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COMPARISON OF QUICK METHODS FOR DETERMINING BODY COMPOSITION IN FEMALE COLLEGIATE ATHLETES AND OBESE FEMALES

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COMPARISON OF QUICK METHODS FOR DETERMINING BODY COMPOSITION IN FEMALE COLLEGIATE ATHLETES AND OBESE FEMALES

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science Hospitality and Dietetics
Administration in the
College of Agriculture, Food, and Environment
at the University of Kentucky

By

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Lexington, KY

Director: Dr. Janet S. Kurzynske, Ph.D., RD

ABSTRACT OF THESIS

COMPARISON OF QUCK METHODS FOR DETERMINING BODY COMPOSITION IN FEMALE COLLEGIATE ATHLETES AND OBESE FEMALES

The Body Mass Index (BMI) is a tool used broadly by public health agencies to assess weight in populations. However, when differentiating between fat mass and fat free mass the formula (BMI = weight in kilograms/height in meters^2) is not applicable. Research suggests that evaluating body fat percentage and adipose tissue deposition may provide a nuanced indication of overall health, making it more accurate on an individual basis. This study evaluated four methods (Body Mass Index, waist circumference, A Body Shape Index, and Waist to Stature Index) that assess body composition and their ability to predict body fat percentage in female collegiate athletes and overweight/obese females. The study also investigated if the CUN-BAE formula could calculate body fat percentage accurately in comparison to air displacement plethysmography in both populations. The study found that the universality of these algorithms is uncertain in diverse populations and that the predictive power of anthropometric-based formulas is inconsistent when considering body fat percentage.

KEYWORDS: Body fat percentage, adiposity, overweight, obesity, body composition

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__________April 18, 2016__________

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Chapter One

Introduction

Background

The prevailing obesity epidemic in the United States has been under close surveillance for more than two decades by many public health agencies and governing bodies. Weight status is a key indicator of the overall health of an individual. Research provides evidence that associates failure to maintain a healthy weight with one's risk of developing cardiovascular disease, type II diabetes, stroke, and other diseases that can lead to preventable deaths (Division of Nutrition, Physical Activity, and Obesity, 2015). In general, weight status is measured as body mass index, a proportion of an individual's weight to their height, and is considered healthy if it falls within what is considered to be the normal range.

The Body Mass Index (BMI) is a tool used broadly by public health agencies to assess weight in populations. However, when differentiating between fat mass and fat free mass the formula (BMI = weight in kilograms/height in meters^2) is not valid. Another limitation of the BMI is that it does not give differentiate between genders, whereas with body fat normal ranges differ for males and females. As a result, the BMI cannot always properly infer the risk of chronic disease that is associated with a higher degree of body fat (Cornier, et al., 2011).

A shift is occurring in the paradigm of research, suggesting that an evaluation of body fat percentage and deposition of adipose tissue may provide a refined indication of overall health, making it more accurate on an individual basis. Presently, new algorithms are being developed and tested. The accuracy of such algorithms should be comparable to that of more intricate methods of assessing body composition as found with air displacement plethysmography (ADP).

Problem Statement

Body Mass Index does not always accurately indicate body fat percentage because it does not differentiate fat free mass from fat mass, it also does not account for sex or age. Therefore, association of obesity related health risks with BMI alone could lead to fallacious assumptions, even for individuals who fall within the normal range. Universal algorithms that can assess body fat accurately are warranted.

Purpose Statement

The purpose of this study is to evaluate the accuracy of a new algorithm for calculating body fat percentage and to examine the effectiveness of other anthropometric formulas in predicting body fat percentage. This study will evaluate the usefulness of these calculations in two different populations, female collegiate athletes and overweight/obese females.

Justification

Alternative methods for determining body composition, specifically body fat percentage are being developed in order to evaluate health and risk of obesity-associated comorbidities. Research that evaluates these methods is limited, especially in diverse populations. If an algorithm can accurately predict body fat percentage, its application as a comprehensive public health tool could be more useful than BMI alone when assessing obesity-related health risk. This study will evaluate the usefulness of some alternative methods of assessing health risk.

Objectives

1. To determine the correlation between BMI, waist circumference, Waist to Stature Index, A Body Shape Index and body fat percentage in a population of female athletes and overweight/obese women. To determine if anthropometric-based algorithms can predict body fat percentage comparatively to a validated instrument that distinguishes fat mass from fat free mass.
2. To determine the correlation between the CUN-BAE calculation and body fat percentage measured by air displacement plethysmography in a population of female athletes and overweight/obese women. To determine how new algorithms' prediction of body fat compares with the prediction of the BMI.

Hypotheses

1. The prediction of body fat percentage will not be as strong with athletes as it is with non-athletes with regards to BMI or other anthropometric-based algorithms.
2. The accuracy of the CUN-BAE algorithm will vary between athletes and non-athletes.

Assumptions

This study necessitates the assumption that all measurement instruments were calibrated and functioning properly, and that measurement protocols were followed precisely. It is also assumed that all participants complied with instructions in order to facilitate accurate measurements.

Chapter Two

Review of Related Literature

Introduction

The focus of this literature review is to overview the emerging research that evaluates the efficacy of the BMI in diverse populations. It will provide a synopsis of some of the alternative methods for assessing body composition and their implications to health. A body of evidence describing of the role of body fat in health and disease is summarized as a basis for necessitating body fat evaluation as a parameter of assessment when determining risk of adverse health conditions associated with excess adiposity.

Obesity and Health

The prevalence of obesity in the United States is of concern given the undoubted association between excess adiposity and adverse health effects. As a result of this correlation, countless population-based studies have substantiated that the relationship between BMI and the comorbidities associated with excess body fat are evident. Among other conditions, excess body fat has been associated with cardiovascular diseases, cancer, sleep apnea, hypertension, osteoarthritis, diabetes mellitus, dyslipidemia, and overall mortality (Division of Nutrition, Physical Activity, and Obesity, 2015).

Emerging research is unveiling that the relationship between body fat and risk of adverse health conditions is founded in the heterogeneity of fat distribution within the body. For instance, the American Heart Association (AHA) reports that abdominal obesity specifically has shown an association with stroke, coronary heart disease, and overall mortality independent of other cardiac risk factors. Furthermore, the AHA also describes that in spite of obese patients' greater risk of comorbidities than normal-weight individuals, some obese patients are classified as "metabolically healthy obese" because they exhibit trivial or no metabolic complications at all. Contrarily, others with the same level of obesity (in regards to BMI) could possess several health risk factors (Cornier, et al., 2011).

The Dallas Heart Study was a cohort of 972 obese and multicultural adults who were followed for a median of 9.1 years. Magnetic Resonance Imaging (MRI) was used to investigate the associations between visceral adipose tissue (VAT) and abdominal subcutaneous adipose tissue (SAT) and other factors with risk for cardiovascular disease (CVD) events. The researchers observed 108 initial or subsequent cardiovascular events among 81 patients (Neeland, et al., 2015). The incidence of CVD increased across sex and race-specific quartiles of VAT from 5.3% to 10% in quartiles 1 and 4 respectively. In a multivariate analysis that adjusted for age, sex, race, hypercholesterolemia, smoking status and BMI, VAT remained associated with CVD. Interestingly, an adjustment for a baseline diabetes status modestly attenuated this association. Lean mass and physical activity correlated inversely with CVD. BMI, along with abdominal SAT and liver fat were not associated with CVD in this study. It can also be proposed that advanced imaging tools can better distinguish phenotypic obesity (Neeland, et al., 2015).

Limitations of the BMI

The Body Mass Index is one of the most well-known and utilized tools for assessing weight and health in populations. Many public health organizations consider a person to be underweight if their BMI (measured in kg/m^2) is less than 18.5, normal weight if between 18.5 and 24.9, from 25-29.9 is overweight, class I obesity is considered between 30-34.9, class II obesity between 35- 39.9, and class III (extreme) obesity is considered at a BMI of 40 or higher, as listed by Cornier, et al (2011). Although BMI typically is associated with adverse health effects at obese levels, it does not differentiate the various tissues within the body composition such as fat mass, lean tissue, bone, etc. The BMI also does not account for other influential health factors such as sex, age, and activity level. For this reason, it is no longer regarded as accurate when assessing individual body composition and associated risk of non-obese persons. Furthermore, it has been proven that being of normal weight, lean, or even underweight does not eliminate one's risk for comorbidities associated with excess adiposity. Therefore, the BMI is not entirely reliable when it comes to evaluating potential health risks of these individuals, and methods that define adiposity should be employed in addition to its use.

Having significant amounts of lean muscle mass can lead to an individual being misclassified as overweight or obese by the BMI. In a study of 226 varsity male and female athletes and healthy college male and female non-athletes, Ode and colleagues concluded that BMI was not accurate measure of body fatness in assessing obesity in college athletes and non-athletes (2007). They found that among all normal fat male athletes, 73% were misclassified as overweight and 40%

of normal fat non-athletes met the same outcome. Within these two groups respectively, a BMI ≥ 25 kg/m^2 incorrectly classified the males as normal fat 87% and 44% of the time. Of all normal fat female athletes, 34% were misclassified. A BMI ≥25 kg/m^2 misclassified female athletes 77% of the time, and 44% of overfat female non-athletes were classified as normal weight (Ode, Pivarnik, Reeves, & Knous, 2007).

