International Journal of EXERCISE SCIENCE

Original Research

The Relationship Between Muscular Strength, Jump Power, and Bone Health in Collegiate Distance Runners

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ABSTRACT

International Journal of Exercise Science 16(4): 563-575, 2023. Participation in sports, especially those involving impact loading, enhance bone mineral content (BMC) and density (BMD). Additionally, participation in impact loading sports may strengthen relationships between strength or power and bone variables. The purpose of this investigation was to examine relationships between measures of muscular performance and bone variables in Division I endurance athletes (29 males, 31 females, 19.6 ± 1.4 years). Dual-energy x-ray absorptiometry (DXA) scans were analyzed at the anterior-posterior (AP) and lateral (LAT) spine, femoral neck (FN), total hip (TH), whole body (WB), and ultra-distal forearm (UD) for BMC and BMD measures. WB scans provided information for bone-free lean mass (BFLM). Performance measures included absolute, and relative (to body weight), grip strength (GS) and absolute lower body power (LBP) derived from a vertical jump. Pearson correlation coefficients were determined between bone variables and muscular performance measures. Hierarchical multiple regression was used to quantify the variance explained in bone variables. Male runners showed strong relationships between absolute and relative GS and numerous bone variables. Female runner had significant relationships between absolute jump power and numerous bone variables. Sex, GS, and LBP explained 41-76% of BMC at the various bone sites and 12-30% of BMD. Results indicate that in collegiate men, greater strength is related to higher BMC and BMD, however this was not the case for women. In female collegiate distance runners, higher jump power was related to greater BMC and BMD.

KEY WORDS: Endurance athletes, college athletes, grip strength, bone health, bone mineral density

INTRODUCTION

The American College of Sports Medicine recommends two approaches to making the skeleton more resistant to fracture: 1) maximize the gain in bone density during the first three decades of life, and 2) minimizing the loss of bone density after the age of 40 (31). There are a number of ways to try and meet these recommendations. One method is encouraging impact type activities across the lifespan, as well as including resistance training as part of fitness programs.

The mechanism leading to the enhancement in bone mineral density (BMD) with impact or loading type activities can be seen in the effects of Wolff's Law. This suggests that mechanical loading on bone resulting from physical activity can produce osteogenic responses in both animals and humans (6, 24, 53). The musculo-tendoninous attachment exerts force strain on the bone, which in turn stimulates remodeling and possibly improving bone density (41). Previous research has shown that voluntarily engaging in mechanical loading can promote alterations in bone shape, architecture, trabecular connectivity, cortical thickness (18), and BMD assessed via absorptiometry (39). These alterations could potentially improve whole-bone strength and, in turn prevent both injuries and long-term concerns, such as osteoporosis (18). BMD is frequently used as a surrogate measure for bone strength and may account for up to 70% of bone strength (40). BMD (g/cm^2) measures grams of bone mineral in a particular two-dimensional region of interest. Bone mineral content (BMC), a simple measure of grams of mineral, is also an important indicator of bone health especially in young populations because it captures the mass of bony material without regard to bone size (22, 23).

Handgrip dynamometry has been established as a valid and reliable measure of strength across the lifespan (11, 36) and due to its simplicity, reliability, and low risk of injury, is one of the most common methods of strength assessment (42). This is particularly useful with the evidence suggesting grip strength (GS) is reflective of both upper body and total body strength (5, 51). Lower body power (LBP) has been assessed utilizing a variety of measurement techniques including free weights, machines, and jump tests wherein, the countermovement jump (CMJ) has been shown to be a valid and reliable test for LBP (9, 35, 43).

