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Original Article

Muscular power and maximum oxygen consumption predict bone density in a group of middle-aged men

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Abstract

Objective: The purpose of this study was to explore the relationships between several physical performance variables and bone parameters in a group of middle-aged men. **Methods**: 50 middle-aged men participated in this study. Body composition and bone variables were evaluated by DXA. Bone mineral density (BMD) was measured at the whole body (WB), total radius (TR), lumbar spine (L1-L4), total hip (TH) and femoral neck (FN). Geometric indices of femoral neck (FN) strength were also calculated by DXA. Handgrip strength, vertical jump, maximum power of the lower limbs (watts), maximal half-squat strength, maximal bench-press strength, sprint performance (10 m) and maximum oxygen consumption (VO_2 max, L/min) were evaluated using validated tests. **Results**: VO_2 max (L/min), maximum power of the lower limbs, maximal half-squat strength, maximal bench-press strength, handgrip and lean mass were positively correlated to many bone parameters. Lean mass was the strongest determinant of WB BMC. VO_2 max (L/min) was the strongest determinant of WB BMD, TH BMD and FN BMD. Maximum power was the strongest determinant of total radius BMD. **Conclusion**: The current study suggests that VO_2 max (L/min), lean mass and maximum power of the lower limbs are the strongest determinants of bone variables in middle-aged men.

Keywords: Men, Prevention of Osteoporosis, Muscular Power, Maximal Strength, Aerobic Endurance

Introduction

Osteoporosis in men is not a rare problem, and it is often ignored[1]. Even though traditionally considered a women's health issue, osteoporosis is a health problem for men as well[2]. Aging leads to a reduction in lean mass (LM) and bone mineral density (BMD) and an alteration of bone quality[2]. While advancing in age, men are estimated to lose bone mineral density (BMD) at a rate of up to 1% per year[3,4], and it is generally believed that one in eight men over the age of fifty will experience an osteoporosis-related fracture in his lifetime[5]. With the increasing size of our elderly population due to a better quality of life, osteoporosis in men will soon become an even bigger problem to society and health care systems worldwide[2]. Regular physical activity practice has been recommended as a low-cost and safe non-pharmacological strategy to counter the loss of bone mass associated with aging[6]. Resistance training alone or in combination with impact-loading activities is safe and may help in the prevention of osteoporosis in middle-aged and older men[6]. Further, recent cross-sectional studies demonstrated that higher physical performance levels are positively correlated to higher BMD values in both genders[7-11]. For instance, maximal oxygen consumption (VO_2 max; L/min) has been shown to be a strong positive predictor of bone mineral content (BMC) and BMD in young adults[11]. Also, maximum power calculated using a vertical jump test was shown to be a positive determinant of several bone parameters also in a group of young adults[9]. Further, maximal strength has been shown to be positively associated with BMD and geometric indices of hip bone strength in young adults and elderly women[10]. The majority of the studies that aimed at exploring the relationships between physical performance variables

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and bone characteristics were conducted on children, young adults and elderly subjects. Up to our knowledge, very few studies were conducted on middle-aged men. Hence, the aim of the current study was to explore the relationships between many physical performance parameters and bone variables (BMC, BMD and geometric indices of hip bone strength) in a group of middle-aged men. Given the previously demonstrated relationships between sarcopenia and osteoporosis in the elderly[12], we hypothesized that the fitness tests related to maximal power and strength would be major determinants of bone variables in our population.

Methods

Subjects and study design

Fifty middle-aged men voluntarily participated in this study. Their mean age was 50.2 ± 4.5. All participants were randomly recruited from Zgharta, a city located in North Lebanon. The participants were healthy men aged between 40 and 58 years and not suffering from any chronic health disease. All participants had no history of major orthopaedic problems or other disorders that affect bone metabolism including diabetes. Subjects with any medical condition likely to affect bone metabolism including history of chronic disease with vital organ involvement or intake of medications that may affect bone metabolism were excluded. This study included evaluation of anthropometric, bone and physical parameters. Before any evaluation, all subjects received a description of the study, its purpose and procedures, and they were well informed about the objective of the study including the risks and benefits of participation. Written informed consent was signed by all subjects before participating in the study. The work described has been carried out in accordance with the declaration of Helsinki (regarding human experimentation developed for the medical community by the World Medical Association). The current study was approved by the University of Balamand Ethics Committee.