Other Anthropometric Measurements and Algorithms

A Body Shape Index

Krakauer and Krakauer developed A Body Shape Index (ABSI) to predict premature mortality independently of the BMI. It is based on waist circumference (WC) that is adjusted for height and weight, and provides insight on the predictive ability of abdominal obesity that the BMI alone cannot produce. The researchers used public-use releases of baseline interview and medical examination and mortality outcome data from the National Health and Nutrition Examination Survey (NHANES) 1999-2004 (Krakauer & Krakauer, 2012). Included in the study were 14,105 subjects ages 12-19 years and 60 years and older. Basic anthropometric measurements were taken during a physical examination at a mobile examination center following a survey conducted in an in-home interview. Mortality outcomes that were based on the National Death Index were used, which represents a 2-8 year follow up. From the data, the algorithm was developed as ABSI: $WC/BMI^{2/3}*Height^{1/2}$ where WC represents waist circumference in meters (Krakauer & Krakauer, 2012).

It was found that correlation between ABSI and height, weight, and BMI was minute. Contrarily, death rates correlated very strongly with baseline ABSI across age, sex, BMI, and white and black ethnicities (overall regression coefficient of z 33% per standard deviation of ABSI with 95% confidence interval of z20%-z48%). Furthermore, comparing the excess mortality hazard from high ABSI with high BMI and high WC revealed that 22% of the population mortality hazard was attributable to high ABSI, while 15% was attributable to each BMI and WC. The association of ABSI with mortality hazard was not attenuated after adjusting for other known risk factors. From this study it was concluded that at a determined height and weight, high ABSI might correspond to a greater fraction of visceral fat compared to peripheral tissue. Body shape, as determined by ABSI, substantiates risk for premature mortality in the general population (Krakauer & Krakauer, 2012).

In a subsequent study, Dhana and colleagues found that among BMI, WC, ABSI, waist-to-height ratio, and waist-to-hip ratio that ABSI had a stronger association with total, cardiovascular, and cancer mortality. Conversely, limitation was expressed with the added predictive value of ABSI in prediction of mortality due to the lack of detailed data on life-threatening conditions at baseline (Dhana, Kavousi, Ikram, Tiemeier, Hofman, & Franco, 2016).

Waist Circumference

Abdominal obesity is a well-known indicator of health risks. Waist circumference (WC) is a simple, economical, and effective method of central obesity assessment. Typically it involves the use of a tape measure while the patient is standing, wearing light clothing, and at the end of expiration. WC has been shown to correlate with abdominal imaging and to have a high association with CVD risk and mortality. The established cut points of the WC correspond to a BMI in the range of 25-29.9 kg/m^2. In women the cut points are 80 and 88 cm and for men 94 and 102 cm, and refer to measurements taken at the midpoint. Measurements beyond these thresholds have correlations with VAT and cardiometabolic risk factors (Bosy-Westphal, et al., 2010).

Despite the ease of use and association with increased risk for adiposity related morbidity and mortality, WC has been poorly adopted in clinical practice. One potential pitfall is that there are multiple different measurement locations that have been documented, which obviously produces varied estimates (Cornier, et al., 2011) One potential solution would be to suggest that practitioners examine the literature and choose a measurement location based on the evidence. Another option is to follow recommendations established by public health organizations. One limitation of WC is the lack of ability to distinguish visceral fat deposition from subcutaneous fat. Moreover, body composition varies with age, sex, and ethnicity however, normative sex and age specific data that defines obesity are lacking (Gurunathan & Myles, 2016).

Waist to Stature Index

There is a growing body of evidence that suggests that waist to stature index (WSI) is a good predictor of health risk, this is in particular regard to hypertension, type II diabetes, and dyslipidemia. The cut off for both males and females is 0.5. The researchers insinuate that an individual's waist circumference should not exceed half of their body height, a measurement above this ratio would be undesirable (Ashwell & Hsieh, 2005).

One study found the WSI as the best indicator of cardiovascular risks when compared to WC, waist to hip ratio (WHR), and BMI. The researchers report that WSR is a good indicator of abdominal visceral fat, CVD risk factors and mortality in cross-sectional and cohort studies. The variables are easily measured and calculated regardless of the unit of measurement utilized. It is also stated that the WSI is likely to be more globally robust than any WC cut off value given a wide range of heights. This allows for individualization within the WSI because as one's stature is fixed, still those with different statures can have separate cut offs for waist circumference. This study implies that it could be promoted to the public that one's waist measurement should not exceed half the body height for both males and females (Ho, Lam, & Janus, 2003).

Clínica Universidad de Navarra-Body Adiposity Estimator

An algorithm known as Clínica Universidad de Navarra-Body Adiposity Estimator (CUN-BAE) has been developed based on BMI, sex, and age for estimating body fat percentage (BF%). The calculation is $BF\% = -44.988 + (0.503 \times age) + (10.689 \times sex) + (3.172 \times BMI) - (0.026 \times BMI^2) + (0.181 \times BMI \times sex) - (0.02 \times BMI \times age) - (0.005 \times BMI^2 \times sex) + (0.00021 \times BMI^2 \times age)$ where male = 0 and female = 1 for sex and age in years (Gomez-Ambrozi, et al., 2012).

In a sample of 6,510 white males and females aged 18-80 years, the usefulness of this equation was evaluated by the researchers and determined to be an accurate body adiposity estimator when compared to other anthropometric methods, body adiposity index (BAI), and air displacement plethysmography (ADP). The mean body fat percentage as determined by ADP for the entire sample was 39.9 ± 10.1%, whereas the mean estimation by the CUN-BAE was 39.3 ± 8.9%. When compared with the anthropometric measurements, CUN-BAE also showed the highest correlation with actual BF%, followed by waist-to-height ratio. This equation was validated in a separate cohort of 1.149 individuals. Again, CUN-BAE showed a higher correlation with ADP BF% than did the BMI in women and men (Gomez-Ambrozi, et al., 2012).

The Bod Pod®

Air displacement plethysmography (ADP) has been use for nearly a century to measure body composition ((Cornier, et al., 2011). The Bod Pod® was developed to be an easier, faster, and safer way to assess adiposity while maintaining ambient conditions. This method relies on the indirect measurement of the volume of an object from the volume of air that it displaces. Body volume is determined by the difference of the volume of air inside the chamber with a subject inside from the volume of air in an empty chamber. The software makes adjustments to volume calculations to account for air in the lungs and isothermal air near skin and hair on the scalp. From the adjusted volume, body density and BF% are calculated by using the subject's body weight and a two-compartment model. The Bod Pod® has been found reliable and valid when compared to other methods such as hydrostatic weighing and dual-energy x-ray absorptiometry (DEXA). Cornier and associates express that more than 30 documents have been published describing the usefulness of the Bod Pod® (2011) One limitation is that it does not give measurements on fat deposition, only a whole body assessment.

Body fat percentage can be classified into five general categories for men and women. Natalie Muth, MD, MPH, RD published the categories via an article found on acefitness.org in 2009. The table below describes the categories.

Table 2.1 General Body Fat Percentage Categories

Classification	Women (%fat)	Men (%fat)
Essential fat	10-13 %	2-5%
Athletes	14-20%	6-13%
Fitness	21-24%	14-17%
Average	25-31%	18-24%
Obese	32% and higher	25% and higher

(Muth, 2009)

Conclusion

The evidence suggests that there is a need for assessing body composition in diverse populations in different ways. The limitation observed with just anthropometric methods prevents accurate determination of health risks in individuals. However, potential exists for new algorithms to be better predictors of health and disease, more research is needed in these areas. Public health agencies and clinical establishments should adopt methods that allow for the adiposity of an individual to be evaluated in order to properly define risks. Studies specific to females and female athletes in the area of body fat percentage in relation to the topics discussed in this review are very limited, emerging research on these populations will be insightful and beneficial.

Chapter Three:

Methodology

The purpose of this study is to determine if correlation exists between current algorithms for calculating adiposity and measured body fat percentage. There is a need for an uncomplicated tool that can assess adiposity for the general public to provide a more accurate indicator of overall health in individuals from diverse populations. From this study, insight will be gained on how these algorithms can be applied in two different populations, and how their accuracy compares with that of the current preferred public health tool, which is the BMI.

Research Design

This study is a non-randomized, quantitative, correlational project. The data that were analyzed were a sample of a larger data set from two prior research projects conducted within the Department of Dietetics and Human Nutrition at the University of Kentucky; Division I Female Athletes representing 11 various sports and adult females from the general public who are classified as overweight or obese. Both studies collected the age of the subjects, anthropometric measurements of height, weight, and waist circumference (the waist circumference value for these subjects was actually an average of two or three separate measurements). Both also employed the Bod Pod® for measurement of body composition. These data were used to fill in the variables of the different algorithms to calculate BMI, ABSI, WSI, and CUN-BAE results. The results of the calculations were then assessed for correlation in comparison to results of body fat percentage measured from the Bod Pod®. A standard t-test was conducted to measure relativity of the body fat calculated from the CUN-BAE algorithm and the body fat measured by the Bod Pod®.

