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Abstract

The purpose of this study was to investigate the relationships between skeletal muscle index (SMI) and bone variables in a group of young adults. Three hundred and thirty-five young adults (129 men and 206 women) whose ages ranged from 18 to 35 years voluntarily participated in this study. Weight and height were measured, and body mass index (BMI) was calculated. Body composition, bone mineral content (BMC), bone mineral density (BMD), geometric indices of hip bone strength and trabecular bone score (TBS) were determined for each individual by Dual-energy X-ray absorptiometry (DXA). Appendicular skeletal mass (ASM, in Kg) was calculated by summing the muscle masses of the four limbs, assuming that all non-fat and none-bone mass is skeletal muscle. Skeletal muscle index (SMI) was defined as ASM / height^2. In young men, SMI was positively correlated to WB BMC ($r = 0.63$; $p < 0.001$), WB BMD ($r = 0.53$; $p < 0.001$), L1-L4 BMC ($r = 0.33$; $p < 0.001$), L1-L4 BMD ($r = 0.30$; $p < 0.001$), L1-L4 TBS ($r = 0.26$; $p < 0.01$), TH BMC ($r = 0.61$; $p < 0.001$), TH BMD ($r = 0.46$; $p < 0.001$), FN BMC ($r = 0.51$; $p < 0.001$), FN BMD ($r = 0.46$; $p < 0.001$), FN cross-sectional area (CSA) ($r = 0.56$; $p < 0.001$), FN cross-sectional moment of inertia (CSMI) ($r = 0.52$; $p < 0.001$) and FN section modulus (Z) ($r = 0.54$; $p < 0.001$) but negatively correlated to FN strength index (SI) ($r = -0.24$; $p < 0.01$). In young women, SMI was positively correlated to WB BMC ($r = 0.61$; $p < 0.001$), WB BMD ($r = 0.60$; $p < 0.001$), L1-L4 BMC ($r = 0.35$; $p < 0.001$),

L1-L4 BMD (r = 0.33; p < 0.001), L1-L4 TBS (r = 0.29; p < 0.001), TH BMC (r = 0.61; p < 0.001), TH BMD (r = 0.53; p < 0.001), FN BMC (r = 0.45; p < 0.001), FN BMD (r = 0.49; p < 0.001), FN CSA (r = 0.60; p < 0.001), FN CSMI (r = 0.52; p < 0.001) and FN Z (r = 0.40; p < 0.001) but negatively correlated to FN SI (r = -0.20; p < 0.01). The current study suggests that SMI is a positive determinant of bone mineral density and geometric indices of hip bone strength in young adults.

Keywords: Appendicular skeletal mass; DXA; Peak bone mass.

Introduction

Sarcopenia is a condition increasingly recognized as an extremely important public health problem (*1*). Because of its largely demonstrated link to poor quality of life, increased risk of mortality, mobility disability and risk of hospitalization, sarcopenia currently has and will continue to have a dramatic impact in the future on public health *(1-3).* Etymologically, the term "sarcopenia" comes from the Greek, “sarx” (meat) and “penia” (loss) *(4).* Sarcopenia is defined as the reduction of skeletal muscle mass with advancing age. It was defined in 1989 by Irwin Rosenberg *(5).* Muscle mass (MM) decreases with age; after the age of 40, studies have shown an annual decline of approximately 1% *(3).* The size and number of type II muscle fibers gradually decrease after the age of 25, which causes a gradual decrease in total MM of approximately 40% between the ages of 25 and 80 *(6)*. The loss in MM with ageing may be associated with increased body fat so that despite normal weight there is marked weakness, this is a condition called sarcopenic obesity *(1).* In fact, the relationship between age-related reduction of MM and strength is often independent of body mass *(1).* According to Portero and Couillandre *(7)*, the origin of sarcopenia is multifactorial; quality of life is affected by a reduction in muscle strength and muscle endurance. Thus, an increased difficulty in being physically active has been observed among older people *(7).*

The definition of sarcopenia (decreased muscle mass) has evolved. Currently, it is defined by the decrease in MM (on biphotonic absorptiometry [DEXA] or CT scanner mainly) and muscle strength (evaluated by hand grip) (*8-13*). It is associated with a decrease in physical performance among young adults, which results in a decrease in autonomy and "fragility" *(8-13).* An individual is classified as sarcopenic when his/her skeletal muscle index (SMI) which is the equivalent of appendicular lean mass / height² (ALM/ht²) is two standard deviations below the mean ALM/ht² of the young reference population *(14-16).* Therefore, SMI is the main criterion to diagnose sarcopenia (*14-16*).

