Original Research

The Relationship between Aerobic Capacity and Bone Health in Young Women

BRITTANY R. MASTELLER†1, CURT B. DIXON‡2, ERIC S. RAWSON‡1 and JOSEPH L. ANDREACCI‡1

1Department of Exercise Science, Bloomsburg University, Bloomsburg, PA, USA; 2Department of Health Science, Lock Haven University, Lock Haven, PA, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 9(1): 56-63, 2016. The purpose of the present investigation was to examine the relationship between maximal oxygen consumption (VO_2max) and bone health in young women. Eighty-three participants (age=21.0±2.2 years; BMI=22.4±3.0 kg/m^2) reported for testing on two occasions separated by 48 hours. During visit 1 body composition assessment via dual-energy X-ray absorptiometry (DXA) and during visit 2, a VO_2max test performed on a motorized treadmill. Weak correlations were found between absolute VO_2max (L/min) and whole-body bone mineral density (WB-BMD: $r=0.24$, $p=0.031$) and whole-body bone mineral content (WB-BMC: $r=0.37$, $p<0.001$). No relation between variables were observed when VO_2max was expressed relative to body mass (mL/kg/min). Moderate correlations were observed between bone variables and body mass (WB-BMD: $r=0.36$, $p<0.001$; WB-BMC: $r=0.62$, $p<0.001$), fat-free mass (WB-BMD: $r=0.45$, $p<0.001$; WB-BMC: $r=0.54$, $p<0.001$), and fat mass (WB-BMD: $r=0.31$, $p=0.004$; WB-BMC: $r=0.60$, $p<0.001$). Body mass, regardless of composition, was a stronger predictor of bone health than aerobic capacity in this sample of young women.

KEY WORDS: Osteoporosis, bone mineral content, bone mineral density, VO_2max

INTRODUCTION

Osteoporosis is a major health concern in the United States as more than 40 million people currently have been diagnosed or are at risk for developing the disease (19). Osteoporosis is characterized by low bone mass and deterioration of bone tissue which leads to bone fragility and an increased risk of fractures of the hip, spine, and wrist (19). During childhood, throughout adolescence, and into early adulthood, new bone is formed at a very high rate until peak bone mass is reached by approximately the third decade of life. Failure to reach an optimal peak bone mass can increase the risk for osteoporosis later in life (4). While men and women are both at risk, the prevalence of developing osteoporosis is much higher in women, specifically following menopause due to the hormonal changes that occur.

Numerous research studies have focused on the causes, risk factors and effects of the osteoporosis (6, 16, 20) but limited research is available on the years leading up to the development of the disease. Risk factors for osteoporosis include gender, age, body size, ethnicity, family history, hormone levels, disordered eating, calcium and vitamin D intake, medication use, cigarette smoking, alcohol intake, and physical activity level (19). Of these, regular physical activity (PA) has been shown to increase bone health in various populations (7-9, 15).

Professional organizations, such as the American College of Sports Medicine, recommend PA as a way to maintain bone health and prevent osteoporosis (2, 4). In particular, high-impact PA is recommended because it activates the restoration and formation of new bone (4). Previous research has examined the relationship between PA levels and bone health in young adult women (8, 16, 24). Wallace and Ballard, reported that lifetime PA levels, assessed by a self-report questionnaire, and calcium intake were related to bone health in young women (24). In addition, they found that lean mass was the strongest predictor of whole-body bone mineral density (WB-BMD) and whole-body bone mineral content (WB-BMC) and suggested that increased PA levels coincide with higher lean mass leading to greater bone health. In support, numerous studies have found body composition variables to have an association with bone health (12, 21-23). However, a direct measurement of aerobic capacity such as maximal oxygen consumption (VO_2max) was not included in these studies.