Anthropometric measurements

Body weight was measured using a standard mechanical scale with a precision of 0.1 kg. Height was measured in a vertical position to the nearest 0.5 cm using a standard stadiometer. The subjects were barefoot and wearing light clothes while measurements were taken. BMI was calculated by dividing body weight to the height squared (kg/m^2). Body composition including lean mass (kg), fat mass (kg) and body fat percentage (FM; %kg) was also assessed by using dual-energy X-ray densitometry (DXA; GE-Lunar iDXA, Madison, WI).

Bone measurements

Whole-body bone mineral content (WB BMC), whole-body bone mineral density (WB BMD), lumbar spine bone mineral density (L1-L4 BMD), total hip bone mineral density (TH BMD), femoral neck bone mineral density (FN BMD) and Total Radius BMD of the right side were determined using dual-energy X-ray densitometry (DXA; GE-Lunar iDXA, Madison, WI)[13,14]. Geometric indices of femoral neck (FN) strength (cross-sectional area (CSA), cross-sectional moment of inertia (CSMI), section modulus (Z), strength index (SI) and buckling ratio (BR)) were also determined by DXA. The use of these indices to evaluate bone geometry has been validated in obese and non-obese subjects[15-20]. The same certified technician (holder of a Bachelor of Science in medical imaging sciences) performed all the DXA scans using the same technique for all measurements. The same DXA machine was used for all participants. In our laboratory, the coefficients of variation were <1% for BMC and BMD[21]. The coefficients of variation for CSA and Z evaluated by duplicate measurements in 10 subjects were <3%[21].

Procedures of physical performance tests

All subjects participated in a familiarizing session before evaluation. The objective of this session was to explain the procedures of the study and to familiarize the participants with the equipment used to perform the physical tests. Testing was done on three non-consecutive days. All the assessments were performed in the following order. During day one, time of the ten-meter sprint was measured by using photoelectric cells (BROWER Timing Systems), vertical jump was measured by using the Sargent test, horizontal jump was also tested and lower body maximal power was calculated by using the Lewis Formula[22]. On the second day, maximal oxygen consumption was calculated by using the Step tool protocol[23,24]. On the third day, one-repetition maximum (RM) of half-squat and bench press on a Smith machine was tested and determined by using the Brzycki equation[25]. The maximal isometric force of the right-handgrip was measured by a dynamometer; the right side was chosen because total Radius BMD was measured at the right side.

Sprint performance

Time of the 10-m sprint was measured by using two pairs of photoelectric cells that were connected to an electronic timer (BROWER Timing Systems). The height of the photocells was 1 m from the ground, and the time was recorded in hundredth of a second. The first pair was positioned at the starting line (0m) and the second pair at the ten-meter finish line. Before beginning the evaluation process, participants performed a specific warmup. The evaluation consisted of four 10 meter maximal sprints that were separated by 3 minutes of passive resting in between them. All participants began with the same standing starting position by putting one leg of their choice (right or left) on the line that was drawn on the floor, 15 cm before the starting line. The time of all four sprints was recorded, and the best time out of the four sprints was taken.

Jumping performance

Vertical jump height was measured by using the jump and reach Sargent test[22]. Before beginning the evaluation process, participants performed a specific warmup. All participants performed a counter movement jump with free movements of the upper limbs. The participants jumped three times, with a resting interval of 2 minutes between the jumps, and the highest value was considered. The highest value of the vertical jump was used to calculate the peak power of the lower limb by using the Lewis Formula[22].

Horizontal jump (HJ) was also calculated. All subjects performed the HJ starting from a standing position. They started the jump by performing a swing movement of their arms. A take-off line was drawn on the ground. Their feet were directly positioned before the line in a shoulder width position. The jump-length measurement was determined using a metric tape measure from the take-off line to the closest point of landing contact (back of the heels). Each participant performed 3 attempts, and the longest distance was considered.