The pathophysiology and etiology of sarcopenia and osteoporosis and the relationship between them are complex and multifactorial *(2)*. Recent studies have demonstrated that muscle and bone share some common genetic, nutritional, lifestyle, and hormonal features (*2*). They also showed a correlation between body composition and muscle strength with bone density *(2)*. In addition, some determinants may influence bone through body composition, and various bone mineral density (BMD) determinants also influence body fat or MM *(2).* There is also evidence of a mechanistic interrelationship between muscle and bone in sarcopenic population with a higher risk of osteoporosis and vice versa *(17).* The relationship between these two pathologies could be established at a younger age; a positive association between skeletal muscle index (SMI) and BMD might be present in young adults.

The relationships between SMI and bone variables in young adults needs to be elucidated since most of the studies were conducted in elderly subjects. The purpose of this study was to investigate the relationships between SMI and bone variables (Bone mineral content (BMC), BMD, hip geometric indices and trabecular bone score (TBS)) in a group of young adults. We hypothesized that SMI would be significantly associated with bone variables in

both sexes. Identification of new determinants of BMC, BMD, hip geometric indices and TBS in young adults would allow screening and early management of future cases of osteopenia and osteoporosis.

Materials and Methods

Subjects and Study Design

Three hundred and thirty-five young adults whose ages ranged from 18 to 35 years voluntarily participated in the present study. They were divided into two groups: 129 young men and 206 young women. All participants were nonsmokers and had no history of major orthopedic problems or other disorders known to affect bone metabolism. Pregnant women, 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 (regarding human experimentation developed for the medical community by the World Medical Association). Other inclusion criteria included no diagnosis of comorbidities and no history of fracture. An informed written consent was obtained from the participants. The current study was approved by the University of Balamand Ethics Committee.

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 kilogram per square

meter) *(18).* 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 Dual-energy X-ray absorptiometry (DXA; GE Healthcare, Madison, WI) at the whole body (WB), lumbar spine (L1-L4), total hip (TH), and femoral neck (FN; GE Healthcare). FN cross-sectional area (CSA), strength index (SI), buckling ratio (BR), FN section modulus (Z), cross-sectional moment of inertia (CSMI) and L1-L4 TBS were also evaluated by DXA *(19-21).* 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 score 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 *(22-25)*. The same certified technician performed all analyses using the same technique for all measurements.

Skeletal Muscle Index

Appendicular skeletal mass (ASM, in Kg) was calculated by summing the muscle masses of the four limbs, assuming that all non-fat and none-bone mass is skeletal muscle. SMI was defined as ASM / height^2 *(26).* A skeletal muscle mass index (SMI) < 5.5 kg/m^2 for women and a SMI < 7.26 kg/m^2 for men were defined as the cut-off points for sarcopenia *(26)*. These cut-off points have been chosen by the European Working Group on Sarcopenia in Older People to define sarcopenia in both genders *(26).*

Statistical Analysis

The means and standard deviations were calculated for all clinical data and for the bone measurements. Intersex differences were specified by Student's t-test. Associations between

SMI and bone variables were given as Pearson correlation coefficients and r values were reported. Multiple linear regression analysis models were used to test the relationship of SMI and FM with bone variables, and R^2 values were reported. Statistical analyses were performed using the SigmaStat 3.1 Program (Jandel Corp., San Rafael, CA). A level of significance of $p < 0.05$ was used.

Results

Clinical Characteristics and Bone Data of the Study Population

Mean values of age, weight, height, BMI, LM, FM, FM percentage, bone variables and SMI are shown in Table 1. 33 women and 7 men were sarcopenic. Age, FM, L1-L4 TBS, BR and FN SI were not significantly different between men and women. Weight, height, BMI, LM, BMC, BMD, FN CSA, FN CSMI, FN Z and SMI were significantly higher in men than in women. FM percentage was significantly higher in women compared to men.

Correlations Between Clinical Characteristics and Bone Variables in young men

SMI was positively correlated to WB BMC ($r = 0.63$; $p < 0.001$), WB BMD ($r = 0.53$; $p < 0.001$), L1-L4 BMC ($r = 0.33$; $p < 0.001$), L1-L4 BMD ($r = 0.30$; $p < 0.001$), L1-L4 TBS ($r = 0.26$; $p < 0.01$), TH BMC ($r = 0.61$; $p < 0.001$), TH BMD ($r = 0.46$; $p < 0.001$), FN BMC ($r = 0.51$; $p < 0.001$), FN BMD ($r = 0.46$; $p < 0.001$), FN CSA ($r = 0.56$; $p < 0.001$), FN CSMI ($r = 0.52$; $p < 0.001$) and FN Z ($r = 0.54$; $p < 0.001$). SMI was negatively correlated to FN SI ($r = -0.24$; $p < 0.01$). LM was positively correlated to WB BMC ($r = 0.80$; $p < 0.001$), WB BMD ($r = 0.54$; $p < 0.001$), L1-L4 BMC ($r = 0.58$; $p < 0.001$), L1-L4 BMD ($r = 0.37$; $p < 0.001$), TH BMC ($r = 0.69$; $p < 0.001$), TH BMD ($r = 0.44$; $p < 0.001$), FN BMC ($r = 0.56$; $p < 0.001$), FN BMD ($r = 0.46$; $p < 0.001$), FN CSA

