Peak bone mass and bone mineral density correlates for 9 to 24 year-old Mexican women, using corrected BMD

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Torres-Mejía G, Guzmán-Pineda R, Téllez-Rojo MM, Lazcano-Ponce E.
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Salud Publica Mex 2009;51 suppl 1:S84-S92.

Abstract

Objective. To determine the age of peak bone mass (PBM) in Mexican women and factors associated with both BMDa and corrected BMD (BMDcorr) at the femoral neck and the spine (L2-L4). **Material and Methods.** Data on 461 women between 9 and 24 years old was used. An interview was performed and height and weight were measured. BMDa was measured by a densitometer and BMDcorr by the method proposed by Kröger *et al*. (1992). **Results.** PBM at the spine (L2-L4) was observed later than at the femoral neck. Both BMDa and BMDcorr at the lumbar spine correlate with age, socio-economic status, body fat percentage and height. BMDa at the femoral neck correlates with overweight and obesity, body fat percentage, height and moderate physical activity; the same variables were associated with BMDcorr except for height. **Conclusions.** The method proposed by Kröger *et al*. was more precise at the femoral neck than at the spine.

Key words: corrected bone mineral density; peak bone mass; Mexican women

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Pico mineral óseo y factores asociados a la densidad mineral ósea en mujeres mexicanas de 9 a 24 años de edad usando densidad mineral ósea corregida.
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Resumen

Objetivo. Determinar la edad del pico de masa ósea (PMO) y los factores asociados a DMOa y a DMOcorr del cuello femoral y de la columna vertebral (L2-L4) en mujeres mexicanas. **Material y métodos.** Se utilizaron datos de 461 mujeres de 9 a 24 años de edad. La DMO se midió mediante un densitómetro y la DMOcorr mediante el método propuesto por Kröger *et al*. (1992). **Resultados.** El PMO en la columna vertebral (L2-L4) se observó más tarde que en el cuello femoral. A la DMOa y DMOcorr de la columna se asociaron: edad, estado socio económico, porcentaje de grasa corporal y la talla. A DMOa del cuello femoral se asociaron: sobrepeso y obesidad, porcentaje de grasa corporal, talla y actividad física moderada; las mismas variables se asociaron con la DMOcorr excepto talla. **Conclusiones.** El método propuesto por Kröger *et al*. fue más preciso para el cuello femoral que para la columna.

Palabras clave: densidad mineral ósea corregida; pico mineral óseo; mujeres mexicanas

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Received on: October 10, 2008 • **Accepted on:** December 11, 2008
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It has been reported that the prevalence of osteoporosis in Mexican postmenopausal women over the age of 50 is 20%, and as in other countries, this prevalence is higher for women than for men.[1-3] It has been suggested that the prevention of this illness might begin in early childhood due to the fact that, according to some authors,[4-5] the maximum mineralization of bone tissue –peak bone mass (PBM)– occurs between the ages of 18 and 30. In addition, it has been suggested that approximately 45% of bone mass is established during adolescence.[6,7] These observations have led several authors to assess correlates of bone mass in adolescents. Some characteristics that have been studied are age, gender, height, body mass index (BMI), calcium consumption, and physical activity, among others.[8-12]

For most of the studies, the measurement of bone mass has been done in terms of areal bone mineral density (BMDa), however this measurement is confounded by the size of the bone. BMDa is defined as the bone mineral content (BMC) in grams per bone mass measured in square centimeters (g/cm^2). This measurement has been widely criticized by several authors because it only permits the approximate estimation of bone resistance. Since this measurement does not take into consideration the anteroposterior diameter of the bone, and is therefore influenced by size, it shows a higher density effect for larger bones than for smaller ones.[13]

Volumetric bone mineral density (BMDv) has been proposed as a more specific measurement of bone resistance due to the fact that it takes size into consideration. BMDv is defined as BMC in grams per bone volume in cubic centimeters (g/cm^3). This measurement may be precisely obtained by means of peripheral quantitative computed tomography, and in a less precise way, by certain densitometers that use dual energy x-ray absorption (DEXA “Dual energy x-ray absorptiometry”).

