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Research article

MUSCLE–BONE INTERACTIONS ACROSS AGE IN MEN

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ABSTRACT

This study examined the relationship of muscular strength and lean tissue with age-related patterns in bone mineral density (BMD) in men 20-81 years of age. Subjects were assigned to one of three age groups, Young Men (YM), (n = 25, 20-39 yrs), Middle-aged Men (MM) (n = 24, 40-59 yrs), and Older Men (OM) (n = 23, 60-81 yrs). Isotonic and isokinetic strength was assessed for the quadriceps and hamstrings muscle groups. DXA (Lunar DPX-IQ) was used to measure spine, hip, and total body BMD and body composition. OM had significantly lower ($p < 0.05$) total lean body mass (LBM) than MM and lower leg lean mass (LM) than YM and MM. OM had significantly lower ($p < 0.01$) BMD than YM and MM at the femoral neck and total hip sites and a higher proportion of OM were osteopenic and osteoporotic at the total hip site. Isotonic and isokinetic strength for both muscle groups was positively related ($p < 0.05$) with the hip BMD sites ($r = 0.38$-$.67$). Leg LM also was positively related to hip BMD ($r = 0.37$-$.58$). Multiple Regression analyses determined that age and lean mass (LBM or leg LM) were significant predictors ($p < 0.05$) of femoral neck, and total hip BMD, while lean mass (LBM or leg LM) was a significant predictor ($p < 0.05$) of BMD at the spine and trochanter sites. Isotonic and isokinetic leg strength variables were significant predictors ($p < 0.05$) of the total body, total hip and trochanter BMD. In conclusion, leg strength, leg LM, and total LBM were significant predictors of BMD in men, independent of age. These findings emphasize the importance of maintaining lean body mass for the bone health of aging men.

KEY WORDS: Lean body mass, osteopenia, osteoporosis, muscle strength, bone density.

INTRODUCTION

Osteoporosis has been viewed primarily as a health issue for postmenopausal women, however, about 20% of all hip fractures occur in men and vertebral fractures may be as common in men as in women (Melton, 1999; Writing Group for the ISCD Position Development Conference, 2004). The male lifetime risk of any fracture of the hip, spine, or distal forearm is 13%, which is similar to the lifetime risk of prostate cancer (Melton, 1999). Osteoporosis may account for 60-85% of hip fractures in men and 70-90% of vertebral fractures, thus there is a relationship between low bone mineral density (BMD) and fracture risk in men (Melton, 1999). Ballard et al. (2003) reported that 71% of the elderly Caucasian men (65-93 years) in their study were osteopenic at the femoral neck and 9.8 % osteoporotic; whereas these prevalences were lower for the spine (25.5% and 7.8%). Taaffe et al. (2003) also determined that 7.8% of their Caucasian male population (ages 70-79 years) were osteoporotic at the femoral neck BMD site.

It is well known that mechanical loading of the skeleton via gravitational forces or forces produced by muscular contraction will influence bone mass (Frost, 1997; Turner, 1998; Turner and Robling, 2003). The changes in bone mass with aging generally follow the age-related changes in muscle strength. Since the bone adapts to alterations in mechanical loading associated with muscle function (Frost, 1997), measurements of muscle strength, muscle mass, and bone mass may be useful indicators of the contribution of muscle to bone

strength. Body weight, comprised of fat mass (FM) and lean body mass (LBM), contributes to gravitational forces on the skeleton, while lean body mass contributes an additional component of force through muscle contraction. As a person ages, body composition changes resulting in losses in bone mass and lean mass and increases in FM (Hameed et al., 2002). Recently, it was reported that men aged 85+ years had significantly lower body weight and lean mass than men 65-69 years of age (Ballard et al., 2003). Several studies have examined the relative contribution of FM and LBM to BMD in the aging population (Kenny et al., 2000; Ravaglia et al., 2000; Taaffe et al., 2001). Bone-free LBM, not FM, has been determined to be a significant contributor to BMD (Ravaglia et al., 2000; Taaffe et al., 2001). Taaffe et al. (2003) examined physical performance of the lower extremities and its relationship with hip BMD. They found that the strongest relationship between physical performance and hip BMD was located at the trochanter. Men with the poorest walking endurance were 2.78 times more likely to have osteoporosis at the hip, supporting the site-specific effects of mechanical loading.

