

An Alternative Body Shape Index (BSI) for Physically Active College Males

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Abstract Background: The growing prevalence of obesity is a known concern along with its associated public health consequences. Body mass index (BMI) is a measure of weight (WT) relative to height (HT) and is the leading metric used to assess weight status. However, waist circumference (WC) may be more predictive of poor health outcomes. A body shape index (ABSI) is a measure of WC that controls for both HT and WT. The primary purpose of this study was to determine the need and justification for a new body shape index (BSI) measure designed specifically for physically active college-aged males. **Methods:** A convenience sample of N = 80 traditional male college students were used in this study. Body measures of HT (cm), WT (kg), and WC (cm) were objectively measured and BMI (kg/m^2) computed. Percent body fat (PBF, %) was used to validate the different indices. A nonlinear power function was developed to create the new allometric-derived BSI. Pearson correlations were used to compare the effectiveness of ABSI and BSI measures. Regression models were used to examine the independence of BSI with HT, WT, and BMI. Cochran-Armitage tests of trend were used to examine the relationships between BSI risk (top 25%) and body measure tertiles. Finally, agreement statistics were computed to present validity evidence for a simpler BSI formula. **Results:** The new allometric-derived BSI was established as $\text{BSI} = \text{WC}/(\text{WT}^{0.516} \times \text{HT}^{0.362})$ with a sample mean of 55.9 ($SD = 3.1$). ABSI was correlated with WT and BMI but not correlated with PBF. Conversely, BSI was not correlated with WT or BMI but was correlated with PBF. Regression models predicting PBF with BSI and HT, BSI and WT, BSI and BMI, and BSI, HT and WT consistently presented BSI as a significant predictor with all VIF values < 1.26. A significant linear trend in proportions was observed with high-risk BSI and PBF tertiles but not HT, WT, or BMI tertiles. Finally, a simpler approximate $\text{BSI} = \text{WC}/(\text{WT}^{1/2} \times \text{HT}^{-1/3})$ showed excellent agreement ($R^2 = .998$, $ICC = .999$, $p < .0001$) with the allometric-derived BSI. **Conclusion:** This study presents evidence for a new BSI measure that is specifically designed for physically active college-aged males. The BSI for this population is adequately scaled for HT and WT, lacks correlation with BMI, independently predicts PBF, and includes a valid and simpler form for field usage. Further research may be needed to justify population-specific and/or study-level BSI measures.

Keywords: Body shape index (BSI), body composition, Physical activity, measurement

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1. Introduction

The prevalence of obesity has been rising in recent decades and is now considered a chronic disease by many health authorities [1]. Body mass index (BMI, kg/m^2) is a measure of body weight (WT) relative to height (HT) and is the primary measure used to assess weight-related health risk. In adult populations, obesity is generally defined as a BMI of 30.0 or greater [2]. In children and adolescents, those with a BMI at or above the 95th percentile are considered obese [3]. BMI is the principal measure used to assess obesity because measuring height and weight is routine healthcare practice. BMI is also predictive of many health conditions such as premature disease, mortality, disability, and even perceived health

[4]. There is criticism though for using BMI, namely that it cannot distinguish between lean and fat mass and cannot indicate where body fat is distributed throughout an individual's body [5,6].

Waist circumference (WC) is another body measure used to gauge weight-related health risk and is assessed with a tape measure just above the hip crest [7]. Since WC can detect excess fat around the midsection, it is often considered a measure of central obesity. WC values of 120 cm or more for men and 88 cm or more for women are used to define abdominal obesity [7]. WC is an important body measure because it is strongly associated with visceral fat [8]. Visceral fat is the deep fat surrounding the organs and is noted to greatly influence morbidity and mortality. Although, like BMI, WC also has limitations as a body composition metric. The main limitation is that a large WC measurement may not always be indicative of

large amounts of visceral or subcutaneous fat. For example, two individuals of the same sex and the same WC measurement could have different heights and in turn different WC-related health risks. Similarly, another two individuals of the same sex and the same WC measurement could have different body weights and again different WC-related health risks.