(r = 0.59; p < 0.001), FN CSMI (r = 0.63; p < 0.001) and FN Z (r = 0.63; p < 0.001). LM was negatively correlated to FN SI (r = -0.29; p < 0.001). FM was positively correlated to WB BMC (r = 0.40; p < 0.001), WB BMD (r = 0.32; p < 0.001), TH BMC (r = 0.36; p < 0.001), TH BMD (r = 0.28; p < 0.01), FN BMC (r = 0.30; p < 0.001), FN BMD (r = 0.26; p < 0.01), FN CSA (r = 0.25; p < 0.01) and FN CSMI (r = 0.21; p < 0.05). FM was negatively correlated to FN SI (r = -0.56; p < 0.001) (Table 2).

Correlations Between Clinical Characteristics and Bone Variables in young women

SMI was positively correlated to WB BMC (r = 0.61; p < 0.001), WB BMD (r = 0.60; p < 0.001), L1-L4 BMC (r = 0.35; p < 0.001), L1-L4 BMD (r = 0.33; p < 0.001), L1-L4 TBS (r = 0.29; p < 0.001), TH BMC (r = 0.61; p < 0.001), TH BMD (r = 0.53; p < 0.001), FN BMC (r = 0.45; p < 0.001), FN BMD (r = 0.49; p < 0.001), FN CSA (r = 0.60; p < 0.001), FN CSMI (r = 0.52; p < 0.001) and FN Z (r = 0.40; p < 0.001). SMI was negatively correlated to FN SI (r = -0.20; p < 0.01). LM was positively correlated to WB BMC (r = 0.82; p < 0.001), WB BMD (r = 0.68; p < 0.001), L1-L4 BMC (r = 0.55; p < 0.001), L1-L4 BMD (r = 0.39; p < 0.001), L1-L4 TBS (r = 0.21; p < 0.01), TH BMC (r = 0.76; p < 0.001), TH BMD (r = 0.58; p < 0.001), FN BMC (r = 0.61; p < 0.001), FN BMD (r = 0.60; p < 0.001), FN CSA (r = 0.74; p < 0.001), FN CSMI (r = 0.67; p < 0.001) and FN Z (r = 0.54; p < 0.001). LM was negatively correlated to FN SI (r = -0.17; p < 0.05). FM was positively correlated to WB BMC (r = 0.41; p < 0.001), WB BMD (r = 0.42; p < 0.001), L1-L4 BMC (r = 0.24; p < 0.001), L1-L4 BMD (r = 0.23; p < 0.001), L1-L4 TBS (r = 0.22; p < 0.01), TH BMC (r = 0.37; p < 0.001), TH BMD (r = 0.33; p < 0.001), FN BMC (r = 0.28; p < 0.001), FN BMD (r = 0.31; p < 0.001), FN CSA (r = 0.42; p < 0.001), FN CSMI (r = 0.39; p < 0.001) and FN Z (r = 0.44; p < 0.001). FM was negatively correlated to FN SI (r = -0.29; p < 0.001) (Table 3).

Multiple Linear Regressions in men

After adjusting for FM, SMI remained positively correlated to WB BMC ($p < 0.001$), WB BMD ($p < 0.001$), L1-L4 BMC ($p < 0.001$), L1-L4 BMD ($p < 0.001$), L1-L4 TBS ($p < 0.001$), TH BMC ($p < 0.001$), TH BMD ($p < 0.001$), FN BMC ($p < 0.001$), FN BMD ($p < 0.001$), FN CSA ($p < 0.001$), FN CSMI ($p < 0.001$) and FN Z ($p < 0.001$). SMI was a stronger determinant of L1-L4 TBS than FM. After adjusting for SMI, FM became negatively correlated to L1-L4 TBS ($p = 0.011$) and positively correlated to BR ($p = 0.049$) and remained negatively correlated to FN SI ($p < 0.001$) (Table 4).

Multiple Linear Regressions in women

After adjusting for FM, SMI remained positively correlated to WB BMC ($p < 0.001$), WB BMD ($p < 0.001$), L1-L4 BMC ($p < 0.001$), L1-L4 BMD ($p < 0.001$), L1-L4 TBS ($p = 0.006$), TH BMC ($p < 0.001$), TH BMD ($p < 0.001$), FN BMC ($p < 0.001$), FN BMD ($p < 0.001$), FN CSA ($p < 0.001$) and FN CSMI ($p < 0.001$). After adjusting for SMI, FM remained positively correlated to FN Z ($p = 0.028$) and negatively correlated to FN SI ($p = 0.001$) and became negatively correlated to BR ($p = 0.037$) (Table 5).