There have been few studies investigating the bone status of adult men across the lifespan, including the years when peak bone mass is attained. The purpose of this study was to examine the influence of muscular strength and body composition on age-related BMD patterns in apparently healthy, sedentary men, 20-81 years of age. It was hypothesized that decreases in spine BMD would be evident by middle-age (40-59 years) whereas the hip BMD would decline in the older age group (60-81 years). We expected that muscle mass and strength would be significant predictors of BMD independent of age for men.

METHODS

Subjects

Seventy-two apparently healthy, sedentary men, 20 – 81 years of age, volunteered to participate in this study. All subjects were selected on the criterion that they had not engaged in a habitual exercise program within the previous year. Subjects were assigned to one of three age groups, Young Men 20-39 years (YM, n = 25), Middle-aged Men 40-59 years (MM, n = 24), or Older Men 60-81 years (OM, n = 23). These age categories were chosen to correspond with the expected age related decline in BMD at the spine and hip, which begins around 40 years at the spine and 60-65 years at the hip (Writing Group for the ISCD Position Development Conference, 2004). Participants completed the PAR-Q, the Godin Leisure-Time Questionnaire, and a medical history questionnaire prior to testing. The Godin Leisure-Time Questionnaire determined the number of times per week subjects performed mild or minimal effort activities (i.e, yoga, archery, bowling, etc.), moderate, not exhausting activities (i.e., fast walking, tennis, badminton, popular and folk dancing, etc.) and strenuous activities (heart beats rapidly) (i.e., running, football, soccer, vigorous swimming, etc.). Subjects, 60 years of age and older, obtained medical clearance from their personal physicians prior to participation in the study. All subjects signed a written informed consent. Exclusion criteria were: 1. current use of medications that affect bone density (e.g., thiazide diuretics, testosterone, calcitonin, chemo-therapeutics, corticosteroids, or anticonvulsants); 2. medical conditions that affect bone density (e.g., hypogonadism, thyroid disease, epilepsy, diabetes, kidney stones); 3. current smokers; and 4. participation in endurance or resistance training within the previous year. The University of Oklahoma Institutional Review Board approved all procedures for this study.

Bone density and body composition assessments

BMD ($g \cdot cm^{-2}$) of the total body, AP lumbar spine (L2-L4), and the left proximal femur (femoral neck, trochanter, and total hip) was assessed by Dual Energy X-Ray Absorptiometry (DXA; GE Lunar DPX-IQ, software version 4.7b). Body composition variables, fat mass (FM), total body bone-free lean mass (LBM), and left leg bone-free lean mass (leg LM), were determined from the total body DXA scan. One qualified technician performed all scan analyses. Quality assurance procedures were performed daily for calibration prior to each scanning session. In vivo precision for the proximal femur, spine and total body are ≤1%. In vitro precision and accuracy for the spine phantom are 0.6% and 0.8%, respectively. The prevalence of osteoporosis and osteopenia was estimated based on the WHO classifications (normal, T-score ≥ –1.0; osteopenia, T-score –1.1 to –2.4; and osteoporosis, T-score ≤ –2.5) using the male reference database (Writing Group for the ISCD Position Development Conference, 2004).

Muscular strength assessment

The quadriceps (knee extension) and hamstring (knee flexion) muscle groups of the right leg were tested for isotonic and isokinetic strength according to the standardized procedures in the neuromuscular laboratory. Isotonic strength assessment consisted of a one-repetition maximum (1-RM) protocol for each muscle group using Cybex® equipment. 1-RMs were obtained within 5 trials after an adequate warm

Table 1. Body composition and physical activity characteristics of Young Men (YM, 20-39 yrs), Middle-Aged Men (MM, 40-59 yrs), and Older Men (OM, 60-81yrs). Data are means (±SE).

