18, 0.59), $r_{BMI\text{-}BF\%}$ =0.43; (0.04, 0.71)]. Although numerically higher the 95% confidence intervals overlapped for both the values with the estimate falling within the bounds. This indicates that two measures are not different. The correlations for men and women are illustrated in Figures 3-9 and 3-10 respectively.

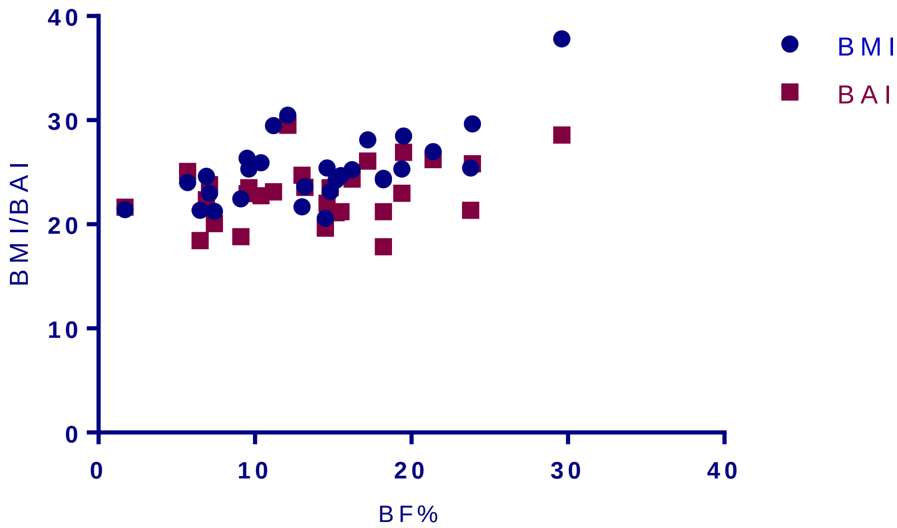

Figure 3-9. Correlation of BMI and BAI to BF% in male athletes

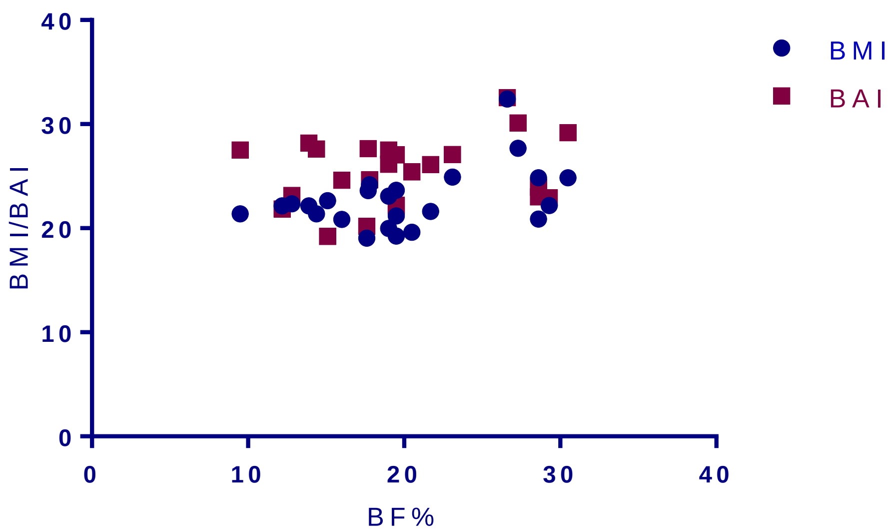

Figure 3-10. Correlation of BMI and BAI to BF% in female athletes

For all athletes BAI and BMI moderately to weakly correlated with BF%, [$r_{BAI-BF\%}$=0.41; (0.16, 0.61) vs. $r_{BMI-BF\%}$ =0.29; (0.02, 0.52)]. This relationship is illustrated in Figure 3-11