Several studies have shown a positive relationship between GS and BMD. The populations reported include children (8, 10, 37), adolescent female athletes (12), young adult men (46), young adult women (44), collegiate athletes (54), post-menopausal women (13, 33), and older adults (15, 21, 34). Additionally, several studies have shown a positive relationship between leg power and BMD or other bone variables in children and young adults (2, 15, 24, 28, 30), collegiate athletes (54), and premenopausal women (44, 52). Yingling et al. studied many types of collegiate athletes collectively as a group, including track, cross-country, volleyball, soccer, swimming, and basketball athletes (54). Further, several studies have shown a significant positive relationship between bone-free lean mass (BFLM) and various bone variables (10, 15, 26). Despite all of these investigations in various populations, more research is needed, specifically among athletes at risk for bone injuries, like distance runners, where weight is a factor and often influences an athletes' decisions about dietary intake and training patterns.

Collegiate distance runners are an athletic population that sometimes experience low BMD (3, 16, 27, 49, 50) and are not known for their high muscular strength. One of the problems with low BMD in this population is the increased risk of stress fractures (3, 4, 7, 47). There is to-date, little research on the relationship between muscular performance and bone variables in collegiate distance runners. If there is a relationship between muscular performance and bone health in this population, coaches and athletes may want to include strength and power training in their workouts to possibly increase bone mass, and lower risk for fracture. Additionally, if this relationship holds true in collegiate distance runners, coaches and medical staff may use muscular performance information, in conjunction with diet and other demographic information, to identify possible candidates for further BMD testing.

The first purpose of this investigation was to examine the relationships between measures of GS and LBP and BMD and BMC in Division I endurance athletes. Secondly, through regression analysis, we sought to estimate the amount of variance in BMD and BMC at various sites explained by GS and LBP. We hypothesized that those participants with higher GS and higher LBP will have greater BMD and BMC.

METHODS

Participants

Sixty NCAA Division I cross-country runners (31 females and 29 males) volunteered for this observational investigation. Data was collected over a 5-year period. The data was collected during the runner's initial testing session as they joined a longitudinal study during their first or transfer year. All strength tests and assessments of bone health were performed in a single testing session. The training routine for the distance runners included 9-10 running sessions per week, accumulating over 100 km with a long run between 20 and 25 km each week. In addition, the runners engaged in two resistance training sessions and two cross-training workouts of aqua jogging or stationary cycling each week. As an observational study, this training routine was developed and implemented by the cross-county coaches as part of their normal training regimen. Before enrollment in this study, all participants completed informed written consent documentation and the investigation was approved by the Loyola Marymount University Institutional Review Board for the Protection of Human Subjects. This research was carried out fully in accordance to the ethical standards of the *International Journal of Exercise Science* (38).

Protocol

Bone Health and Body Composition Measurements: Dual-energy x-ray absorptiometry (DXA) was utilized to measure BMC, BMD, and BFLM (Hologic Discovery A, Waltham, MA). The DXA was calibrated daily prior to participant scans. The scans of the whole body (WB), proximal left femur for total hip (TH), femoral neck (FN), non-dominant ultra-distal forearm (UD), and anterior-posterior (AP) and lateral (LAT) spine were conducted and examined by the same technician. BFLM was determined from the WB DXA scan. Body mass index ($kg \cdot m^{-2}$) was determined by dividing body weight (kg) by height (m) squared. A Health-O-Meter Professional scale (Neosho, MO) was utilized to determine height (cm) and weight (kg). For the DXA scan, participants were asked to wear light clothing without zippers and remove anything with metal, such as jewelry.

Strength Measurements: Maximum voluntary grip strength (GS) was measured utilizing a hand dynamometer (Takei Physical Fitness Test Grip-D, Takei Scientific Instruments Co., Ltd, Niigata City, Japan), with participants in a standing position with the arm flexed 90 degrees. The dynamometer was supported by one of the investigators, who gave the participant a 3 s countdown to the "go" command. Participants squeezed the dynamometer with maximal voluntary effort for 3 to 5 s. Encouragement was provided by the study staff. Three trials with each hand were performed by the participants, with the highest measure of each hand summed and this total used for analysis. Testing was alternated between dominant (DOM) and non-dominant (NDOM) hands. Two minutes recovery was given between consecutive trials with the same hand.