Maximum oxygen consumption

Maximal oxygen consumption was calculated by using the STEP tool protocol[23,24]. This indirect test was chosen because the subjects were middle-aged and this test is more suitable for this population than a triangular maximal test; it is also valid and reliable in this kind of population[23,24]. VO_2 max was expressed either as an absolute rate (L/min) or as a relative rate (mL/min/Kg).

Maximal strength measurements

Half-squat on Smith machine was used as an exercise to identify lower limb maximal strength. Direct measure of 1-RM was not used since participants were afraid to perform squats with heavy weights. Furthermore, individuals with little or no experience using heavy weights in strength training increase their chance for accident and injuries. A prediction of one-repetition-maximum (1-RM) from a 4-6 RM submaximal strength test was used. A specific standardized warmup was done before starting the test. The test was stopped when the participant failed to perform a full range of motion of the exercise. In addition, participants who performed more than 6 repetitions were stopped and told to repeat the test after increasing the load. The test was successful when the subject reached his RM between 4 to 6-RM. Each participant performed the squat technique following the protocol established by the National Strength and Conditioning Association[26]. During all attempts, the participants were required to squat to a depth where a 90-degree knee angle was achieved. Bench press on Smith machine was used to evaluate upper limb maximal strength. The same protocol has been used to predict 1-RM from a 4-6 RM submaximal strength test. Each participant performed the bench press technique following the protocol established by the National Strength and Conditioning Association[26].

Questionnaires

Sleep quality

The Pittsburgh Sleep Quality Index (PSQI) was used to assess sleep quality and disturbances over a 1-month time interval. Seven "components" related to subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction were scored. The addition of scores for these seven components produces one global score[27]. Sleep quality was collected since previous studies have shown independent correlations between sleep and bone health parameters[28-30].

Daily calcium and protein intakes

Daily calcium intake (DCI) and daily protein intake (DPI) were evaluated by validated semi-quantitative food frequency questionnaires[31-33].

Physical activity

The duration of physical activity per week (hour/week) was evaluated using the global physical activity questionnaire (GPAC)[34].

Statistical analysis

The mean and standard deviations were calculated for all clinical, physical performance and bone parameters. All variables were evaluated for normality using the Shapiro-Wilk test. Univariate correlations between bone variables and anthropometric, clinical characteristics and physical parameters were computed using Pearson's Test. Multiple linear regression analysis models were used to test the relationship of WB BMC and Total Radius BMD with LM and maximal power of the lower limbs (watts). Multiple linear regression analysis models were also used to test the relationships of WB BMD, L1-L4 BMD, TH BMD, FN BMD, FN CSA and FN CSMI with lean mass and VO_2 max (L/min). The Data was analysed using Number Cruncher Statistical System software (NCSS, 2001, Kaysville, UT). A level of significance of $p < 0.05$ was used.

Results

Clinical characteristics and bone variables of the study population

Age, weight, height, BMI, lean mass, fat mass, fat mass percentage, daily calcium intake, daily protein intake, PSQI, Physical activity and bone variables are shown in Table 1.

Physical performance variables of the study population

CMJ, maximum power, horizontal jump, handgrip, 1-RM half-squat, 1-RM bench press, 10 m sprint performance, VO_2 max and bone variables are listed in Table 2.

Table 1. Clinical characteristics and bone variables of the study population.