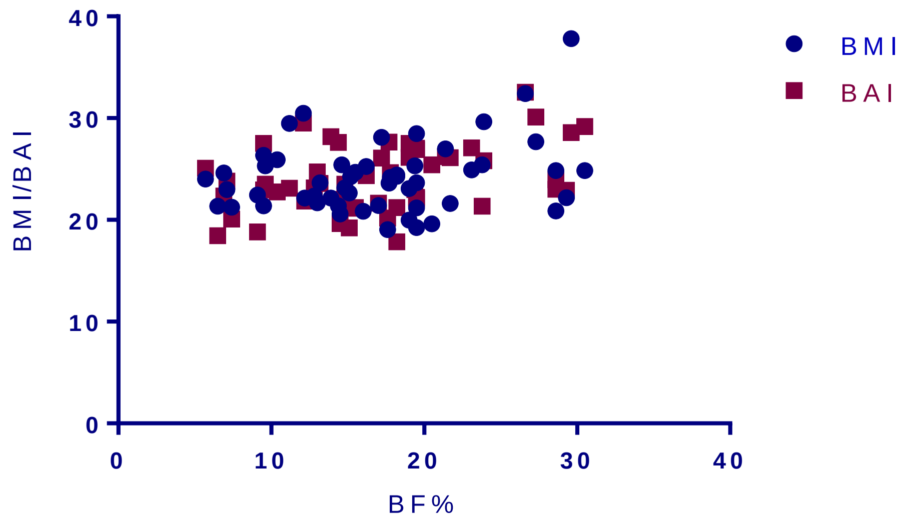

Figure 3-11. Correlation of BMI and BAI to BF% in all athletes

Bland-Altman limits of agreement plot between BAI and BF% in athletes is illustrated in Figure 3-12

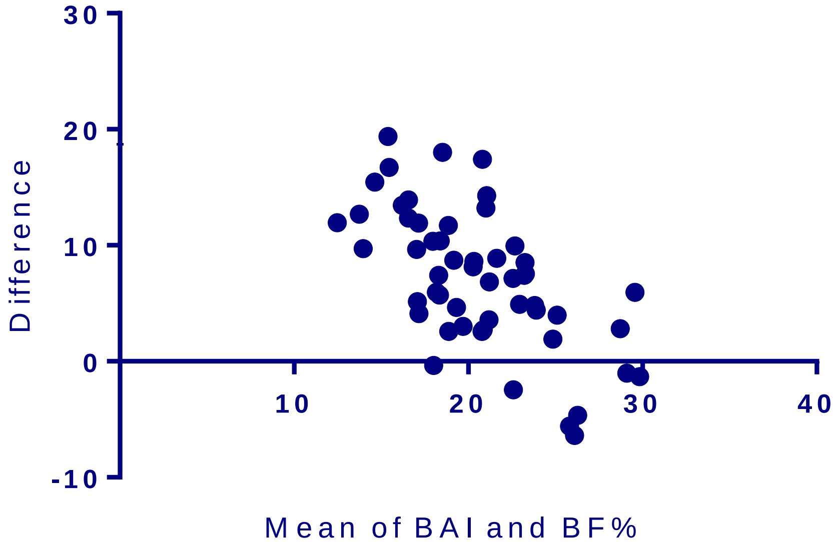

Figure 3-12. Bland-Altman limits of agreement plot between BAI and BF% in athletes

The limits of agreement (95% confidence intervals) between the BAI and BF% ranged between -4.5 and 18.8. According to this plot BAI overestimated BF% at all levels of adiposity

CHAPTER 4
DISCUSSION

Body adiposity index is a new anthropometric measure that has been shown to better reflect BF% than BMI in a variety of populations (60,72-77). The scientific literature is limited for BAI because of its relative newness. The purpose of this research was to determine whether BAI is an appropriate measure of adiposity in young non-athletes and athletes ages 18-24.

When separated by sex both BAI and BMI correlated similarly to BF%. This is consistent with the findings of Barreira et al. (75). They investigated the sex-specific relationship between BAI and BF% and BMI and BF% in a large biracial sample and found that in each sex and race group that the correlations with BF% were similar for BMI and BAI. Lopez et al (73), Johnson et al.(74), and Freedman et al.(76) showed the correlation between BAI and BF% was stronger than that of BMI and BF%, but BAI overestimated BF% in men and slightly underestimated BF% in women. The findings by Lopez et al. (73), Johnson et al. (74), and Freedman et al.(76) that BAI overestimated BF% in men and underestimated BF% in women could be explained by the fact that men tend to have lower BF%, whereas women tend to have higher BF% and BAI overestimates BF% at lower levels of adiposity and underestimate BF% at higher levels of adiposity. The findings by Lopez et al. (73), Johnson et al. (74), and Freedman et al.(76) could also be explained by the differences in hip circumferences of men and women. Bergman et al.(60) stated that hip circumference has the potential to introduce error when estimating BF% using BAI. A 10% change in hip circumference could produce a 10% change in BAI predicted BF% because it is in the numerator of the fraction defining BAI.

The correlation between BAI and BF% was stronger than the correlation between BMI and BF% for all subjects. These results agree with those reported in other studies of African Americans and Mexican Americans (60), Caucasians(74), and Europeans of all different ages(72,73). Although there was not enough subjects in the current study to analyze by race/ethnicity, BAI appears to reflect adiposity better than BMI in young adults of mixed ethnicities.