Variables	YM (n=25)	MM (n=24)	OM (n=23)
Age (yrs)	28.9 (1.3)	48.4 (.9)	67.8 (1.3)
Height (cm)	179.4 (1.3)	178.7 (1.3)	176.4 (1.7)
Weight (kg)	88.3 (3.2)	94.3 (3.8)	82.2 (3.5)
BMI ($kg \cdot m^{-2}$)	27.3 (.81)	29.5 (1.1)	26.2 (.7) [b]
Fat Mass (kg)	21.8 (1.7)	25.1 (1.7)	20.8 (1.2)
Lean Body Mass (kg)	65.9 (2.0)	67.9 (2.1)	60.0 (2.4) [b]
Left Leg Lean Mass (kg)	10.4 (.3)	10.3 (.4)	9.0 (.3) [a,b]
Strenuous Exercise (bouts/week)	0.89 (.22)	.98 (.27)	.57 (.29)
Moderate Exercise (bouts/week)	1.56 (.35)	2.50 (.52)	1.91 (.44)
Mild Exercise (bouts/week)	2.70 (.45)	2.40 (.42)	2.39 (.51)

BMI = body mass index. Strenuous, Moderate, Mild Exercise = raw score from Godin Leisure-Time Questionnaire.

[a] Significantly different ($p < 0.05$) between OM and YM.

[b] Significantly different ($p < 0.05$) between OM and MM.

up and one minute of rest between trials. Isokinetic strength (peak torque, PT), at three contraction speeds, $60°\cdot s^{-1}$, $180°\cdot s^{-1}$, and $240°\cdot s^{-1}$, was assessed using a Biodex® dynamometer. Chair and dynamometer adjustments were made individually to maintain proper joint angles with the dynamometer. The subject was secured in the chair by a waist belt, chest belts, and a leg belt to ensure isolation of the involved muscle groups. Each contraction speed began with several practice trials, followed by three maximal repetitions (extension and flexion) performed consecutively. The practice trials and the three contraction speeds each were separated by a one minute rest period. PT was determined as the highest torque value obtained from the three trials. The day to day intraclass correlation coefficients were 0.80 - 0.99 for isokinetic strength measures and 0.95 - 0.98 for isotonic strength measures.

Statistical analysis

All data are reported as means ± standard error (SE). SPSS Version 11.5 was used to analyze the data. Descriptive statistics were computed for the dependent variables. One way analysis of variance was used to detect age group differences in BMD and body composition variables. The Bonferroni post hoc multiple comparison procedure was used to determine the source of significant differences when a significant age group effect was found. Chi-square analysis was performed to detect associations between age group and the prevalence of osteopenia and osteoporosis for the spine and total hip BMD sites. Pearson's Zero-order Correlation Coefficients were computed to determine relationships of muscular strength and body composition variables with BMD variables. Stepwise Multiple Regression was used to determine whether age and body composition variables (FM, LBM or leg LM) were significant predictors of BMD. Additional Stepwise Multiple Regression analyses were used to determine whether age and isotonic leg strength (quadriceps 1-RM, hamstrings 1-RM) or age and isokinetic leg strength (quadriceps PT, hamstrings PT at 60, 180, and $240°\cdot s^{-1}$) were significant predictors of BMD. The level of significance was set at $p \leq 0.05$.

RESULTS

The physical characteristics of the three age groups are shown in Table 1. The older men had significantly ($p < 0.05$) lower BMI ($kg\cdot m^{-2}$) and LBM (kg) than the middle-aged men. The older men had significantly ($p < 0.05$) lower leg LM (kg) than both the young men and middle-aged men. Although not statistically significant, there was a trend for an age group effect for body weight ($p = 0.063$), with the older men being 12.1 kg lighter than middle-aged men. There were no significant ($p > 0.05$) differences in height, fat mass, or physical activity scores between the three age groups.