One way to control for the confounding influence of body size in WC assessment is to adjust the WC measure so that it accounts for both HT and WT. In other words, remove the effects of HT and WT from the WC measure. This type of adjustment is known as *allometric scaling* which uses a power function to properly model the relationships observed between physical body measurements [9]. Allometric scaling of WC has been exercised by others using HT and WT and the resulting measure labeled a *body size index* (ABSI) [10]. ABSI was created as a health metric independent of HT, WT, and BMI. For example, ABSI has been shown to predict premature mortality as well as correlate with lean body mass [10,11]. However, ABSI was developed on a large nationally represented sample of U.S. adults and may differ in a physically active population of traditional college-aged males. The purpose of this study was to: 1) show the need for a new BSI measure specifically developed for the physically active college-aged male population, 2) provide evidence that the new BSI lacks correlation with HT, WT, and BMI yet relates to percent body fat (PBF), 3) show that BSI can be modeled as an independent predictor of PBF while including other contributing body measures without excessive collinearity, 4) show that a binary high risk BSI variable can detect a linear trend in proportions across groups of ordered levels of PBF, and finally 5) establish validity for a simpler form of the new BSI formula that is easier to calculate in the field.

2. Methods

Study design

This study was a secondary analysis of a larger campus-based study that administered several different tests across the five components of health-related fitness [12,13,14,15]. Participants were included in the current study if they were male college students between the ages of 18 and 24 years and had complete body measures data. Students were initially recruited using public flyers and word-of-mouth. The university system's institutional review board (IRB) approved all study methods and procedures.

A body shape index (ABSI)

ABSI was computed with measured study variables of HT, WT, and WC. The following formula was used:

$$ABSI = \frac{WC}{\frac{2}{BMI^3 \times Height^2}}$$

With WC and HT converted to units of meters (m) and BMI units of kg/m² [10,16]. ABSI was developed from regression allometry using log HT and log WT as predictors of log WC [10,16]. Regression coefficients were used to form a power function as a more robust representation of the curvilinear relationship. Dividing the

power function into WC creates a new scaled version of WC. Larger values of BSI indicate a greater health risk associated with WC.

New body shape index (BSI)

A new BSI was created in this study by fitting sample data to the same allometric regression model with log transformed variables. The 95% CI for each coefficient was examined to initially justify new BSI exponents. A follow-up nonlinear model was also employed on the original variables to confirm the estimated coefficients and assess its fit. The new BSI formula has the same power function ratio form as above but with new study-level exponents. A second approximate BSI formula was also developed using cleaner exponents to simplify its computation in the field. Finally, a binary BSI risk status variable was created where values in the upper 25th percentile were considered "high risk" and otherwise "low risk".

Physical Activity (PA)

Physical activity was assessed in this study using the physical activity rating (PAR) tool [17]. PAR consisted of a single response to a physical activity scenario describing the participant's overall level of activity. PAR responses ranged from 0 (avoid walking or exertion) to 10 (run over 25 miles per week or equivalent). All male students in this study responded with a value of 2 (moderate activity for 10 to 60 minutes per week) or greater and thus were considered at least moderately physically active.

Body measures

Five different body measures were either measured or calculated using objectively measured variables. Measurements were each assessed twice in rotational order and then averaged unless large differences were found. HT (in) was assessed using a wall mounted stadiometer (Seca, Model: 216) to the nearest 0.5 cm. WT (kg) was assessed with a digital floor scale (Seca, Model: 803) to the nearest 0.1 kg. BMI (kg/m²) was calculated by dividing WT by HT in meters squared (m²). WC (cm) was assessed to the nearest 0.5 cm using an elastic tape and measuring the narrowest point between the participant's umbilicus and xiphoid process. Finally, PBF (%) was assessed with a handheld bioelectric impedance device (Omron, Model: BF306) and collected using the manufacturer's protocol.

