# Low Peak Bone Mineral Density in Healthy Lebanese Subjects

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**Osteoporosis is a major public health problem in Western countries and is projected to have a similar impact in the Middle East. It has been suggested that peak bone mineral density (BMD), a major determinant of osteoporotic fractures later in life, may be lower in this part of the world compared with the Western world. However, subjects have not been randomly selected or systematically screened to rule out secondary causes of bone loss. The purpose of this study was to determine peak bone mass and lifestyle risk factors for bone loss in a randomly chosen sample of healthy Lebanese subjects from the greater Beirut area. Subjects 25–35 years of age were randomly selected from greater Beirut, which comprises one third of the Lebanese at large, and studied during the Fall of 1999. BMD was measured at the lumbar spine, hip, forearm, and total body. A questionnaire on lifestyle factors was administered to all subjects. Results were compared with the database of subjects from the USA provided by the manufacturer, and to the NHANES database for the total hip. Two hundred thirteen subjects were studied; 45 subjects rotated at all three centers for cross-calibration purposes. Peak BMD in Lebanese subjects was 0.2–0.9 SD below that of peak BMD in American subjects, depending on skeletal site, gender, and densitometer. These differences persisted after attempting to adjust for body size. Osteoporosis and osteopenia were more prevalent than in healthy young Americans. Height, weight, and total body fat were the most significant correlates of BMD/bone mineral content (BMC), accounting for 0.3–0.7 of the variance in bone mass measurement. Lifestyle factors had a very modest but significant contribution to bone mass variance. This is the first population-based study from the Middle East demonstrating that peak BMD is slightly lower in Lebanese subjects compared as with an established database from the USA. Due to the selection of relatively healthier subjects in our study than in the NHANES study, the actual differences between the two populations may be even greater. The impact of our findings on the epidemiology of osteoporotic fractures in Lebanon remains to be determined. (Bone 31:520–528; 2002) © 2002 by Elsevier Science Inc. All rights reserved.**

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## Introduction

Osteoporosis is a public health problem affecting one third of women in the USA. It is of increasing social and economic importance as the size of the aging population continues to grow. It is projected that the magnitude of the problem may be even larger in developing countries, including the Middle East.[5] A recent survey from Lebanon has suggested that the prevalence of fractures in postmenopausal women after age 50 years is 11%.[2] Bone mineral density (BMD) is the best predictor of fractures.[6,23,39] Because of the strong relationship between bone density and fractures, in 1994 the World Health Organization working group developed guidelines for the diagnosis of osteoporosis based on bone density solely.[26] There are geographical variations in BMD worldwide,[4,7,34] and studies from the Middle East have suggested that peak BMD is lower in this region,[8,10,20,35]; however, none of these observations were based on representative samples of the population.

Peak BMD is one of the major determinants of BMD at older age and therefore of osteoporotic fractures. Peak BMD has also been proposed as a major target for osteoporosis prevention strategies. Genetic, anthropometric, as well as lifestyle and reproductive factors are all predictors of bone mass. The latter two include weight, body mass index (BMI), smoking (that may be confounded by weight), calcium and vitamin D intake, physical activity, and in some studies parity and late menarche.[1,16,22,24,25,37,46] Various studies evaluating the impact of these factors on BMD have yielded conflicting results. A recent study conducted on Saudi subjects has suggested that the low BMD in their female subjects, in comparison to a normative database from the USA, was partially due to the greater number of pregnancies, longer lactation, and potentially lower vitamin D levels.[20] In Lebanon, a large proportion (>40%) of the population smokes,[3] and we and others have recently demonstrated that vitamin D insufficiency is prevalent in healthy adolescents as well as young adults.[12,13,18]

The objectives of our investigation therefore were:

1. To characterize peak bone density in a random sample of healthy young adults from the Lebanese population.
2. To compare BMD of our Lebanese subjects to a normative database from the USA, provided by the manufacturer at the spine, forearm, and total body, and to the NHANES database at the hip.

3. To investigate lifestyle correlates of peak bone mass in our population.

## Methods

### Sample Selection

Two hundred thirteen normal subjects, aged 25–35 years, were randomly selected from the greater Beirut area by Stat-Ipsos Co. (Sin-El-Fil, Beirut), using a multilevel cluster technique with which Stat-Ipsos is familiar. We chose the age range of 25–35 years as preliminary results from analysis of several hundred spinal BMD studies on Lebanese subjects has suggested that peak is achieved by the age of 35 years, rather than 30 years (P. Rizk, unpublished observations). Greater Beirut constitutes 33% of the Lebanese population at large (Lebanese Ministry of Social Affairs and UNFPA, 1996). Furthermore, there are well-known seasonal migrations of the Lebanese population from rural areas to greater Beirut in the winter months (October to June), during which our survey was conducted. In short, Stat-Ipsos Co. has maps of greater Beirut broken down into regions and subregions with households. The households were chosen randomly from the maps and the subject/household fitting the age range was selected. If more than one subject/household did fit the entry criteria (including age range), then one household member was randomly selected from that household. Less than 10% of randomly selected subjects declined to enter the study or were excluded from participation. As it turned out, 8% (17 of 213) of the subjects were outside the age range specified: 14 subjects were 24 years of age, and 3 were 36 years of age. This was noted upon entering the date of birth of the subjects while implementing bone density analyses.