Due to the fact that some densitometers only measure BMDa, Kröger, *et al*. (1992)[14] proposed a technique to estimate the measurement of BMDv based on results obtained from the DEXA densitometer. BMDcorr is defined as BMC in grams per bone volume in cubic centimeters. The formula used by Kröger, *et al*.[14] is based on the assumption that both the femoral neck and vertebral body have a cylindrical form. Therefore, volume is obtained by using the cylinder volume formula. This method has been validated using magnetic resonance imaging[15] and by measuring the amount of water displaced by bones from animals that were sacrificed.[16]

The objective of this study was to assess the average age at which PBM was reached and the correlates associated with BMDa and BMDcorr at the femoral neck and lumbar spine (L2-L4) using the method proposed by Kröger, *et al*.[14]

Methods

Study population

The information that was used for this work has been previously described.[17] For the present study, 9 to 24-year-old women who participated in the PBM study and whose densitometries were recovered were included.

To summarize, the information was provided by a cross-sectional study that was performed on 461 Mexican women who were randomly selected from different age strata in 1999. The participants were students from elementary, junior high, high school and college levels. The study included clinically healthy women between 9 to 24 years of age who were born in the state of Morelos, who signed a consent form to participate in the study, and in the case of minors, those whose parents signed a consent form. The study was approved by the National Institute of Public Health IRB.

Women who reported previous fractures and chronic degenerative illnesses were excluded from the study. The population for the study was essentially urban (based on governmental statistics). Socio-economic status (SES) was generated using principal components analysis.

All women were interviewed. The questionnaire included socio-demographic characteristics and gynecological history (e.g. age at menarche, age at menopause), frequency of food consumption[18] (e.g. calories/24 hrs, vitamin D, calcium, dairy products and tortillas), and time spent doing physical activity, watching TV and sleeping.[19] Height and weight were measured using a stadimeter and a floor scale; women were dressed in light clothes and did not wear shoes.

A certified technician measured BMDa at the femoral neck and the lumbar spine (L2 to L4) using a DEXA Hologic type series A densitometer. Finally, for this particular study, BMDcorr at the femoral neck and spine (L2-L4) was estimated using the method proposed by Kröger *et al*.[14]

BMDcorr measurements

In order to calculate BMDcorr, volumes at the femoral neck and vertebral bodies were estimated using the method proposed by Kröger, *et al*.[14] From the images obtained by the densitometer, height (h^*) and width (b^*) of each vertebra (L2, L3, L4) and femoral neck were measured using a digitalized vernier (Mitutoyo). To calculate real height (h) and width (b), a scale factor was obtained using the area (A) obtained by the densitometer, as follows:

$A = (\alpha\, b^*)\,(\alpha\, h^*)$
$A = \alpha^2\,(b^*\, h^*)$
$\alpha = \sqrt{A/(b^*\, h^*)}$

Where: *A*= real coronal area at the vertebra or femoral neck

α= constant
b^*= width of the vertebra measured with a vernier
h^*= height of the vertebra measured with a vernier

Then, to obtain the real width (*b*) and height (*h*), b^* and h^* were multiplied by the constant *a*:

$b = \alpha b^*$
$h = \alpha h^*$

Subsequently, the cylinder volume formula was applied to obtain the volume as follows:

Femoral Neck

Volume= $\pi\, x\, (A^2 / 4h)$
Where *A*= real coronal area at the femoral neck
h= real height at the neck
The BMDcorr at the femoral neck was measured as follows:
BMDcorr= BMC/volume

Vertebral bodies

Volume= $\pi\, (b/2)^2\, (A/b)$
Where *b*= width for each of the vertebra
A= coronal area of each vertebra
The BMDcorr from each vertebra was measured as follows:
BMDcorr= BMC/volume

Once the volume for each vertebra was calculated, we proceeded to calculate the BMDcorr from the lumbar column (L2 , L3 and L4) as follows:

$$\text{BMDcorr (mg/cm}^3) = \frac{(\text{BMC}_{L2} + \text{BMC}_{L3} + \text{BMC}_{L4}) \times 1000}{\text{Volume}_{L2} + \text{Volume}_{L3} + \text{Volume}_{L4}}$$

Lean body mass and body fat mass (%) were obtained from the densitometer.

Calculation of the body mass index

Body mass index is defined as the weight in kilograms (kg) divided by the square of the height in meters (m^2), which is expressed in kg/m^2. For women between 9 to 17 years of age, weight status was defined, according to CDC and WHO recommendations, by using age- and gender-specific BMI percentiles from the revised 2000 Center for Health Statistics growth charts for the United States.[20] For women 18 and over, a BMI of 25 for overweight and 30 for obesity were used. Women under 18 years were classified into three categories according to their BMI, based on percentiles: adequate weight (<85), overweight (≥85, <95) and obesity (≥95).