Subjects

A total of 285 subjects were sampled from both larger data sets, of which 205 were female collegiate athletes and 80 were overweight/obese females from the general public. The female athletes were dispersed among 11 different Women's Division I sports including Softball, Volleyball, Tennis, Track & Field, Swimming and Diving, Gymnastics, Cross Country, Basketball, Soccer, Rifle, and Golf. Measurements from this group were collected between August and December 2014. The sample of overweight and obese women was collected in the Spring of 2014, and was a convenience sample of women enrolled in a weight loss study.

All subjects were de-identified prior to sampling, and codes were assigned to each sport. For the purpose of continuity, the obese women were assigned a "sport code" as well and assigned to a "team" referred to as Unaffiliated. All subjects were also classified as either "Athlete" or "Non-athlete". Any subject who had missing anthropometric or body composition measurements was excluded from the study. Thirty-six of the female athletes had to be excluded for this reason.

Instruments

Anthropometric data for the subjects was collected in the Nutrition Assessment Laboratory at the University of Kentucky. All subjects participated in body composition measurement via the Bod Pod® which uses air displacement plethysmography (ADP) to measure the volume of air displaced within a sealed chamber of a pre-determined volume. To ensure accuracy, subjects are instructed not to eat or exercise heavily within the 2 hours prior to analysis, and they are encouraged to empty their bladders prior to entrance of the chamber. They must also wear tight fitting clothing such as Spandex or a swimming suit along with a swim cap.

Procedure

From the pre-existing data sets, the measured data were applied in the algorithms previously mentioned to calculate results. The formulas are as follows:

BMI = weight in kilograms/height in meters^2

ABSI = WC (m)/BMI$^{2/3}$*Height (m)$^{1/2}$

WSI = WC (m)/ Height (m)

CUN-BAE → BF% = -44.988 + (0.503 x age) + (10.689 x sex) + (3.172 x BMI) – (0.026 x BMI^2) + (0.181 x BMI x sex) – (0.02 x BMI x age) – (0.005 x BMI^2 x sex) + (0.00021 x BMI^2 x age) where male = 0 and female = 1 for sex; age in years

Data Analysis

The statistical software employed for this study was IBM SPSS v.23. Simple linear regression was applied between the measured percent body fat and each of the algorithms and waist circumference in order to examine the predictability of the models. Each test was performed in the female athletes as a whole and by sport, and in the obese women. For both activities a paired t-test was performed on the CUN-BAE and body fat percentage in order to examine the differences in means.

Chapter Four

Results

Demographics

A total of 249 female subjects were analyzed in this study, of which 169 were NCAA Division I Athletes and the remaining 80 were overweight/obese females who were not affiliated with an NCAA Division I sports team. Table 4.1 displays the average age, height, and weight of the Athletes and Non-Athletes.

Table 4.1 Demographics

Activity		age	height (m)	weight (kg)
Non-Athlete	**N**	**80**	**80**	**80**
	Mean	48.6875	1.61830	84.06625
	Minimum	22.00	1.480	61.010
	Maximum	65.00	1.740	118.980
	Std. Deviation	10.59686	.055026	12.122112
Athlete	**N**	**169**	**169**	**169**
	Mean	19.9519	1.68680	66.70846
	Minimum	17.90	1.412	48.862
	Maximum	24.44	1.937	101.601
	Std. Deviation	1.21077	.079921	10.707573
Total	**N**	**249**	**249**	**249**
	Mean	29.1842	1.66479	72.28526
	Minimum	17.90	1.412	48.862
	Maximum	65.00	1.937	118.980
	Std. Deviation	14.74960	.079491	13.800072

The mean age of the Athletes was 19.9 ±1.2 years and of the Non-Athletes was 48.7 ± 10.6 years. The mean height of the Non-Athletes was 1.6 ±0.05 m and for the Athletes the mean height was 1.7 ±0.08 m. The mean weight of the Non-Athletes was 84.1 ± 12.1 kg and the mean weight of the Athletes was 66.7 ±10.7 kg.

Analysis of Participation

Figure 4.1 displays the breakdown of participation followed by Table 4.2 exhibiting the descriptive statistics of each algorithm according to participation.

Figure 4.1 Participation Totals by Sport (N=249)

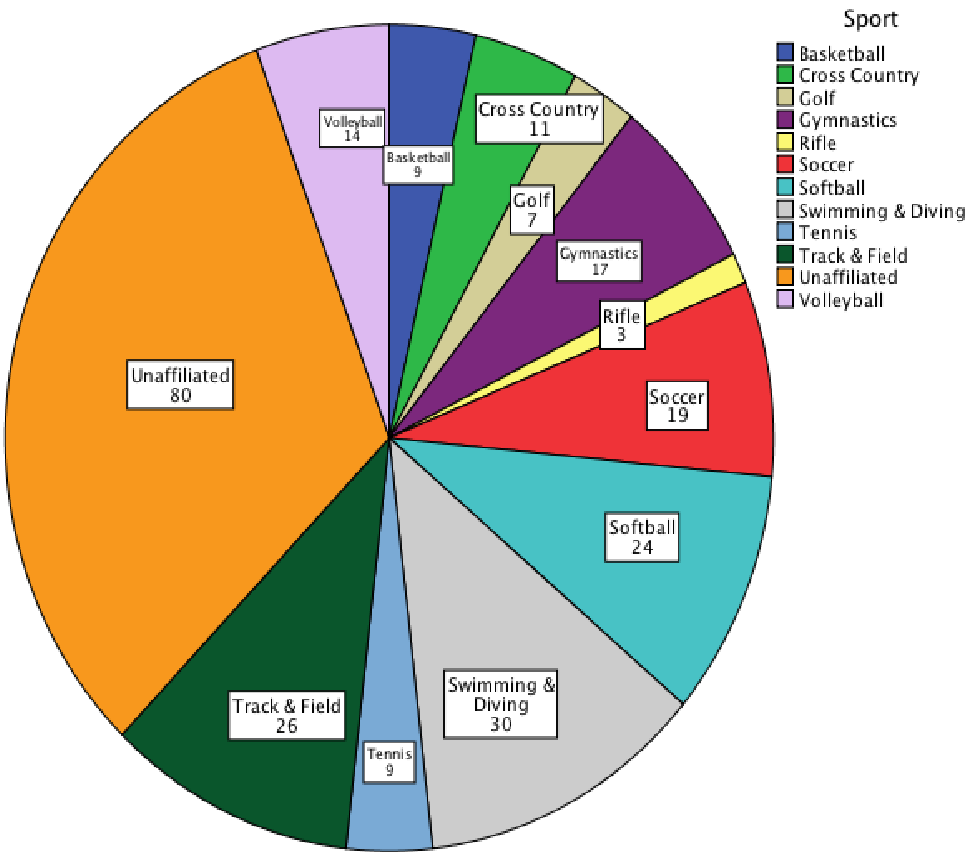


Table 4.2 Descriptive Statistics of Algorithms by Participation

Sport	Statistic	BMI	Waist m	WSI	ABSI	% fat	CUN-BAE
Swimming & Diving	Mean	23.03	.74	.432	.070	21.5	29.436
	Minimum	19.14	.63	.391	.065	10.2	22.096
	Maximum	25.83	.80	.475	.074	29.3	33.960
	Standard Deviation	1.83	.04	.020	.002	4.7	3.150
	Total N	**30**	**30**	**30**	**30**	**30**	**30**
Tennis	Mean	22.96	.67	.413	.065	17.6	29.412
	Minimum	19.26	.48	.295	.049	12.9	22.969
	Maximum	27.84	.74	.449	.071	22.7	37.420
	Standard Deviation	2.45	.08	.048	.007	3.1	4.101
	Total N	**9**	**9**	**9**	**9**	**9**	**9**
Golf	Mean	22.86	.78	.465	.075	27.4	29.112
	Minimum	20.10	.70	.406	.070	19.8	24.328
	Maximum	26.09	.96	.553	.085	36.1	34.485
	Standard Deviation	2.31	.09	.047	.005	6.1	3.956
	Total N	**7**	**7**	**7**	**7**	**7**	**7**
Track & Field	Mean	23.66	.70	.417	.066	15.3	30.169
	Minimum	18.22	.59	.343	.062	4.4	20.243
	Maximum	35.62	.91	.554	.070	35.1	46.845
	Standard Deviation	4.41	.08	.047	.002	7.8	6.683
	Total N	**26**	**26**	**26**	**26**	**26**	**26**
Rifle	Mean	21.72	.68	.424	.069	27.4	27.012
	Minimum	19.80	.65	.406	.064	22.5	23.349
	Maximum	24.15	.73	.434	.073	30.5	31.334
	Standard Deviation	2.22	.04	.016	.005	4.3	4.033
	Total N	**3**	**3**	**3**	**3**	**3**	**3**
Soccer	Mean	22.90	.67	.404	.065	19.3	29.237
	Minimum	19.17	.60	.364	.059	13.7	22.580
	Maximum	26.90	.78	.463	.068	32.3	35.928
	Standard Deviation	2.12	.05	.024	.002	4.2	3.653
	Total N	**19**	**19**	**19**	**19**	**19**	**19**

Table 4.2 (continued)