### Inclusion/Exclusion Criteria

Subjects were entered according to the following inclusion criteria: both parents were to be of Middle East origin and Lebanese residents, and women were to be having regular menstrual cycles with at least ten cycles per year. Women on the birth control pill (BCP) were entered into the study, and the duration of BCP use was noted. Exclusion criteria were: a history of radiation therapy or chemotherapy; a history of atraumatic fractures (i.e., fractures without a fall or without a motor vehicle accident); intake of medications that affect bone metabolism; a history of breastfeeding within the last year; pregnancy; family history of fractures before age 15 years in first-degree relatives; major chronic diseases (intestinal, liver, kidney, heart); bed-rest for >1 month within 6 months prior to the study; and previous surgery on the spine, hip, or forearm; or having undergone an imaging contrast procedure within 4 days.

### Timeframe

The project was conducted between October and December 1999.

### Sample Size

In the large National Health and Nutrition Examination Survey (NHANES) study in the USA, 380–400 subjects were studied for determination of peak bone mass.[33] Based on previous studies conducted in the region, we anticipated an average peak BMD difference of, at most, 0.05 g/cm$^2$ (0.5 SD) compared with the American database. Assuming an SD of 0.11 g/cm$^2$, the number of subjects needed for study to detect such a difference as being significant would be N = 77, based on a power of 80%

and two-sided $\alpha = 0.05$ (INSTAT v2.0, Prism, San Diego, CA). Because osteoporosis is more common in women, we weighted the sample toward almost twice as many women and studied a total of 150 female and 63 male subjects.

### Data Collection

*Anthropometric lifestyle and reproduction factors.* Age, height, weight, and dietary calcium intake were expressed as continuous variables, and physical activity (expressed on a scale of 1–5), caffeine intake (expressed on a scale of 1–5), smoking (none, previous, current), and alcohol intake (none, previous, current) were obtained as ordinal variables for the lifestyle measures. Because of the manner in which the data clustered, they were transformed into categorical (Y/N) variables as follows: for smoking and alcohol intake, "no" was coded for never and "yes" for former or current consumer. The following reproductive information was obtained from female subjects: age at menarche; number of pregnancies; number of children born alive; total duration of breastfeeding (in months); and total duration of BCP use (in months).

*Bone density measurement.* Bone density was measured using the Lunar DPX-L (Lunar Corp., Madison, WI) at the American University of Beirut Medical Center in 78 female and 19 male subjects, using a Hologic 2000 densitometer at Rizk Hospital in 78 female and 22 male subjects, and using a Hologic 4500W at Hotel Dieu de France in 77 female and 22 male subjects. This was to ensure the availability of a Lebanese peak normative database using the two most commonly available types of densitometers in Lebanon, and also in the region.

The protocol was approved by the research committee and the institutional review board of the American University of Beirut.

### Cross Calibration of Densitometers

Cross calibration was performed by having a total of 45 women simultaneously submit to bone density measurement at all skeletal sites at the three centers. Linear regression was applied to allow conversion of densitometry measurements from one machine to the other. The following formulas were derived:

- Lumbar spine (Lunar) = 1.10 × lumbar spine (Hologic) + 0.073 ($R^2 = 0.95$).
- Total hip BMD (Lunar) = 0.976 × total hip (Hologic) + 0.145 ($R^2 = 0.82$).
- One-third radius BMD (Lunar) = 0.87 × one-third radius (Hologic) + 0.074 ($R^2 = 0.78$).
- Total body BMD (Lunar) = 0.747 × total body BMD (Hologic) + 0.355 ($R^2 = 0.73$).
- These conversion formulas and their corresponding $R^2$ values were very similar, if not identical, to those published previously and considered as standards for cross calibration of densitometers in the literature.[19] The mean (±SD) for lumbar spine (L1–4), femur (neck, trochanter, total femur), forearm (distal, one-third proximal), and total body is presented by gender in two ways, using the aforementioned conversion formulas:

1. As if all subjects were measured on the Lunar DPX-L densitometer
2. As if all subjects were measured on the Hologic 4500W densitometer

### Quality Assurance of Densitometers

For quality control, spine phantoms were measured daily and the mean coefficient of variation (CV%; expressed as [SD/mean] ×

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**Table 1.** Clinical characteristics of study subjects

| Variable | Overall | Women | Men | $t$-test |
|---|---|---|---|---|
| N | 213 | 150 | 63 | |
| Age (years) | 29.6 (3.8) | 30.1 (3.8) | 28.4 (3.7) | 0.002 |
| Height (cm) | 163.3 (8.4) | 159 (5.6) | 173 (5.6) | 0.001 |
| Weight (kg) | 67.4 (14.9) | 62 (11.8) | 80 (13.3) | 0.001 |
| BMI (kg/m$^2$) | 25.2 (4.6) | 24.4 (4.5) | 27 (4.3) | 0.001 |
| Calcium intake (mg/day) | 328 (245) | 331 (240) | 321 (259) | n.s. |
| Smoking, Y/N (%) | 45%/55% | 45%/55% | 46%/54% | n.s. |
| Alcohol, Y/N (%) | 53%/47% | 45%/55% | 70%/30% | n.s. |
| # of pregnancies | | 1.6 (2.2) | NA | |
| # of children | | 1.3 (1.6) | NA | |
| Lactation (months) | | 6.7 (12.4) | NA | |
| BCP (months) | | 3.0 (13.1) | NA | |

Data expressed as mean ± SD.
KEY: BCP, birth control pill; BMI, body mass index; NA, not available; n.s., not significant.

