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USING THE LEAN TISSUE INDEX (LTI) AS A PREDICTOR VARIABLE FOR BONE MINERAL DENSITY OF ELITE, ADOLESCENT, FEMALE CROSS-COUNTRY RUNNERS

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ABSTRACT

Purpose: Determine the best body-composition variable for predicting bone mineral density (BMD) in the sub-population, which included body weight (WGT), lean tissue (LT), body mass index (BMI), body fat (BF), lean tissue index (LTI = LT/Height^2), and body fat index (BFI = BF/Height^2). **Methods**: Measured BMD using DXA and estimated skeletal maturity (SM) using questionnaire data of subjects: 28 female runners (Mean Age $\pm$ SD = 14.9 $\pm$ 1.6 yrs). **Results**: Partial correlations indicated LTI was the variable most highly associated (ρ = .712) with BMD. Multiple linear regression indicated LTI was the predictor variable with the best fit. Predictions of the dependent criterion variables, BMDleg and BMD, were calculated using the independent predictor variables, LTI and SM. Significant regression equations were found. The subjects' BMDleg was found to be equal to (-2.486) + (2.912)SM + (5.540E-02)LTI, [F(2,23) = 20.161, SEE = .0634] with an R^2 = .637; and the subjects' BMD was found to be equal to (-1.645) + (2.209)SM + (4.068E-02)LTI, [F(2,23) = 18.828, SEE = .0487] with an R^2 = .621. **Conclusion**: LTI was the body composition variable most highly associated with BMD (ρ = .712). LTI was also the best body-composition component to predict BMD (r = .788). Additional research regarding the LTI is recommended.

Keywords: Body Composition, Body Mass Index, Bone Growth, Amenorrhea

INTRODUCTION

Female athletes have a number of unique physiological issues compared to their male counterparts. Young female athletes who are driven to excel athletically and desire to maintain a certain body image are at risk for developing three distinct, interrelated disorders, disordered eating, amenorrhea, and osteoporosis. Together these three disorders are commonly referred to as the *female athlete triad* syndrome (1, 2). Disordered eating is a condition that ranges from improper nutritional intake to eating disorders, such as anorexia nervosa and bulimia, and is related to amenorrhea and lower BMD (3, 4). Amenorrhea is associated with higher injury rates, such as stress factures, and lower BMD in female athletes (5,6). These two disorders are interrelated and, if left untreated, place the athlete at greater risk of the third and final disorder of the syndrome, osteoporosis (7).

Exercise also influences BMD. Exercise that stimulates lean tissue growth stimulates BMD as well (8). High volumes of physical exercise place more mechanical strain on the skeleton and stimulates metabolic acidosis which promotes bone remodeling (9). In eumenorrheic athletes, categorized as a low-body weight group (BMI < 20.0 kg/m²), Madsen et al. (10) found those athletes had significantly greater BMD than a control group of age- and height-matched, average-body weight, sedentary women (mean BMI $\pm$ SD = 22.7 $\pm$ 1.5). While this suggests that weight-bearing exercise enhances BMD in adult eumenorrheic women runners, other research by Drinkwater (11) revealed that amenorrheic runners displayed significantly lower BMD. Furthermore, a study of active adolescent athletes by Dhuper et al. (12) found that the loss of estrogen exposure due to amenorrhea negatively impacted bone mass. Loss of BMD in amenorrheic athletes was unexpected because one of the benefits of weight-bearing exercise was thought to be increased BMD. With minor behavioral changes, some of the amenorrheic women in Drinkwater's study resumed menstruation, but follow-up research indicated that their bone mass never returned to the levels of athletic women who menstruate regularly.

Female cross-country runners are at risk of osteoporosis because they are prone to exercise-associated amenorrhea (EAA). Many female runners mistakenly believe that decreasing their body weight will improve their performance and, consequently, develop improper behavioral habits that lead to disordered eating. Female athletes who suffer from both disordered eating and amenorrhea are at a greater risk of developing osteoporosis. BMD is the measure in which osteoporosis is defined. Therefore, the factors that influence BMD must be explored in order to determine how to reduce the risk of osteoporosis.

Although Pocock et al. (13) found genetics was the major determinant of BMD in adults, they also discovered that body composition and physical activity were major factors in attaining peak BMD during adolescence. Given these findings, we sought to determine body composition components that influence BMD in female, adolescent cross-country runners. Body weight (WGT), body fat (BF), lean tissue (LT), and body mass index (BMI) are all body composition components that are used in studying BMD and bone mineral content (BMC). The Body Mass Index (BMI) is used in body composition studies because it incorporates bodyweight and height into one term and provides a measure of size. It is defined as total body weight (in kilograms) divided by the height (in meters) squared. Dividing BMI into its components, the LTI, BFI, and the BI, and utilizing them in lieu of the BMI in certain situations may provide greater insight into the associations among body composition components and BMD. In a previous study (14), fat (BFI) and fat-free (LTI) indices were used in a multiple regression analysis to determine what body size and body composition variables were most highly associated with physical activity. One of the purposes of the current study was to determine the viability of BMI components,

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LTI, BFI, and BI, as predictor variables for BMD.