The age group comparisons for BMD are shown in Table 2. There were no significant ($p > 0.05$) age differences at the spine or total body sites, however older men had significantly ($p < 0.05$) lower BMD at the femoral neck and the total hip sites compared to both the young and middle-aged groups. Percent differences in age group means for each BMD site are shown in Figure 1. The older men were 14.5% lower than the middle-aged men and were 20.7% lower than the younger men at the femoral neck. Likewise, the older men were 13.4% (vs. middle-aged) and 14.2% (vs. younger) lower at the total hip. The prevalence of osteopenia and

Table 2. Bone mineral density (BMD) in Young Men (YM, 20-39 yrs), Middle-Aged Men (MM, 40-59 yrs), and Older Men (OM, 60-81yrs). Data are means (±SE).

BMD (g ·cm^{-2})	YM (n = 25)	MM (n = 24)	OM (n = 23)
Total Body	1.297 (.028)	1.301 (.018)	1.217 (.028)
Spine L2-L4	1.242 (.027)	1.217 (.033)	1.254 (.059)
Femoral Neck	1.121 (.025)	1.040 (.024)	.889 (.029) [a,b]
Trochanter	.937 (.023)	.934 (.045)	.840 (.030)
Total Hip	1.119 (.024)	1.112 (.025)	.960 (.032) [a,b]

[a] Significantly different ($p < 0.05$) between OM and YM.
[b] Significantly different ($p < 0.05$) between OM and MM.

osteoporosis at the spine and total hip for each age group is shown in Table 3. T-scores in the range for osteopenia were observed for each age group for the spine and total hip sites. Chi-square analyses detected a significant association ($p = 0.012$) between age groups and the prevalence of osteopenia at the total hip as a higher percentage (39%) of older men had osteopenia than the young men (8%) and middle aged men (17%) at this BMD site. A small proportion of middle-aged and older men had T-scores ≤ –2.5for the spine site.

Correlation coefficients between isokinetic and isotonic strength with BMD are shown in Table 4. Generally, leg strength showed significant moderate positive relationships with hip BMD. Both quadriceps and hamstring strength was related with hip BMD variables, with the strongest correlations found between the quadriceps and the femoral neck (ranging from r = 0.62 to 0.67).

Table 3. Chi Square analyses for the prevalence (%) of osteopenia and osteoporosis for the Spine and Total Hip BMD Sites in Young Men (YM, 20-39 yrs), Middle-Aged Men (MM, 40-59 yrs), and Older Men (OM, 60-81yrs).

Variables	YM (n=25)	MM (n=24)	OM (n=23)
Spine (L2-L4)			
%Osteopenic	20	13	30
%Osteoporotic	0	8	4
Total Hip			
%Osteopenic	8	17	39 *
%Osteoporotic	0	0	9

Percentage of subjects who met the criterion for osteopenia or osteoporosis.
Osteopenia: T-score -1.1 to –2.4; Osteoporosis: T-score ≤ –2.5 (Writing Group for the ISCD Position Development Conference, 2004)
* Significant Chi Square p = 0.012.