According to the Bland-Altman limits of agreement plot, BAI overestimated BF% at lower levels of adiposity by as much as 16.2% and underestimated BF% at higher levels of adiposity by as much as 9.5% for all subjects. The same relationship of BAI and BF% was observed by other studies in different populations (60, 72, 74, 76). Vinknes et al. (72) suggested the underestimation of BF% by BAI at higher levels of adiposity may be explained by, as weight increases, abdominal adiposity increases and this increased abdominal obesity is not captured well by hip circumference. Three subjects from this study have been chosen that illustrate this finding. Subject A had a lower BF% of 10.2% and BAI estimated BF% to be 22.1%. BAI overestimated BF% by 11.9%. Subject B had a high BF% of 33.1% and BAI estimated BF% to be 25.5%. BAI underestimated BF% by 7.6%. Subject C had a BF% to be 26.7% and BAI estimated BF% of 26.1%.

When athletes were separated from non-athletes a strong correlation was found between BAI and BF% in non-athletes, which was stronger than the correlation between BMI and BF%. The Bland-Altman limits of agreement plot in non-athletes also showed that BAI overestimated BF% at lower levels of adiposity by as much as 14.4% and underestimated BF% at higher levels of adiposity by as much as 9.9%. In addition, although neither BAI nor BMI correlated strongly to BF% in athletes, the correlation was higher for BAI. This finding coupled with the finding that BAI overestimates BF% at lower levels of adiposity suggest that BAI suffers from the limitations of BMI in this population. BMI does not correlate strongly with BF% in athletes because it only accounts for weight and has the inability to distinguish between fat and lean body mass, and athletes have elevated lean body mass. Even though BAI does not take into account weight when estimating BF% it does not correlate strongly with BF% in athletes because of their increased hip circumferences. In athletes the muscles around the hip region are very active and tend to be larger than the non-athlete population.

When comparing the correlation between BAI and BF% to that of BMI and BF% in the sex-by-athletic status sub-populations, BMI was more strongly correlated to BF% than BAI in male athletes and female athletes. Although numerically higher the 95% confidence intervals overlapped for both the values with the estimate falling within the bounds. This indicates that two measures are not different. These results are similar to those of Esco (77) who evaluated whether BAI reflected BF% better than BMI in 30 collegiate female athletes, but did not explore this same relationship in male athletes or in non-athletes. They found that neither BMI nor BAI correlated strongly to BF% but the correlation was higher for BMI.

Although BAI and BF% correlated more strongly than the correlation between BMI and BF% in the overall sample and the nonathlete sample, BAI and BMI correlated similarly to BF% when divided into sex, non-athlete, athlete, sex-by-non-athlete, and sex-by-athlete populations. The lack of differentiation in these sample populations, between BAI and BMI in this study could be a result of lost statistical power due to the division of the overall sample population into smaller and smaller subpopulations.

In conclusion, the results of this study have been consistent with other studies comparing BAI, BMI, and BF%. Body adiposity index, not BMI, correlates more strongly with BF% in the overall and non-athlete sample but BMI and BAI correlated similarly to BF% when the overall sample was divided into sex, non-athlete, athlete, sex-by-non-athlete, and sex-by-athlete populations. Body adiposity index may still suffer from the same limitations of BMI, such as overestimating BF% at lower levels of adiposity and underestimating BF% at higher adiposity. Body adiposity index appears to be good measure of adiposity in large epidemiological studies because of its convenience and low cost. When estimating BAI, a scale is not needed this could be an invaluable advantage of BMI especially when evaluating body composition in populations were a scale is not readily accessible. Although BAI offers advantages over BMI, it still remains inconclusive whether BAI is a more useful predictor of obesity related morbidity and mortality compared with BMI.

APPENDIX A
INFORMED CONSENT

Nonathletes

UF | UNIVERSITY of FLORIDA

INFORMED CONSENT

The Usefulness of Body Adipose Index to Reflect Adiposity in Young Adults

Please read this consent document carefully before you decide to participate in this study.

Purpose of the research study:

The purpose of this study is to determine whether Body Adiposity Index is a good indicator of body fatness in young adults.

What you will be asked to do in the study:

Everyone who chooses to participate in this study will be asked to:

1. Schedule physical assessments with the study coordinator and come to the Clinical Lab in the Food Science and Human Nutrition building at their assigned day and time.
2. Participate in a physical assessment (height and weight; hip and waist circumference; body fat percentage using air displacement plethysmography – BodPod, Life Measurement, Inc.).