Volleyball	Mean	22.83	.72	.397	.066	20.5	29.219
	Minimum	19.66	.66	.366	.063	12.4	23.716
	Maximum	25.84	.82	.425	.070	31.9	34.235
	Standard Deviation	1.74	.04	.018	.002	5.2	2.972
	Total N	**14**	**14**	**14**	**14**	**14**	**14**
Basketball	Mean	24.76	.73	.416	.065	19.4	32.362
	Minimum	21.63	.65	.384	.062	9.5	27.264
	Maximum	26.83	.79	.453	.069	27.9	35.532
	Standard Deviation	1.89	.04	.025	.002	5.6	3.028
	Total N	**9**	**9**	**9**	**9**	**9**	**9**
Gymnastics	Mean	23.22	.70	.436	.068	19.9	29.789
	Minimum	20.25	.65	.413	.064	11.9	24.306
	Maximum	27.31	.79	.487	.071	28.1	36.216
	Standard Deviation	1.82	.04	.022	.002	4.7	3.042
	Total N	**17**	**17**	**17**	**17**	**17**	**17**
Softball	Mean	25.84	.75	.445	.066	24.3	33.916
	Minimum	20.71	.63	.374	.061	13.5	25.553
	Maximum	34.14	.96	.570	.071	34.5	45.305
	Standard Deviation	3.03	.07	.045	.003	4.8	4.363
	Total N	**24**	**24**	**24**	**24**	**24**	**24**
Cross Country	Mean	20.06	.69	.413	.072	15.3	23.974
	Minimum	17.22	.64	.373	.070	2.5	18.413
	Maximum	22.25	.74	.447	.078	24.0	27.976
	Standard Deviation	1.46	.03	.018	.002	5.9	2.827
	Total N	**11**	**11**	**11**	**11**	**11**	**11**
All Athletes	Mean	23.38	.72	.424	.068	20.1	29.922
	Minimum	17.22	.48	.295	.049	2.5	18.413
	Maximum	35.62	.96	.570	.085	36.1	46.845
	Standard Deviation	2.91	.06	.365	.004	6.3	4.656
	Total N	**169**	**169**	**169**	**169**	**169**	**169**
Unaffiliated	Mean	32.03	.97	.599	.076	44.2	44.783
	Minimum	25.10	.77	.490	.067	31.0	36.498
	Maximum	40.80	1.20	.727	.090	54.9	52.363
	Standard Deviation	3.70	.10	.058	.004	4.8	3.948
	Total N	**80**	**80**	**80**	**80**	**80**	**80**

Table 4.2 displays the descriptive statistics of each type of algorithm utilized in this study, it is divided by participation including a summary of the athletes as a whole. The mean BMI of the athletes was 23.38 ± 2.91 kg/m^2; the team with the highest mean BMI was Softball at 25.84 ± 3.03 kg/m^2 and the Cross Country team had the lowest with 20.06 ±1.46 kg/m^2. The mean waist circumference was 0.72 ± 0.06 m; the highest mean was found with the Golf team as 0.78 ±0.09 m and the lowest was Tennis (0.67 ±0.08 m) and Soccer (0.67 ±0.05 m). The mean WSI was 0.424 ± 0.365; the highest mean WSI was found with Golf at 0.465 ±0.047 and the lowest was Volleyball at 0.397±0.018. The ABSI mean was 0.068 ± 0.004; the Golf team had the highest with 0.075 ±0.005 while Tennis, Soccer, and Basketball had the lowest of 0.065 (±0.007, 0.002, 0.002 respectively). The mean body fat percentage (as measured by the Bod Pod®) was 20.1 ±6.3%; Track & Field and Cross Country both had the lowest BF% of 15.3% (±7.8% and 5.9% respectively) while the Golf and Rifle teams had the highest of 27.4% (±6.1% and 4.3% respectively). The mean body fat percentage as estimated by the CUN-BAE formula for the athletes was 29.9 ±4.7%; the Softball team had the highest estimate at 33.9% and the Cross Country team had the lowest with 23.9%.

For the Non-Athletes, the mean BMI was 32.03 ±3.7 kg/m^2. The mean waist circumference was 0.97 ±0.1 m. The mean WSI was 0.6 ±0.06 and the mean ABSI was 0.076 ±0.004. The mean body fat percentage for the Non-Athletes as measured by the Bod Pod® was 44.2 ±4.8%, and the CUN-BAE formula estimated very similar results at 44.8 ±3.9%.

Predictions Body Fat Percentage

The following figures display the linear regression results of the algorithms (BMI, WSI, and ABSI) and waist circumference predictive models concerning body fat percentage as measured by the bod pod. Each test was applied to the Athletes as a whole group and by sport, and also to the Non-Athletes.

Figure 4.2 Non-Athlete: BMI vs. Body Fat Percentage

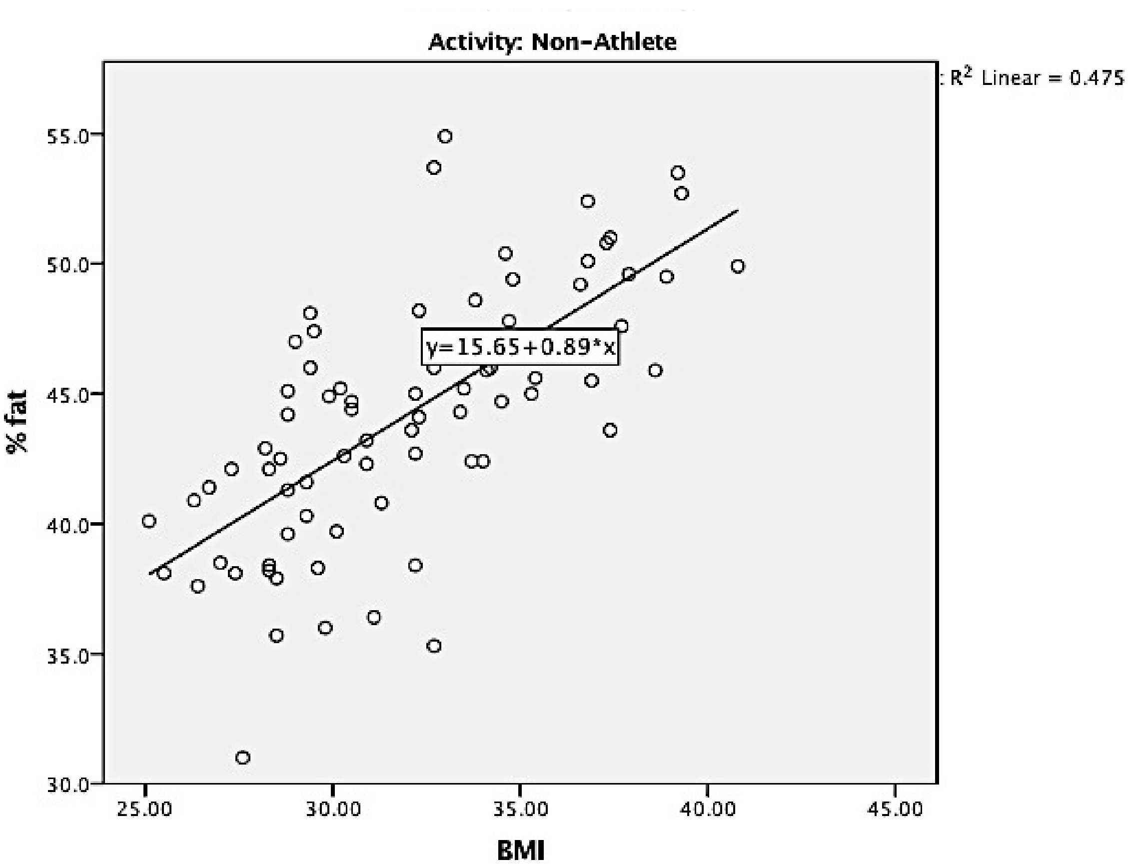
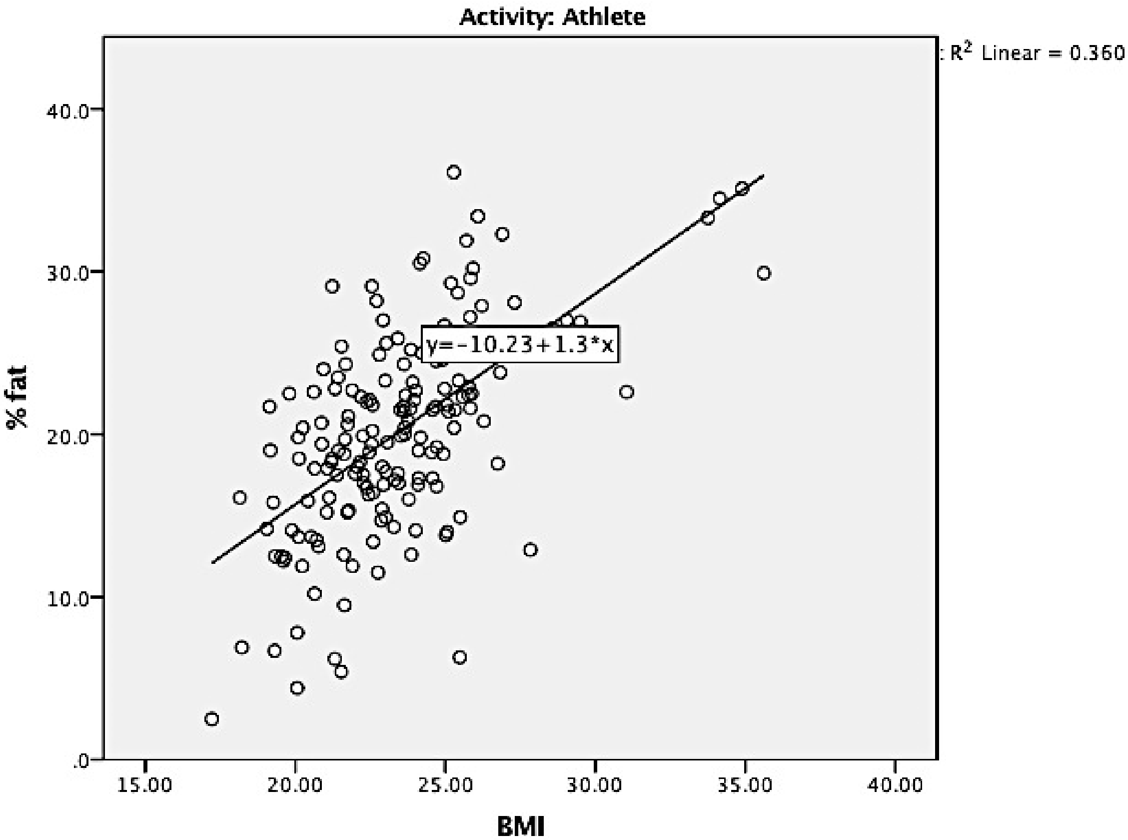