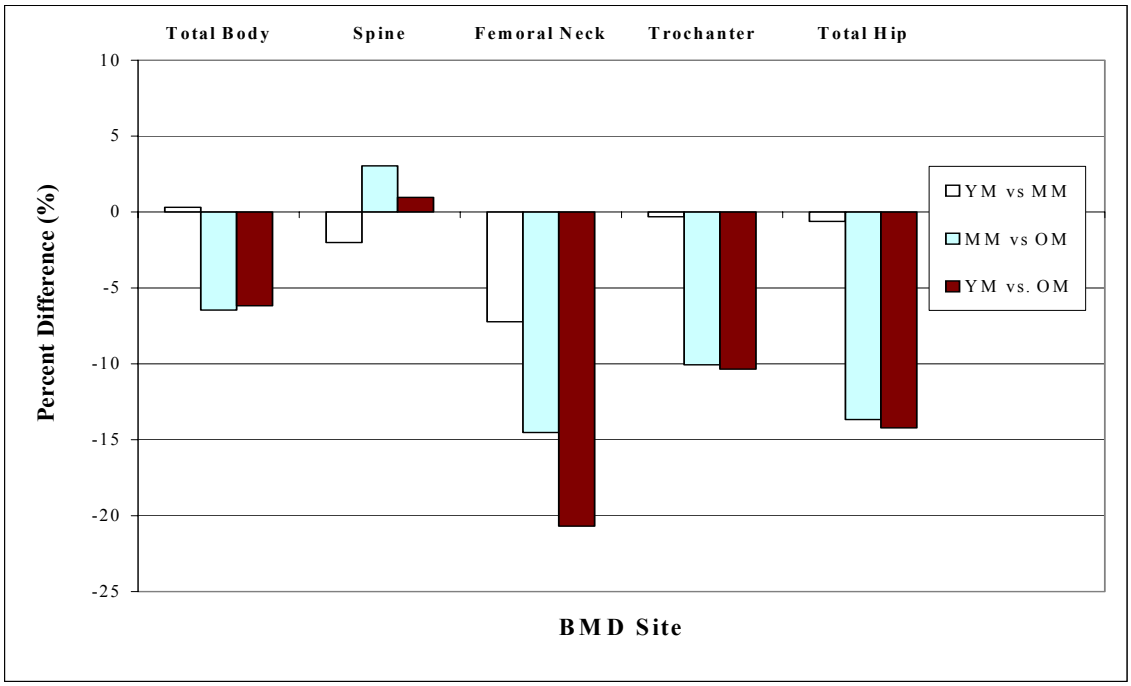

Figure 1. Age group percent differences for Bone Mineral Density. YM, young (20-39 yrs); MM, middle-aged (40-59 yrs.); OM, older (60-81 yrs).

Table 5. Stepwise Multiple Regression predicting bone mineral density (BMD) from body composition variables in combined age groups.

BMD Site	Predictor Variable	β	SEE	R^2
Total Body	[1]FM	.412	.111	.216 ***
	Age	-.262		
	[2]FM	.399	.112	.202 ***
	Age	-.237		
Spine	[1]Total LBM	.305	.192	.080 ***
	[2]Left leg LM	.248	.195	.048 *
Femoral Neck	[1]Age	-.557	.108	.537 ***
	Total LBM	.386		
	[2]Age	-.474	.114	.488 ***
	Left leg LM	.401		
Trochanter	[1]Total LBM	.415	.155	.160 **
	[2]Left leg LM	.374	.158	.128 **
Total Hip	[1]Total LBM	.517	.112	.440 **
	Age	-.339		
	[2]Left leg LM	.498	.116	.393 **
	Age	-.277		

[1] Independent variables: age, fat mass (FM), total body bone-free lean body mass (LBM).
[2] Independent variables: age, fat mass (FM), and left leg bone-free lean mass (LM).
* significant $p < 0.05$, *** significant $p < 0.001$.

Table 4. Pearson Correlation Coefficients (r) between bone mineral density (BMD) sites and isokinetic and isotonic strength in Young Men (YM, 20-39 yrs), Middle-Aged Men (MM, 40-59 yrs), and Older Men (OM, 60-81yrs).

Variables	BMD Site		
	Total Hip	Femoral Neck	Trochanter
Quadriceps strength			
Isokinetic 60°·s^{-1}	.584	.624	.437
Isokinetic 180°·s^{-1}	.598	.660	.430
Isokinetic 240°·s^{-1}	.596	.669	.408
Isotonic (1-RM)	.650	.657	.395
Hamstring strength			
Isokinetic 60°·s^{-1}	.586	.561	.468
Isokinetic 180°·s^{-1}	.576	.579	.481
Isokinetic 240°·s^{-1}	.522	.527	.413
Isotonic (1-RM)	.604	.628	.384

All relationships are significant ($p < 0.01$).

Weak to moderate positive correlations were found between lean mass variables (LBM, leg LM) and the BMD measures. Significant ($p < 0.05$) correlation coefficients were found between LBM and the hip BMD sites (r = 0.59 total hip, r = 0.50 femoral neck, r = 0.42 trochanter). Similar correlations existed between leg LM and the hip sites (r = 0.58 total hip, r = 0.55 femoral neck, r = 0.37 trochanter). Both LBM and leg LM were positively related ($p < 0.05$) to BMD at the total body (r = 0.41, r = 0.37, respectively) and spine (r = 0.31, r = 0.25, respectively) BMD sites.