Time Required: 30 minutes

Potential risks:

There is minimal risk to the participants. The BodPod assessment only uses air displacement as a measurement and is considered non invasive. It is an enclosed space, however, so there is a possibility of unease. Please let us know beforehand if you have ever experienced such an event, and we will closely monitor you during the assessment in order to stop immediately should a problem arise.

Benefits:

There is no direct benefit from this study but you will receive a copy of your weight and body fat percentage results.

Compensation:

You will not receive any form of payment for your participation in this study.

Confidentiality:

1

Your participation in this research is confidential to the extent provided by law. This means that only the research team will be able to see your data. Your study ID will be confidential. Your information will not be connected to your identity.

If you agree to take part in this research study, your personal information will not be given to anyone unless we get your permission in writing. It will only be given if the law requires it. We will make every effort to keep your information private, but it cannot be totally guaranteed.

The data will be stored and secured at the University of Florida Family Youth and Community Sciences Department. In the event of any publication or presentation resulting from the research, no personally identifiable information will be shared.

Costs of Participating:

There are no costs associated with participating in this study.

Voluntary Participation:

Your participation in this study is completely voluntary. There is no penalty for not participating.

Right to withdraw from the study:

You have the right to withdraw from the study at anytime without consequence. If you stop being in this research study, it will not affect how you are treated at University of Florida.

Whom to contact if you have questions about the study:

Karla P. Shelnutt, PhD, RD
Department of Family, Youth and Community Sciences
3038 McCarty Hall D
PO Box 110310
Gainesville, FL 32611-0310
Telephone: 325-273-3535
Email: kpagan@ufl.edu

Anne Mathews, PhD, RD
Food Science and Human Nutrition Department
359 FSHN Building,
PO BOX 110370
Gainesville, FL 32611-0370
Telephone 352-392-1991 X286
Email: anne.mathews@ufl.edu

Research Related Injury:

Emergency medical treatment will be given to you if you are hurt or get sick as a direct result of being in this research study. You or your insurance carrier are to pay for any such medical care. Any needed medical care is available at the usual cost. All needed facilities, emergency treatment, and professional services are available to you, just as they are to the general public. There are no plans to pay for your treatment if you get hurt or sick as part of this study. There are no plans for the University of Florida to pay for your treatment if you get hurt or sick as part of this study.

Whom to contact about your rights as a research participant in the study:

If you have questions about your rights as a research study subject, the University of Florida Institutional Review Board 02 (IRB) at (352)392-0433. The mailing address for the Univeristy of Florida IRB 02 is Box 112250, University of Florida, Gainesville, FL 32611-2250.

Federal law requires the Institutional Review Board to review and approve any research study involving humans. This must be done before the study can begin. The study is also reviewed on a regular basis while it is in progress.

Agreement:

I have read the procedure described above. I voluntarily agree to participate in the study, and I have received a copy of this description.

Participant:____ Date:________________

Study Representative:________________________ Date:________________

Athletes

UF UNIVERSITY of FLORIDA

INFORMED CONSENT

The Usefulness of Body Adipose Index to Reflect Adiposity in Student Athletes

Please read this consent document carefully before you decide to participate in this study.

Purpose of the research study:

The purpose of this study is to determine whether Body Adiposity Index is a good indicator of body fatness in student athletes.

What you will be asked to do in the study:

Everyone who chooses to participate in this study will be asked to:

Participate in a physical assessment (height and weight; hip and waist circumference; body fat percentage using air displacement plethysmography – BodPod, Life Measurement, Inc.).

Time Required: 30 minutes

Potential risks:

There is minimal risk to the participants. The BodPod assessment only uses air displacement as a measurement and is considered non invasive. It is an enclosed space, however, so there is a possibility of unease. Please let us know beforehand if you have ever experienced such an event, and we will closely monitor you during the assessment in order to stop immediately should a problem arise.

Benefits:

There is no direct benefit from this study but you will receive a copy of your weight and body fat percentage results.

Compensation:

You will not receive any form of payment for your participation in this study.

Confidentiality:

Your participation in this research is confidential to the extent provided by law. This means that only the research team will be able to see your data. Your study ID will be confidential. Your information will not be connected to your identity.

1

If you agree to take part in this research study, your personal information will not be given to anyone unless we get your permission in writing. It will only be given if the law requires it. We will make every effort to keep your information private, but it cannot be totally guaranteed.

The data will be stored and secured at the University of Florida Family Youth and Community Sciences Department. In the event of any publication or presentation resulting from the research, no personally identifiable information will be shared.

Costs of Participating:

There are no costs associated with participating in this study.

Voluntary Participation:

Your participation in this study is completely voluntary. There is no penalty for not participating.