Discussion

The current study conducted on a group of young adults mainly shows that SMI is positively correlated to BMC, BMD, TBS, FN CSA, FN CSMI, and FN Z in both sexes. Most of these associations remained significant after adjustment for fat mass.

After adjusting for FM, SMI remained positively correlated to BMC, BMD, TBS, FN CSA and FN CSMI in both sexes. This is one of few studies that used such analysis to investigate whether SMI is an independent determinant of DXA variables in young adults. Accordingly, SMI seems to be an independent determinant of bone variables in both sexes. To our

knowledge, the present study is the first study that aimed at exploring the associations between SMI and bone variables in young adults since most of the previous studies have been conducted on older people. Interestingly, SMI was a stronger determinant of TBS than lean mass in both genders. The reasons that may explain such results remain unclear. The current study encourages the use of SMI as a new determinant of TBS in young adults. Moreover, SMI was correlated with most of the bone variables and these associations were present in both sexes. Our results are consistent with those of many previous studies conducted on elderly subjects *(3,27-31)*. An earlier study conducted by Hida et al. *(3)* demonstrated a positive correlation between appendicular skeletal muscle index and WB BMD in a group of women who did not have osteoporotic vertebral fractures. Another study conducted on a group of men aged 50 years or older found an association between appendicular skeletal mass (ASM) and FN BMD *(27)*. Similarly, some studies *(28-30)* have shown that the ASM is correlated to FN BMD in adult and older men, more than leg muscle mass. In a previous work, Di Monaco et al. *(31)* analyzed the relation between osteoporosis and sarcopenia in three hundred and thirteen women who suffered recent fractures of the hip. They demonstrated a significant positive correlation between ALM/height^2 and BMD assessed at both total proximal femur and femoral neck. 58 % of the three hundred and thirteen women were sarcopenic, whereas 73% were affected by osteoporosis. They have shown a significant correlation between sarcopenia and osteoporosis. This correlation remained significant after adjustment for age. The results also revealed that the odds for osteoporosis is 1.8 higher in sarcopenic women *(31)*. Moreover, two studies have shown positive correlations between ASM and several bone strength parameters such as BMD, bending strength and cortical thickness *(30,32).*

Our results confirm the positive importance of LM on bone health in young adults. In young men, LM is positively correlated to BMC, BMD, FN CSA, FN CSMI and FN Z, whereas LM is negatively correlated to FN SI. In young women, LM is positively correlated to BMC, BMD, TBS, FN CSA, FN CSMI and FN Z, whereas LM is negatively correlated to FN SI. LM is the main determinant of bone variables in both sexes. Accordingly, LM appears to be a predictor of BMC, BMD and hip geometric indices in young adults. Our results are in accordance with those of many previous studies that have shown that LM is an important determinant of WB BMC, FN CSA and FN Z *(33-40)*. A study conducted on a group of overweight and obese young men confirms the positive importance of LM on bone mass in overweight men *(33)*. Similarly, LM appears to be a predictor of BMD and hip geometric indices in overweight or obese men and normal weighted men *(33).* In a cohort study (17,891 subjects aged from 18 to 97 years), He et al. *(2)* found significant positive correlations between whole-body, regional BMD and LM. LM was positively correlated to BMD at all skeletal sites *(2).* Genaro et al. *(41)* conducted a cross-sectional study that included 70 osteoporotic postmenopausal women. They demonstrated a significant correlation between LM and bone variables such as BMC and BMD. They have suggested that FN BMD and femur BMD were correlated to LM *(41).* In addition, a positive correlation was observed between LM and bone mass in sarcopenic population *(42,43).*

The current study suggests that, in young men, FM is positively correlated to WB BMC, WB BMD, TH BMD, FN BMD, FN CSA and FN CSMI but negatively correlated to FN SI. Our study also suggests that, in young women, FM is positively correlated to BMC, BMD, TBS, FN CSA, FN CSMI and FN Z but negatively correlated to FN SI. After adjusting for SMI, FM became negatively correlated to L1-L4 TBS and positively correlated to BR and remained negatively

correlated to FN SI in young men. In young women, FM remained positively correlated to FN Z and negatively correlated to FN SI while FM became negatively correlated to BR after adjusting for SMI. The strength of the associations between fat mass and bone variables were poor in both sexes. However, based on our results, the relationships between FM and bone variables seem to be stronger in women compared to men.