Stepwise Multiple Regression analyses were performed to determine significant body composition and strength predictors of each BMD site. Since LBM and leg LM were highly correlated (r = 0.96, $p < 0.001$), these variables were used in two separate regression analyses (age, FM and LBM or age, FM, and leg LM) (Table 5). The two analyses yielded nearly identical regression results. FM and age were significant ($p < 0.001$) predictors for total body BMD. LBM or Leg LM alone was a significant predictor for spine ($p < 0.05$) and trochanter BMD ($p < 0.001$). LBM or Leg LM and age were significant predictors ($p < 0.001$) for the femoral neck and total hip BMD. In order to assess the contribution of leg strength, isotonic strength of the quadriceps and hamstrings were used as independent variables for each BMD site (Table 6). Quadriceps strength and age significantly ($p < 0.001$) predicted femoral neck BMD, while quadriceps strength alone significantly ($p < 0.001$) predicted total body, trochanter, and total hip BMD. The contribution of isokinetic leg strength to BMD was evaluated using the peak torque of the quadriceps and hamstrings at three different speeds of contraction (60, 180, and 240°·s^{-1}) as independent variables (Table 7). Quadriceps PT at each speed

Table 6. Stepwise Multiple Regression predicting bone mineral density (BMD) from isotonic leg strength variables in combined age groups.

BMD Site	Predictor Variable	β	SEE	R^2
Total Body	Quadriceps 1-RM	.402	.116	.150 ***
Spine	none			
Femoral Neck	Quadriceps 1-RM	.423	.112	.501 ***
	Age	-.371		
Trochanter	Quadriceps 1-RM	.395	.156	.144 ***
Total Hip	Quadriceps 1-RM	.650	.114	.414 ***

RM = repetition maximum. Independent variables: age, quadriceps 1-RM, and hamstrings 1-RM. *** $p < 0.001$.

and age significantly ($p < 0.001$) predicted femoral neck BMD, while quadriceps PT at each speed alone significantly ($p < 0.01$) predicted TB BMD. Hamstrings PT and quadriceps PT at 60°·s^{-1} were significant ($p < 0.001$) predictors of total hip BMD, while quadriceps PT at 180 and 240°·s^{-1} alone significantly ($p < 0.001$) predicted total hip BMD. Hamstrings PT at each speed significantly ($p < 0.001$) predicted trochanter BMD.

DISCUSSION

In this cross-sectional study, we examined the relationship of body composition and muscular strength variables with bone mineral density in apparently healthy, sedentary men, 20-81 years of age. In contrast to previous studies (Ballard et al., 2003; Center et al., 2000; Kenny et al., 2000; Ravaglia et al., 2000; Taaffe et al., 2001; 2003), our subjects were evaluated for isotonic and isokinetic strength of the knee flexors and extensors. Additionally, most previous studies focused only on elderly men in their analyses (Ballard et al., 2003; Kenny et al., 2000; Taaffe et al., 2001; 2003), whereas this study included a wide age range of 20 - 81 years. Decreased LBM and leg LM became evident in the older age group (60-81 years), which coincided with decreased muscle strength for the quadriceps and hamstrings muscle groups (Runnels et al., 2005). However, we did not find an age group difference in FM and there was only a trend for an age group effect for body weight. In a cross-sectional study of men 65 – 93 years of age, Ballard et al. (2003) reported that as men aged, both body weight and LBM decreased.

Older men, 60-81 years of age, had lower BMD at the femoral neck and total hip sites compared to both the young (20-39 years), and

Table 7. Stepwise Multiple Regression predicting hip bone mineral density (BMD) from isokinetic leg strength variables in combined age groups.