Statistical analyses

Descriptive statistics were computed on the study variables of AGE, HT, WT, BMI, WC, and PBF. Regression was used on log transformed variables with WC as the dependent variable and HT and WT as the predictors. Variable coefficients from the regression model supplied the exponents for the allometric scaling. Where the 95% CI for each estimated coefficient was examined to initially justify new BSI exponents. Additionally, a follow-up nonlinear power model using PROC NLIN was explicitly specified and examined to confirm the estimated coefficients from the linearized model as well as assess model fit. Pearson correlation coefficients were computed to examine the presence and/or removal of body size effects from the original ABSI and new BSI measures. Ordinary least squares

regression models were employed to examine the extent to which the new BSI was an independent predictor of PBF while including other contributing body measures without excessive collinearity. Chi-square tests of independence and Cochran-Armitage trend tests were used to examine the extent to which binary high-risk BSI was related to the different body measure tertile groups. Finally, the coefficient of determination (R^2) from regression and the intraclass correlation coefficient (ICC) from ANOVA were used to evaluate agreement between the new allometric-derived BSI and an approximate BSI with cleaner exponents.

3. Results

Table 1 contains the sample characteristics with a mean age of 20.5 yr ($SD = 1.58$) and mean BMI of 27.5 ($SD = 4.67$). Table 2 displays the regression estimates for the log transformed variables where the coefficients serve as the new BSI exponents. The coefficient for $\ln$ WT of 0.516 has a 95% CI of 0.438 – 0.594, which excludes the ABSI exponent of 0.667. Similarly, the coefficient for $\ln$ HT of -0.362 has a 95% CI of -0.650 – -0.074, which excludes the ABSI exponent of -0.833. Thus, the new population-specific BSI was defined as follows:

$$BSI = \frac{WC}{WT^{.516} \times HT^{-.362}}$$

Table 1. Descriptive statistics for the study sample

Variable	Mean	Median	SD	Min	Max
AGE (yr)	20.49	20.00	1.58	18.00	24.00
HT (cm)	180.62	180.00	9.08	159.00	208.50
WT (kg)	89.94	86.05	17.38	62.00	152.70
BMI (kg/m ²)	27.53	26.65	4.67	20.80	41.60
WC (cm)	86.24	84.00	9.43	71.50	122.00
PBF (%)	17.72	17.65	6.93	4.60	35.40

Note. N = 80. HT is height. WT is body weight. BMI is body mass index. WC is waist circumference. PBF is percent body fat.

Table 2. Parameter estimates for linearized model of WC regressed onto HT and WT

Parameter	Estimate	SE	t	p	95% CL	
					LL	UL
Intercept	4.02144	0.68528	5.87	<.000	-2.56204	1.94333
$\ln$ WT (kg)	0.51605	0.03937	13.11	<.000	0.43766	0.59444
$\ln$ HT (cm)	-0.36241	0.14462	-2.51	.0143	-0.65038	0.07444

Note. N = 80. Dependent variable is $\ln$ WC (cm). $R^2 = 0.71$. RMSE = 0.056. ABSI WT exponent = 0.667. ABSI HT exponent = -0.833. Nonlinear power model $R^2 = .699$.

Figure 1 displays the nonlinear power model contour fit plot with WT on the horizontal axis, HT on the vertical axis, and WC as the contour lines inside the plot. This graph identifies how well the data fit the power model. Specifically, the circled points have an inside color representing their observed WC values (i.e., darker shades equal larger observed WC) and the background color represents the predicted values of WC. Thus, a circle with an inside color different from its background color depicts

misfit and those with similar color depict good fit. Note, the scatter in the plot appear to fit the allometric power model well ($R^2 = .699$). Additionally, coefficients from the nonlinear power model were the same as those of the linearized model within rounding error. Figure 2 displays the sample distribution of BSI scores for traditional physically active college-aged males.

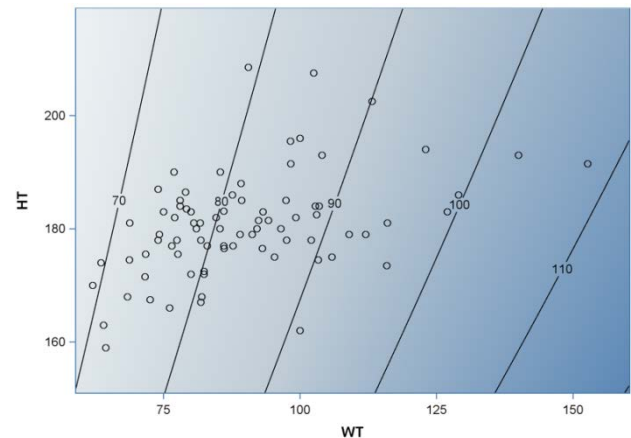


Figure 1. Nonlinear power model contour fit plot predicting waist circumference (WC)

