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Physical Performance Variables and Bone Parameters in a Group of Young Overweight and Obese Women

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Abstract

The aim of this study was to explore the relationships between physical performance variables and bone parameters such as bone mineral density (BMD), bone mineral content (BMC), hip geometry indices, and trabecular bone score (TBS) in a group of young overweight and obese adult women. Sixty-eight overweight/obese (body mass index ≥ 25 kg/m^2; 25.5 – 42.4 kg/m^2) young women whose ages range from 18 to 35 years participated in this study. Body composition and bone outcomes were measured by dual-energy X-ray absorptiometry (DXA). Maximum oxygen consumption (VO_2 max, in liter per minute) was determined indirectly using a progressive shuttle run test. One-repetition-maximum half-squat was directly measured. Vertical jump was measured and maximum power (P max) of the lower limbs was calculated. Lean mass was positively correlated to whole body (WB) BMD, total hip (TH) BMD, femoral neck (FN) BMD, femoral neck cross-sectional area (FN CSA) and femoral neck cross sectional moment of inertia (FN CSMI) ($p < 0.05$). VO_2 max (in liter per minute) and muscle power were positively correlated to WB BMD, TH BMD, FN BMD, FN CSA and FN CSMI ($p < 0.05$). One-repetition-maximum half-squat was positively correlated with lumbar spine TBS, WB BMD, FN BMD, FN CSA and FN CSMI ($p < 0.05$). This study suggests that lean mass, vertical jump, VO_2 max (liter per minute), muscle power and one-repetition-maximum half squat are positive determinants of BMD and hip geometry indices in young overweight and obese women.

Introduction

Obesity and overweight among young adults are becoming a major health problem worldwide (1). Despite being a risk factor for several comorbidities and for mortality (2), obesity is generally considered to be beneficial for bone health. Excess body weight is associated with higher mechanical loading conferring positive effects on bone formation. However, excess body weight caused by excessive fat accumulation may have detrimental effects on bone health. Obese patients are in constant pro-inflammatory imbalance and present increased bone marrow adiposity leading to decreased bone formation and increased bone resorption (3). Positive effects of body weight could offset some of the detrimental effects of obesity on bone health, at least on weight-bearing bones. The available evidence shows that the impact of fat on bone in obese individuals varies according to bone site (4–6). For instance, obesity is associated with higher bone mineral density at the hip but may be associated with lower BMD at non-weight bearing sites (7,8). Furthermore, fracture risk may be decreased at weight-bearing sites but increased at the humerus and forearm (2,8).

Physical activity is a potential environmental factor that positively affects bone physiology. Several meta-analyses demonstrated that high impact exercises have positive effects on bone mass at the lumbar spine (LS) and the femoral neck (FN) (9–11), and resistance training has a predominant positive effect on the LS BMD (12,13). Further, cross-sectional studies demonstrated that high fitness levels are positively correlated to bone mineral density (BMD), geometry and texture (as reflected by the trabecular bone score (TBS)) in normal-weight women (14–16) and overweight/obese young men (17). Whether such correlations exist in overweight/obese young women remains unknown. We have previously identified in a previous study several physical performance variables closely related to bone parameters in a group of young overweight and obese men (17). Therefore, we sought to identify in the present study the correlations between physical performance variables (including muscle power/strength and cardiorespiratory fitness) and bone parameters including bone mineral content, bone mineral density, hip geometry indices and TBS in a group of young overweight and obese women.

Materials and Methods

Subjects and Study Design

Sixty-eight overweight and obese (body mass index [BMI] > 25 kg/m^2; 25.5 – 42.4 kg/m^2) (18) young women whose ages ranged from 18 to 35 years participated in the present study. The 68 participants were recruited from two private universities located in Beirut, Lebanon. Women suffering from diseases affecting bone metabolism, smokers, pregnant, amenorrheic, and those taking medications that may affect bone and calcium metabolism (corticosteroid or anticonvulsant therapy) were excluded from the study. All participants completed an interview about medical history including menstrual history and medication use. The work described has been carried out in accordance with the declaration of Helsinki. This study was approved by the

Bellevue Medical Center Ethics Committee, and written informed consent was obtained from all individual participants included in the study.

Anthropometrics

Height (in centimeters) was measured in the upright position to the nearest 1mm with a standard stadiometer. Body weight (in kilograms) was measured on a mechanic scale with a precision of 100 g. Subjects were weighed wearing only underclothes. Body mass index (BMI) was calculated as body weight divided by height squared (in kilograms per square meter). Waist and hip circumferences were measured by a standardized Gulick tape (North Coast Medical, Gilroy, CA). Body composition, including lean mass (LM; kg) and fat mass (FM; %, kg) was evaluated by dual-energy X-ray absorptiometry (DXA; GE Healthcare, Madison, WI).