[Note: LTI is defined as total lean tissue (in kilograms) divided by the height squared (in meters). BFI is defined as total body fat (in kilograms) divided by the height squared (in meters); and BI is defined as total bone mineral content (in kilograms) divided by the height squared (in meters).]

There has been considerable research conducted to investigate body composition relationships of collegiate and post-collegiate athletes from training programs and competitive activities. However, research regarding body composition relationships of adolescent female athletes from high school programs is limited. In fifty-five studies cited in a literary review investigating the relationship of vigorous exercise to BMD by Gutin and Kasper (15), none of the subjects were less than 18 years old. The purpose of this study was to investigate the body composition relationships as related to BMD of elite, adolescent cross-country runners. The specific aims were:

1. To compare the relationships of the lean tissue index (LTI), body weight (WGT), body mass index (BMI), lean body tissue (LT), body fat index (BFI) and body fat (BF) to bone mineral density (BMD).
2. To compare the lean tissue index (LTI) to body weight (WGT), body mass index (BMI), lean body tissue (LT), body fat index (BFI) and body fat (BF) as a predictor variable for bone mineral density (BMD).

METHODS

Participants

A total of 28 female high school cross-country runners were recruited for the study. The subjects were from an all-girls secondary parochial school in New Orleans, Louisiana. In the last ten years, the school's cross-country program has distinguished itself as an elite program that consistently finished first, second, or third overall in the 5A Division (large schools) of the Louisiana High School Athletic Association (LHSAA) cross country state championships.

Prior to participation in the study the investigator explained the experimental protocol to the subjects and their parents. The parents received a Parental Permission/Informed Consent form and the subjects were given a Minor Subject's Assent Form to read and sign before any research began. They were told the purpose of the study, that their participation was completely voluntary, and that they had the right to refuse to participate or withdraw from the study at any time. The study was approved by the Committee for the Use of Human Subjects at the University of New Orleans.

General Experimental Procedure

Body composition measurements were conducted on the subjects using dual-energy x-ray absorptiometry (DXA) during the cross-country season. The subjects were also weighed, measured for height, and responded to a questionnaire regarding their menarchal age, menstrual irregularity, and maturational status. Skeletal maturity (stated as a percentage) was estimated using the algorithms noted by Bayer and Bayley (16) utilizing the subjects' biological parents' heights.

Procedures

All measurements were performed at the University of New Orleans according to standard procedures as specified by the equipment manufacturers.

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Body composition was obtained from whole-body scans using dual-energy x-ray absorptiometry (DXA). A Lunar DPX-L densitometer was used to perform full body scans. Subjects were positioned according to the standard protocols for whole body scans. Analysis was determined using the manufacturer's automated algorithms. Subjects were scanned in light weight clothing after removing all jewelry. The variables measured included fat-mass, fat-free mass, bone mineral content, bone calcium, and bone mineral density. The DXA was calibrated before each scan.

Standing height was measured in centimeters using a fixed Schorr stadiometer, and body weight was measured in kilograms using the Seca Model 780 scale calibrated with a standard weight.

Analysis

IBM SPSS Statistics Version 23 for Windows was used for statistical analysis. Partial correlations were used to examine the relationships among BMD and LTI, BMI, weight, LT, BFI and BF, controlling for estimated skeletal maturity (SM), menarchal age (MA), and number of periods missed within the last year (PM). Linear multiple regression analysis was used to predict the dependent criterion variable, BMD, using SM and the following body composition components as independent predictor variables: LTI, BMI, weight, LT, BFI and BF. Analysis of variance (ANOVA) was used to determine the significance of the regression function. Pearson product-moment correlation coefficients were used to examine the relationships among variables including BMD, SM, LTI, BMI, weight, LT, BFI, and BF. Mahalanobis distance and chi square critical values were determined to identify data outliers, and residual plots were used to evaluate univariate normality.

Limitations

Menarchal age and menstrual irregularity along with the heights of the biological parents that were used to estimate skeletal maturational status was self-reported by the subjects in the study's questionnaire. Therefore, the validity of the study is dependent upon accurate reporting by the subjects.

plots of metabolic rate observations versus estimations (W) from each model.