Figure 4.3 Athlete: BMI vs. Body Fat Percentage



In figure 4.2 the R^2 value is 0.475, and in figure 4.3 it is 0.36 respectively. The BMI is showing moderately strong predictive power for body fat percentage in the Non-Athletes whereas with the Athletes it is not as strong.

Figure 4.4 Non-Athlete: Waist Circumference vs. Body Fat Percentage

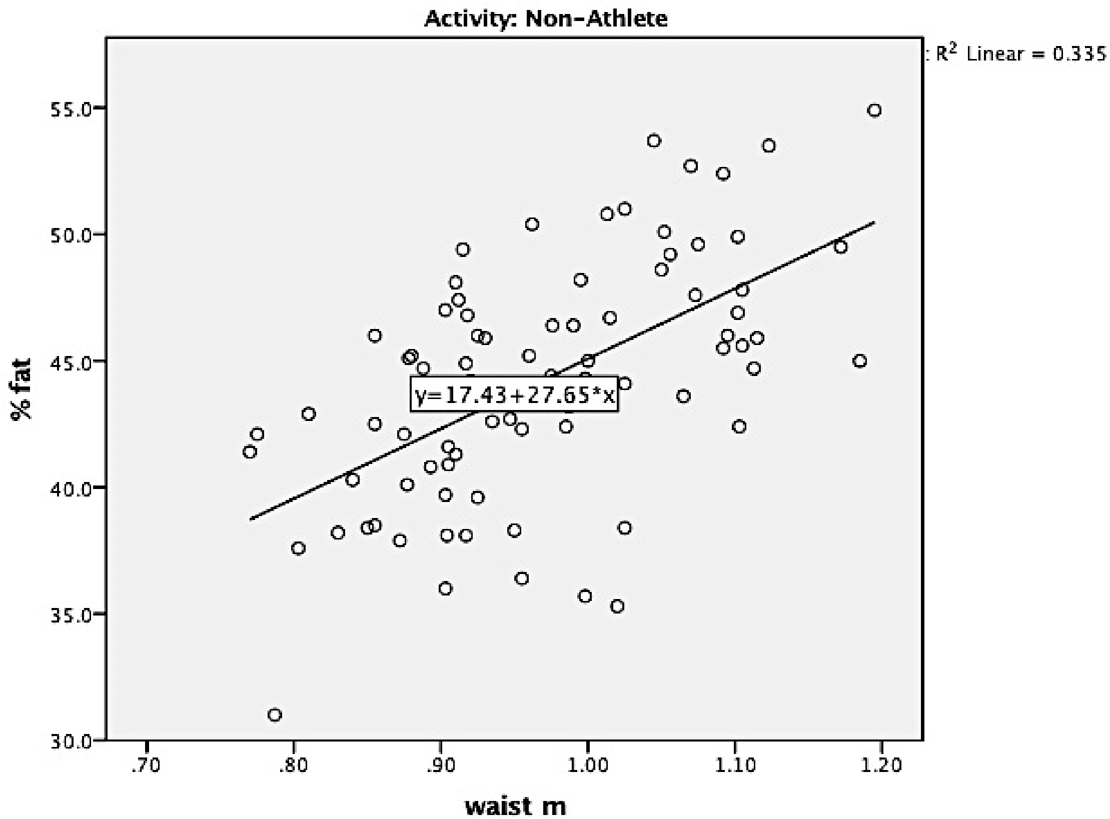
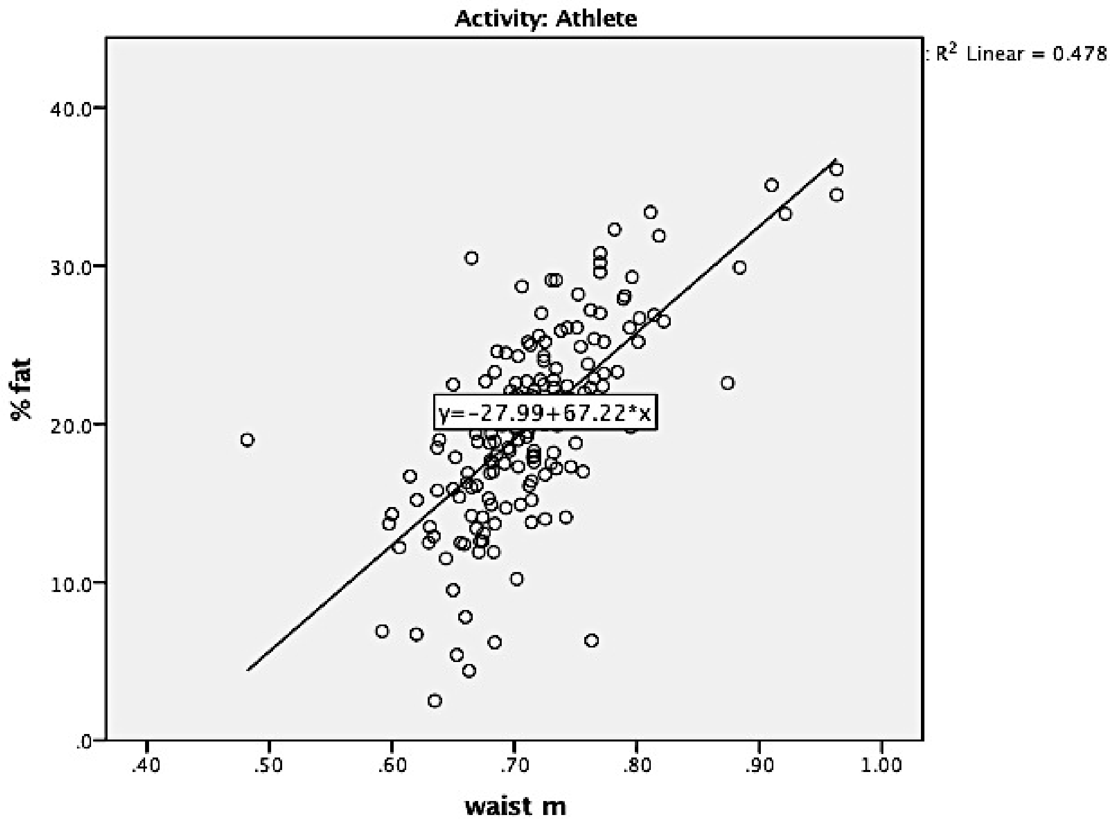


Figure 4.5 Athlete: Waist Circumference vs. Body Fat Percentage



Figures 4.4 and 4.5 display waist circumference (in meters) and body fat percentage. Waist circumference does not indicate strong predictive power in the Non-Athlete group, whereas it is moderately strong in the Athlete group. The R^2 value for the Non-Athlete group was 0.335 and for the Athletes it was 0.478.