	Mean ± Standard Deviation	Range (Min – Max)
Age (years)	50.2 ± 4.5	41 – 58
Weight (kg)	90.3 ± 13.4	59 – 126
Height (cm)	173.5 ± 6.1	159 – 190
BMI (kg/m^2)	29.9 ± 3.8	21.4 – 42.5
Lean mass (kg)	57.571 ± 6.844	35.999 – 70.593
Fat mass (kg)	30.3 ± 8.385	18.295 – 59.095
Fat mass percentage	32.9 ± 4.9	23.5 – 46.4
Daily calcium intake (mg/d)	646 ± 176	335 – 1076
Daily protein intake (g/d)	82.8 ± 15.5	45.9 – 113.6
PSQI	3.2 ± 2.0	0 – 10
Physical activity (min/week)	104.2 ± 37.4	50 – 180
WB BMC (g)	3071 ± 338	2321 – 3664
WB BMD (g/cm^2)	1.318 ± 0.097	1.162 – 1.535
L1-L4 BMD (g/cm^2)	1.238 ± 0.138	0.962 – 1.594
TH BMD (g/cm^2)	1.114 ± 0.109	0.898 – 1.350
FN BMD (g/cm^2)	1.059 ± 0.117	0.841 – 1.331
Total Radius BMD (g/cm^2)	0.804 ± 0.0657	0.675 – 0.972
CSA (mm^2)	180.6 ± 25.1	124 – 233
CSMI (mm^4)	17502 ± 4328	9530 – 29655
Z (mm^3)	1120 ± 1360	577 – 10461
SI	1.576 ± 0.382	0.8 – 2.6
BR	3.80 ± 1.62	1.6 – 9.1

Min: Minimum; Max: Maximum; BMI: body mass index; PSQI: Pittsburgh sleep quality index; WB: whole body; BMC: bone mineral content; BMD: bone mineral density; L1-L4: Lumbar spine; TH: total hip; FN: femoral neck; CSA: cross-sectional area; CSMI: cross-sectional moment of inertia; Z: section modulus; SI: strength index; BR: buckling ratio.

Table 2. Physical performance variables of the study population.

	Mean ± Standard Deviation	Range (Min – Max)
CMJ (cm)	35.4 ± 5.4	23 – 45
Maximum Power (Watts)	1159 ± 159	770 – 1506
HJ (m)	1.8 ± 0.25	1.15 – 2.5
HG (kg)	47.3 ± 6.7	36 – 67
1-RM half-squat (kg)	85.2 ± 22.6	50 – 149
1-RM bench press (kg)	54.5 ± 10.2	28 – 75
10 m sprint performance (s)	2.04 ± 0.16	1.75 – 2.46
VO_2 max (L/min)	3.5 ± 0.3	2.76 – 4.48
VO_2 max (ml/min/kg)	39.3 ± 4.8	29.1 – 51.0

Min: Minimum; Max: Maximum; CMJ: counter movement jump; HJ: horizontal jump; HG: handgrip; RM: Repetition Maximum; VO_2 max: maximal oxygen consumption.

Correlations between physical performance variables and bone characteristics of the study population

Maximum power of the lower body was positively correlated to WB BMC (r=0.74; p<0.001), WB BMD (r=0.57; p<0.001), L1-L4 BMD (r=0.32; p<0.05), TH BMD (r=0.51; p<0.001), FN BMD (r=0.51; p<0.001), Total Radius BMD (r=0.50; p<0.001), CSA (r=0.58; p<0.001) and CSMI (r=0.46; p<0.001). Handgrip strength was positively correlated to WB BMC (r=0.45, p<0.001), WB BMD (r=0.31; p<0.5), FN BMD (r=0.29; p<0.05), Total Radius BMD (r=0.30; p<0.05), CSA (r=0.37; p<0.01) and CSMI (r=0.43; p<0.01). 1-RM half squat

Table 3. Correlations between physical performance variables and bone characteristics of the study population.