RESULTS

Physical characteristics of the subjects can be found in Table 1. There were 28 female subjects (mean age $\pm$ SD = 14.9 $\pm$ 1.6 yrs).

Table 1: Physical Characteristics of Subjects

(N = 28 females)

Variables	Mean	Standard Deviation
Age (yr)	14.9	1.6
Weight (kg)	54.0	7.3
Height (cm)	160.1	5.9
BMD (gms/cc)	1.12	0.08
BMD legs (gms/cc)	1.19	0.11
LT (kg)	38.1	3.9
BF (kg)	12.9	4.5
BMC (kg)	2.4	0.39
%BF	23.7	5.8
BMI (wgt/hgt^2)	21.1	2.6
LTI (LT/hgt^2)	14.8	1.2
BFI (BF/hgt^2)	5.0	1.8
Calcium (gms)	900.9	148.4
Age of Menarche (yr)	12.7	1.1
Periods missed last 12 mos	2.2	3.7
Estimated skeletal maturity	98.1	1.6
BMD z-score	0.65	0.89

Table 2 lists a matrix of partial correlations controlled for estimated skeletal maturity, age of menarche, and number of periods missed in the last year. The matrix

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consists of six partial correlations listing the associations among six body composition components and bone mineral density. LTI was the strongest association (ρ = .712) with bone mineral density.

Table 2: Partial Correlation Matrix

Variables (Controlled for SM, MA, PM)*	ρ
LTI vs BMD	.712
BMI vs BMD	.575
Wgt vs BMD	.639
LT vs BMD	.633
BFI vs BMD	.241
BF vs BMD	.254

***SM – Skeletal Maturity**
MA - Menarchal Age
PM - Periods missed in the last 12 months

Multiple linear regressions were calculated to predict bone mineral density of the leg (BMDleg) using the independent predictor variables *estimated skeletal maturity* (SM) and one of six body composition measures (LTI, BMI, LT, WGT, BF, BFI) to determine which equation provided the best fit. Pearson product moment correlations were computed to determine the relationships of the independent predictor variables. Models with moderate or strong associations between independent variables were excluded. Mahalanobis distance and chi-square critical values were computed to determine outliers. Two data sets were excluded because they exceeded the critical values. The study met the recommended value of at least 13 subjects for each independent variable. Residual scatterplots were generated to evaluate univariate normality. No transformations of variables were required. Multicollinearity was also confirmed. All independent variables had tolerance values greater than 0.2 and VIF values less than 5.0. The multiple linear regression using the independent predictor variables SM and LTI provided a significant equation with the best fit. Table 3 lists the model summaries.

Table 3: Model Summaries for BMD Leg Multiple Regression

IVs	R	R^2	Adj R^2	F (2,23)	r
LTI & SM*	.798	.637	.605	20.161	.282
BMI & SM	.716	.513	.471	12.119	.385
WGT & SM	.715	.511	.469	12.029	.505
LT & SM	.714	.510	.467	11.973	.387
BF & SM	.574	.330	.272	5.664	.399
BFI & SM	.577	.333	.275	5.747	.385

*** SM – Skeletal Maturity**

A multiple linear regression was calculated to predict the dependent criterion variable, BMDleg, based upon the independent predictor variables, LTI and the estimated skeletal maturity (SM). A significant regression equation was found [$F(2,23) = 20.161$, $p < .001$] with an R Square of .637 and a standard error of the estimate equaling .0634. The subjects' BMDleg is equal to (-2.486) + (2.912)SM + (5.540E-02)LTI where BMDleg is in grams/centimeter squared, SM is measured in percent, and LTI is measured in kilograms/meters squared.

Similar multiple linear regressions were also calculated to predict bone mineral density (BMD) using the independent predictor variables *estimated skeletal maturity* (SM) and one of six body composition measures (LTI, BMI, LT, WGT, BF, BFI) to determine which equation provided the best fit. The multiple linear regression using the independent predictor variables SM and LTI provided a significant equation with the best fit. Table 4 lists the model summaries.

Table 4: Model Summaries for BMD Multiple Regression

IVs	R	R^2	Adj R^2	F (2,23)	r
LTI & SM*	.788	.621	.588	18.828	.282
BMI & SM	.730	.533	.493	13.147	.385
WGT & SM	.768	.590	.554	16.530	.505
LT & SM	.748	.560	.521	14.619	.387
BF & SM	.595	.354	.248	6.301	.399
BFI & SM	.590	.348	.292	6.143	.385

*** SM – Skeletal Maturity**

A multiple linear regression was calculated to predict the dependent criterion variable, BMD, based upon the independent predictor variables, LTI and the estimated skeletal maturity (SM). A significant regression equation was found [F(2,23) = 18.828, p <.001] with an R Square of .621 and a standard error of the estimate equaling .0487. The subjects' predicted BMD is equal to (-1.645) + (2.209)SM + (4.068E-02)LTI where BMD is in grams/centimeter squared, SM is measured in percent, and LTI is measured in kilograms/meters squared.