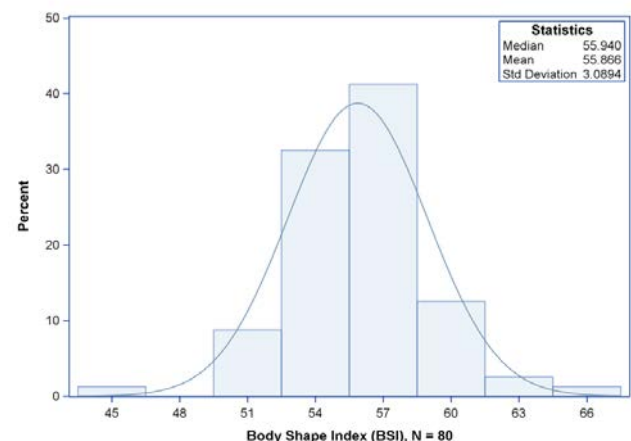


Figure 2. Sample distribution of BSI scores for traditional physically active college-aged males

Table 3 shows results for the body measures correlations with the original ABSI and new BSI measures. ABSI was significantly correlated with WT ($r = -.251$, $p = .0247$) and BMI ($r = -.383$, $p = .0004$) but not correlated with PBF ($r = -.065$, $p = .5671$). It should be highlighted that ABSI was surprisingly negatively correlated with WT and BMI. Conversely, BSI was not correlated with HT ($r = .009$, $p = .9347$), WT ($r = .025$, $p = .8284$) or BMI ($r = .030$, $p = .7902$) but was correlated with PBF ($r = .278$, $p = .0125$). It should be equally highlighted that the effects of HT, WT, and BMI were in fact removed from BSI and BSI as hypothesized was positively correlated with PBF.

Table 4 contains four (4) different regression models examining the relationship between PBF and BSI while adding other contributing body measures as predictors. Each model displays BSI as a significant independent predictor of PBF. Therefore, BSI explains PBF variation above that explained by the other body measures. Additionally, no extreme collinearity was noticed (VIFs <

1.26). These findings were consistent in all four models including model 4 that showed BSI, HT, and WT each as independent predictors of PBF.

Table 3. Pearson correlations for original ABSI and new BSI with body measures

	HT	WT	BMI	PBF
ABSI	.188	-.251	-.383	-.065
<i>p</i>	.0958	.0247	.0004	.5671
BSI	.009	.025	.030	.278
<i>p</i>	.9347	.8284	.7902	.0125

Note. N = 80. ABSI is the original body shape index. BSI is the new body shape index. Values in bold are significant at $\alpha = .05$.

Table 4. Models showing the relationship between PBF and new BSI with other body measures

Parameter	θ	<i>b</i>	SE	<i>t</i>	<i>p</i>	VIF
Model 1:						
HT (cm)	0.0719	0.0550	0.0834	0.66	.5119	1.00
BSI	0.2773	0.6224	0.2450	2.54	.0131	1.00
Model 2:						
WT (kg)	0.7501	0.2992	0.0273	10.96	<.0001	1.00
BSI	0.2595	0.5825	0.1536	3.79	.0003	1.00
Model 3:						
BMI (kg/m ²)	0.8045	1.1943	0.0889	13.43	<.0001	1.00
BSI	0.2537	0.5694	0.1345	4.23	<.0001	1.00
Model 4:						
HT (cm)	-0.3360	-0.2567	0.0511	-5.02	<.0001	1.26
WT (kg)	0.9021	0.3598	0.0267	13.48	<.0001	1.26
BSI	0.2589	0.5811	0.1340	4.34	<.0001	1.00

Note. N = 80. VIF is variance inflation factor.

Table 5. Relationship between BSI risk status and body measure tertile groups

Body measure	BSI risk	Body measure tertile groups			χ^2	<i>Z</i> _{trend}
		1st	2nd	3rd		
		%	%	%	<i>p</i>	<i>p</i>
HT					.353	.149
	Low	30.0	35.0	35.0	5	3
	High	45.0	35.0	20.0		
WT					.063	.068
	Low	35.0	38.3	26.7	2	1
	High	25.0	20.0	55.0		
BMI					.206	.131
	Low	35.0	36.7	28.3	7	8
	High	25.0	25.0	50.0		
PBF					.002	.004
	Low	38.3	38.3	23.3	8	7
	High	20.0	15.0	65.0		

Note. N = 80. χ^2 is chi-square test of independence. *Z*_{trend} is Cochran-Armitage trend test. High-risk BSI defined as the top 25% BSI.