LBP was evaluated using two-legged countermovement jumps performed with a Tendo™ Power Output Unit (Tendo Sports Machines, Trencin, Slovak Republic). Participants conducted three jump trials with a 2-minute rest period between jumps. All jumps were performed with hands on hips and the jump was performed in one continuous motion once the participant began their downward movement. The highest measurement (W) was utilized for LBP analyses.

Statistical Analysis
Pearson's product correlations were utilized to evaluate the relationships between muscular performance measurements (GS and LBP) and bone variables (BMC and BMD) at the various sites. Significant relationships between GS and bone variables were determined utilizing absolute strength (kg) and relative strength (RGS in kg/BW). Significant relationships between LBP and bone variables were determined using absolute jump power (W). Hierarchical multiple regression (HMR) was used to calculate the amount of variance explained by GS and LBP. Three models were used in the analysis for the group. Model one included sex as the first variable, followed by adding GS (model two) and then LBP (model three). Analysis of variance was used to determine differences in the demographic data between men and women. An alpha level of 0.05 was used to determine significance. The statistical package SPSS version 24 (IBM Corp., Armonk, NY) was utilized to determine significant relationships and correlations. Data is presented as mean ± standard deviation. G*Power version 3.1.9.7 (Heinrich Heine University, Düsseldorf, Germany) was used to estimate sample sizes. Power analysis for correlations revealed that an n = 23 was necessary for a statistical power of 0.80.

Table 1. Participant Descriptive Statistics

Variable	Male Runners (n = 29)	Female Runners (n = 31)
Age (yrs)	19.5 ± 1.3	19.8 ± 1.5
Height (cm)	177.1 ± 5.2	163.6 ± 6.4*
Weight (kg)	65.4 ± 4.6	54.2 ± 5.9*
BMI (kg/m²)	20.8 ± 1.3	20.3 ± 1.8
BFLM (kg)	53.1 ± 3.8	39.9 ± 4.0*
Percent BF	15.5 ± 1.9	23.0 ± 3.6*
GS (kg)	78.9 ± 11.2	56.6 ± 7.9*
RGS	1.23 ± 0.19	1.05 ± 0.13*
GS/BFLM	1.48 ± 0.17	1.42 ± 0.17
LBP (W)	1,689.8 ± 219.1	1,239.9 ± 185.8*
LBP/BW	26.4 ± 4.3	22.7 ± 2.1*
LBP/BFLM	31.4 ± 4.4	30.4 ± 3.0

*Indicates significant difference between males and females ($p \leq 0.001$). GS = grip strength absolute; RGS = relative grip strength (GS/BW); LBP = lower body power absolute; BMI = body mass index; BFLM = bone free lean mass; BF = body fat; BW = body weight

RESULTS

The descriptive data for the participants is presented in Table 1. Results of the correlation analysis are shown in Table 2 (spine and WB results) and Table 3 (FN, TH, and UD results).

Table 2. Correlations between Muscular Performance Measures and Spine and Whole-Body Bone Variables.

		AP BMD	AP BMC	LAT BMD	LAT BMC	WB BMD	WB BMC
Group							
GS	r	0.304	0.608	0.467	0.687	0.564	0.756
	R^2	0.092	0.370	0.218	0.472	0.318	0.572
	p	0.019	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001
RGS	r	0.075	0.235	0.174	0.297	0.372	0.313
	R^2	0.006	0.055	0.030	0.088	0.138	0.098
	p	0.574	0.073	0.187	0.022	0.004	0.016
LBP	r	0.394	0.635	0.573	0.744	0.549	0.735
	R^2	0.155	0.403	0.431	0.553	0.301	0.540
	p	0.003	≤0.001	≤0.001	≤0.001	≤0.001	≤0.001
Men							
GS	r	0.510	0.726	0.496	0.775	0.673	0.785
	R^2	0.260	0.527	0.246	0.601	0.453	0.616
	p	0.005	≤0.001	0.006	≤0.001	≤0.001	≤0.001
RGS	r	0.324	0.298	0.303	0.385	0.428	0.356
	R^2	0.105	0.089	0.092	0.148	0.183	0.127
	p	0.086	0.117	0.110	0.039	0.020	0.058
LBP	r	0.251	0.402	0.226	0.393	0.244	0.366
	R^2	0.063	0.162	0.051	0.154	0.059	0.134
	p	0.197	0.034	0.247	0.039	0.211	0.055
Women							
LBP	r	0.459	0.511	0.573	0.643	0.446	0.567
	R^2	0.211	0.261	0.328	0.413	0.199	0.321
	p	0.014	0.005	0.001	≤0.001	0.017	0.002