	WB BMC (g)	WB BMD (kg/m²)	L1-L4 BMD (kg/m²)	TH BMD (kg/m²)	FN BMD (kg/m²)	Total Radius BMD (kg/m²)	CSA (mm²)	CSMI (mm⁴)	Z (mm³)	SI	BR
CMJ (cm)	0.02	-0.01	0.13	0.06	0.26	0.12	0.20	0.04	0.07	0.31*	0.05
Maximum Power (watts)	0.74***	0.57***	0.32*	0.51***	0.51***	0.50***	0.58***	0.46***	0.08	-0.21	0.19
Handgrip (Kg)	0.45***	0.31*	0.22	0.23	0.29*	0.30*	0.37**	0.43**	0.07	0.02	0.15
1-RM half-squat (kg)	0.40**	0.40**	0.30*	0.42**	0.52**	0.25	0.53**	0.41**	0.21	0.13	0.00
1-RM BP (kg)	0.50***	0.45**	0.22	0.24	0.30*	0.32*	0.45**	0.40**	0.16	-0.05	-0.10
10m sprint performance (s)	-0.248	-0.22	-0.28*	-0.13	-0.40**	-0.20	-0.45***	-0.35*	-0.24	-0.38**	-0.09
VO_2 max (L/min)	0.66***	0.62***	0.37*	0.56***	0.56***	0.18	0.63***	0.47***	0.22	-0.06	0.01
VO_2 max (ml/min/kg)	-0.28	-0.14	0.01	-0.09	0.05	-0.34	-0.01	-0.08	0.14	0.42**	-0.16
HJ (m)	0.13	0.06	0.25	0.10	0.26	0.15	0.27	0.06	0.19	0.27	0.04

*WB: whole body; BMC: bone mineral content; BMD: bone mineral density; L1-L4: Lumbar spine; TH: total hip; FN: femoral neck; CSA: cross- sectional area; CSMI: cross-sectional moment of inertia; Z: section modulus; SI: strength index; BR: buckling ratio; CMJ: Counter movement jump; RM: Repetition Maximum; BP: Bench press; VO_2 max: maximal oxygen consumption; HJ: Horizontal jump; * p<0.05; ** p<0.01; *** p<0.001.*

was positively correlated to WB BMC (r=0.40; p<0.01), WB BMD (r=0.40; p<0.01), L1-L4 BMD (r=0.30; p<0.05), TH BMD (r=0.42; p<0.01), FN BMD (r=0.52; p<0.01), CSA (r=0.53; p<0.01) and CSMI (r=0.41; p<0.01). 1-RM Bench press was positively correlated to WB BMC (r=0.50; p<0.001), WB BMD (r=0.45; p<0.01), FN BMD (r=0.30; p<0.05), Total Radius BMD (r=0.32; p<0.05), CSA (r=0.45; p<0.01) and CSMI (r=0.40; p<0.01). 10-m sprint was negatively correlated to L1-L4 BMD (r=-0.28; p<0.05), FN BMD (r=-0.40; p<0.01), CSA (r=-0.45; p<0.001), CSMI (r=-0.35; p<0.05) and SI (r=-0.38; p<0.01). VO_2 max (L/min) was positively correlated to WB BMC (r=0.66; p<0.001), WB BMD (r=0.62; p<0.001), L1-L4 BMD (r=0.37; p<0.05), TH BMD (r=0.56; p<0.001), FN BMD (r=0.56; p<0.001), CSA (r=0.63; p<0.001) and CSMI (r=0.47; p<0.001). VO_2 max (ml/min/kg) was positively correlated to SI (r=0.42; p<0.01). Horizontal jump was not correlated to bone variables (Table 3).

Correlations between clinical variables and bone characteristics of the study population

Body weight was correlated to WB BMC (r=0.69; p<0.001), WB BMD (r=0.56; p<0.001), TH BMD (r=0.47; p<0.001), FN BMD (r=0.35; p<0.05), Total Radius BMD (r=0.40; p<0.01), CSA (r=0.44; p<0.01) CSMI (r=0.40; p<0.01) and SI (r=-0.37; p<0.01). BMI was correlated to WB BMC (r=0.43; p<0.01), WB BMD (r=0.46; p<0.001), TH BMD (r=-0.43; p<0.01), Total Radius BMD (r=0.30; p<0.05), and SI (r=-0.43; p<0.01). LM was positively correlated to WB BMC (r=0.78; p<0.001), WB BMD (r=0.53; p<0.001), TH BMD (r=0.41; p<0.01), FN BMD (r=0.43; p<0.01), Total Radius BMD (r=0.43; p<0.01), CSA (r=0.57; p<0.001) and CSMI (r=0.52; p<0.001). FM was correlated to WB BMC (r=0.43; p<0.01), WB BMD (r=0.45; p<0.001), TH BMD (r=0.37; p<0.01), Total Radius BMD (r=0.27; p<0.05) and SI (r=-0.39; p<0.01). FM % was negatively correlated to SI (r=-0.35; p<0.05) (Table 4). DPI was positively correlated to WB BMD (r=0.38; p<0.01), L1-L4 BMD (r=0.30; p<0.05) and TH BMD (r=0.36; p<0.05). Physical activity (h/week) was positively correlated to L1-L4 BMD (r=0.29; p<0.05), TH BMD (r=0.36; p<0.01), FN BMD (r=0.60; p<0.001), CSA (r=0.57; p<0.001), CSMI (r=0.42; p<0.01) and SI (r=0.40; p<0.01) (Table 4).