A common assumption is that individuals who exhibit high relative VO_2max values are more physically active and therefore may have improved bone health. However, VO_2max, much like bone health, is the resultant of a variety of factors including genetic predisposition (6) and few studies have actually examined whether aerobic capacity is related to bone health in younger populations (9, 23). Recently, El Hage et al. explored the relation between VO_2max and WB-BMD in young Lebanese adults (10). The authors reported moderate to very strong correlations between absolute VO_2max (L/min) and bone variables (both sexes). When VO_2max was expressed relative to body mass (mL/kg/min), moderate correlations were observed in the women but not the men. To our knowledge, this was the first study to show a relationship between absolute VO_2max (L/min) and bone health in young adults. Although interesting, these previous findings were limited to a relatively small sample of women (n=20). The aim of the present study was to further explore the potential relation between VO_2max and bone health in a larger cohort of young women.

METHODS

Participants

Eighty-three healthy females between the ages of 18 and 31 participated in this study. The Bloomsburg University Institutional Review Board approved the study protocol and methods. Prior to participation, all subjects signed an informed consent document consistent with the Bloomsburg University policy for the protection of human subjects, and answered a physical activity readiness questionnaire. Each subject made two visits to the laboratory for testing separated by a period of approximately 48 hours with each visit lasting no more than one hour. All subjects were free from bone-related disease and not taking any prescription medications for the treatment of any bone-related illnesses.

Table 1. Characteristics for the study participants.

N = 83	Mean ± SD	Range
Age (years)	21.0 ± 2.2	18.0 – 31.0
Height (cm)	164.7 ± 5.6	149.5 – 177.5
Body Mass (kg)	61.2 ± 8.4	43.8 – 89.7
BMI (kg/m^2)	22.4 ± 3.0	16.3 – 32.5
%BF (%)	30.4 ± 7.3	12.9 – 57.8
FM (kg)	18.0 ± 6.8	7.6 – 46.2
FFM (kg)	40.1 ± 4.4	31.3 – 51.5
Total BMD (g/cm^2)	1.2 ± 0.1	1.0 – 1.4
Total BMC (g)	2581.7 ± 361.9	1829 – 3683
Total Ca^{2+} Intake (mg/day)	705.8 ± 439.4	186 – 2254
Total Vit D Intake (IU/day)	309.1 ± 318.0	16 – 1742

BMI, body mass index; %BF, percent body fat; FM, fat mass, FFM, fat-free mass; BMD, bone mineral density; BMC, bone mineral content

Protocol

Height and body mass were measured prior to testing using a wall-mounted stadiometer and a digital scale. Dual-energy X-ray absorptiometry (DXA; General Electric, Lunar Prodigy Pro, Madison, WI, USA) was used to measure fat mass (FM), fat-free mass (FFM) and bone variables (WB-BMC, WB-BMD). Each day prior to any testing, the DXA was calibrated using the standard calibration block to control for possible baseline drift. All measurements were maintained within the manufacturers precision standards of ≤1.5%. Subjects, wearing only a t-shirt and shorts, removed all metal objects and lay in a supine position according to the guidelines established by the manufacturer. In order to control for testing variability, subjects were asked to adhere to the following pretesting guidelines: a) no physical exercise within 12 hours of your scheduled test; b) no eating or drinking within 2 hours of the test; c) empty bladder within 30 min of the test; d) no alcohol consumption within 48 hours of the test; and e) no diuretic medications within 7 days of the test.

Subjects completed the Block Ca^{2+}/Vitamin D screener developed by Nutrition Quest during their first visit. It included 19 food items, 3 supplemental questions, and questions to adjust for food fortification practices. This screener took approximately 7-8 minutes to complete and each subject was encouraged to answer the survey honestly and to be as accurate as possible. The questionnaire has been validated as a reliable method of assessing dietary Ca^{2+}/vitamin D intake (7).