GS = grip strength absolute; RGS = grip strength relative to body weight; LBP = lower body power absolute; AP = anterior-posterior spine; LAT = lateral spine; WB = whole body; BMD = bone mineral density; BMC = bone mineral content.

Correlation Results

The men showed significant relationships between GS and all bone variables. RGS correlated with LAT BMC, WB BMD, FN BMD, TH BMD, and UD BMC and BMD. For the men, LBP correlated with TH, UD, AP, and LAT BMC. For the women, GS and RGS did not significantly correlate with any bone variables. LBP correlated with all bone variables except FN BMD, UD BMC and BMD. For the group, BFLM was significantly related to all bone variables with the results ranging from $r = 0.352$ at UD BMD to $r = 0.904$ at TH BMC.

HMR Results

Results of the regression analysis are presented in Table 4. GS added significantly (8-12%) to all BMC bone sites and LBP added significantly (5-9%) to all BMC bone sites, except FN and UD. Sex, GS, and LBP together account for 76% of the variance in BMC at TH. For BMC, the explained variance for Model 3 (Sex, GS, and LBP) ranged from 41% at AP spine to the previously mentioned 76% at TH. For BMD, GS and LBP significantly added only to the variance at LAT spine. Sex, GS, and LBP in combination accounted for 30% of the variance in BMD at the WB. The range for variance explained in BMD was 12% at the AP spine to the 30% at the WB.

Table 3. Correlations between Muscular Performance Measures and Hip/Femur/Forearm Bone Variables.

		FN BMD	FN BMC	TH BMD	TH BMC	UD BMD	UD BMC
Group							
	r	0.478	0.772	0.486	0.799	0.428	0.669
GS	R^2	0.228	0.596	0.236	0.638	0.183	0.448
	p	≤0.001	≤0.001	≤0.001	≤0.001	0.001	≤0.001
	r	0.317	0.427	0.277	0.458	0.400	0.490
RGS	R^2	0.100	0.182	0.077	0.210	0.160	0.165
	p	0.014	0.001	0.034	≤0.001	0.002	≤0.001
	r	0.450	0.700	0.468	0.806	0.347	0.641
LBP	R^2	0.203	0.490	0.219	0.650	0.120	0.411
	p	0.001	≤0.001	≤0.001	≤0.001	0.009	≤0.001
Men							
	r	0.489	0.674	0.380	0.520	0.337	0.475
GS	R^2	0.239	0.454	0.144	0.270	0.114	0.226
	p	0.007	≤0.001	0.042	0.001	0.08	0.011
	r	0.415	0.275	0.311	0.372	0.383	0.393
RGS	R^2	0.172	0.076	0.097	0.138	0.147	0.154
	p	0.025	0.120	0.10	0.047	0.044	0.039
	r	0.303	0.319	0.209	0.399	0.135	0.427
LBP	R^2	0.092	0.102	0.044	0.159	0.018	0.182
	p	0.117	0.097	0.286	0.036	0.502	0.026
Women							
	r	0.151	0.420	0.477	0.662	0.120	0.281
LBP	R^2	0.023	0.176	0.228	0.438	0.014	0.079
	p	0.425	0.026	0.010	≤0.001	0.542	0.148

GS = grip strength absolute; RGS = grip strength relative to body weight; LBP = lower body power absolute; FN = femoral neck; TH = total hip; UD = ultra-distal forearm; BMD = bone mineral density; BMC = bone mineral content.