Our results are in accordance with those of a previous study *(44)* conducted on three hundred healthy sexually mature adolescents and young adults (150 men and 150 women) between 13 and 21 years old. This study has found positive correlations between FM and DXA and computed tomography (CT) bone variables in women, while these correlations were weaker or nonexistent in men *(44)*. Another previous study conducted on postmenopausal women has shown a significant correlation between FM and bone variables such as BMC and BMD *(41).* In addition, in postmenopausal women, FM was correlated to BMD at all sites *(42).* Two recent studies have reported an inverse relationship between body fat and BMD after controlling the effects of mechanical body weight load on bone mass *(44,45).* Finally, Di Monaco et al. *(46,47)*, demonstrated a significant correlation between FM and BMD in elderly women with hip fracture.

Our study had some limitations. First, the cross-sectional nature of the present study is a limitation because it cannot evaluate the confounding variables. The second limitation is the 2-dimensional nature of DXA *(48,49).* The third limitation is the disproportionality in the number of subjects in each group. The fourth limitation is the lack of physical activity level measurement. Finally, mean BMI was significantly different between men and women. However, to our knowledge, the present study is the first study that aimed at exploring the

relationships between SMI and bone variables such as BMC, BMD, hip geometric indices and TBS in young adults.

In conclusion, the current study suggests that SMI is a positive determinant of BMC, BMD, TBS, FN CSA, FN CSMI and FN Z in young adults. Our results demonstrate also that SMI is an independent determinant of BMC, BMD, FN CSA and FN CSMI in both genders. To our knowledge, the current study is the first study that demonstrates positive correlations between SMI and bone variables in young adults. Furthermore, implementing strategies to increase SMI in young adults may be useful for preventing osteoporosis later in life. Finally, our study may be useful for the prevention and early detection of osteoporosis and osteopenia and encourages the use of SMI as a new determinant of bone variables in young adults.

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Conflict of Interest

None of the authors reported a conflict of interest related to the study.

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Table 1: Physical Characteristics of the Study Population

Characteristics	Men (n = 129)	Women (n = 206)
	Mean ± SD	Mean ± SD
Age (yr)	24.3 ± 4.8	24.0 ± 3.9
Weight (kg)	88.0 ± 20.0 ***	65.0 ± 14.0
Height (m)	1.75 ± 0.07 ***	1.61 ± 0.06
BMI (kg/m^2)	28.5 ± 5.8 ***	24.8 ± 5.0
Lean Mass (kg)	59.530 ± 8.850 ***	38.412 ± 6.399
Fat Mass (kg)	26.714 ± 14.889	24.673 ± 9.159
Fat Mass %	27.2 ± 8.7 ***	36.6 ± 6.7
WB BMC (g)	3076 ± 419 ***	2241 ± 325
WB BMD (g/cm^2)	1.238 ± 0.121 ***	1.086 ± 0.101
L1-L4 BMC (g)	74.2 ± 14.5 ***	59.3 ± 9.9
L1-L4 BMD (g/cm^2)	1.210 ± 0.157 ***	1.144 ± 0.127
L1-L4 TBS	1.408 ± 0.111	1.425 ± 0.102

TH BMC (g)	40.6 ± 6.8 ***	28.6 ± 5.5
TH BMD (g/cm^2)	1.132 ± 0.146 ***	0.997 ± 0.130
FN BMC (g)	6.10 ± 1.08 ***	4.51 ± 0.88
FN BMD (g/cm^2)	1.136 ± 0.159 ***	0.956 ± 0.144
FN CSA (mm^2)	196.6 ± 30.6 ***	145.8 ± 25.8
FN CSMI (mm^2)^2	17673 ± 4626 ***	10120 ± 3312
FN Z (mm^3)	955 ± 230 ***	572 ± 126
BR	5.883 ± 2.574	6.947 ± 4.295
FN SI	1.587 ± 0.411	1.651 ± 0.441
SMI (kg/m^2)	9.224 ± 1.216 ***	6.551 ± 1.128

BMI, body mass index; WB, whole body; BMC, bone mineral content; BMD, bone mineral density; TBS, trabecular bone score; L1-L4, Lumbar spine; TH, total hip; FN, femoral neck; CSA, cross-sectional area; CSMI, cross-sectional moment of inertia; Z, section modulus; BR, buckling ratio; SI, strength index; SMI, skeletal muscle index; SD, standard deviation. *p < 0.05; **p < 0.01; ***p < 0.001.