Right to withdraw from the study:

You have the right to withdraw from the study at anytime without consequence. If you stop being in this research study, it will not affect how you are treated at University of Florida.

Whom to contact if you have questions about the study:

Karla P. Shelnutt, PhD, RD
Department of Family, Youth and Community Sciences
3038 McCarty Hall D
PO Box 110310
Gainesville, FL 32611-0310
Telephone: 325-273-3535
Email: kpagan@ufl.edu

Anne Mathews, PhD, RD
Food Science and Human Nutrition Department
359 FSHN Building,
PO BOX 110370
Gainesville, FL 32611-0370
Telephone 352-392-1991 X286
Email: anne.mathews@ufl.edu

Research Related Injury:

Emergency medical treatment will be given to you if you are hurt or get sick as a direct result of being in this research study. You or your insurance carrier are to pay for any such medical care. Any needed medical care is available at the usual cost. All needed facilities, emergency treatment, and professional services are available to you, just as they are to the general public. There are no plans to pay for your treatment if you get hurt or sick as part of this study. There are no plans for the University of Florida to pay for your treatment if you get hurt or sick as part of this study.

Whom to contact about your rights as a research participant in the study:

If you have questions about your rights as a research study subject, the University of Florida Institutional Review Board 02 (IRB) at (352)392-0433. The mailing address for the Univeristy of Florida IRB 02 is Box 112250, University of Florida, Gainesville, FL 32611-2250.

Federal law requires the Institutional Review Board to review and approve any research study involving humans. This must be done before the study can begin. The study is also reviewed on a regular basis while it is in progress.

Agreement:

I have read the procedure described above. I voluntarily agree to participate in the study, and I have received a copy of this description.

Participant:____Date:________________

Study Representative:_________________________Date:________________

APPENDIX B
DATA COLLECTION SHEETS

ID_______________

DATA FORM FOR MEN

BIRTHDATE (mo/day/yr):	
Year in School (circle) First Second Third Fourth	**Major:**
Race: (Please Circle) American Indian or Alaska Native Asian Black or African American Native Hawaiian or Other Pacific Islander White	**Ethnicity: (Please Circle)** Hispanic or Latino Not Hispanic or Latino

A certain amount of body 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. If too much accumulates over time, health may be compromised.

1. Have you ever had your body fat percentage measured by a trained professional? yes no

2. What is your current body fat percentage range (circle one)?

<5% 5-8% 9-12% 13-20% 21-30% >30%

3. Which of the following best describes your current body fat percentage (circle one)?

Risky (Too Low) Ultra Lean Lean Moderately Lean Excess Fat Risky (Too High)

4. What is your current Height? ___________

5. What is your Current weight? ___________

6. Do you know what body mass index is?

Yes No

7. Which of the following best describes your current weight (circle one)?

underweight normal weight overweight obese

Data collector initials ____________________

Weight (pounds)	
Height (inches)	
Hip Circumference (cm)	
Waist Circumference (cm)	
Body Fat Percentage	
Sagittal Abdominal Diameter	

ID________________

DATA FORM FOR WOMEN

BIRTHDATE (mo/day/yr):	
Year in School (circle) First Second Third Fourth	**Major:**
Race: (Please Circle) American Indian or Alaska Native Asian Black or African American Native Hawaiian or Other Pacific Islander White	**Ethnicity: (Please Circle)** Hispanic or Latino Not Hispanic or Latino
Are you currently pregnant or lactating?	

A certain amount of body 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 12-15% for women. If too much accumulates over time, health may be compromised.

1. Have you ever had your body fat percentage measured by a trained professional? yes no

2. What is your current body fat percentage range (circle one)?

<15% 15-18% 18-22% 22-30% 30-40% >40%

3. Which of the following best describes your current body fat percentage (circle one)?

Risky (Too Low) Ultra Lean Lean Moderately Lean Excess Fat Risky (Too High)

4. What is your current Height? __________

5. What is your Current weight? __________

6. Do you know what body mass index is?

   Yes No

7. Which of the following best describes your current weight (circle one)?

   underweight normal weight overweight obese

Data collector initials ____________________

Weight (pounds)	
Height (inches)	
Hip Circumference (cm)	
Waist circumference (cm)	
Body Fat Percentage	
Sagittal Abdominal Diameter	

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BIOGRAPHICAL SKETCH

Blake Bartholomew received his Bachelor of Science in food science and human nutrition from the University of Florida in the spring of 2010. After graduating Blake taught at Vero Beach High School for one year. In the spring of 2013 he received his Master of Science in human nutrition from the University of Florida and hopes to become a Registered Dietician.