Figure 4.6 Non-Athlete: WSI vs. Body Fat Percentage

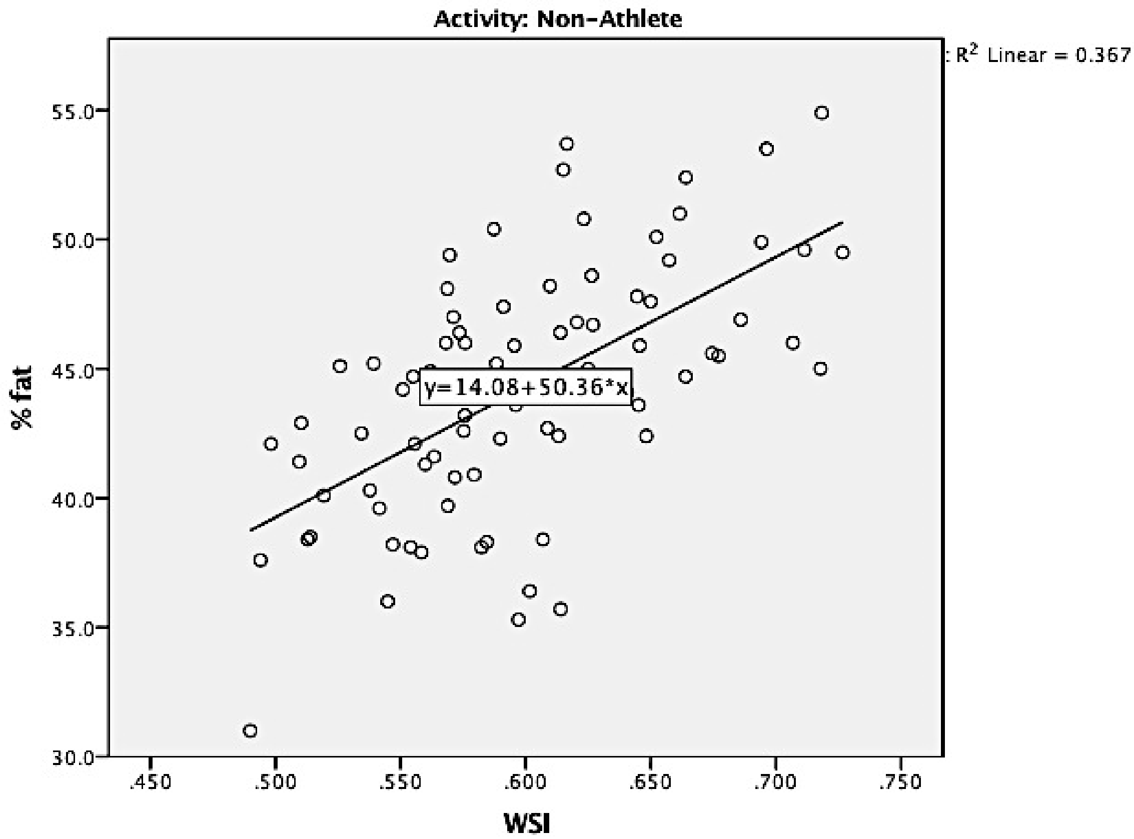
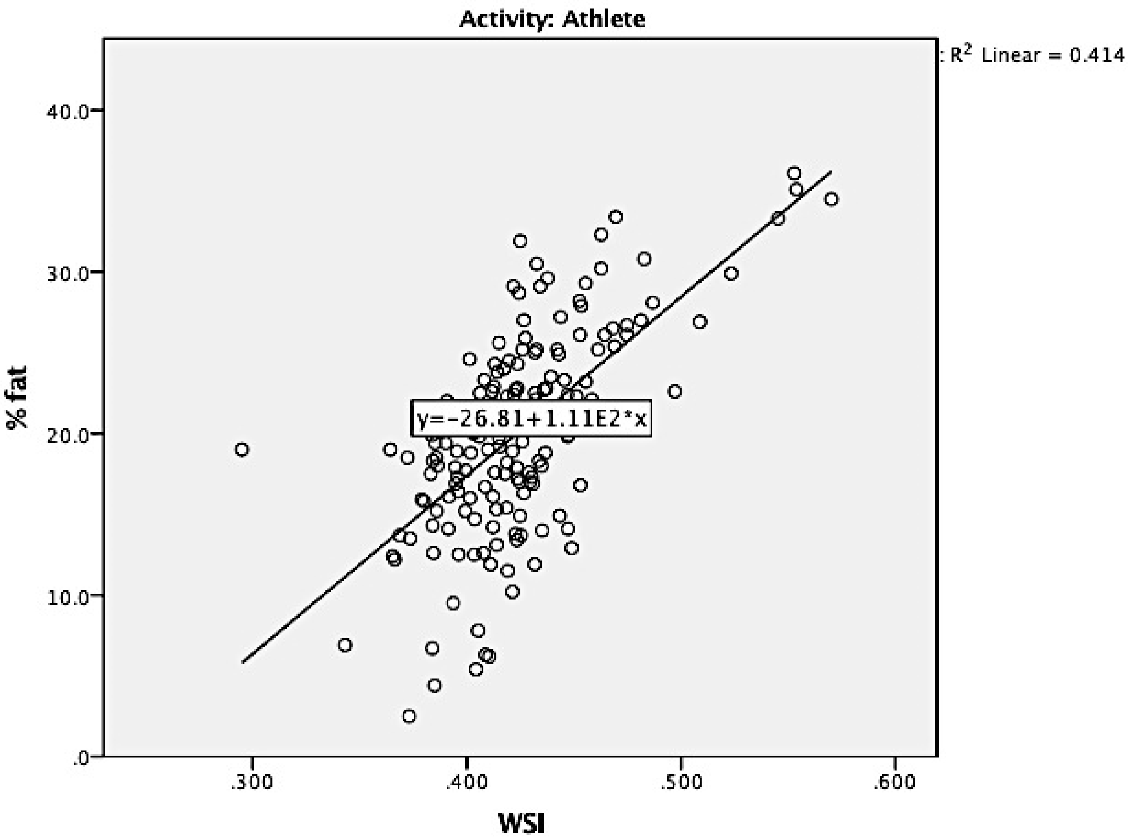


Figure 4.7 Athlete: WSI vs. Body Fat Percentage



The predictive power of the WSI shows little strength ($R^2 = 0.367$) in the Non-Athlete group (Figure 4.6). However, it does indicate moderate predictive power ($R^2 = 0.414$) in regards to body fat in the Athlete group (Figure 4.7).

Figure 4.8 Non-Athlete: ABSI vs. Body Fat Percentage

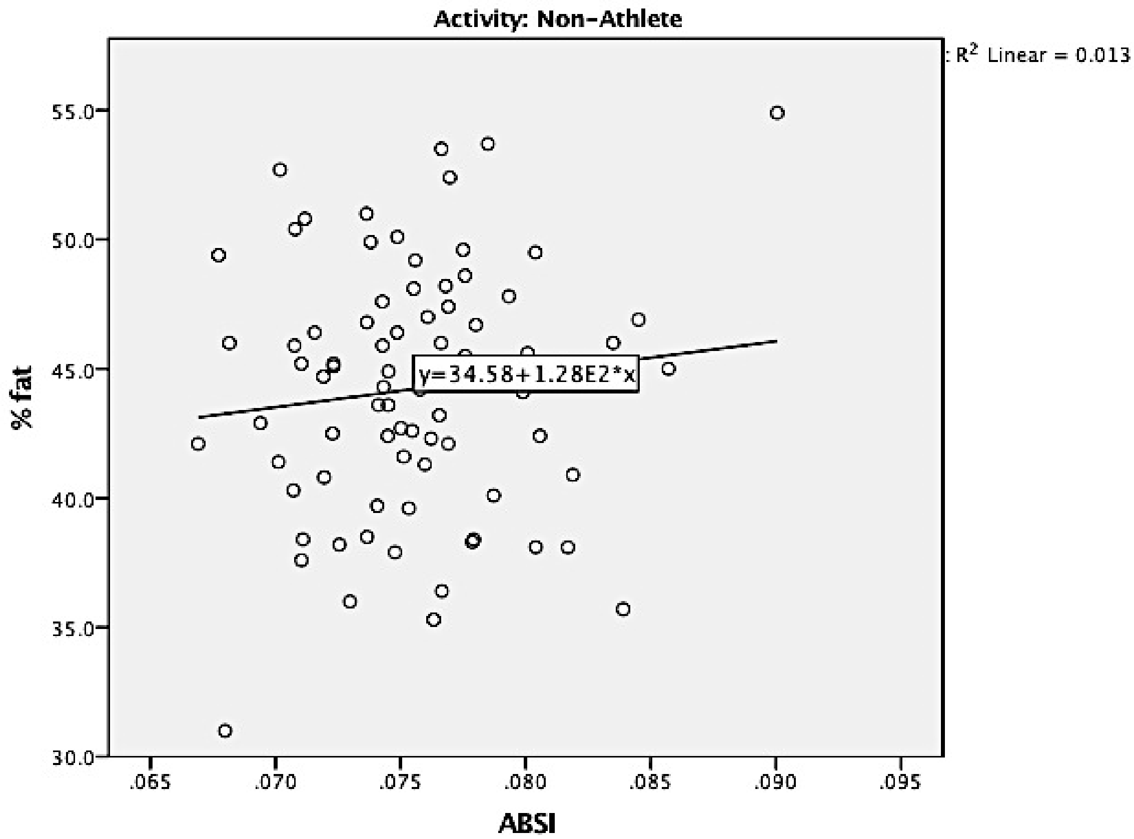
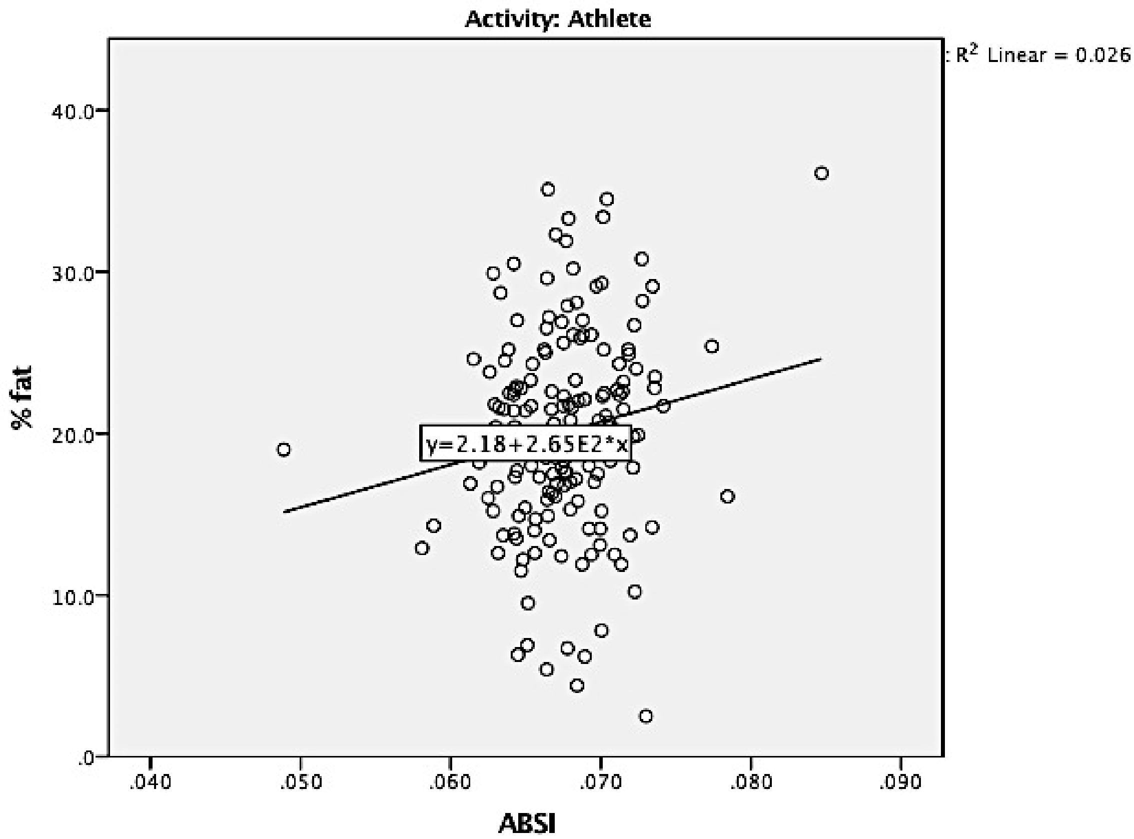