VO_2max was assessed using the Bruce protocol (5) on a Quinton (model Q-65) motor-driven treadmill. Heart rate was continuously monitored by a Polar heart rate monitor (Polar, Port Washington, NY, USA). Subjects breathed through a Hans-Rudolph respiratory valve while wearing a nose clip and were acclimated to this device prior to testing. Expired concentrations of O_2 and CO_2 were analyzed by open circuit spirometry in 15-second intervals using a ParvoMedics TrueMax 2400 metabolic measurement system (ParvoMedics, Inc., Sandy, UT, USA). The criteria for attainment of VO_2max was based on the achievement of four of the five following criteria: (a) a change in VO_2 of < 2.1 mL/kg/min with increasing exercise intensity; (b) a respiratory exchange ratio of ≥1.10; (c) heart rate ±10 beats per minute of the age-predicted maximum at the end of the exercise test; (d) a rating of perceived exertion using the OMNI scale of ≥9; and (e) volitional termination due to exhaustion (17).

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences Version 22.0 (SPSS, Inc., Chicago, IL, USA). All values are expressed as mean ± standard deviation. Pearson-product moment correlations were used to determine the relationship between VO$_2$max and, bone and body composition variables. Significance was established *a priori* for all analyses at $p \leq 0.05$.

RESULTS

Characteristics of the 83 women who participated in this study are displayed in Table 1. The subjects were recreationally active and approximately 50% participated in 1-3 strength training workouts per week. Subjects varied greatly in body mass and composition, as well as WB-BMD and WB-BMC (Table 1). Self-reported total Ca^{2+} and vitamin D intake values for the women were 706 mg/day and 309 IU/day, respectively (Table 1). Mean VO$_2$max values were 2.5±0.42 L/min and 41.1±5.47 mL/kg/min, respectively (Table 2). As demonstrated in Table 3, absolute VO$_2$max (L/min) was positively correlated to WB-BMC (r=0.37, $p<0.001$) and WB-BMD (r=0.24, $p=0.031$). Moderate correlations were observed between bone variables and body mass (Table 3).

A moderate relationship was observed between absolute VO$_2$max (L/min) and BMC and BMD (Figures 1A, 2A). However, no relationship was observed between relative VO$_2$max (ml/kg/min) and BMC or BMD (Figures 1B, 2B).

Table 2. Physiological data obtained from maximal oxygen consumption test.

	Mean ± SD	Range
Relative VO$_2$max (mL/kg/min)	41.1 ± 5.5	29.0 – 55.0
Absolute VO$_2$max (L/min)	2.5 ± 0.4	1.7 – 3.7
Respiratory Exchange Ratio	1.17 ± 0.10	1.05 – 1.30
Rating of Perceived Exertion	9 ± 1	8– 10
Heart Rate (bpm)	192 ± 23	176 – 216

VO$_2$max, maximal oxygen consumption.

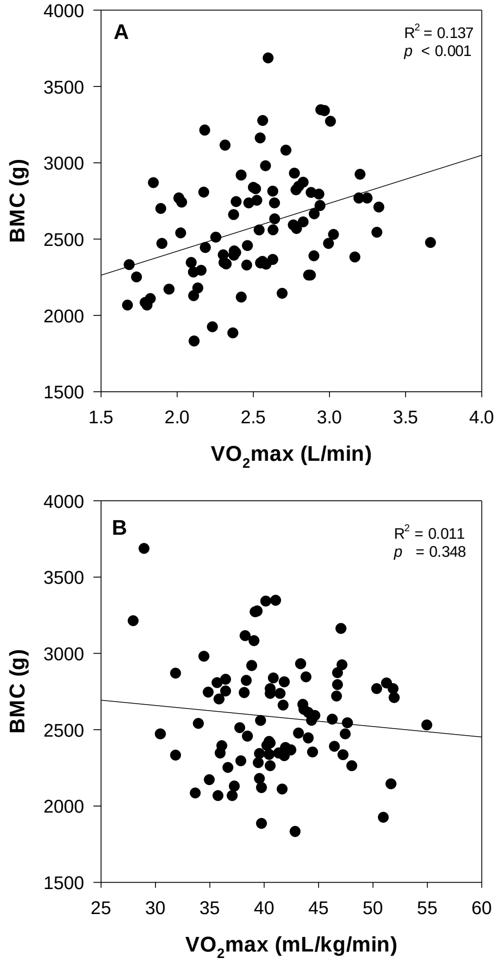

Figure 1. The relationship between bone mineral content (BMC) and maximal oxygen consumption (VO$_2$max; (**A**) absolute (L/min); and (**B**) relative (mL/kg/min)).