Statistical analyses

Initially, the study population was described. To determine the age at which PBM was reached, spine and femoral neck BMDa and BMDcorr were estimated by using two-year strata. Multiple lineal regressions were used to estimate the association between all characteristics and BMDa and BMDcorr. In addition, generalized additive models were used in order to graphically observe the association between continuous predictors and the outcomes.[21] The statistical analysis was done with the use of STATA statistical packages version 10.

The intraclass correlation coefficient was used to assess intra- and inter-observer reliability.

Results

Reliability

The reliability study was performed for 138 measurements obtained at the femoral neck and at each vertebra. The intraclass correlation for the femoral neck height was 0.90 (CI 95% 0.86-0.95) and was 0.80 (CI 95% 0.72-0.89) for the base. The intraclass correlation for the height of each vertebra (L2-L4) varied from 0.73 (CI 95% 0.62-0.84) for L4 to 0.95 (CI 95% 0.93-0.97) for L3. The intraclass correlation corresponding to the base varied from 0.70 (CI 95% 0.58-0.82) for L2 to 0.94 (CI 95% 0.92-0.97) for L4.

Study population characteristics

Out of 461 women, 21 were excluded from the analysis due to the fact that they had no menarche, and 41 were excluded because information from the questionnaire on food frequency was not complete. Finally, data on 399 women were analyzed. The mean age was 19.6 years (range 10.2 to 25.9 years). The majority of women belonged to middle SES (65.7%). The mean age at menarche was 12 years (range 9 to 15 years). It was observed that 79% of women had normal weight at the time the study was performed, 17.3% were overweight and 3.3% were obese. The mean intake of calcium was 507 mg/day, the mean time performing moderate physical activity was 0.6 hrs/day and vigorous activity was 0.5

hrs/day. Women reported watching TV a mean of 3 hours/day and sleeping 8.6 hours/day. Results for only 175 women were obtained for calcium and vitamin D.

BMDa, BMDcorr and BMC at the spine and femoral neck had a normal distribution. The mean BMDa at the spine was 0.954 g/cm^2, while for BMDcorr it was 0.283 g/cm^3. The mean values at the femoral neck were 0.826 g/cm^2 and 0.348 gr/cm^3 for BMDa and BMDcorr, respectively.

PBM was reached at 18 years of age at the femoral neck and at 25 years at the spine. The same results were observed for BMDa and BMDcorr.

Univariate analysis

Spine

Regarding the correlates of BMDa at the spine, the associated variables observed were: age (R^2= 0.27), years post menarche (R^2= 0.24), weight (R^2=.33), BMI (R^2= 0.22), height (R^2= 0.12), body fat percentage ($R^{2=}$ 0.13) and lean body mass percentage (R^2= 0.13). The results were similar for the BMDcorr except for height, where R^2 was 0.002. In both analyses, age at menarche was positively associated (*p*= 0.005; p= 0.004, respectively). Calcium consumption was inversely associated with both BMDa and BMDcorr, although the association was borderline for BMDa (*p*= 0.06) and statistically significant for BMDcorr (*p*= 0.04). Likewise, there was a negative association between calorie consumption and both densities (*p*= 0.007; *p*= 0.006, respectively). Regarding physical activity, there was no statistically significant association.

Femoral neck

Age was positively associated with BMDa and BMDcorr at the femoral neck. In both analyses, the association was statistically significant (*p*<0.001), however the strength of the association was negligible (R^2= 0.07). Age at menarche and diet were not statistically significantly associated with either density. Regarding height, it was statistically significantly associated with BMDa (*p*<0.001), however with BMDcorr there was no association (*p*= 0.734). Regarding body composition, there was a positive and statistically significant association between total body fat percentage and both densities (*p*<0.001; *p*<0.001, respectively). In contrast, there was a negative association between lean mass percentage and both densities (*p*<0.001; *p*<0.001, respectively). Finally, total physical activity was positively associated with BMDa and BMDcorr (*p*= 0.04; *p*= 0.03) and moderate physical activity was only associated with BMDcorr (*p*= 0.081).