Bone Variables

BMC (in grams) and BMD (in grams per square centimeter) were determined for each individual by DXA at the whole body (WB), lumbar spine (L1–L4), TH, and femoral neck (FN). FN cross-sectional area (CSA), Cross sectional moment of inertia (CSMI), Strength Index (SI) and L1–L4 TBS were also evaluated by DXA as previously described (19,20). The TBS is derived from the texture of the DXA image and has been shown to be related to bone microarchitecture and fracture risk. The TBS can assist the healthcare professional in assessing fracture risk (20,21). In our laboratory, the coefficients of variation were less than 1% for BMC and BMD and less than 3% for FN CSA (22). The same certified technician performed all analyses using the same technique for all measurements.

Daily Calcium Intake (DCI)

The estimation of the DCI was based on a frequency questionnaire (23). Selection of items was based on the food composition diet, frequency of use, and relative importance of food items as a calcium source. The total number of food items was 30. The questionnaire included the following food items: milk and dairy products, including calcium-enriched items such as yogurt, cheese, and chocolate. Items such as eggs, meat, fish, cereals, bread, vegetables, and fruits were also included (23). The adequacy of calcium intake was assessed using the adequate intake guidelines of 1000 mg of calcium (24).

Daily Protein Intake (DPI)

The estimation of the DPI was based on a frequency questionnaire (25). The self-administered questionnaire comprises 20 items and can be filled up without any help. The DPI allows one to appreciate the intakes of foods providing the majority of protein (25).

Physical Activity

The duration of physical activity (hour per week) was evaluated using a validated questionnaire (26). The questionnaire assesses weekly and occasional sports and activities (26).

Maximum Oxygen Consumption (VO_2 max) Testing

VO_2 max (mL/min/kg) of the participants was assessed indirectly using a progressive shuttle run test performed in accordance with the guidelines (27) and VO_2 (L/min) was then calculated.

Explosive and Maximal Strength

A one-repetition-maximum (1-RM) test, following the protocol established by the National Strength and Conditioning Association, was performed to measure back half squat maximal strength on a Smith machine (28). Vertical jump (countermovement jump) was measured as previously described (28), and lower limb maximum power (*P* max, in watts) was calculated (29). Explosive and maximal strength measurements were performed on the same day in the following order: 1-RM half squat then vertical jump. Five minutes of recovery were taken between the 2 exercises. For the vertical jump, 3 trials were performed (with 3 min of recovery between trials), and the best performance was recorded.

Statistical Analysis

The means and standard deviations were calculated for all clinical data and for the bone measurements. All variables were evaluated for normality using the Shapiro-Wilk test and for equality of variance using Levene's mean test. Univariate correlations between bone parameters and both anthropometric and clinical characteristics were computed using Pearson's test. Multiple linear regression analysis models were used to test the relationship of DXA variables with LM and VO_2 max and with LM and physical performance variables (vertical jump, maximal power and 1-RM half-squat). Data were analyzed with Number Cruncher Statistical System (NCSS, 2001, Kaysville, UT). A level of significance of $p < 0.05$ was used.

Results

Clinical characteristics and bone data of the study population

Mean values of age, anthropometric parameters, dietary calcium and protein intake, physical performance variables, and bone parameters are displayed in Table 1. The mean BMI was 29.07 ± 3.79 kg/m^2.

Correlations between clinical characteristics and bone variables

The association between different bone parameters and anthropometric measures are presented in Table 2. Body weight was correlated with the overall bone parameters except for lumbar spine and total hip BMD and TBS. LM was more strongly correlated with bone outcomes than FM. LM was positively correlated with WB BMC, WB BMD, TH BMD, FN BMD, FN CSMI, and FN CSA. FM (kg) was positively correlated with FN CSMI ($p < 0.05$). None of the bone parameters was significantly correlated with waist to hip ratio, calcium and protein intake ($p > 0.05$).

Muscle power (W) and absolute VO_2 max (L/min) were positively correlated with WB BMC, WB BMD, TH BMD, FN BMD, FN CSA, and FN CSMI ($p < 0.05$). 1-RM half squat was positively correlated with WB BMD, FN BMD, FN CSA, FN CSMI, and lumbar spine TBS ($p < 0.05$). Vertical jump was positively correlated with all bone parameters ($p < 0.05$) except for lumbar spine TBS and FN SI ($p > 0.05$). VO_2 max relative to body weight (mL/min/kg) and MAS (km/h) were positively correlated with WB BMC ($p < 0.001$)

Multiple linear regression models

VO_2 max (L/min) was a stronger determinant of WB BMC than lean mass. VO_2 max (L/min) remained significantly correlated with WB BMC after adjusting for LM. LM was a stronger determinant of WB BMD, FN CSA and FN CSMI than VO_2 max (L/min) (Table 4). LM was not correlated with TH BMD and FN BMD after adjusting for VO_2 max (L/min) (Table 4).