Table 3. Correlations between body composition variables and bone variables.

	WB-BMC (g)			**WB-BMD (g/cm^2)**		
	r	**r^2**	***p*-value**	**r**	**r^2**	***p*-value**
Body Mass (kg)	0.62	0.38	0.001*	0.36	0.13	0.001*
Fat-free Mass (kg)	0.54	0.29	0.001*	0.45	0.20	0.001*
Fat Mass (kg)	0.60	0.36	0.001*	0.31	0.10	0.004*
Total Ca^{2+} Intake (mg/day)	0.03	0.00	0.825	0.01	0.00	0.901

Statistically significant ($p < 0.05$)

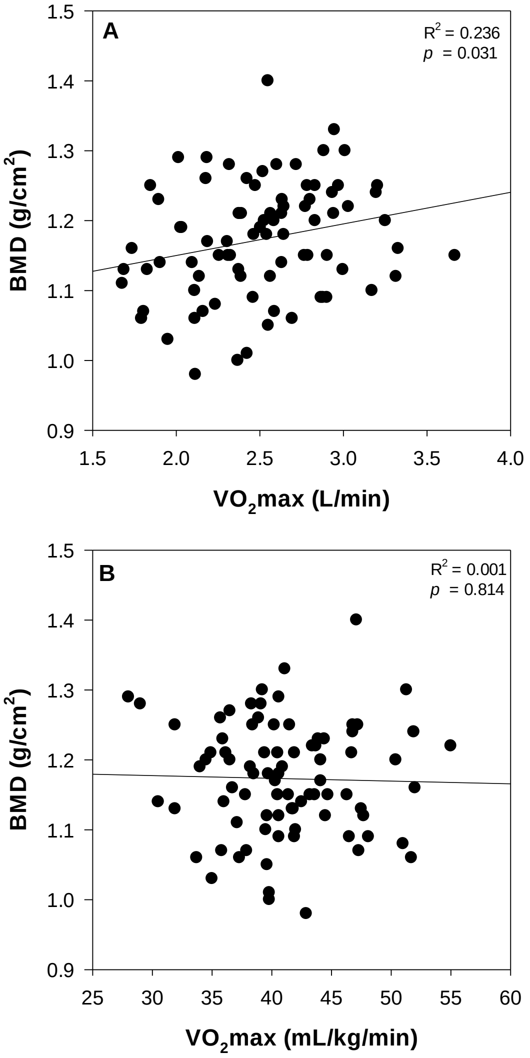

Figure 2. The relationship between bone mineral density (BMD) and maximal oxygen consumption (VO_2max; (**A**) absolute (L/min); and (**B**) relative (mL/kg/min)).

DISCUSSION

The primary aim of this study was to examine the impact of aerobic capacity on bone health in young women. The mean VO_2max values (2.5±0.42 L/min; 41.1±5.5 mL/kg/min) rated as "good" for this age group according to guidelines outlined by the ACSM (1). We hypothesized that women with a higher aerobic capacity would display a higher WB-BMC and WB-BMD. Our data supported this hypothesis when absolute VO_2max (L/min) was compared to WB-BMC (r=0.37, $p<0.001$) and WB-BMD (r=0.24, $p<0.031$). However, no relationship was observed between relative VO_2max (mL/kg/min) and WB-BMC (r=0.10, $p=0.348$) or WB-BMD (r=0.03, $p=0.814$).