Multivariate analysis

Results for the multiple lineal regression analyses are shown in Table I

Characteristics associated with BMDa and BMDcorr at the spine (L2-L4)

There was a positive association between BMDa and age (β=12.7 mg/cm^2; CI 95% 9.9, 15.4 mg/cm^2), body fat percentage (β= 6.9 mg/cm^2; CI 95% 4.7, 15.4 mg/cm^2) and height (β= 5.7% mg/cm^2; CI 95% 4.1, 7.2 mg/cm^2). Weight status (normal/overweight and obesity) was not associated with BMDa and, therefore, it was not included in the model. The model was adjusted for calories and SES; all variables explained 42% of the variability (Table I) (Figure 1). A similar figure was observed for BMDcorr (Table I) (Figure 2).

Characteristics associated with BMDa and BMDcorr at the femoral neck

There was a positive association between BMDa and age (β= 5.0 mg/cm^2; CI 95% 2.1, 7.9 mg/cm^2), weight status (β= 52 mg/cm^2; CI 95% 19.9, 84.2 mg/cm^2), height (β= 3.9 mg/cm^2; CI 95% 2.2, 5.6 mg/cm^2), and body fat percentage (β= 5.8 mg/cm^2; CI 95% 2.8, 8.7 mg/cm^2). Moderate physical activity was not statistically significantly associated with BMDa (β= 35.2 mg/cm^2; CI 95% -2.3, 72.7 mg/cm^2). The model was adjusted for calories and all variables explained 26% of the variability (Table 1) (Figure 3). A similar figure was observed for BMDcorr, and height was not included in the model (Table 1) (Figure 4).

Discussion

In the present study, it was observed that PBM for the spine (L2-L4) was reached between 24 and 25 years, while for the femoral neck the peak was reached at a lower age (between 18 and 19 years). Similar results have been observed before.[5]

It has been reported that the association between age and BMD begins in puberty[22,23] due to an increase of growth hormones and sex steroid blood levels which have a positive effect on bone mineralization.[24] In the present study, PBM was reached at the same age whether using BMDa or BMDcorr. This suggests that BMD is not associated with the size of the bones as other studies have suggested.[4,5,14,16,22,23]

The correction proposed by Kroger *et al*. was more precise for the femoral neck than for the spine, probably due to the femoral neck being more similar to a cylinder

Table I

CORRELATES FOR BMDA* AND BMDCORR‡ FROM THE SPINE (L2-L4) AND FEMORAL NECK FOR 9 TO 24 YEAR OLD MEXICAN WOMEN, MORELOS, 1999

	Bone mineral density from the spine (L2-L4)§					
	*BMDa**			*BMDcorr‡*		
	_ Coefficient	*95% confidence interval*	*p value*	*_ Coefficient*	*95% confidence interval*	*p value*
Sociodemographic characteristics						
Age in years	12.7	9.9 - 15.4	<0.001	4	3.1 - 4.8	<0.001
Corporal composition						
Body fat (%)	6.9	4.7 - 9.2	<0.001	2.1	1.4 - 2.8	<0.001
Anthropometric measurements						
Height (cm)	5.7	4.1 - 7.3	<0.001	0.5	0.02 - 0.99	0.042
Diet						
Calories (day)	-0.01	-0.03 - 0.001	0.069	-0.004	-0.01 - 0.0002	0.041
Constant	966.7	946.1 - 987.2		287.8	281.7 - 293.8	
R2	0.42			0.38		
	Bone mineral density from the femoral neck#					
Sociodemographic characteristics						
Age in years	5.0	2.1 - 7.9	0.001	3.1	1.6 - 4.6	<0.001
Anthropometric measurements						
BMI adjusted by age and sex						
Normal (percentile <85)	0			0		
Overweight and obesity (percentile ≥85)	52.0	19.9 - 84.2	0.002	19.7	2.7 - 36.6	0.023
Height (cm)	3.9	2.2 - 5.6	<0.001	-	- -	-
Corporal composition						
Body fat (%)	5.8	2.8 - 8.7	<0.001	2.2	0.7 - 3.8	0.005
Physical activity						
Moderate activity (hrs/day)	35.2	-2.3 - 72.7	0.065	20.0	0.1 - 40.0	0.049
Diet						
Calories (kcal/day)	-0.002	-0.02 - 0.01	0.790	0.001	-0.01 - 0.01	0.803
Constant	743.4	692.1 - 794.6		311.0	284.0 - 338.1	
R2	0.26			0.16		

* BMDa= Bone mineral density area
‡ BMDcorr= Corrected bone minaral density
§ Model adjusted by all variables in the table and by socioeconomic status, n= 342
\# Model adjusted for all variables in the table, n= 337

than vertebrae. In the present study, the correlates of BMDa and BMDcorr at the spine were the same: age, body fat percentage, height, and calorie consumption. The effect of height decreased for BMDcorr, but did not disappear. In contrast, at the neck, height was only associated with BMDa and not with BMDcorr.