Vertical jump was a stronger determinant of L1-L4 BMD, TH BMD and FN BMD than lean mass. Vertical jump remained significantly correlated with L1-L4 BMD, TH BMD and FN BMD after adjusting for lean mass (Table 4).

LM remained significantly correlated to WB BMC, WB BMD, TH BMD, FN BMD, FN CSMI, and FN CSA after adjustment for 1-RM half-squat ($p < 0.05$).

The positive associations between maximum power and bone variables disappeared after adjusting for LM ($p > 0.05$).

Discussion

This study conducted in a group of young overweight women mainly shows that lean mass, vertical jump, VO_2 max (L/min), muscle power, and 1-RM half-squat are positively correlated with BMD at several sites and hip geometry indices.

Our results confirm the positive importance of LM on bone health in overweight women. LM was positively associated with WB BMC, WB BMD, TH BMD, FN BMD, CSMI and CSA. Further analysis demonstrated that LM remained a significant predictor of several bone parameters. In fact, lean mass was the strongest predictor of WB BMD, FN CSMI and FN CSA. On the other hand, fat mass was not correlated with most of the bone parameters. Our results are in accordance with those of many previous studies (30) demonstrating that bone strength adapts primarily to dynamic loads represented by muscle forces and not to static loads represented by fat mass (31,32). Muscles are the load suppliers for bone; they provide the mechanical stimuli to preserve skeletal mass (33). Furthermore, the interaction between muscle and bone surpasses the mechanical interactions, and these two organs communicate at the biochemical and molecular levels (33).

Vertical jump was correlated with WB BMC, WB BMD, lumbar spine BMD, TH BMD, FN BMD, CSMI and CSA. In our study, vertical jump was one of the strongest predictors of bone variables. Importantly, among all studied variables, only vertical jump was positively correlated to lumbar spine BMD. Accordingly, increasing vertical jump performance may help to optimize BMD at the lumbar spine. Our study has identified a new positive determinant of lumbar spine BMD in young overweight and obese women. In addition, vertical jump was the strongest predictor of TH BMD and FN BMD. Our results are original and may have clinical implications in the field of osteoporosis prevention. Vertical jump can mechanically influence cortical and trabecular components of hip and lumbar spine.

1-RM half-squat and lower limb muscle power were positively associated with BMD and FN geometry indices. This highlights the importance of muscular maximal strength and power in determining bone phenotype in overweight and obese young adult women. Therefore, increasing muscle mass and enhancing the explosive force in the lower limbs could be an effective strategy to optimize bone health at the FN and prevent osteoporosis later in life in overweight or obese young individuals. Interestingly, among all physical performance variables, only 1-RM half-squat was positively correlated to TBS. Accordingly, increasing maximal strength in this specific exercise may help to optimize bone texture at the lumbar spine. Our study has identified a new positive determinant of TBS in young overweight and obese women. Half-squat can mechanically influence the trabecular component of lumbar spine.

VO_2 max (L/min) was positively correlated with WB BMC, WB BMD, TH BMD, FN BMD, FN CSA and FN CSMI. These results are in line with previous studies that showed a positive influence of

VO_2 max on bone resistance (16,17,34), which may reveal the importance of aerobic training in increasing bone mass and protecting against fracture. The mechanisms that can explain these correlations are not completely understood. High values of VO_2 max may reflect higher habitual physical activity and increased bone vascularization. Furthermore, the positive correlations between VO_2 max and bone parameters may be mediated by its correlation with LM (35). Several positive associations between VO_2 max (L/min) and bone variables disappeared after adjusting for LM. However, VO_2 max (L/min) was the strongest predictor of WB BMC in our study. VO_2 max (L/min) was a stronger determinant of TH BMD and FN BMD than lean mass.