Table 5 displays results examining the extent to which a binary high risk BSI variable can detect a linear trend across tertile groups of varying levels of HT, WT, BMI, and PBF. As expected, no significant differences or linear trends were found for high-risk BSI percentage across HT, WT, or BMI tertile groups. However, as expected, high-risk BSI percentages were significantly ($\chi^2 = 11.72$, $p = .0028$) different across PBF tertile groups. Additionally, high-risk BSI percentages trended significantly ($Z_{\text{trend}} = -2.83$, $p = .0047$) in linear form across PBF tertile groups. Specifically, a lower percentage of males had high-risk BSI (20.0%) compared to low-risk BSI (38.3%) in the 1st PBF tertile and a larger percentage had high-risk BSI (65.0%) compared to low-risk BSI (23.3%) in the 3rd PBF tertile.

Figure 3 displays regression and ANOVA results as a means of providing validity evidence for a simpler form of the new BSI formula. The new exponents were approximated by finding cleaner fractions close in value to the original exponents that were also within the 95% CI range of their estimated values. The simpler BSI suggested for field use was approximated as follows:

$$BSI = \frac{WC}{WT^{\frac{1}{2}} \times HT^{\frac{1}{3}}}$$

The regression line fit to the scatter clearly indicates strong agreement ($R^2 = .998$, $p < .0001$) between the original allometric BSI formula and the approximate BSI formula. Additionally, the absolute reliability coefficient, using a mixed factor ANOVA model, indicates acceptable agreement ($ICC = .999$, $p < .0001$).

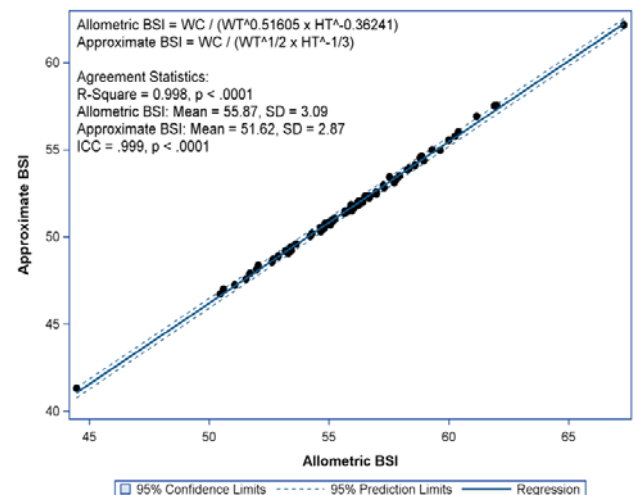


Figure 3. Scatter plot with regression line and agreement statistics for the two BSI formulae

4. Discussion

The primary purpose of this study was to determine the need and justification for a new body shape index (BSI) formula designed specifically for physically active college-aged males. The first step in addressing this purpose was to compute the original ABSI and examine its correlations with other body measures used in the study. Results from this step indicated that ABSI remained dependent on WT and BMI, revealing ABSI as a biased

WC measure in physically active college-aged males. Moreover, ABSI was not dependent on PBF, showing that ABSI may be a less valid measure of body composition in this population [11,18]. The sum from this step highlights the need for a new population-specific BSI measure. The second step in addressing the study's purpose was to develop a new BSI formula fit specifically to the study group and examine its correlations with the same body measures. Findings from this step were in complete contrast to those of the previous step. That is, BSI was not associated with HT, WT, or BMI but dependent on PBF. Additionally, 95% CIs for the allometric power function exponents excluded the ABSI exponents. This provided additional evidence that a population-specific BSI formula was needed. The sum of which emphasizes that the new BSI is a measure of central body composition (i.e., WC) that is unbiased in terms of body size and is fit specifically to the study population.