DISCUSSION

The current research found that the LTI was the best body composition component choice to use as an independent variable to predict BMD in the study's subjects. Substantial research has been conducted investigating the relationships among BMD, body composition components, and exercise. For example, body weight and body fat are thought to influence BMD by placing an additional mechanical load on the skeleton (17). Felson et al. (18) found that body weight and body mass index (BMI) accounted for a substantial proportion (8.9% - 19.8%) of the total variance in BMD in women. Furthermore, Reid, Plank and Evans (19) found a significant correlation between body weight and BMD (r = .69) in premenopausal women (mean age $\pm$ SD = 33 $\pm$ 8 yr; mean BF % $\pm$ SD = 31 $\pm$ 8%). They also observed that total body fat was a better predictor (r = .60) of BMD than lean tissue (r = .55). Contrary to these findings, Madsen, Adams, and Van Loan (10) found lean tissue to be a better predictor of BMD in eumenorrheic athletes (mean age $\pm$ SD = 20.8 $\pm$ 2.5 yrs; mean BF % $\pm$ SD = 18.5 $\pm$ 3.9%). These findings demonstrate that body composition components as well as body weight influence BMD. In the current study, LTI was the body composition component most associated with BMD (ρ = .712) with respect to the subjects (mean age $\pm$ SD = 14.9 $\pm$ 1.6 yrs; mean BF % $\pm$ SD = 23.7 $\pm$ 5.8%).

Previous studies indicate that amenorrhea is more prevalent in athletic sub-populations than in the general population. Wolman et al (20) noted in a study of 226 elite female athletes that the incidence of amenorrhea was 71% in gymnasts, 46% in lightweight rowers and 45% in runners while in the general female population the range was only 2 to 5%. Nichols et al (21) in a study of 8 sports from 6 high schools in southern California found 23.5% of 170 female athletes were amenorrheic. Whatever the sport, it can be said that women athletes demonstrate a higher prevalence of amenorrhea than non-athletes. In the current study, eleven of the twenty-eight subjects were classified as amenorrheic (39.3%), by indicating on the questionnaire that they had missed three or more menstrual cycles in the twelve moths prior to the analysis.

Low percentages of body fat, weight loss, excessive training and poor nutritional habits may be contributing factors that influence amenorrhea (22)., Although menstruation ceases when energy intake is insufficient (23), previous research suggests that there is no "set" level of body fat that is applicable to all athletes for normal menstrual function. Many female athletes with low body fat retain their monthly cycle (24, 25). However, elite-level female cross-country runners may find it difficult to avoid occasional bouts of amenorrhea. In most cases these events can be controlled so that their duration is short enough for hormonal levels to remain within the limits of normalcy (26, 27). In order to minimize health risks, weight loss and/or body fat reduction should be regulated over reasonable time periods, allowing the body to acclimate to the change.

The total body fat percentage for the subjects of the current study seemed to be high for an elite, female cross-country program (mean BF % ± SD = 23.7 ± 5.8%). However, the subjects were adolescents and were younger (mean age ± SD = 14.9 ± 1.6 yrs) than subjects in previous studies. Despite the higher values of BF percentage, LTI was still the best choice of predictor variable of BMDleg and BMD for this subject population.

While LTI was the best body composition component to use as an independent variable to predict BMD of this sub-population of elite, adolescent cross-country runners, its applicability as a predictor variable in larger sub-populations for BMD remains unknown. Groups of athletes whose BMD are primarily influenced by high-intensity aerobic activity with little influence due to bodyweight, body fat, or massive amounts of lean tissue are likely sub-populations that would utilize LTI as an independent predictor variable for BMD. Future BMD research of subjects in these populations will reveal its applicability.

The effects of amenorrhea are dramatic and they demand attention, especially with its prevalence in female athletes who participate in size-sensitive sports. For example, Drinkwater's research (11) that revealed long-term cessation of menstrual periods due to EAA can lead to irreversible bone loss. It is an issue that must be of concern to at-risk female athletes. These runners must remain alert to the signs of amenorrhea and consult a physician immediately if appropriate.

In conclusion, the identification of new ways to predict BMD in female athletes, such as the use of LTI, may provide deeper insights into understanding the complex association between osteoporosis, body composition, and physical activity; and eventually help reduce the risk of osteoporosis in this sub-population. The results of the current study reinforce the need for further investigation among LTI, osteoporosis, and BMD, especially in larger populations and/or other subpopulations.

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