Multiple linear regressions

Lean mass was the strongest determinant of WB BMC and CSMI. VO_2 max (L/min) was the strongest determinant of WB BMD, TH BMD, FN BMD and CSA. Maximum power was the strongest determinant of total radius BMD (Table 5).

Discussion

This study conducted on a group of middle-aged men mainly shows that VO_2 max (L/min), lean mass and maximum power of the lower limbs are the main predictors of bone mineral density and geometric indices of femoral neck strength.

LM was positively correlated to WB BMC, WB BMD, TH

Table 4. Correlations between clinical variables and bone characteristics of the study population.

	WB BMC (g)	WB BMD (kg/m²)	L1-L4 BMD (kg/m²)	TH BMD (kg/m²)	FN BMD (kg/m²)	Total Radius BMD (kg/m²)	CSA (mm²)	CSMI (mm⁴)	Z (mm³)	SI	BR
Age (years)	-0.08	-0.21	0.02	-0.26	-0.13	-0.04	-0.16	-0.24	-0.03	0.15	0.00
Weight (Kg)	0.69***	0.56***	0.24	0.47***	0.35*	0.40**	0.44**	0.40**	0.03	-0.37**	0.13
BMI (kg/m²)	0.43**	0.46***	0.17	-0.43**	0.22	0.30*	0.25	0.18	-0.00	-0.43**	0.00
LM (kg)	0.78***	0.53***	0.23	0.41**	0.43**	0.43**	0.57***	0.52***	0.09	-0.24	0.22
FM (Kg)	0.43**	0.45***	0.18	0.37**	0.16	0.27*	0.20	0.19	0.05	-0.39**	0.03
FM%	0.07	0.20	0.05	0.17	-0.07	0.10	-0.10	-0.05	0.02	-0.35*	-0.03
DCI (mg/d)	0.04	0.2	0.23	0.11	0.07	0.16	-0.00	0.02	-0.17	-0.06	0.23
DPI (g/d)	0.21	0.38**	0.30*	0.36*	0.31	0.23	0.26	0.22	-0.06	-0.11	0.18
PA (h/week)	0.25	0.22	0.29 *	0.36 **	0.60 ***	-0.05	0.57 ***	0.42 **	0.13	0.40 **	-0.14
PSQI	0.03	-0.08	0.03	-0.19	-0.10	-0.11	-0.06	0.05	-0.08	-0.05	0.17

*WB: whole body; BMC: bone mineral content; BMD: bone mineral density; L1-L4: Lumbar spine; TH: total hip; FN: femoral neck; CSA: cross-sectional area; CSMI: cross-sectional moment of inertia; Z: section modulus; SI: strength index; BR: buckling ratio; BMI: Body mass index; LM: lean mass; FM: fat mass; FM%: fat mass percentage; DCI: daily calcium intake; DPI: daily protein intake; PA: Physical Activity; PSQI: Pittsburgh sleep quality index; *p<0.05; **p<0.01; ***p<0.001.*

BMD, FN BMD, total Radius BMD, CSA and CSMI. Our study confirms the importance of LM on bone health in middle-aged men. Our results are in accordance with those of previous studies conducted on adolescents, young adults and elderly subjects[8,10,35]. The multiple linear regression analysis demonstrated that LM was the strongest determinant of WB BMC and CSMI. Muscles are the load suppliers for bone; they provide mechanical stimuli to preserve skeletal mass[36]. Furthermore, muscle and bone do not only communicate at biochemical and molecular levels but also at a mechanical level[36]. Low muscle mass has been correlated with low bone density values in several populations[37]. Accordingly, this study supports the strategy of increasing lean mass as a prevention strategy against osteoporosis and osteopenia in men.