Table 2: Correlations Between Clinical Characteristics and Bone Variables in Young Men

N = 129	WB BMC (g)	WB BMD (g/cm^2)	L1-L4 BMC (g)	L1-L4 BMD (g/cm^2)	L1-L4 TBS	TH BMC (g)	TH BMD (g/cm^2)	FN BMC (g)	FN BMD (g/cm^2)	FN CSA (mm^2)	FN CSMI $(mm^2)^2$	FN Z (mm^3)	BR	FN SI
Age (yr)	-0.06	-0.07	0.07	-0.04	-0.09	-0.19 *	-0.24 **	-0.23 **	-0.25 **	-0.26 **	-0.17 *	-0.29 *	0.01	-0.07
Weight (kg)	0.63 ***	0.45 ***	0.30 **	0.18 *	0.05	0.53 ***	0.37 ***	0.42 ***	0.36 ***	0.42 ***	0.42 ***	0.41 ***	0.12	-0.51 ***
Height (m)	0.58 ***	0.20 *	0.49 ***	0.19 *	-0.06	0.37 ***	0.13	0.31 ***	0.19 *	0.31 ***	0.42 ***	0.42 ***	-0.10	-0.23 **
BMI (kg/m^2)	0.46 ***	0.42 ***	0.11	0.12	0.08	0.43 ***	0.35 ***	0.34 ***	0.32 ***	0.34 ***	0.29 ***	0.27 *	0.17	-0.48 ***
FM (kg)	0.40 ***	0.32 ***	0.03	0.06	-0.03	0.36 ***	0.28 **	0.30 ***	0.26 **	0.25 **	0.21 *	0.21	0.19	-0.56 ***
FM %	0.22	0.20	-0.06	-0.02	-0.09	0.15	0.15	0.12	0.14	0.08	0.02	-0.01	0.27	-0.59

	*	*											*	***
LM (Kg)	0.80 ***	0.54 ***	0.58 ***	0.37 ***	0.17	0.69 ***	0.44 ***	0.56 ***	0.46 ***	0.59 ***	0.63 ***	0.63 ***	-0.03	-0.29 ***
SMI (kg/m^2)	0.63 ***	0.53 ***	0.33 ***	0.30 ***	0.26 **	0.61 ***	0.46 ***	0.51 ***	0.46 ***	0.56 ***	0.52 ***	0.54 ***	-0.05	-0.24 **

BMI, body mass index; FM, fat mass; LM, lean mass; SMI, skeletal muscle index; WB, whole body; BMC, bone mineral content; BMD, bone mineral density; TBS, trabecular bone score; L1-L4, Lumbar spine; TH, total hip; FN, femoral neck; CSA, cross-sectional area; CSMI, cross-sectional moment of inertia; Z, section modulus; BR, buckling ratio; SI, strength index. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Table 3: Correlations Between Clinical Characteristics and Bone Variables in Young Women

N = 206	WB BMC (g)	WB BMD (g/cm^2)	L1-L4 BMC (g)	L1-L4 BMD (g/cm^2)	L1-L4 TBS	TH BMC (g)	TH BMD (g/cm^2)	FN BMC (g)	FN BMD (g/cm^2)	FN CSA (mm^2)	FN CSMI $(mm^2)^2$	FN Z (mm^3)	BR	FN SI
Age (yr)	0.03	0.03	-0.01	-0.01	-0.11	-0.03	-0.11	-0.05	-0.15 *	-0.04	0.08	0.11	0.02	-0.08
Weight (kg)	0.67 ***	0.62 ***	0.44 ***	0.35 ***	0.29 ***	0.63 ***	0.51 ***	0.51 ***	0.52 ***	0.65 ***	0.59 ***	0.52 ***	-0.12	-0.26 ***
Height (m)	0.57 ***	0.27 ***	0.40 ***	0.13	-0.15 *	0.44 ***	0.23 ***	0.39 ***	0.33 ***	0.41 ***	0.38 ***	0.33 **	-0.15	-0.11
BMI (kg/m^2)	0.47 ***	0.53 ***	0.29 ***	0.32 ***	0.36 ***	0.47 ***	0.44 ***	0.37 ***	0.41 ***	0.51 ***	0.45 ***	0.44 ***	-0.08	-0.24 ***
FM (kg)	0.41 ***	0.42 ***	0.24 ***	0.23 ***	0.22 **	0.37 ***	0.33 ***	0.28 ***	0.31 ***	0.42 ***	0.39 ***	0.44 ***	-0.13	-0.29 ***
FM %	0.08	0.18	0.01	0.11	0.18	0.08	0.14	0.07	0.11	0.17	0.13	0.28	-0.12	-0.28

		**			**		*			*		**		***
LM (Kg)	0.82 ***	0.68 ***	0.55 ***	0.39 ***	0.21 **	0.76 ***	0.58 ***	0.61 ***	0.60 ***	0.74 ***	0.67 ***	0.54 ***	-0.03	-0.17 *
SMI (kg/m^2)	0.61 ***	0.60 ***	0.35 ***	0.33 ***	0.29 ***	0.61 ***	0.53 ***	0.45 ***	0.49 ***	0.60 ***	0.52 ***	0.40 ***	0.01	-0.20 **