In this study, age at menarche was not included in the model due to the high correlation of this variable with age (r= 0.956, <0.00l). However, other studies have found a positive association.[5,14,16,25]

According to the hypotheses formulated by Glauber *et al*,[26] if the relationship between obesity and BMD is due to a mechanical effect of load, the effect of weight should be higher for bones which support a larger load (e.g. femoral neck). Our results are consistent with this hypothesis because weight status (normal/overweight and obesity) was associated with BMDa and BMDcorr at the femoral neck but not with bone density at the spine. Our results support those who have suggested that high BMI is associated with a decrease in femoral or

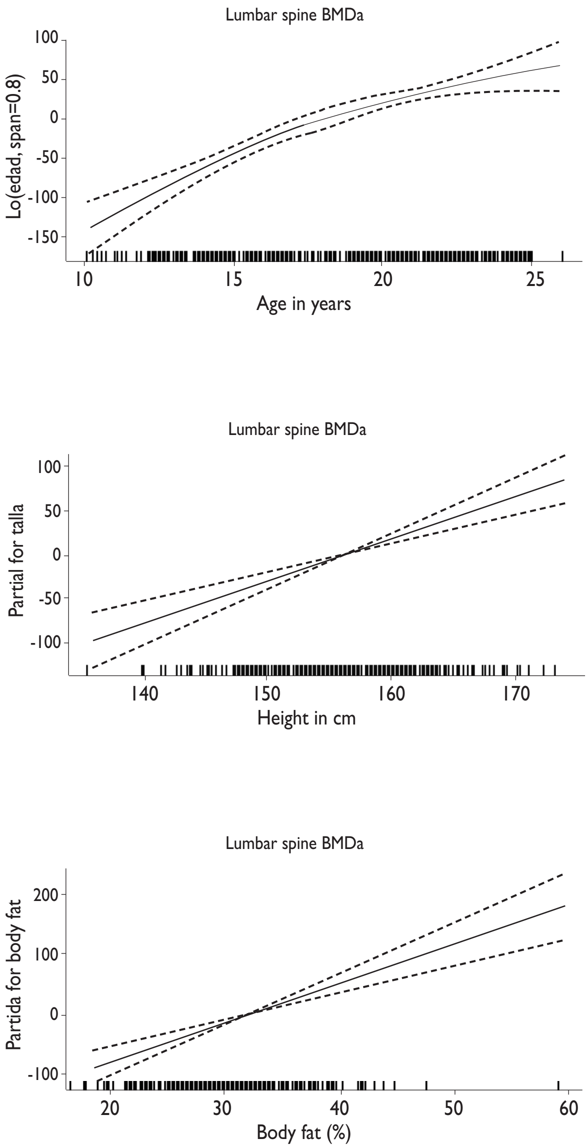

FIGURE 1. CORRELATES FOR BONE MINERAL DENSITY AREA (BMDA) AT THE SPINE (L2-L4) FOR MEXICAN WOMEN BETWEEN 9 TO 24 YEARS OLD