100 of all daily replicate measurements for the spine phantom for the duration of the study) was <1% for all three densitometers. In vivo quality control was conducted at each center by performing duplicate measurements on 30 patients measured on the same day. The mean (SD) CV% for the spine duplicates was 1.23 (0.83), total hip 1.00 (0.79), femoral neck 1.84 (1.25), trochanter 1.70 (1.28), and forearm 1.65 (1.17). These data are comparable to those published by other leading institutions in the USA.[14,29,38]

### Bone Mineral Apparent Density

To adjust for body size differences between the Lebanese and American counterparts, we estimated volumetric bone mineral apparent density (BMAD; in grams per cubic centimeter) from our data as described earlier using the formula: spine BMAD = bone mineral content/area$^{3/2}$.[27] Our results were compared with those published in a study of white subjects by Marquez et al.,[36] using the mean, SD, and $t$-test. We undertook this comparison because similar data on healthy subjects in from NHANES study were not readily available.

### T-score Calculation

The $T$ score for the lumbar spine and hip was calculated using the following formula: $T$ score = subject's BMD − peak mean BMD/SD of peak BMD. Peak BMD was provided by each densitometer's software. For the Hologic densitometer, peak BMD is in the age range of 20–29 years. For the Lunar densitometer, BMD is higher in the 20–29 year age group than in the 30–39 year age group — at the hip in women and at both sites in men. Spine BMD is higher for the 30–39 year age group than in the 20–29 year age group in women only. NHANES-based total hip $T$ scores were calculated for each individual patient based on information provided in the updated study describing the NHANES database. The following formula was used: total hip NHANES-based $T$ score = subject's BMD (on Hologic) −0.942/0.122.[33] $T$ scores of healthy Lebanese subjects were compared with zero to determine whether peak BMD in the Lebanese subjects differed significantly from that of a representative group of young adults in the USA.

### Statistical Methods

Results are expressed as mean ± SD, unless mentioned otherwise. Comparison of continuous variables between various subgroups of subjects was also performed using a two-tailed $t$-test. All analyses were conducted separately for each gender, and then for the group overall. The association between the outcome variable (BMD/BMC) and the correlates was examined by bivariate analysis and then by adjusted stepwise multiple regression analyses. The outcome variables were BMD of the lumbar spine, total hip, one-third radius, total body, and total body BMC. The covariates evaluated were age, height, weight, body mass index (BMI), total body fat, calcium intake, caffeine intake, physical activity, age at menarche, months of breastfeeding, number of children born alive, months of use of BCP, smoking, and alcohol intake. Although height, weight, BMI, and body fat are highly correlated measures of body size, they have been previously demonstrated to be independent correlates of BMD, especially in weight-bearing areas.[9] The analyses were performed using SPSS software v10.0 (SPSS, Chicago, IL) and STATA v6. All model assumptions, including normal distribution of the outcome variable, independent distribution of errors, and homogeneity of variance, were verified by examination of the residuals using SPSS.

Statistical significance was set at $p$ <0.05; $p$ values were unadjusted for multiple testing.

## Results

### Clinical Characteristics

The clinical characteristics of study subjects are summarized in **Table 1**. The mean age of the study group overall was 29.6 (3.8) years. The average calcium intake of these healthy young subjects was lower than the accepted recommendations. Almost half of the study group subjects were smokers, over 50% consumed some alcohol, 70% drank coffee more than occasionally, and only 27% exercised in a regular manner.

### Bone Mineral Density

BMD of the study subjects is presented by gender and densitometer type in **Table 2**. As expected, peak mean BMD was 6%–13% lower in women than in men, depending on the skeletal site, except for spine BMD, which was the same in both genders. Overall, mean BMD was 0.2–0.9 SD below that of the manufacturer's American database peak BMD, depending on the densitometer used and gender and skeletal site measured (Table 2 [part a] and **Figures 1 and 2** ). These decrements were more accentuated when the data were compared with the Hologic, as opposed to the Lunar normative database. Because the mean height was 4 cm lower in our healthy men and women compared with NHANES subjects, the observed differences in areal BMD may reflect differences in bone size. We therefore calculated