DISCUSSION

The GS results from this group of men collegiate distance runners are comparable to those reported by Garcia-Pinillos (19) in male recreational runners; however, using the reference data published by Schlüssel et al. (42) the men in our study would fall into approximately the 30th percentile. The women's GS results are similar to those reported by Emslander et al. (14) in collegiate runners, swimmers and controls and would be in the 60th percentile when using the reference data provided by Schlüssel et al. (42).

When examining the correlation results of the present investigation, there were numerous significant relationships between muscular performance measures and the bone variables. For the men in the present study, GS was moderately to strongly correlated to all BMC measures and most BMD measures. This is similar to results of Finianos et al. (15) in 50-year-old men and Sutter et al. (46) in 24-year-old men. In a slightly younger population (11- to 19-year-olds), Cossio-Bolanos and colleagues (10) reported significant correlations between absolute GS (dominant and non-dominant) and WB BMD in boys/men. Chan et al. (8) showed significant correlations between GS and TH BMD, AP BMD, and WB BMD in boys (11-12 years old). Thus, our findings are similar to previous results in male populations of various age groups.

Table 4. Hierarchical Regression Results.

Site		r	R^2_{adj}	p-value	Site		r	R^2_{adj}	p-value
AP BMC					AP BMD				
	Model 1	0.497	0.233	<0.001		Model 1	0.215	0.028	0.115
	Model 2	0.592	0.326	0.006		Model 2	0.265	0.034	0.252
	Model 3	0.666	0.411	0.005		Model 3	0.413	0.122	0.016
LAT BMC					LAT BMD				
	Model 1	0.642	0.401	<0.001		Model 1	0.452	0.189	0.001
	Model 2	0.710	0.485	0.003		Model 2	0.476	0.197	0.212
	Model 3	0.773	0.575	0.001		Model 3	0.576	0.292	0.007
FN BMC					FN BMD				
	Model 1	0.706	0.488	<0.001		Model 1	0.328	0.091	0.014
	Model 2	0.788	0.606	<0.001		Model 2	0.444	0.166	0.020
	Model 3	0.799	0.617	0.118		Model 3	0.490	0.196	0.093
TH BMC					TH BMD				
	Model 1	0.808	0.647	<0.001		Model 1	0.354	0.109	0.008
	Model 2	0.855	0.720	<0.001		Model 2	0.450	0.172	0.029
	Model 3	0.881	0.762	0.002		Model 3	0.500	0.206	0.078
WB BMC					WB BMD				
	Model 1	0.685	0.460	<0.001		Model 1	0.472	0.208	<0.001
	Model 2	0.766	0.571	<0.001		Model 2	0.547	0.272	0.021
	Model 3	0.797	0.614	0.012		Model 3	0.584	0.302	0.077
UD BMC					UD BMD				
	Model 1	0.593	0.339	<0.001		Model 1	0.374	0.123	0.005
	Model 2	0.678	0.439	0.002		Model 2	0.421	0.145	0.134
	Model 3	0.702	0.463	0.074		Model 3	0.422	0.129	0.805

Model 1 = sex; Model 2 = sex + Grip Strength; Model 3 = sex + Grip Strength + Jump Power; p-value = significance value of the change in the F-value; Significant p-value = <0.05

Interestingly, for the women in the present study, GS was not related to any of the bone variables at any site, which is what Hyde at al. (26) reported in 11-year-old girls, but different from what Chan et al. (8) reported in 10-11-year-old girls where significant correlations between GS and several BMD measurements were found. When their data was analyzed as a group, a sample of

18-29-year-old Division II athletes from track, cross-country, soccer, and basketball, Yingling and colleagues (54), did not find significant relationships between RGS and cortical BMD which is different than the present study group findings as seen in Tables 2 and 3. These contrasting findings could be due to different methodologies as we used DXA and Yingling et al. used peripheral quantitative computed tomography (pQCT) at 50% tibia length.