BMI, body mass index; FM, fat mass; LM, lean mass; SMI, skeletal muscle index; WB, whole body; BMC, bone mineral content; BMD, bone mineral density; TBS, trabecular bone score; L1-L4, Lumbar spine; TH, total hip; FN, femoral neck; CSA, cross-sectional area; CSMI, cross-sectional moment of inertia; Z, section modulus; BR, buckling ratio; SI, strength index. *$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Table 4: Multiple Linear Regressions in Men

Men (n = 129)	Coefficient ± SE	*t* value	*p* value
Dependent variable: WB BMC (R^2 = 0.645)			
Constant	1105.120 ± 245.364	4.504	<0.001
SMI (kg/m^2)	210.487 ± 29.734	7.079	<0.001
Fat Mass (kg)	1.335 ± 2.462	0.542	0.589
Dependent variable: WB BMD (R^2 = 0.535)			
Constant	0.747 ± 0.0804	9.294	<0.001
SMI (kg/m^2)	0.0527 ± 0.00974	5.411	<0.001
Fat Mass (kg)	0.000186 ± 0.000807	0.231	0.818
Dependent variable: L1-L4 BMC (R^2 = 0.364)			
Constant	31.125 ± 11.549	2.695	0.008
SMI (kg/m^2)	5.271 ± 1.391	3.791	<0.001
Fat Mass (kg)	-0.201 ± 0.132	-1.517	0.132
Dependent variable: L1-L4 BMD (R^2 = 0.351)			
Constant	0.745 ± 0.117	6.389	<0.001
SMI (kg/m^2)	0.0556 ± 0.0141	3.953	<0.001
Fat Mass (kg)	-0.00188 ± 0.00116	-1.619	0.108
Dependent variable: L1-L4 TBS (R^2 = 0.350)			
Constant	1.103 ± 0.0824	13.397	<0.001
SMI (kg/m^2)	0.0395 ± 0.00994	3.978	<0.001

Fat Mass (kg)	-0.00212 ± 0.000823	-2.579	0.011
Dependent variable: TH BMC (R^2 = 0.632)			
Constant	7.734 ± 4.133	1.872	0.064
SMI (kg/m^2)	3.567 ± 0.501	7.127	<0.001
Fat Mass (kg)	0.00108 ± 0.0413	0.0261	0.979
Dependent variable: TH BMD (R^2 = 0.479)			
Constant	0.600 ± 0.0995	6.034	<0.001
SMI (kg/m^2)	0.0573 ± 0.0121	4.751	<0.001
Fat Mass (kg)	0.0000657 ± 0.000995	0.0661	0.947
Dependent variable: FN BMC (R^2 = 0.531)			
Constant	1.705 ± 0.716	2.380	0.019
SMI (kg/m^2)	0.477 ± 0.0868	5.500	<0.001
Fat Mass (kg)	-0.0000440 ± 0.00716	-0.00615	0.995
Dependent variable: FN BMD (R^2 = 0.490)			
Constant	0.538 ± 0.107	5.040	<0.001
SMI (kg/m^2)	0.0653 ± 0.0129	5.047	<0.001
Fat Mass (kg)	-0.000231 ± 0.00107	-0.217	0.829
Dependent variable: FN CSA (R^2 = 0.586)			
Constant	53.379 ± 19.178	2.783	0.006
SMI (kg/m^2)	16.252 ± 2.323	6.997	<0.001
Fat Mass (kg)	-0.245 ± 0.192	-1.278	0.204

Dependent variable: FN CSMI (R^2 = 0.549)			
Constant	-2773.708 ± 2999.326	-0.925	0.357
SMI (kg/m^2)	2349.293 ± 363.278	6.467	<0.001
Fat Mass (kg)	-43.238 ± 29.984	-1.442	0.152
Dependent variable: FN Z (R^2 = 0.606)			
Constant	-92.141 ± 192.140	-0.480	0.633
SMI (kg/m^2)	121.803 ± 23.286	5.231	<0.001
Fat Mass (kg)	-2.694 ± 2.042	-1.319	0.193
Dependent variable: BR (R^2 = 0.272)			
Constant	8.246 ± 2.562	3.218	0.002
SMI (kg/m^2)	-0.430 ± 0.310	-1.386	0.172
Fat Mass (kg)	0.0546 ± 0.0271	2.012	0.049
Dependent variable: FN SI (R^2 = 0.571)			
Constant	1.663 ± 0.258	6.447	<0.001
SMI (kg/m^2)	0.0417 ± 0.0312	1.334	0.185
Fat Mass (kg)	-0.0175 ± 0.00258	-6.775	<0.001

WB, whole body; BMC, bone mineral content; BMD, bone mineral density; TBS, trabecular bone score; L1-L4, Lumbar spine; TH, total hip; FN, femoral neck; CSA, cross-sectional area; CSMI, cross-sectional moment of inertia; Z, section modulus; BR, buckling ratio; SI, strength index; SMI, skeletal muscle index.