**Table 2.** BMD in study subjects by gender and densitometer maker compared with american normative database

(a) All subjects

| | Women | | Men | |
|---|---|---|---|---|
| | Study subjects (N = 150) | Densitometer (database) | Study Subjects (N = 63) | Densitometer (database) |
| Age (years) | 30.1 (3.8) | 20–29 | 28.4 (3.7) | 20–29 |
| Spine BMD (L)[a] | 1.18 (0.12) | 1.2 (0.12) | 1.18 (0.14) | 1.24 (0.12) |
| $T$ score | −0.24 (0.99)[b] | 0 | −0.45 (1.17)[b] | 0 |
| Spine BMD (H)[a] | 1.01 (0.11) | 1.08 (0.11) | 1.01 (0.13) | 1.12 (0.11) |
| $T$ score | −0.66 (0.98)[b] | 0 | −0.94 (1.16)[b] | 0 |
| Hip BMD (L) | 0.97 (0.11) | 1.00 (0.12) | 1.07 (0.15) | 1.11 (0.13) |
| $T$ score | −0.3 (0.89)[b] | 0 | −0.2 (1.17) | 0 |
| Hip BMD (H) | 0.84 (0.10) | 0.98 (0.12) | 0.94 (0.15) | 1.06 (0.13) |
| $T$ score | −0.79 (1.02)[b] | 0 | −0.63 (1.16)[b] | 0 |
| One-third radius BMD (L) | 0.68 (0.05) | 0.70 (0.07) | 0.78 (0.05) | 0.79 (0.07) |
| One-third radius BMD (H) | 0.67 (0.05) | 0.69 (0.06) | 0.75 (0.06) | 0.82 (0.05) |
| Total body BMD (L) | 1.14 (0.06) | 1.12 (0.08) | 1.22 (0.08) | 1.21 (0.08) |
| Total body BMD (H) | 1.05 (0.08) | 1.10 (0.09) | 1.15 (0.11) | NA |
| Spine BMAD[c] | 0.13 (0.01) | | 0.12 (0.012) | |

(b) Subjects broken down into two age groups: 24–30 and 31–36 years

| | Women | | Men | |
|---|---|---|---|---|
| | 24–30 years | 31–36 years | 24–30 years | 31–36 years |
| N | 77 | 73 | 46 | 16 |
| Age (years) | 27 (2) | 34 (1) | 26 (2) | 34 (1) |
| Spine BMD (L)[a] | 1.18 (0.11) | 1.17 (0.12) | 1.18 (0.13) | 1.18 (0.16) |
| $T$ score | −0.20 (0.9) | −0.29 (1)[b] | −0.46 (1.13)[b] | −0.45 (1.31) |
| Spine BMD (H)[a] | 1.01 (0.10) | 1.00 (0.11) | 1.01 (0.12) | 1.01 (0.14) |
| $T$ score | −0.62 (0.93)[b] | −0.70 (1.03)[b] | −0.94 (1.12)[b] | −0.94 (1.3)[b] |
| Hip BMD (L) | 0.98 (0.10) | 0.96 (0.11) | 1.09 (0.14) | 1.03 (0.17) |
| $T$ score | −0.24 (0.86)[b] | −0.39 (0.91)[b] | −0.10 (1.10) | −0.49 (1.33) |
| Hip BMD (H) | 0.85 (0.10) | 0.84 (0.11) | 0.96 (0.14) | 0.91 (0.17) |
| $T$ score | −1.02 (0.83)[b] | −1.16 (0.90)[b] | −0.78 (1.09)[b] | −1.17 (1.33)[b] |
| One-third radius BMD (L) | 0.65 (0.04) | 0.66 (0.04) | 0.74 (0.05) | 0.73 (0.05) |
| One-third radius BMD (H) | 0.66 (0.05) | 0.67 (0.04) | 0.76 (0.06) | 0.75 (0.06) |
| Total body BMD (L) | 1.14 (0.06) | 1.14 (0.06) | 1.22 (0.07) | 1.21 (0.08) |
| Total body BMD (H) | 1.06 (0.08) | 1.05 (0.08) | 1.15 (0.10) | 1.15 (0.14) |

BMD expressed as if all subjects had their BMD measured either on the Hologic 4500A or the Lunar DPX-L densitometers using the cross-calibration formulas detailed in *Methods*.
[a] L stands for Lunar DPX-L derived numbers, and H indicates Hologic 4500W derived data.
[b] *T* score significantly different from zero, $p < 0.05$.
[c] BMAD estimated volumetric density $= BMC/area^{3/2}$.

BMAD data in our subjects and compared them with those found by Maquez et al.[36] (Table 2 [part a]). BMADs calculated in our healthy subjects were significantly lower than those reported in healthy white subjects ($p < 0.0001$ for both women and men). In Table 2 (part b), BMD is separated by the age groups 24–30 years and 31–36 years. Although BMD at the lumbar spine, forearm, and total body was almost identical in the two age groups, there was a trend for a lower BMD at the hip only in the older age group. However, none of the differences in BMD between the two age groups were significant.

*T Scores and Prevalence of Osteopenia/Osteoporosis*

Figures 1 and 2 display individual *T* scores at the lumbar spine and hip by gender and manufacturer plotted against age. In general, *T* scores were more likely to be negative than positive, as demonstrated by the regression line suggesting that peak BMD is indeed lower in healthy Lebanese subjects than their American counterparts. Comparing all of the subjects' *T* scores against zero

demonstrated that the mean *T* score was significantly lower at both the spine and the total hip in the study group overall ($p < 0.0001$; Table 2). When this was also evaluated by gender, the *T* score was again significantly less than zero in women at both skeletal sites, whether measured on the Lunar or the Hologic ($p < 0.03$). However, in men the *T* score was significantly less than zero at the lumbar spine on both densitometers, and at the hip only on the Hologic densitometer (Table 2 [part a]). The NHANES-derived total hip mean *T* score (SD) for female subjects was −0.8 (0.9), and for men the corresponding value was −0.7 (1.0), both being significantly less than zero.

The slope of the regression lines in Figures 1 and 2 was not significantly different from zero, demonstrating that there was no age-related bone loss in the group studied.