BMD Site	Predictor Variable	β	SEE	R^2
Total Body	Quad PT 60°·s^{-1}	.404	.116	.151 ***
	Quad PT 180°·s^{-1}	.358	.119	.116 *
	Quad PT 240°·s^{-1}	.347	.119	.108 *
Spine	none			
Femoral Neck	Quad PT 60°·s^{-1}	.413	.118	.448 ***
	Age	-.344		
	Quad PT 180°·s^{-1}	.470	.115	.471 ***
	Age	-.294		
	Quad PT 240°·s^{-1}	.486	.115	.473 ***
	Age	-.273		
Trochanter	Ham PT 60°·s^{-1}	.468	.150	.208 ***
	Ham PT 180°·s^{-1}	.481	.149	.220 ***
	Ham PT 240°·s^{-1}	.413	.155	.159 ***
Total Hip	Ham PT 60°·s^{-1}	.337	.118	.371 ***
	Quad PT 60°·s^{-1}	.328		
	Quad PT 180°·s^{-1}	.598	.121	.348 ***
	Quad PT 240°·s^{-1}	.596	.121	.346 ***

PT = Peak Torque. Independent variables: age; Quad, Quadriceps PT; and Ham, Hamstrings PT. * $p < 0.01$, *** $p < 0.001$.

middle-aged (40-59 years) men. However, there were no detectable age group differences in the spine or total body BMD. The young men in our study had a surprisingly high prevalence (20%) of low spine bone density. In a cohort of men 20-80 years of age, Clarke et al. (2002) reported an age-related decline only in the femoral neck BMD with no age group differences in spine, total body or other hip sites. There are several possible explanations for differences in our findings compared to previous studies. Clarke et al. (2002) excluded men reporting a sedentary lifestyle from their study; therefore, their subjects may have been more physically active than our subjects. The spine BMD of the older men in our study also may have been influenced by artifact, such osteoarthritis in the lumbar spine (Melton et al., 1998; O'Neill and EPOS Group, 2002; Szulc et al., 2000; Vallarta-Ast et al., 2002). Taken together, evidence of young men having lower bone spine BMD than expected and the possibility of an artificially increased spine BMD in older men may explain the lack of age-related changes in spine BMD.

The older men exhibited a similar prevalence of osteoporosis as those reported in previous studies (Ballard et al., 2003; Taaffe et al., 2003). Some caution should be used when evaluating BMD T-scores in men, as the diagnosis of osteoporosis in men is not as definitive as it is in postmenopausal women. The World Health Organization (1994) classification compares a patient's BMD to the young adult female reference population for the diagnosis of osteoporosis and osteopenia in Caucasian postmenopausal women. However, the application of these criteria in men as well as the appropriate reference database to use are controversial (Binkley et al., 2002; De Laet et al., 2002; Faulkner and Orwoll, 2002; O'Neill and EPOS Group, 2002). The International Society for Clinical Densitometry (2004) recommends the application of several modifications to the WHO classifications for the diagnosis of osteoporosis in men.

Regression analysis was used to examine the interactions between bone mass and total LBM, an indicator of gravitational stress, or leg LM, which relates to the contractile forces placed upon the bone. Total LBM and age were significant predictors of femoral neck and total hip BMD sites (54 and 44% of the variance, respectively). Total LBM alone was a significant predictor of the spine and trochanter BMD sites, explaining 8 and 16% of the variance respectively. Regression analyses using leg LM yielded similar results as those using total LBM. Leg LM and age were significant predictors of the femoral neck and total hip BMD sites, explaining 49 and 39% of the variance, respectively. Leg LM was the only significant predictor of the spine and trochanter sites (5 and 13% of the variance, respectively). The standardized regression coefficients indicated that increased leg LM had a positive effect on BMD, while increased age had a negative effect on BMD. These results suggest the importance of maintaining leg LM in aging men. FM and age were entered into the model for total body BMD, accounting for 20% of the variance. Total body BMD was the only site influenced by fat tissue, likely due to its contribution to body weight, and therefore, gravitational stress on the skeleton.

It is well understood that excess forces imposed upon the skeleton through muscular contraction and/or gravitational loading will result in increased bone mass. In order to examine the contribution of muscular contractile forces on hip BMD, separate multiple regression analyses were performed with isotonic leg strength replacing body composition as independent variables. Quadriceps strength alone was entered into the models for the total body, trochanter, and total hip BMD sites explaining 15, 14, and 41% of the variance, respectively; whereas both quadriceps strength and age were significant predictors for the femoral neck site. Therefore, quadriceps strength and leg LM, independent of age, were influential for the proximal femur BMD, with each variable accounting for similar proportions of the variance at these sites. These findings are consistent with those of Taaffe et al. (2001) who found that LBM was the significant contributor to BMD at the femoral neck, upper and lower limbs, and for the whole body in men. Ravaglia et al. (2000) also found significant associations between bone mass and muscle mass in men 20-95 years of age.