Previously, El Hage and colleagues reported a relationship between relative VO_2max and WB-BMC (r=0.51), WB-BMD (r=0.50), and absolute VO_2max and WB-BMC (r=0.82), WB-BMD (r=0.80) in 20 young women (10). Although our subjects demonstrated similar anthropometric measures, the mean aerobic capacity values of the women in the El Hage et al. study were substantially lower than the present investigation (VO_2max values: 1.8±0.47 vs. 2.5±0.42 L/min and 30.7±6.8 vs. 41.1±5.5 mL/kg/min). The difference in the aerobic fitness level of these women may partially explain the conflicting findings related to absolute VO_2max in these studies. In addition, we examined a much larger sample of women (N=83) than the previous work by El Hage et al. (10).

In the present study, body mass, regardless of body composition, was related to bone health. Significant relationships were observed when body mass was compared to WB-BMC and WB-BMD (r=0.62 and r=0.37, respectively). We expected this finding due to the increased load placed on the body when a person has a higher body mass. This observed relationship between body mass and BMD, BMC is supported in the literature (6, 13, 18, 22).

Previous research has also reported a relation between FFM and WB-BMC in young women (12, 22, 24). Wallace and Ballard concluded that FFM was the strongest predictor of WB-BMC (r=0.89) and WB-BMD (r=0.75) (24). In our subjects, FFM was also significantly related to WB-BMC (r=0.54) and WB-BMD (r=0.45). The subjects with more FFM displayed higher WB-BMC and WB-BMD than those with less FFM.

Another important factor that could influence bone health is habitual dietary intake. Consuming nutrients such as Ca^{2+} and vitamin D has been proven to increase and maintain bone health (19). If these nutrients are under-consumed, it may result in weaker bones when combined with other risk factors such as low PA level and smoking. The Ca^{2+}/vitamin D nutritional questionnaire provided information on the consumption of these nutrients. Of the 83 subjects who participated in this study, 73% reported regularly taking supplemental Ca^{2+} and 65% reported taking supplemental vitamin D. However, the mean levels of total Ca^{2+} (706 mg/day) and vitamin D (309 IU/day) intake were significantly below the suggested RDA for each nutrient (Ca^{2+}=1000 mg/day; vitamin D=600 IU/day) (14). When nutrient intake was correlated to WB-BMC and WB-BMD, no relationship was observed. This finding was consistent with previously research that also reported no relationship between Ca^{2+} intake and BMD in young women (16, 18). Similar to this study, the cross-sectional nature of the designs did not account for long-term evaluation of Ca^{2+} intake. Lifetime history of Ca^{2+} intake could be helpful in identifying relationships between lifetime Ca^{2+} intake and BMC/BMD as research has shown (24). While current Ca^{2+} intake provides important information about current habits, the repercussions of under-consuming Ca^{2+} may not be observed until much later in life.

There are several limitations surrounding this study. One limitation is the lack of data regarding past and present habitual PA levels. Additional information about history of PA could aid in better explanations our findings. Another limitation is the use of self-reported questionnaires for obtaining dietary information. A third limitation is the cross-sectional nature of the study design. Other study designs allowing for longitudinal data may offer more to the literature surrounding this topic. Lastly, the women who participated in this study were all college students, limiting the ability to generalize our findings to the common population of young women.

In conclusion, we further examined the potential relationship between aerobic capacity and bone health that has been previously reported in the literature. Overall, we found that VO_2max was not a strong predictor of WB-BMC and WB-BMD. Future research should continue to examine the prevalence and prevention of risk factors in younger populations by incorporating longitudinal study designs.

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REFERENCES

1. American College of Sports Medicine. ACSM's Guidelines for Exercise Testing and Prescription. Philadelphia, PA: Lippincott, Williams and Wilkins; 2013.

2. American College of Sports Medicine. ACSM's resource manual for guidelines for exercise testing and prescription. Philadelphia, PA: Lippincott Williams & Wilkins; 2012.

3. Basset DR, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. Med Sci Sports Exerc 32(1): 70-84, 1999.

4. Bloomfield SA, Little KD, Nelson ME, Yingling VR. ACSM Position Stand: physical activity and bone health. Med Sci Sports Exerc 36(11): 1985-1996, 2004.