Using the WHO *T*-score-based definition of osteoporosis, the proportions of women with osteoporosis were 2% at the lumbar spine and 0% at the total hip (using the NHANES-derived *T* score), and for osteopenia the corresponding proportions were 26% and 38% at the total hip, respectively. A
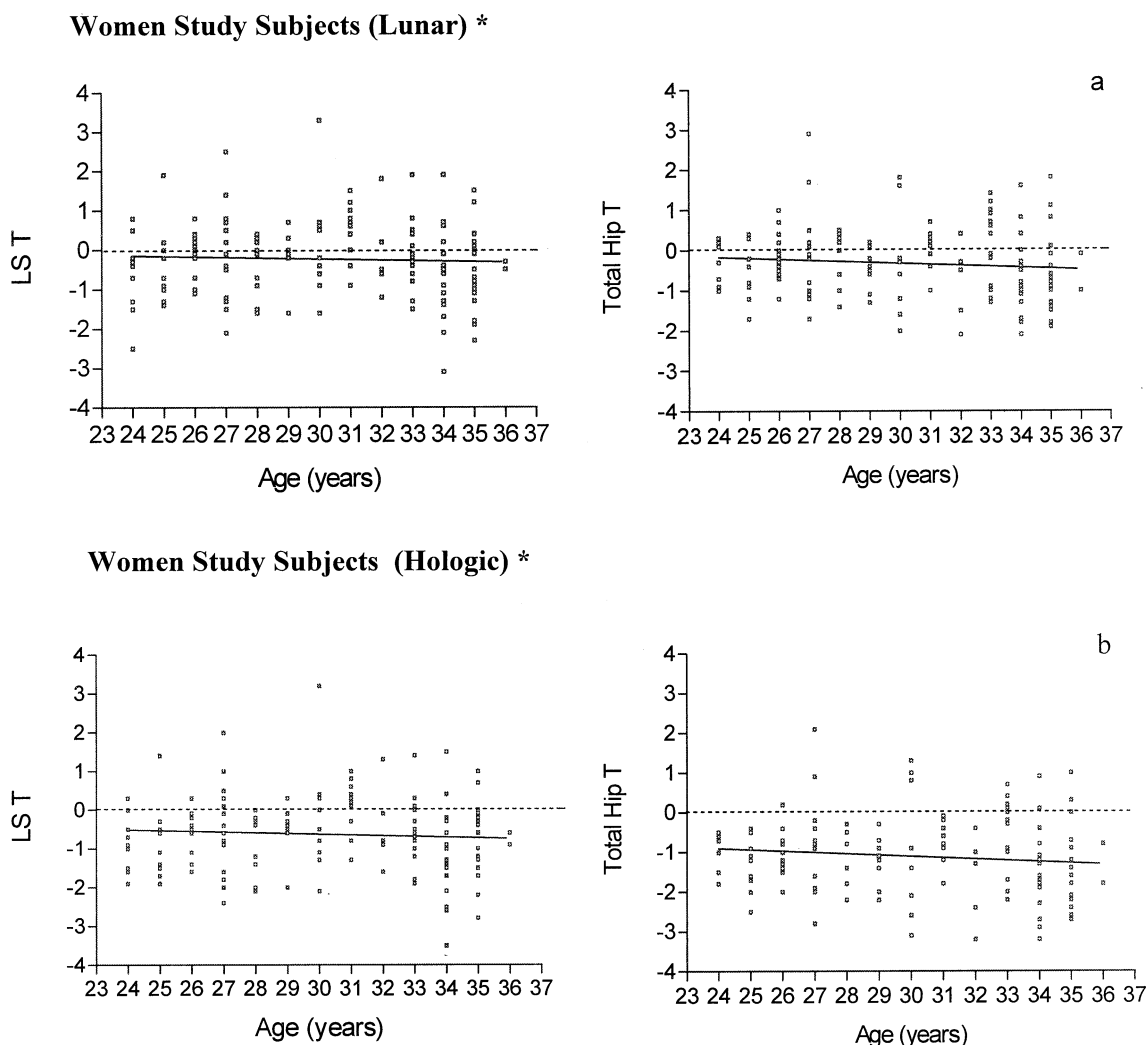
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## Women Study Subjects (Lunar) *



## Women Study Subjects (Hologic) *



**Figure 1.** Individual lumbar spine (LS) *T* scores and total hip *T* scores for women. The dotted line represents the regression around data points using the manufacturer database for *T*-score calculation, the slope of which does not differ from zero. Data obtained using the (a) Lunar and (b) Hologic densitometer. * A total of 150 women evaluated with *T* scores derived from conversion formulas as detailed in Methods.

similar analysis on men revealed that an even higher proportion suffered from both osteoporosis and osteopenia, with these numbers being 8% at the lumbar spine and 2% at the total hip for osteoporosis, and for osteopenia 41% and 33%, respectively.

### Correlates of BMD

For the overall group, the significant correlates of BMD were age, height, weight, BMI, total body fat, activity level, calcium intake, and caffeine consumption, depending on the skeletal site (**Table 3**). Smoking and alcohol intake were not significant predictors of BMD at any skeletal site.

Subgroup analysis by gender revealed that height, weight, BMI, total body fat, calcium intake, and caffeine consumption were all significantly correlated with BMD/BMC in women, with an $R = |0.2–0.6|$ depending on the variable and skeletal site. Reproductive variables were not significant predictors of BMD at any skeletal site in women. In men, height, weight, BMI, total

body fat, activity, and caffeine consumption were correlates of BMD/BMC, with an $R = |0.3–0.5|$.