Among the men in the present study, LBP was only related to UD BMC. This is unlike the results of Finianos et al. (15) in 50-year-old men and Khawaja et al. (30) in 18- to 35-year-old men, who both reported numerous relationships between jump power and BMC and BMD measures. Contrary to the men, the women in the present study had significant relationships between LBP and all BMC measures as well as BMD measures at AP, LAT, WB, and TH which is similar to the results reported by Khawaja et al. (30) in 18- to 35-year-old women. In a dataset with both sexes, when examining LBP, Yingling et al. (54) reported similar results to their GS data reported above. They found no significant correlations between jump power and cortical BMD at 50% of the tibia.

Bone-free lean mass (BFLM) was significantly correlated with all bone variables when Pearson tests were performed with the group data. When the data was split into groups by sex, BFLM for the men was significantly correlated with all bone variables except AP BMD, TH BMD, UD BMC and BMD. For the women, BFLM was significantly correlated to all bone variables except UD BMD. This is similar to previous research where lean mass was related to BMD and/or BMC in 50-year-old men (15), 11-year-old girls (26), and 23-year-old men (32). This finding supports the muscular performance measures relationship mentioned above indicating that more muscle mass is related to enhanced bone quality.

In this group of collegiate distance runners, muscular performance measures helped explain nearly 20% of the variance at the spine (AP & LAT) and WB BMC measures. The addition of muscular performance measures added significantly to predicting BMC at all sites except the FN and UD. This did not hold true for BMD measures, where muscular performance measures only added significantly to predicting BMD measures at the LAT spine. In a younger population of boys (15.7 years) and girls (15.5 years), Cossio-Bolanos and colleagues (10) reported GS accounting for 18-19% of the variance in whole body BMD and 20-23% of variance in whole body BMC in boys and 12-13% of the variance in whole body BMD and 17-18% of the variance in whole body BMC in girls. In a study utilizing pQCT and GS, Hasegawa et al. (20) reported muscle strength is a strong determinant of mechanical characteristics of bone (radius). In examining bone characteristics of the tibia from pQCT and utilizing a vertical jump, Janz et al. (28) reported lower body muscle power is a good predictor of bone strength in the tibia. Yingling and colleagues (54), utilizing pQCT reported vertical jump power explained 54-59% of the variance in bone strength. They also reported that relative leg extensor strength or RGS were not predictors of cortical BMD of the tibia. The present findings in collegiate distance runners support previous research when examining the variance explained by muscular performance measures when measuring bone variables.

An interesting finding in this study was the relationship between bone variables at the spine and LBP. Future research should further examine this relationship by performing exercises such as squats and deadlifts and evaluating their potential impact on spine BMC and BMD. Additionally, the finding that there were no relationships between any bone variables and GS in the women needs further research. One explanation for the lack of correlation between GS and bone variables could be the relatively tight range in GS performance in the homogenous group of women runners in this study.

A strength of the present investigation is the large number of distance runners that were tested. Additionally, there were multiple bone sites measured allowing for in depth analysis of both upper body and lower body correlations between bone variables and muscular performance measures. These findings are important since this population at times may have problems with low bone mass and poor skeletal health. A limitation of the present study was the small range of some of the data due to this being a relatively homogenous group of athletes. Also, there was an inability to draw a conclusive cause and effect relationship using correlational analysis between measures of muscular performance and bone health.

In conclusion, the present study confirms that relationships between muscular performance measures and bone variables seen in adolescents and young adults holds true in collegiate distance runners with the exception of no relationships between GS and bone variables in this group of women collegiate distance runners. When considered in combination with previous literature showing skeletal benefits of resistance training (1, 2, 17, 25, 29, 37, 45), the current findings encourage incorporation of resistance exercise into training programs to enhance strength, power, and bone health in distance runners. Some endurance athletes experience low bone mass and are at greater risk for bone injuries (48). Developing a stronger athlete through resistance training that focuses on strength and power, will likely lead to greater muscle and bone mass, thereby decreasing risk for injury and propensity towards osteoporosis later in life.

ACKNOWLEDGEMENTS

We would like to thank the University Cross-Country Team for their participation in this investigation and Coaches Scott Guerrero, Jason Zarb-Cousin, and Chloe Curtis for their help.

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