Figure 4.9 Athlete: ABSI vs. Body Fat Percentage

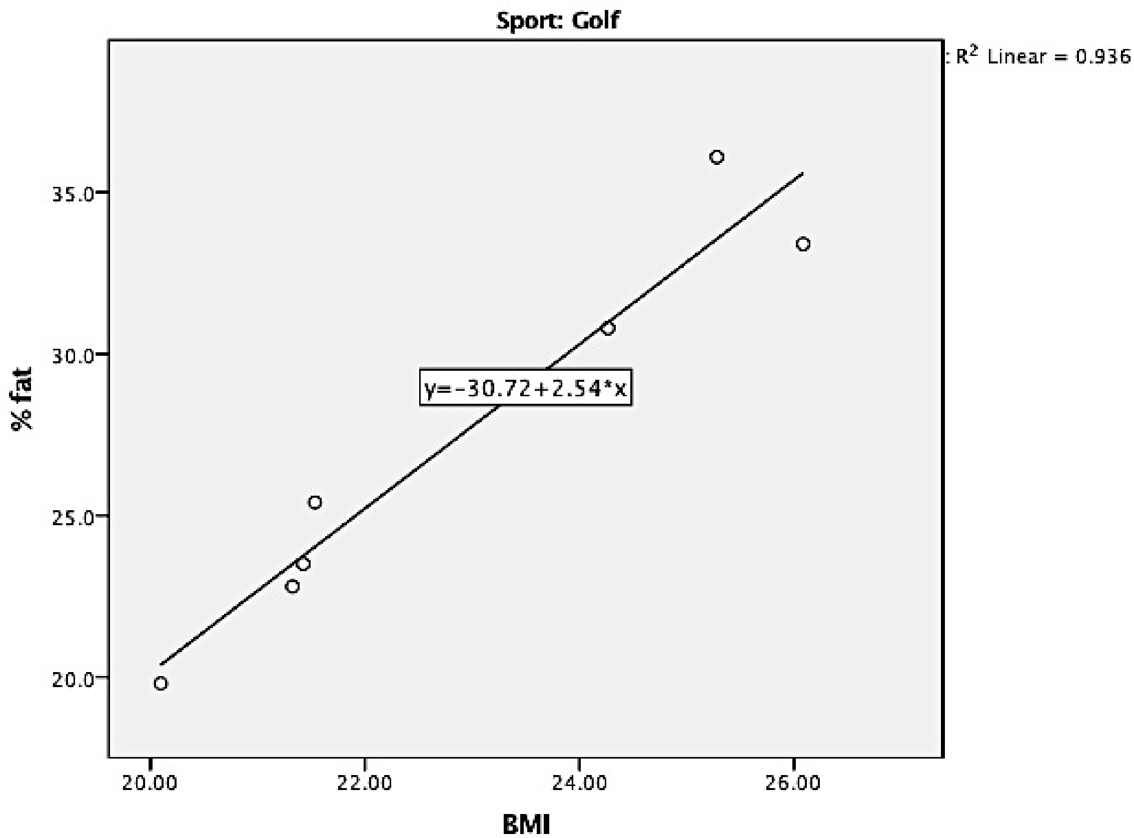


The predictability of ABSI with body fat percentage is relatively weak in both groups. In the Non-Athlete group (Figure 4.8) $R^2 = 0.013$ and in the Athlete group (Figure 4.9) $R^2 = 0.026$.

In the Non-athlete group, BMI appears to have the most predictability with body fat percentage. In the athlete group, waist circumference posed the strongest relationship with body fat percentage. Overall, no single algorithm showed significantly strong predictability.

When investigating each of the sports separately, varied relationships were observed. Regression was applied to each of the algorithm and analyzed with each team. The figures that follow display the linear models of the team experienced the most predictability (as judged with the R^2 value) with each test.

Figure4.10 Team with Best Body Fat Prediction According to BMI



The Golf team exhibited strong predictability of the BMI in regards to body fat percentage. The R^2 value was 0.936 (Figure 4.10).