### Adjusted Analyses for Correlates of BMD

The details of the regression model, with correlates of BMD, respective β estimates, partial $R^2$, and *p* values, are presented for the overall study group, and also broken down by gender in the Appendix. The most significant single correlate of BMD/BMC for the overall study group and for each gender was body weight, accounting for 7%–41% of BMD variance and 54% of BMC variance.

The significant correlates of BMD/BMC in the overall study group for each skeletal site were as follows:

- Lumbar spine: The significant predictors were weight, gender, and total body fat ($R^2 = 0.12$).
- Total hip: The significant predictors were weight and total body fat ($R^2 = 0.3$).
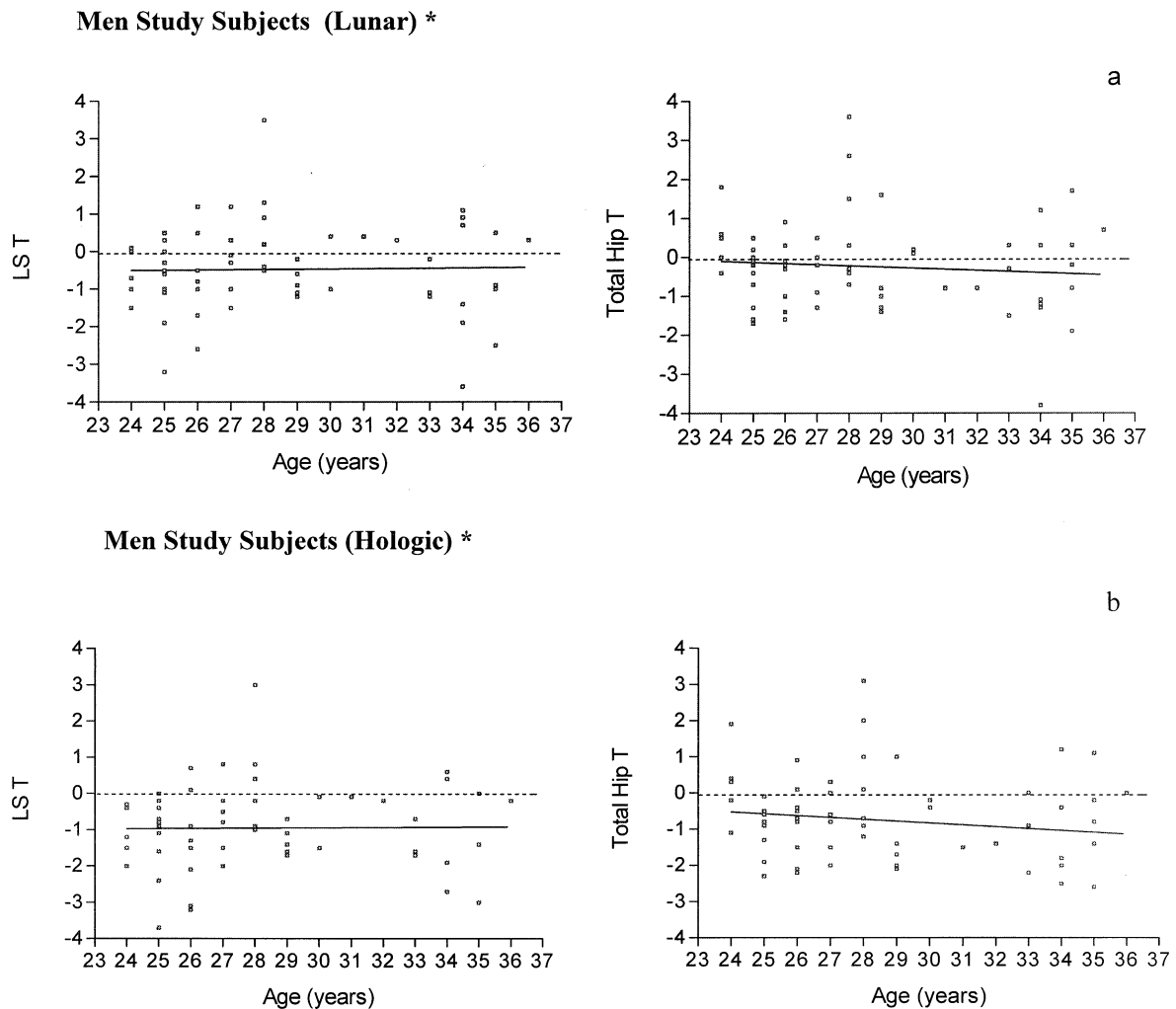- One-third radius: The significant predictors were gender and weight ($R^2 = 0.41$).

**Men Study Subjects  (Lunar) ***



**Men Study Subjects (Hologic) ***



**Figure 2.** Individual lumbar spine (LS) *T* scores and total hip *T* scores for men. The dotted line represents the regression around data points using the manufacturer database for *T*-score calculation, the slope of which does not differ from zero. Data obtained on the (a) Lunar and (b) Hologic densitometer. * A total of 63 men evaluated with *T* scores derived from conversion formulas as detailed in Methods.