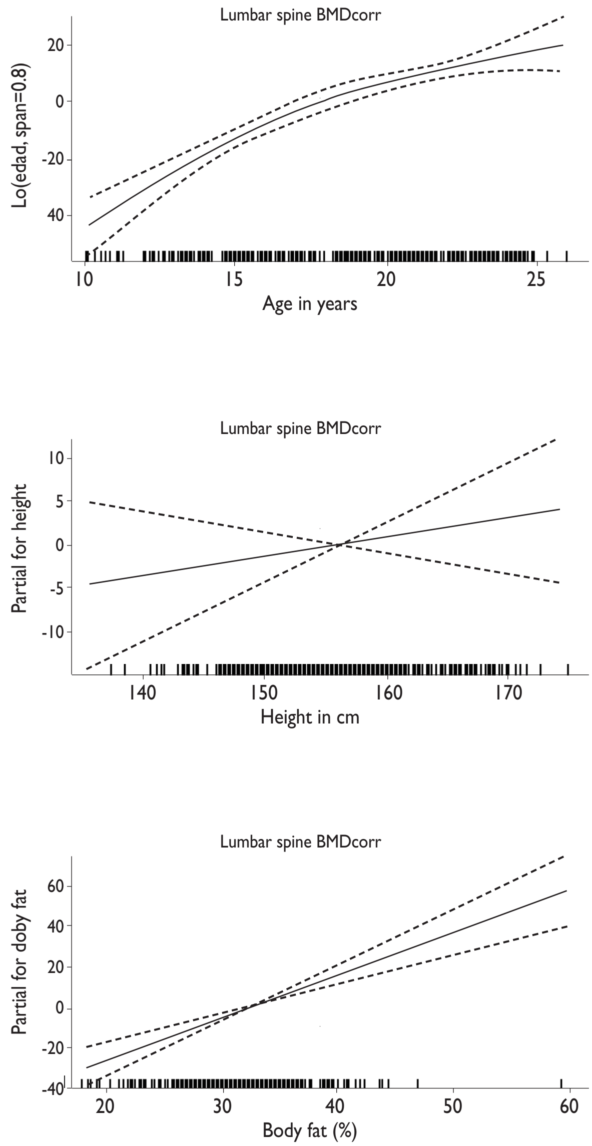

FIGURE 2. CORRELATES FOR CORRECTED BONE MINERAL DENSITY (BMDCORR) AT THE SPINE (L2-L4) FOR MEXICAN WOMEN BETWEEN 9 TO 24 YEARS OLD

lumbar spine fractures due to osteoporosis.[13,27] Results from other studies are similar to what we found.[11,15]

Our results are consistent with those who have found a positive association between adiposity and BMDa.[28,29] If the effect of adipose tissue on BMD is due to metabolic and hormonal activity, the effect of body fat percentage should be a determinant of BMD for any bone. In our study, body fat percentage was associated with both BMDa and BMDcorr at the femoral neck and the spine. Lazcano *et al*. showed an inverse association between the percentage of fat and BMD at the spine; when analyzing these women, however, they used saturated models for their analyses.

Our results showed an inverse association between SES and BMDa and BMDcorr at the spine (data not shown). This is probably due to the fact that women