5. Bruce RA, Hornsten TR. Exercise stress testing in evaluation of patients with ischemic heart disease. Prog Cardiovasc Dis 11(5): 371-390, 1969.

6. Cummings S, Kelsey J, Nevitt M, O'Dowd K. Epidemiology of osteoporosis and osteoporotic fractures. Epidemiol Rev 7:178-208, 1985.

7. Cummings SR, Block G, McHenry K, Baron RB. Evaluation of two food frequency methods of measuring dietary calcium intake. Am J Epidemiol 126(5): 796-802, 1987.

8. Dalen N, Olsson KE. Bone mineral content and physical activity. Acta Orthop Scand 45(2): 170-174, 1974.

9. Davee AM, Rosen CJ, Adler RA. Exercise patterns and trabecular bone density in college women. J Bone Miner Res 5(3): 245-250, 1990.

10. El Hage R, Zakhem E, Theunynck D, et al. Maximal oxygen consumption and bone mineral density in a group of young Lebanese adults. J Clin Densitom 17(2): 320-324, 2014.

11. Friedlander AL, Genant HK, Sadowsky S, Byl NN, Glüer CC. A two-year program of aerobics and weight training enhances bone mineral density of young women. J Bone Miner Res 10(4): 574-585, 1995.

12. Goran M, Fields DA, Hunter GR, Herd SL, Weinsier RL. Total body fat does not influence maximal aerobic capacity. Int J Obes Relat Metab Disord 24(7): 841-848, 2000.

13. Henderson NK, Price RI, Cole JK, Gutteridge DH, Bhagat CI. Bone density in young women is associated with body weight and muscle strength but not dietary intakes. J Bone Miner Res 10(3): 384-393, 1995.

14. Institute of Medicine, Food and Nutrition Board. Dietary reference intakes for calcium and vitamin D. Washington, DC: National Academy Press; 2010.

15. Lohman T, Going S, Pamenter R, et al. Effects of resistance training on regional and total bone mineral density in premenopausal women: a randomized prospective study. J Bone Miner Res 10(7): 1015-1024, 1995.

16. Mazess R, Barden H. Bone density in premenopausal women: effects of age, dietary

intake, physical activity, smoking and birth control pills. Am J Clin Nutr 53(1): 132-142, 1991.

17. Midgley A, McNaughton L, Polman R, Marchant D. Criteria for determination of maximal oxygen uptake: A brief critique and recommendations for future research. Sports Med 37(12): 1019-1028, 2007.

18. Miyabara Y, Yoshiko O, Harada A et al. Effect of physical activity and nutrition on bone mineral density in young Japanese women. J Bone Miner Metab 25(6): 414-418, 2007.

19. Osteoporosis and Related Bone Diseases National Resource Center: Osteoporosis Overview. Bethesda, MA: National Institutes of Health; 2015.

20. Sandler R, Slemenda C, LaPorte R et al. Post-menopausal bone density and milk consumption in childhood and adolescence. Am J Clin Nutr 42(2): 270-274, 1985.

21. Stewart KJ, Deregis JR, Turner KL, et al. Fitness, fatness and activity as predictors of bone mineral density in older persons. J Intern Med 252(5): 381-388, 2002.

22. Valdimarsson O, Kristinsson JO, Stafansson SO, Valdimarsson S, Sigurdsson G. Lean mass and physical activity as predictors of bone mineral density in 16-20-year old women. J Intern Med 245(5): 489-496, 1999.

23. Vicente-Rodríguez G, Urzanqui A, Mesana MI. Physical fitness effect on bone mass is mediated by the independent association between lean mass and bone mass through adolescence: A cross-sectional study. J Bone Miner Metab 26(3): 288-294, 2008.

24. Wallace LS, Ballard, JE. Lifetime physical activity and calcium intake related to bone density in young women. J Wom Health 11(4): 389-398, 2002.