Overall, vertical jump was the strongest predictor of lumbar spine BMD, TH BMD and FN BMD. Lean mass was the strongest predictor of WB BMD, FN CSA and FN CSMI. VO_2 max (L/min) was the strongest predictor of WB BMC, 1-RM-half squat and BMI were the strongest predictors of TBS and fat mass was the strongest predictor of SI. Maximum power of the lower limbs (watts) was a fair determinant of several bone parameters. Consequently, there is a site specific effect of each physical performance variable on bone parameters. However, increasing maximal strength, explosive strength, maximal power of the lower limbs (watts), total lean mass and absolute maximum oxygen consumption (L/min) may lead to optimize bone health in young overweight and obese women. Accordingly, a combined resistance and high-intensity aerobic training may increase all the above mentioned physical performance parameters.

Our study had some limitations. The cross-sectional nature of this study is a limitation because it cannot evaluate the confounding variables. The second limitation is the small number of subjects in our study group. The third limitation is the two-dimensional nature of DXA (36,37).

Furthermore, DXA scan image quality tends to worsen with obesity so that geometry precision degrades on heavier patients (38). Finally, menstrual cycle phases were not evaluated when performing physical performance tests. However, to our knowledge, it is one of the few studies that aimed at finding new determinants of BMD and hip geometry indices in overweight and obese women. Some of these determinants are easily calculated when performing simple physical tests.

Conclusion

In conclusion, this study found that lean mass, vertical jump, VO_2 max (L/min), maximal power (watts) and 1-RM half-squat are positively correlated with bone parameters in overweight and obese adult women. Our results may be useful for building new exercise programs that aim for the prevention and early detection of osteoporosis and/or osteopenia.

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Table 1: Characteristics of the participants

	Mean ± SD	Range
Age (years)	23.9±3.8	18-35
Anthropometrics		
Weight (kg)	73.3±11.6	52-109
Height (cm)	1.58±0.06	1.42-1.79
BMI (kg/m^2)	29.07±3.79	25.23-42.46
Lean mass (kg)	40.76±5.26	30.88-57.67
Fat mass (kg)	31.33±7.48	19.40-55.43
Fat mass (%)	42.46±4.62	31.60-56.10
Waist circumference (m)	0.91±0.10	0.71-1.16
Hip circumference (m)	1.05±0.08	0.86-1.22
Waist/hip ratio	0.86±0.09	0.70-1.17
Physical fitness		
Vertical jump (cm)	16.1±1.6	12-19
Maximum Power (watts)	640.7±117.4	391.1-1004.2
VO$_2$ max (ml/min/kg)	28.404±2.218	23.6-35.6
VO$_2$ max (L/min)	2.08±0.33	1.38-3.08
MAV (km/h)	9.29±0.39	8-10.5
1-RM half-squat (kg)	36.45±4.44	28-48
Questionnaires		
Physical activity (h/week)	1.9±0.7	1-4.1
Daily calcium intake (mg/d)	984±128	735-1250
Daily protein intake (g/d)	73.2±13.3	50-120
Bone outcomes		
WB BMC (g)	2241.25±247.52	1613-2824
WB BMD (g/cm^2)	1.108±0.0836	0.940-1.302
L1-L4 BMD (g/cm^2)	1.157±0.120	0.881-1.447

L1-L4 TBS	1.464±0.0981	1.290-1.744
TH BMD (g/cm^2)	1.004±0.107	0.756-1.237
FN BMD (g/cm^2)	0.983±0.113	0.725-1.227
FN CSA	1.594±0.441	0.800-3.200
FN CSMI (mm^2)	10947.2±2925.1	5366-20897
FN SI	1.594±0.441	0.800-3.200

BMI, Body mass index; WB, Whole body; FN, Femoral neck; BMC, Bone mineral content; BMD, Bone mineral density; CSA, Cross-sectional area; CSMI, Cross-sectional moment of inertia; TBS, Trabecular bone score; SI, Strength index; MAV, Maximum aerobic velocity; VO_2 max, maximum oxygen consumption

Table 2: Correlations between bone variables and anthropometrics

	Age (years)	Weight (kg)	BMI (kg/m^2)	LM (kg)	FM (kg)	FM (%)	Waist/hip ratio
WB BMC (g)	0.239	0.425***	0.213	0.509***	0.235	-0.0521	-0.023
WB BMD (g/cm^2)	-0.008	0.411***	0.372**	0.515***	0.225	-0.0448	-0.208
L1-L4 BMD (g/cm^2)	-0.162	0.099	0.137	0.176	-0.0506	-0.142	-0.143
L1-L4 TBS	-0.172	0.172	0.257*	0.125	0.117	0.0578	-0.199
TH BMD (g/cm^2)	-0.205	0.177	0.166	0.300*	0.0634	-0.0548	-0.108
FN BMD (g/cm^2)	-0.110	0.299*	0.203	0.379**	0.182	0.0541	0.044
FN CSMI (mm^2)	0.006	0.439***	0.295*	0.492***	0.245*	-0.064	-0.098
FN CSA (mm^2)	-0.075	0.427***	0.273*	0.532***	0.222	-0.056	-0.079
FN SI	-0.028	-0.303*	-0.256*	-0.207	-0.381**	-0.350**	-0.217