Figure 4.11 Team with Best Body Fat Prediction According to WC

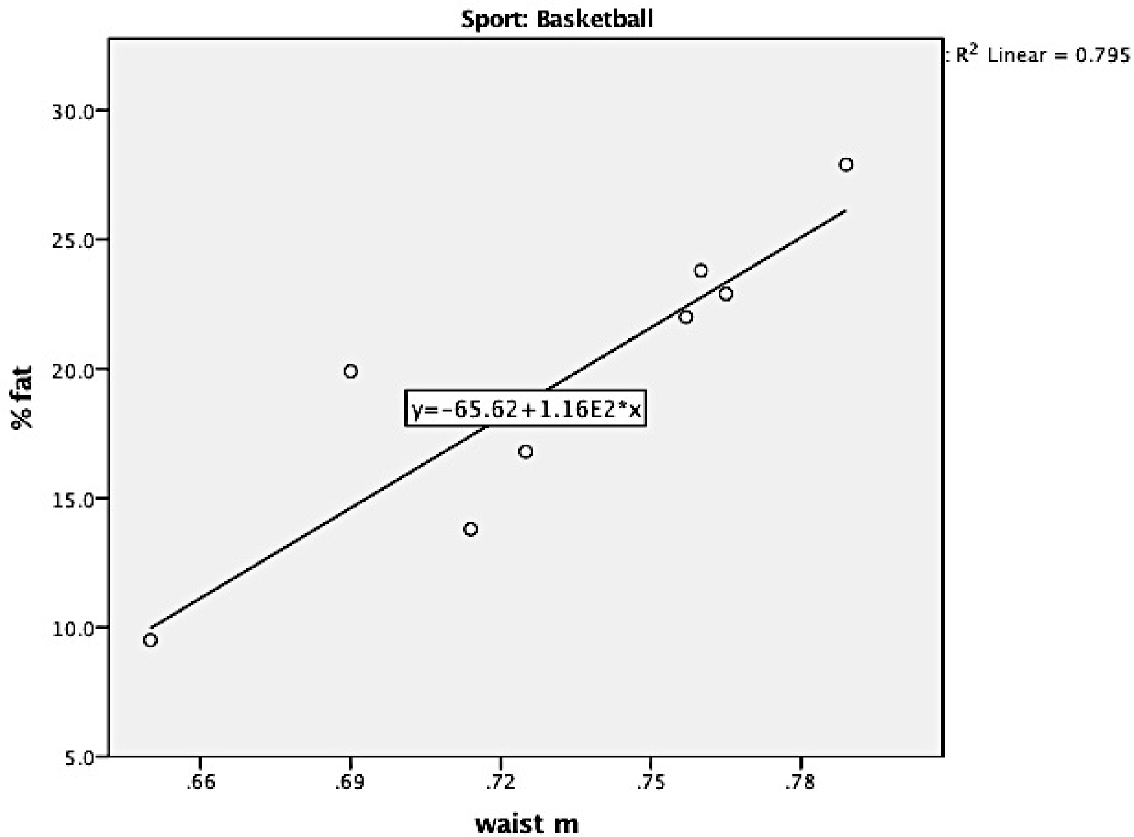
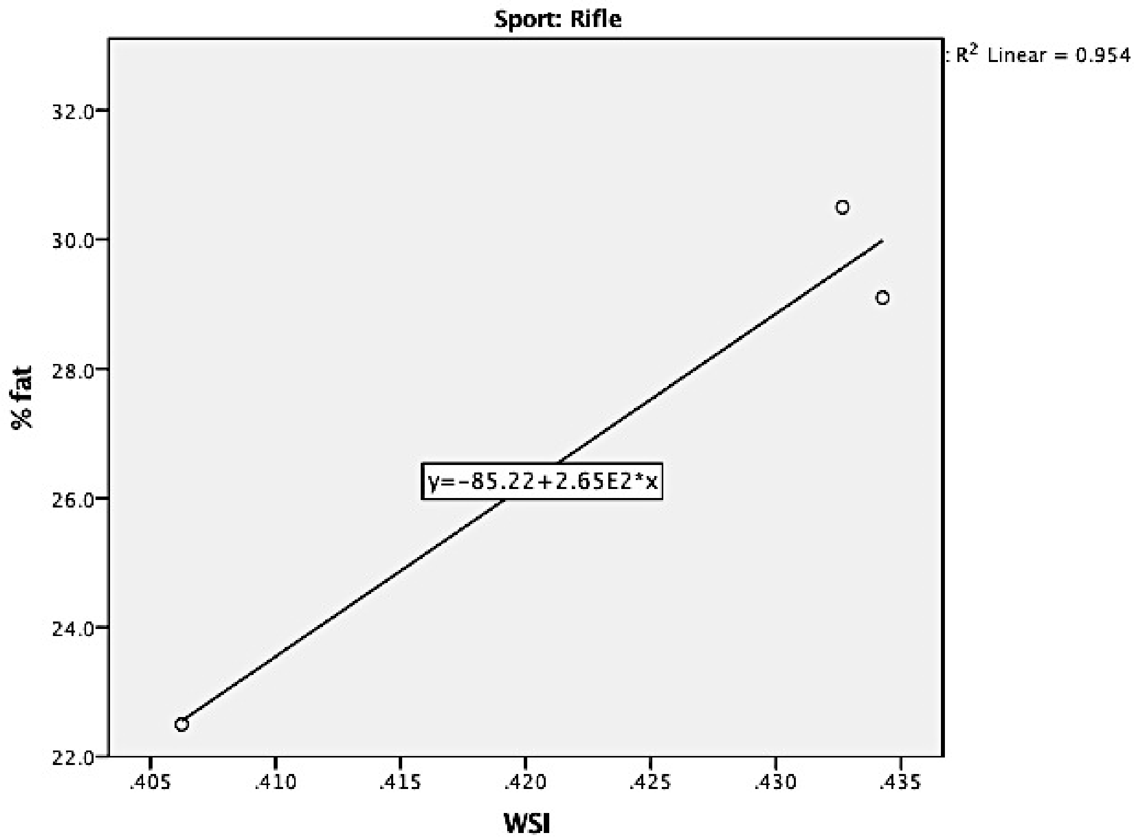


Figure 4.11 shows the results of the model of observed body fat percentage as predicted by waist circumference. The Basketball team had the strongest relationship with an R2 of 0.795.

Figure 4.12 Team with Best Body Fat Prediction According to WSI



The Rifle team showed the strongest relationship between WSI and body fat percentage. The R^2 value was 0.954 indicating very strong predictive power of the WSI (Figure 4.12). This team only had 3 members included in the study, this represents a small subset of the sample.

No significant relationship was observed between ABSI and body fat percentage by any team. The same was observed for the Athlete group as a whole and the Non-Athlete group.

Comparison of Body Fat Percentage and CUN-BAE

Paired -tests were conducted on the two variables of body fat percentage as measured by the Bod Pod® and the body fat percentage as estimated by the CUN-BAE algorithm. The differences in means were examined for both the Athlete group and the Non-Athlete group. Table 4.3 displays the results.

Table 4.3 Paired t-tests of BF% and CUN-BAE in Athletes and Non-Athletes

		Paired Differences					
		Mean Diff	Std. Dev.	95 % CI Lower	95 % CI Upper	t	Sig. (2 tailed)
Pair 1 Athlete	% Fat / CUN-BAE	-9.86	5.1	-10.63	-9.08	25.1	0.000
Pair 2 Non-Athlete	% Fat / CUN-BAE	-0.55	3.45	-1.32	0.22	1.42	0.159

In a paired comparison (t-test) the measured body fat percentage (from the Bod Pod®) to the theoretical body fat percentage (CUN-BAE), no significant difference was noticed in the means of the Non-Athlete group. However, in the Athlete group a significant difference was observed between the means. These results indicate that the CUN-BAE algorithm may be applicable in estimating body fat percentage in overweight/obese females, but not in female collegiate athletes.

Chapter 5
Discussion

The purpose of this study was to examine the effectiveness of anthropometric based formulas in predicting body fat. The WSI, ABSI, BMI, and waist circumference were all regressed with measured body fat percentage to determine the predictability of each formula. A newer algorithm, CUN-BAE, actually predicts body fat percentage based on an individual's BMI, age and sex. The results with this formula were compared with the results of measured body fat percentage in the subjects.

Findings

The first objective of this study was to determine if other anthropometric-based formulas would predict body fat percentage comparatively to the BMI. It was hypothesized that the predictive power of these formulas would be stronger in the Non-Athlete group. In comparing linear regression of BMI to %Fat, the Non-Athlete group had an R^2 value of 0.475 whereas the Athlete group value was 0.360. These results are in favor of the hypothesis. The opposite was found in the case with waist circumference, the Non-Athlete group had a predictive value of 0.335 while the Athlete group value was 0.478. The same circumstances were observed with the results of WSI where the Non-Athlete group's predictive value was 0.367 and the value for the Athlete group was 0.414. The ABSI, despite having significantly weak values for both groups, also found the predictive value to be weaker for the Non-Athlete group; the R^2 value was 0.013 while for the athletes it was 0.26. Considering that WSI and ABSI both account for waist circumference in their formulas, it seems fitting that the predictability for all would have strength with the same group. The results of the linear regressions of ABSI, WSI, and WC with %Fat all oppose the hypothesis.

Although the predictive power was examined to determine if there was a difference in predictability between athletes and overweight/obese non-athletes, the values were not significantly dissimilar with the exception of the ABSI, which was considerably weaker than the other algorithms. It must be considered however that ABSI was developed in order to predict mortality, not body fat percentage. Variability was also observed among the individual teams. There were no studies found comparing these algorithms in athletes and non-athletes. There is literature that supports these similarities in clinical studies (Flegal, et al., 2009). Evidence in support of each algorithm is growing as well.

The second objective in the present study was to determine if an anthropometric based algorithm could predict body fat percentage comparatively to a validated instrument that distinguishes fat mass from fat free mass. The hypothesis was that the accuracy of the CUN-BAE algorithm would vary between athletes and non-athletes. A paired t-test was performed between the mean of the measured body fat % and the CUN-BAE estimated body fat %. The values were paired into the Athlete or Non-Athlete group. The results were in favor of the hypothesis. The mean body fat percentage in the Athlete pair was 20.1% and the mean value of the CUN-BAE estimate was 29.9%. The significance value of 0.000 indicates that a significant difference exists between the means of the measured body fat percentage and the estimated body fat percentage. In the Non-Athlete pair, the significance value was 0.159, which signifies that no significant difference was observed between the means of the measured body fat percentage and that of the estimated. The means of the body fat percentage and the CUN-BAE estimate were 44.2% and 44.8% respectively.

Literature on the viability of the CUN-BAE equation is limited and clinical studies are emerging and controversial at this time. This study coincides with the notion that this equation may not be applicable in all situations.

Since diverse sports require different body compositions in order to optimize performance it is very important that athletes' body composition be scrutinized beyond the BMI in order to ensure accuracy, and so that their actual health and any potential risks can be assessed. A study by Santos and colleagues has established a framework of references for body composition and anthropometric measurements for various sports for males and females (Santos, et al., 2014).

Limitations

In addition to only involving females, the samples used for this study are a small representation of the population of female collegiate athletes and overweight/obese females. Also, it is known that the female athletes have very active lifestyles whereas the activity level of the obese females is unknown. The sample sizes were very dissimilar as well. There are many alternative algorithms available, this study only evaluated a small percentage.

Future Research

Future research should explore these algorithms with the impact of other influential factors such as activity level, diet, sex, and ethnicity. It would also be more beneficial to scrutinize the subjects' body composition beyond the body fat percentage, but could also evaluate adipose deposition.

Conclusion

This study provides evidence that anthropometric based algorithms are lacking in strength of predicting body composition across diverse populations. The reliability of these formulas varies within individual populations so more research is needed in order to determine their most useful applications. Presently, indirect evaluation of body composition proves the most accurate in determining body fat percentage and furthermore has the capability of determining the deposition of adipose tissues. These methods should be employed when determining the health risks of individuals in order to avoid the potential fallacies that anthropometric-based formulas can diagnose and/or misdiagnose.

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