- Total body BMD: The significant predictors were weight and total body fat ($R^2 = 0.36$).
- Total body BMC: The significant predictors were weight, total body fat, height, gender, and caffeine consumption (model $R^2 = 0.72$, $p < 0.001$; model without caffeine: $R^2 = 0.71$, $p < 0.03$).
- Although total body fat was directly correlated with BMD in the univariate analyses (Table 3), the relationship became negative in the regression model once body weight was entered, underscoring the technical impact of obesity on BMD measurement using dual-energy X-ray absorptiometry.

## Discussion

To our knowledge, the present investigation is the first population-based study characterizing peak bone mass in healthy subjects in the Middle East. It demonstrates that peak bone mass is 0.2–0.9 SD lower in Lebanese subjects compared with their American counterparts. The magnitude of the decrement was more accentuated when comparing our results with the Hologic normative database. Clinical characteristics, including, height, weight, total body fat, contributed to 30%–70% of the BMD/

BMC variance. Although lifestyle factors contributed significantly in the univariate analyses to BMD variance, their additional contribution to bone mass variance was extremely modest. The strengths of the study are that it was multicentered and based on a representative sample of the population, which was carefully screened and systematically excluded subjects with risk factors for bone loss. These important considerations were not fulfilled in any of the previous studies conducted in Lebanon or elsewhere in the Middle East.[8,10,20,35] Although the group studied represents greater Beirut (33% of the total population at large), we believe it is still a fair representation of the Lebanese population at large due to the migration from rural to urban areas in winter, during which the study was performed.

The first question that arises from our study is: What are some possible explanations for the slightly lower peak BMD observed in our study? In general, peak BMD may be low due to an inappropriate choice of age group for peak BMD determination, the age and characteristics of the normative database used, or the type of densitometer used.[15,32] These factors are, however, not relevant to our study. First, even though the age group studied was 25–35 years of age and peak BMD for both Lunar and

**Table 3.** Correlation matrix of bone mineral density (BMD) with its anthropometric and lifestyle correlates

|  | Age (years) | Height (m) | Weight (kg) | Body mass index (kg/m²) | Total body fat (gs) | Exercise (scale: 1–5) | Caffeine (scale: 1–5) | Ca intake (mg/day) |
|---|---|---|---|---|---|---|---|---|
| **L2–4 BMD** | | | | | | | | |
| $R$[a] | | 0.148 | 0.268 | 0.234 | 0.211 | | | |
| $P$[b] | | 0.032 | 0.000 | 0.001 | 0.002 | | | |
| **Total hip BMD** | | | | | | | | |
| $R$ | −0.171 | 0.351 | 0.520 | 0.431 | 0.237 | 0.157 | −0.176 | 0.171 |
| $P$ | 0.013 | 0.000 | 0.000 | 0.000 | 0.001 | 0.025 | 0.012 | 0.018 |
| **One-third radius BMD** | | | | | | | | |
| $R$ | | 0.546 | 0.478 | 0.257 | | 0.201 | | |
| $P$ | | 0.000 | 0.000 | 0.000 | | 0.004 | | |
| **Total body BMD** | | | | | | | | |
| $R$ | | 0.423 | 0.566 | 0.434 | 0.222 | 0.171 | | |
| $P$ | | 0.000 | 0.000 | 0.000 | 0.001 | 0.015 | | |
| **Total body BMC** | | | | | | | | |
| $R$ | | 0.706 | 0.743 | 0.483 | 0.233 | 0.196 | −0.173 | |
| $P$ | | 0.000 | 0.000 | 0.000 | 0.001 | 0.005 | 0.013 | |

[a]Correlation coefficient.
[b]$p$ value for significance.

Hologic densitometers is generally reached in the age range 20–29 years, the differences in BMD scores between the two age groups at 24–30 and >30 years were very small and not significant. Furthermore, the slope of the $T$-score regression line vs. age was not significantly different from zero. Second, peak BMD was lower in our study group regardless of the database used — that is, whether the densitometer or NHANES databases were used, and whether the results were expressed as if all subjects were measured on the Hologic or the Lunar densitomer (see *Methods*). However, detection of lower $T$ scores observed when the data were expressed using the Hologic-based BMD and database as compared with the Lunar is consistent with similar observations from studies done in the USA, which confirmed significant differences between the databases of the two densitometer makers worldwide.[15,32] Indeed, when we expressed our data as if all patients were measured on the Lunar densitometer, the mean spine BMD was very close, if not identical, to that of white patients, similar to what has been described in a recent study of Kuwaiti volunteers.[8]

In this work we have compared our results with those of another population-based study, NHANES. We recognize that, due to the selection of potentially healthier subjects in our study than in the NHANES study, the actual differences between the two populations may be even greater. The slightly lower peak BMD described herein is similar to what has been described in most studies from the region,[8,10,20,35] where BMD was found to be 0.3–0.8 SD below the densitometer reference database from the USA. These few studies were not population-based, however, and dealt with mostly female subjects. The low peak BMD in our study translated into a higher proportion of subjects with osteopenia and osteoporosis than would be expected for their young age, more so in male than female subjects.[26] Although lifestyle factors such as activity level, caffeine consumption, and calcium intake have been shown in our study to correlate significantly with BMD/BMC, their relative contribution was very modest, averaging around 15%, results consistent with previous observations worldwide and in this region.[16,22,24,37,42] This is not surprising in view of the cross-sectional nature of the data obtained and at a single timepoint that may not necessarily reflect long-term exposure. Anthropometric characteristics, such as weight, height, and total body fat, accounted for a significant proportion of variance in BMD, ranging between 27% and 30% for BMD and 70% for BMC. In our study, as in many others, the single most significant correlate of BMD/BMC was weight. We