Table 5: Multiple Linear Regressions in Women

Women (n = 206)	Coefficient ± SE	*t* value	*p* value
Dependent variable: WB BMC (R^2 = 0.613)			
Constant	1074.848 ± 111.296	9.658	<0.001
SMI (kg/m^2)	180.452 ± 22.062	8.179	<0.001
Fat Mass (kg)	-0.623 ± 2.717	-0.229	0.819
Dependent variable: WB BMD (R^2 = 0.609)			
Constant	0.732 ± 0.0345	21.236	<0.001
SMI (kg/m^2)	0.0536 ± 0.00684	7.837	<0.001
Fat Mass (kg)	0.000122± 0.000842	0.145	0.885
Dependent variable: L1-L4 BMC (R^2 = 0.358)			
Constant	38.165 ± 4.113	9.280	<0.001
SMI (kg/m^2)	3.239 ± 0.804	4.026	<0.001
Fat Mass (kg)	0.00369 ± 0.0986	0.0374	0.970
Dependent variable: L1-L4 BMD (R^2 = 0.336)			
Constant	0.891 ± 0.0528	16.895	<0.001
SMI (kg/m^2)	0.0383 ± 0.0104	3.694	<0.001
Fat Mass (kg)	0.0000778 ± 0.00127	0.0614	0.951
Dependent variable: L1-L4 TBS (R^2 = 0.294)			
Constant	1.260 ± 0.0420	30.017	<0.001

SMI (kg/m^2)	0.0233 ± 0.00832	2.803	0.006
Fat Mass (kg)	0.000533 ± 0.00102	0.520	0.604
Dependent variable: TH BMC (R^2 = 0.620)			
Constant	8.194 ± 1.884	4.350	<0.001
SMI (kg/m^2)	3.317 ± 0.372	8.909	<0.001
Fat Mass (kg)	-0.0508 ± 0.0458	-1.110	0.268
Dependent variable: TH BMD (R^2 = 0.534)			
Constant	0.566 ± 0.0475	11.899	<0.001
SMI (kg/m^2)	0.0655 ± 0.00940	6.973	<0.001
Fat Mass (kg)	-0.000762 ± 0.00116	-0.659	0.511
Dependent variable: FN BMC (R^2 = 0.461)			
Constant	2.082 ± 0.341	6.104	<0.001
SMI (kg/m^2)	0.391 ± 0.0676	5.791	<0.001
Fat Mass (kg)	-0.00527 ± 0.00833	-0.633	0.528
Dependent variable: FN BMD (R^2 = 0.498)			
Constant	0.533 ± 0.0538	9.914	<0.001
SMI (kg/m^2)	0.0672 ± 0.0107	6.304	<0.001
Fat Mass (kg)	-0.000701 ± 0.00131	-0.534	0.594
Dependent variable: FN CSA (R^2 = 0.603)			
Constant	56.158 ± 8.928	6.290	<0.001
SMI (kg/m^2)	13.422 ± 1.770	7.584	<0.001

Fat Mass (kg)	0.0717 ± 0.218	0.329	0.743
Dependent variable: FN CSMI (R^2 = 0.530)			
Constant	210.623 ± 1213.980	0.173	0.862
SMI (kg/m^2)	1432.812 ± 240.646	5.954	<0.001
Fat Mass (kg)	21.243 ± 29.641	0.717	0.474
Dependent variable: FN Z (R^2 = 0.454)			
Constant	316.355 ± 99.070	3.193	0.002
SMI (kg/m^2)	24.732 ± 21.089	1.173	0.244
Fat Mass (kg)	5.048 ± 2.252	2.242	0.028
Dependent variable: BR (R^2 = 0.276)			
Constant	2.795 ± 3.692	0.757	0.451
SMI (kg/m^2)	1.300 ± 0.786	1.655	0.102
Fat Mass (kg)	-0.178 ± 0.0839	-2.117	0.037
Dependent variable: FN SI (R^2 = 0.298)			
Constant	1.995 ± 0.182	10.967	<0.001
SMI (kg/m^2)	0.00233 ± 0.0361	0.0646	0.949
Fat Mass (kg)	-0.0145 ± 0.00444	-3.275	0.001

WB, whole body; BMC, bone mineral content; BMD, bone mineral density; TBS, trabecular bone score; L1-L4, Lumbar spine; TH, total hip; FN, femoral neck; CSA, cross-sectional area; CSMI, cross-sectional moment of inertia; Z, section modulus; BR, buckling ratio; SI, strength index; SMI, skeletal muscle index.