In addition to LM, body weight was positively correlated to WB BMC, WB BMD, TH BMD, FN BMD, total Radius BMD, CSA and CSMI but negatively correlated to SI. BMI was positively correlated to WB BMC, WB BMD, TH BMD and total Radius BMD but negatively correlated to SI. This result is in accordance with those of many studies that showed that being overweight or obese is associated with higher BMD values in both genders[7,8]. These higher values are observed because obesity and overweight are usually associated with higher lean mass and higher muscular strength. However, fat mass excess is usually associated with lower SI values[38]. According to Faulkner et al.[39], SI is the ratio of estimated compressive yield strength of the femoral neck to the expected compressive stress of a fall on the greater trochanter adjusted for the patient's age, height and weight. Accordingly, the positive association between VO_2 max (ml/min/kg) and SI may be in part mediated by body weight since body weight and SI are negatively correlated.

When assessing the relations between body composition parameters and bone indices, we found that LM is positively correlated to bone parameters and that body fat percentage was not positively correlated to any of the bone parameters. Beside muscle mass, our results confirm that muscle strength is a major determinant of bone health. Maximal muscle strength of the lower limbs was positively correlated to WB BMC, WB BMD, L1-L4 BMD, TH BMD, FN BMD, CSA and CSMI. 1-RM bench press was positively correlated to WB BMC, WB BMD, FN BMD, Total Radius BMD, CSA and CSMI. Handgrip strength was positively correlated to WB BMC, WB BMD, FN BMD, total Radius BMD, CSA and CSMI. These findings demonstrate that the correlations between muscle strength variables and bone parameters in middle-aged men are not necessarily site-specific. The relationship can be site-specific, depending on the mechanical loading, as well as general, depending on other factors such as hormones and growth factors[40].

Overall, the correlations between maximal strength indices and bone variables were weaker compared to those between VO_2 max (L/min) and bone variables or those between maximum power and bone variables. Furthermore, VO_2 max (L/min) was positively correlated to WB BMC, WB BMD, L1-L4 BMD, TH BMD, FN BMD, CSA and CSMI. These results are also in line with those of previous studies that showed that VO_2 max positively affects bone resistance[7,8,11,41,42]. The mechanisms to explain these associations are not completely understood. High values of VO_2 max may be the cause of higher habitual physical activity levels that led to an increase in bone mass through several mechanisms which include an increased lean mass, a better vascularisation of bone tissue and higher mechanical impact loading on bones. Furthermore, VO_2 max only showed positive correlations when expressed in L/min

Table 5. Multiple linear regression models.

	Coefficient ± SE	p-value
Dependent variable: WB BMC (R^2 = 0.649)		
Constant	801.840 ± 247.859	0.002
Power (Watts)	0.652 ± 0.325	0.051
Lean mass (Kg)	0.0263 ± 0.00760	0.001
Dependent variable: WB BMD (R^2 = 0.447)		
Constant	0.692 ± 0.104	<0.001
VO_2 max (L/min)	0.113 ± 0.0332	0.001
Lean mass (Kg)	0.00000409 ± 0.00000186	0.033
Dependent variable: L1-L4 BMD (R^2=0.139)		
Constant	0.773 ± 0.185	<0.001
VO_2 max (L/min)	0.120 ± 0.0618	0.058
Lean mass (Kg)	0.000000826 ± 0.00000351	0.815
Dependent variable: TH BMD (R^2 = 0.329)		
Constant	0.512 ± 0.130	<0.001
VO_2 max (L/min)	0.133 ± 0.0415	0.002
Lean mass (Kg)	0.00000240 ± 0.00000233	0.307
Dependent variable: FN BMD (R^2 =0.336)		
Constant	0.400 ± 0.139	0.006
VO_2 max (L/min)	0.138 ± 0.0445	0.003
Lean mass (Kg)	0.00000307 ± 0.00000249	0.225
Dependent variable: Total Radius BMD (R^2 =0.259)		
Constant	0.556 ± 0.0700	<0.001
Power (Watts)	0.000198 ± 0.0000920	0.037
Lean mass (Kg)	0.000000315 ± 0.00000215	0.884
Dependent variable: FN CSA (R^2 = 0.475)		
Constant	11.416 ± 26.433	0.668
VO_2 max (L/min)	28.418 ± 8.462	0.002
Lean mass (Kg)	0.00122 ± 0.000474	0.013
Dependent variable: FN CSMI (R^2 = 0.351)		
Constant	-6811.061 ± 5100.213	0.188
VO_2 max (L/min)	2328.856 ± 1632.725	0.161
Lean mass (Kg)	0.282 ± 0.0915	0.003