have elected to use concomitantly several intercorrelated anthropometric measures of body size, such as height, weight, BMI, and body fat, as they were independent additional correlates of BMD in our study, as has been demonstrated previously in the large Rancho-Bernardo study of elderly men and women.[9] Our results are consistent with other observations in the literature,[9,31,41–43] suggesting that 60%–80% of BMD variance is genetically determined.[41,45] It is therefore possible that there is suboptimal representation/unequal segregation of bone anabolic genes[41,45] in the Lebanese population, and/or that a specific interaction between environmental and genetic variables may explain some of our findings. Data in support of this hypothesis have been put forth previously.[17,28]

One additional complexity in comparing BMD across ethnic background pertains to body size. Racial differences in body size will probably affect areal measures of BMD, but not volumetric BMD, similar to observations made for gender differences in BMD.[40,44] Indeed, in our study, height, a marker of body size, correlated significantly with BMD at all skeletal sites studied. In this case, Lebanese subjects are, on average, 4 cm shorter than their American counterparts and therefore would be expected to have a lower areal BMD, a difference that may not necessarily be reflected in volumetric BMD, and therefore possibly fracture risk. However, calculated BMAD was significantly lower in our study subjects than in published results of healthy white subjects,[36] ruling out body size as the sole reason for the lower areal BMD in the young Lebanese subjects.

The second question is: What is the normative database that should be used to report BMD in Lebanese subjects? We do not believe that the normative peak BMD database presented should be used for calculations of Lebanese-based $T$ scores to estimate fracture risk in elderly subjects, at least not yet. Indeed, the WHO study group definition of osteoporosis was based on the fact that, within the same population (i.e., in white women in the USA), the prevalence of osteoporosis, as defined by a $T$ score of $<-2.5$, corresponds to that defined by fracture prevalence.[6,26] Prospective data comparing BMD and fractures in the elderly in Lebanon are unavailable to date. Furthermore, there is no evidence to date that fracture risk relates to population-based $T$ score to a greater extent than it does to a numerical BMD value, within the same racial group (i.e., whites), as is the case in the Lebanese population. Indeed, preliminary studies conducted on hip fracture subjects at the American University of Beirut have

**Appendix.** Stepwise linear regression model and its estimates

| | β estimate | $R^{2a}$ | p value |
|---|---|---|---|
| **Overall: women + men (N = 213)** | | | |
| Lumbar spine BMD | | | |
| Weight | 6.7E-03 | 0.07 | 0.000 |
| Gender | 0.13 | 0.10 | 0.001 |
| TB fat | −5.6E-06 | 0.12 | 0.015 |
| Total hip BMD | | | |
| Weight | 6.0E-03 | 0.27 | 0.000 |
| TB fat | −3.5E-06 | 0.30 | 0.007 |
| One-third radius BMD | | | |
| Gender | −6.9E-02 | 0.39 | 0.000 |
| Weight | 7.1E-04 | 0.41 | 0.007 |
| Total body BMD | | | |
| Weight | 4.0E-03 | 0.31 | 0.000 |
| TB fat | −2.8E-06 | 0.36 | 0.000 |
| Total body BMC | | | |
| Weight | 35 | 0.54 | 0.000 |
| TB fat | −2.9E-02 | 0.69 | 0.000 |
| Height | 11 | 0.7 | 0.002 |
| Gender | 191 | 0.71 | 0.022 |
| Caffeine intake | −23 | 0.72 | 0.03 |
| **Women (N = 150)** | | | |
| Lumbar spine BMD | | | |
| Height | 4.2E-03 | 0.06 | 0.018 |
| Weight | 1.8E-03 | 0.08 | 0.034 |
| Total hip BMD | | | |
| Weight | 3.9E-03 | 0.20 | 0.000 |
| One-third radius BMDb | | | |
| Total body BMD | | | |
| Weight | 2.0E-03 | 0.15 | 0.000 |
| **Men (N = 63)** | | | |
| Lumbar spine BMD | | | |
| Weight | 8.6E-03 | 0.21 | 0.000 |
| TB fat | −7.7E-06 | 0.26 | 0.043 |
| Total hip BMD | | | |
| BMI | 3.8E-02 | 0.16 | 0.000 |
| TB fat | −1.5E-05 | 0.33 | 0.000 |
| One-third radius BMD | | | |
| Weight | 2.0E-03 | 0.07 | 0.035 |
| Total body BMD | | | |
| BMI | 2.5E-02 | 0.25 | 0.000 |
| TB fat | −9.1E-06 | 0.44 | 0.000 |

KEY: BMD, bone mineral density; TB, total body.
[a]Cumulative $R^2$ in each row shown as additional significant variables are added to the model.
[b]No significant correlates of one-third radius BMD in women.

suggested that the mean hip BMD in Lebanese patients with hip fractures is almost identical to that of American patients with hip fractures.[11,21,30]

In summary, our study provides the first evidence from a population-based sample in the Middle East that peak BMD is slightly lower than that of young American subjects, even after adjusting for body size. Whether the lower peak BMD in our population translates into a greater risk of osteoporotic fractures remains to be determined.

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