BMI, Body mass index; FM, Fat mass; LM, Lean mass, WB, Whole body; FN, Femoral neck; BMC, Bone mineral content; BMD, Bone mineral density; CSA, Cross-sectional area; CSMI, Cross-sectional moment of inertia; TBS, Trabecular bone score; SI, Strength index

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Table 3: Correlations between bone parameters and physical performance variables

	Vertical jump (cm)	Maximum Power (W)	VO_2 max (mL/min/kg)	VO_2 max (L/min)	MAS (km/h)	1-RM half-squat (kg)
WB BMC (g)	0.439***	0.487***	0.312***	0.575***	0.326**	0.198
WB BMD (g/cm^2)	0.483***	0.496***	0.212	0.489***	0.150	0.259*
L1-L4 BMD (g/cm^2)	0.339**	0.190	0.168	0.170	0.143	0.096
L1-L4 TBS	0.199	0.212	0.0294	0.179	-0.0117	0.245*
TH BMD (g/cm^2)	0.432***	0.277*	0.203	0.261*	0.148	0.146
FN BMD (g/cm^2)	0.484***	0.398***	0.231	0.387**	0.173	0.267*
FN CSMI (mm^2)	0.289*	0.459***	0.0222	0.420***	0.007	0.312*
FN CSA (mm^2)	0.444***	0.495***	0.182	0.482***	0.131	0.359**
FN SI	-0.059	-0.283*	0.186	-0.222	0.194	-0.162

WB, Whole body; FN, Femoral neck; BMC, Bone mineral content; BMD, Bone mineral density; CSA, Cross-sectional area; CSMI, Cross-sectional moment of inertia; TBS, Trabecular bone score; SI, Strength index; MAV, Maximum aerobic velocity

*p < 0.05; **p < 0.01; ***p < 0.001

Table 4: Multiple linear regression models

	Coefficient	SE	t-value	p-value
WB BMC (R^2 = 0.340)				
Constant	1247.030	194.733	6.404	<0.001
Lean mass (kg)	7.053	7.620	0.926	0.358
VO_2 max (L/min)	339.713	120.426	2.821	**0.006**
WB BMD (R^2 = 0.284)				
Constant	0.772	0.068	11.281	<0.001
Lean mass (kg)	0.005	0.003	2.017	**0.048**
VO_2 max (L/min)	0.056	0.042	1.315	0.193
L1-L4 BMD (R^2 = 0.075)				
Constant	0.736	0.154	4.77	<0.001
Lean mass (kg)	0.001	0.003	0.376	0.708
Vertical jump (cm)	0.023	0.009	2.49	0.015
TH BMD (R^2 = 0.143)				
Constant	0.500	0.125	4.005	<0.001
Lean mass (kg)	0.002	0.002	1.185	0.24
Vertical jump (cm)	0.023	0.007	3.04	0.003
TH BMD (R^2 = 0.092)				
Constant	0.754	0.099	7.655	<0.001
Lean mass (kg)	0.005	0.004	1.305	0.196
VO_2 max (L/min)	0.021	0.061	0.350	0.727
FN BMD (R^2 = 0.173)				
Constant	0.367	0.126	2.916	0.005
Lean mass (kg)	0.004	0.002	1.829	0.072
Vertical jump (cm)	0.002	0.007	3.381	0.001
FN BMD (R^2 = 0.165)				
Constant	0.648	0.100	6.509	0.000

Lean mass (kg)	0.004	0.004	1.069	0.289
VO2max (L/min)	0.079	0.062	1.286	0.203
FN CSMI (R^2 = 0.245)				
Constant	-159.169	2461.988	-0.065	0.949
Lean mass (kg)	233.752	96.534	2.421	**0.018**
VO$_2$ max (L/min)	762.140	1523.687	0.500	0.619
FN CSA (R^2 = 0.293)				
Constant	67.677	16.884	4.008	<0.001
Lean mass (kg)	1.562	0.662	2.360	**0.021**
VO$_2$ max (L/min)	10.387	10.449	0.994	0.324

WB, Whole body; FN, Femoral neck; BMC, Bone mineral content; BMD, Bone mineral density; CSA, Cross-sectional area; CSMI, Cross-sectional moment of inertia; TBS, Trabecular bone score; SI, Strength index.