WB: whole body; BMC: bone mineral content; BMD: bone mineral density; L1-L4: Lumbar spine; TH: total hip; FN: femoral neck; CSA: cross-sectional area; CSMI: cross-sectional moment of inertia; VO_2 max: maximal oxygen consumption.

but not in ml/min/kg. This may be explained by its correlation with LM because participants with higher lean mass showed higher maximal oxygen consumption. However, the multiple linear regression analysis revealed that VO_2 max (L/min) was the strongest predictor of WB BMD, TH BMD, FN BMD and CSA in our population. These results show the importance of high-intensity aerobic training and resistance training as methods to increase bone mass and protect against osteoporotic fractures in middle-aged men.

Sprint performance was significantly correlated to L1-L4 BMD, FN BMD, CSA and SI. However, these correlations were poor to moderate. A previous study conducted on a group of young women showed significant correlations between the 30-m running speed test and several bone parameters[43].

Physical performance variables were more strongly correlated to FN BMD than L1-L4 BMD. In fact, the cortical component of the femoral neck is more influenced by mechanical factors than the trabecular component of the lumbar spine; the latter is much more affected by genetic factors[44].

Maximum power of the lower limbs was positively correlated to WB BMC, WB BMD, L1-L4 BMD, TH BMD, FN BMD, Total Radius BMD, CSA and CSMI. The multiple linear regression analysis showed that maximum power was the strongest determinant of total Radius BMD. Although there is no direct mechanical relationship between maximum power of the lower limbs and total Radius BMD, this correlation may be in part mediated by body weight since

body weight and maximum power are strongly related (r=0.82; p<0.001). Hence, increasing maximal power of the lower limbs is beneficial for bone health in middle-aged men. In practice, increasing lean mass, maximal oxygen consumption (L/min), maximal power of the lower limbs and maximal strength may lead to the improvement of bone health in middle-aged men. Therefore, a combined high-intensity aerobic and resistance training may improve bone health and physical parameters in men.

Daily calcium intake and sleep quality were not correlated to bone variables. Mechanical factors seem to influence bone variables more than these two factors. Daily protein intake was positively correlated to WB BMD, L1-L4 BMD and TH BMD; however, these correlations were relatively weak to moderate. The positive influence of protein intake on bone health has been previously described[45]. Physical activity duration was positively correlated to many bone variables. Our result confirms the outcomes of previous studies regarding the osteogenic effect of physical activity[46].

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 relatively small number of subjects in our study group. The third limitation is the 2-dimensional nature of DXA[13]. Finally, several bone health determinants (insulin-like growth factor, testosterone, insulin, leptin, vitamin D and PTH levels) were not controlled in this study. Up to our knowledge, it is one of the few studies that aimed at exploring the relationships between physical performance variables and bone indices in middle-aged men. In our study, several bone determinants are easily calculated when performing simple physical tests.

In conclusion, this study shows that VO_2 max (L/min), lean mass and maximal power of the lower limbs (watts) are the strongest determinants of bone parameters in middle-aged men. Our results may be useful for building new exercise programs for the prevention and early detection of osteoporosis or osteopenia in men. These programs must focus on combined high-intensity aerobic and resistance training.

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