Examination of isokinetic muscle strength in this study offers a unique approach to determining the contribution of muscular contraction on BMD. Separate multiple regression analyses using PT strength of the quadriceps and hamstrings (at 60, 180, and 240°·s^{-1}) as independent variables, revealed similar results to the isotonic variables, with PT having a positive influence on BMD. The main difference between the two types of contraction occurred with the trochanter BMD regression model. Hamstrings isokinetic strength, rather than quadriceps, entered the model. At the trochanter, the hamstrings PT (60, 180, and 240°·s^{-1}) was found to explain 16 – 22% of the variance in BMD, which is slighter higher than that determined by the isotonic strength of the quadriceps (14%). Hamstring PT at 60°·s^{-1} was also entered into the model for the total hip BMD, which, along with quadriceps PT at 60°·s^{-1}, accounted for 37% of the variance in BMD. These

results strengthen the argument that muscular contraction has an important influence on BMD, especially at the hip.

There are several limitations to this study. We did not assess calcium intake which is an important factor for bone health in men as higher BMD values have been associated with higher calcium intakes in elderly men (Ballard et al., 2003; Nguyen et al., 2000). For example, Nguyen et al. (2000) reported that men (69.5 ± 6.5 years) in the highest dietary calcium intake tertile (>710 mg·day^{-1}) exhibited femoral neck and spine BMD values 5% higher than the men of the lowest tertile (<460 mg·day^{-1}). However, they also found that the variation in dietary calcium intake accounted for only 1% of the total variance in BMD. The average BMD values for our older men were similar to those reported by Nguyen et al. (2000) for the spine (1.24 ± 0.20) and slightly lower for the femoral neck (0.92 ± 0.14).

Another limitation is that occupational physical activity data was not assessed. Leisure time physical activity showed no differences between the age groups, however this accounts for only a portion of time spent being physically active during the day. A comprehensive account of the daily mechanical loading of the skeleton by these subjects could provide meaningful data in explaining the prevalence of low bone mass. Generally, physically active individuals of any age have higher BMD than their sedentary counterparts (Beck and Snow, 2003). Another lifestyle factor that can influence bone density is the incidence of previous fracture, which was not documented in this study. It has been shown that men without previous fracture have a higher BMD than those who have fractured at least one time at some point in their life (Ballard et al., 2003).

CONCLUSIONS

Older men, 60-81years of age, had lower femoral neck and total hip BMD than their young (20-39 years) and middle-aged (40-59 years) counterparts. Low bone mass for the spine was exhibited by each age group with prevalence of osteoporosis evident in the middle-aged and older men. The prevalence of osteopenia and osteoporosis were greater in the older men at the total hip site. Regression analyses revealed that total LBM and leg LM had similar contributions to hip BMD. Isotonic and isokinetic leg strength and leg lean mass were significant predictors of hip BMD, independent of age, reinforcing the importance of contractile forces on bone. Based on our findings, it appears that men as young as 60 years of age should be concerned about bone loss and osteoporosis risk. Maintenance of lean body mass should be encouraged in aging men for preservation of bone mass, especially at the hip. The prevention of osteoporosis is of critical importance for aging men as the life expectancy of men in the United States is projected to increase.

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KEY POINTS

- Osteoporosis is an important health problem for men.
- Bone mineral density for the hip was lower in older men compared to their younger and middle-age counterparts. There were age group differences in the prevalence of osteopenia and osteoporosis for the total hip BMD site.
- Muscular strength and bone-free lean body mass were significant predictors of hip BMD, independent of age, thus reinforcing the importance of contractile forces on skeletal health.
- Maintenance of muscle mass and strength should be encouraged in aging men for the reduction of osteoporosis risk.

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