The third step in addressing the study's purpose was to show BSI as an independent predictor of PBF while including other contributing body measures without excessive collinearity. The logic driving this step was that if the effects of other body measures were indeed removed from BSI, then they would simultaneously contribute to the prediction of PBF while not inflating variance due to excessive collinearity. This was tested in four different models where no model for obvious reasons contained HT or WT along with BMI. Thus, as expected, BSI predicted PBF in all four regression models. The model with BSI and HT, not surprisingly, did not see HT as a significant independent predictor of PBF. However, the models with BSI and WT, BSI and BMI, and BSI, HT, and WT, showed that all variables significantly and independently predicted PBF. Finally, for this step, there was no excess variance inflation for either model. The sum of which underscores BSI as an independent body measure able to coincide and contribute with body composition variables such as WT and BMI.

The fourth step in addressing the study's purpose was to show that a binary high-risk BSI variable can detect a linear trend in proportions across groups of varying levels of HT, WT, BMI, and PBF. The logic here was like the last step except that a BSI status variable is being examined and the body measure variables are tertile groups. These findings were as expected and showed no differences or linear trends in BSI status proportions across HT, WT, or BMI tertile groups. Differences in BSI status proportions and a linear trend in BSI status proportions were however found across PBF tertile groups. Specifically, a much larger percentage of males in the upper PBF tertile were identified as having high-risk BSI and a much lower percentage in the lowest PBF tertile. These findings highlight BSI status as a useful indicator of high-risk central body composition. A noteworthy comment however is that the BSI cutoff value of the 75th percentile was arbitrarily set in this study. Therefore, research is needed to find an optimal BSI status cut point indicative of poor health outcomes in this population [19,20].

The last step in addressing the study's purpose was to establish validity evidence for a simpler form of the new BSI formula that is conducive to field usage. This was accomplished first by closely approximating the exponents

with cleaner fractions that also remained within the limits of their 95% CIs. This led to new exponents of 1/2 for WT and -1/3 for HT. Next, score agreement between the two BSI formulae was examined using a regression line, explained variance (R^2), and an absolute reliability coefficient (ICC). Results from this step clearly defend using the simpler BSI form in lieu of its allometric-derived form.

Although these findings support the new BSI formulae as valid measures of abdominal obesity without the confounding influence of body shape (i.e., HT, WT, and BMI), there are a few concerns needing discussion. Firstly, the new BSI formulae developed in this study are specific to traditional aged (18 to 24 years) college students who are physically active. This study found that the BSI metric was without bias in this population and this population only. Secondly, the underlying mechanism explaining the observed ABSI and BSI differences was not identified or discussed in this research. Rather, evidence for the BSI over the ABSI was completely data driven. Identifying and explaining the physical differences in this population may be an area for future research. However, from a mathematical perspective, the ABSI gives WT an exponent of 2/3 instead of the approximate 1/2 given by the BSI [10]. This would suggest that WC requires more adjustment from WT among physically active college students than the general population. This applies the logic that an exponent close to |1.0| provides little to no adjustment. Similarly, the ABSI gives HT an exponent of -5/6 instead of the approximate -1/3 given by the BSI [10]. Once again, the mechanism explaining the different adjustments could be explored in future research. Thirdly, it is not completely clear to what extent the BSI will generalize to other traditional-aged college students who are physically active. In other words, it is not known if the BSI developed here will effectively remove HT, WT, and BMI from WC in other similar populations. It has been suggested by others that "study-level" scaling may be required to effectively remove all bias from a metric [21]. Therefore, it is recommended that before using the BSI for evaluation purposes that simple correlations be inspected to ensure the absence of body shape (i.e., HT, WT, and BMI) confounding. Fourthly, and finally, results from this study are limited by the fact that all body measure assessments were collected using field techniques. In any case, the same field techniques assessed on this population are known to have acceptable measurement stability with all test-retest correlations greater than .95 [22].

5. Conclusions

This study presents evidence for a new BSI measure that is specifically designed for physically active traditional-aged college males. The new BSI for this population is adequately scaled for HT and WT and lacks an association with BMI. Additionally, the BSI is necessarily correlated with PBF. Finally, the simpler BSI form with cleaner exponents has acceptable psychometric properties and can be considered for use in the field. Further research may be needed though to justify population-specific and/or study-level BSI measures.

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