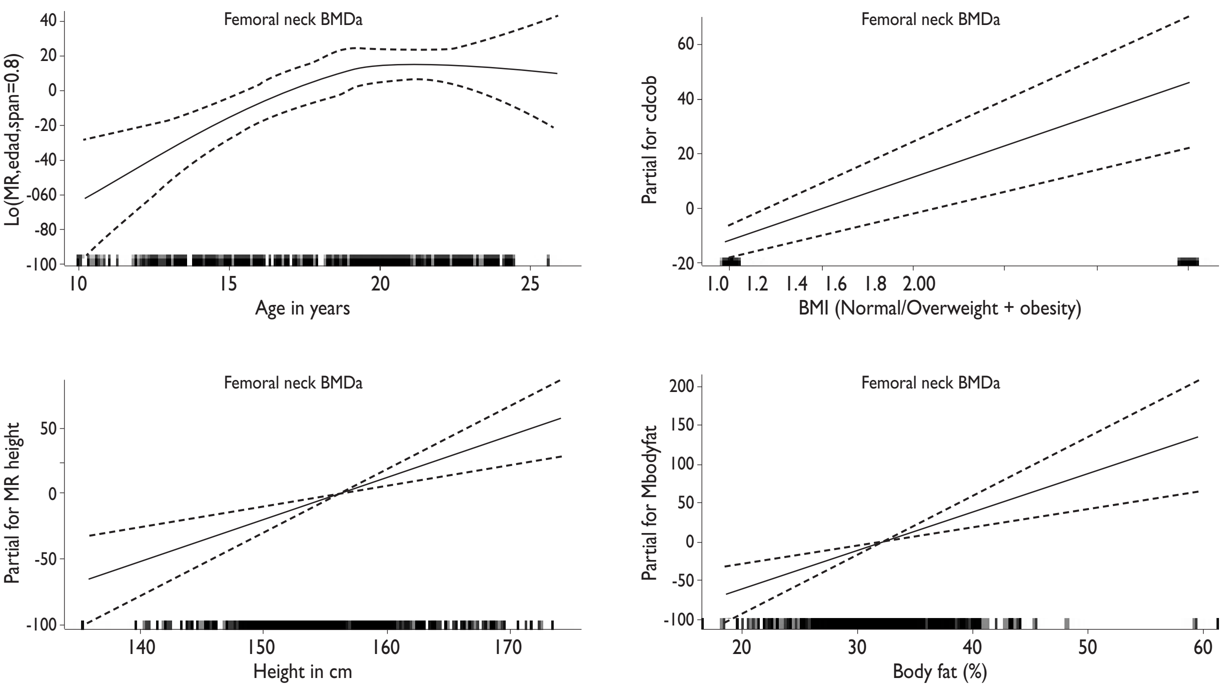

Figure 3. Correlates for bone mineral density area (BMDa) at the femoral neck for Mexican women between 9 to 24 years old

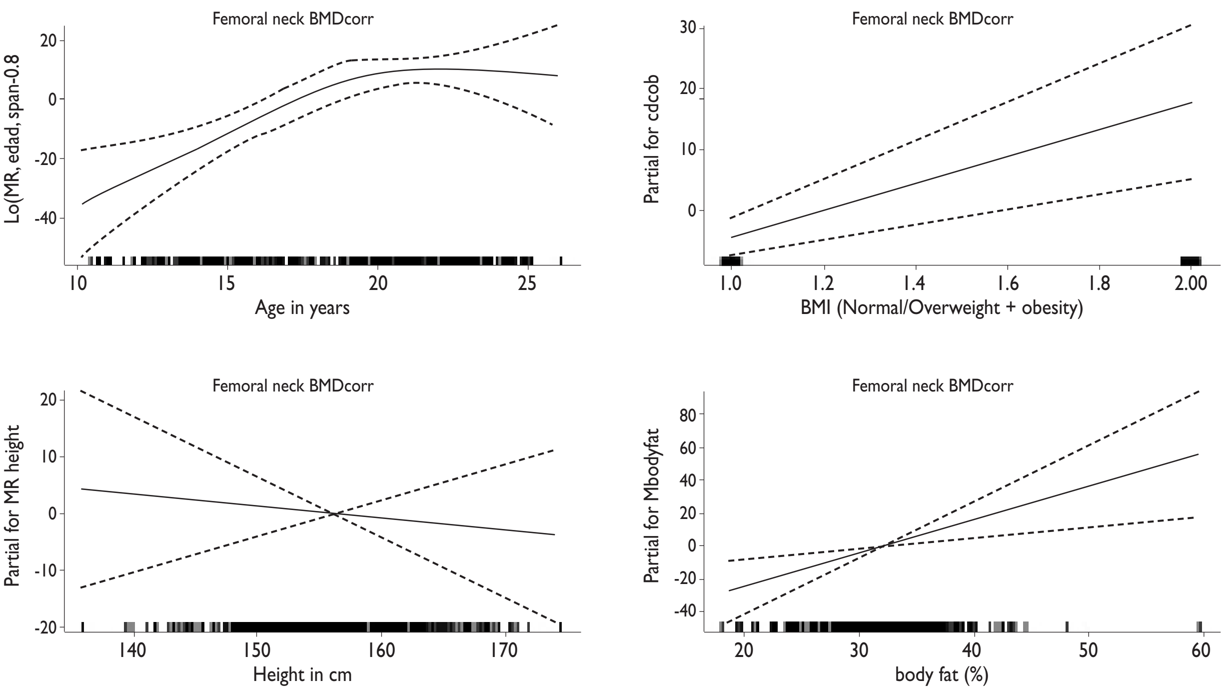

Figure 4. Correlates for the corrected bone mineral density (BMDcorr) at the femoral neck for Mexican women between 9 to 24 years old

with higher SES were thinner than those with lower SES. Some studies have shown that women with higher SES consume fewer calories and are thinner than women from a high socioeconomic level.[30] Furthermore, more fractures have been observed among slim women and those with a high socio-economic status.[2,3] SES was not associated with BMD at the femoral neck.

Moderate physical activity was positively associated with BMDa and BMDcorr at the femoral neck. Our results are consistent with intervention studies which have found that moderate physical activity increases both BMDa[31] and BMDcorr in elementary and junior high students.[32-34] Intense physical activity has also been positively associated with BMD,[32,33,35,36] however, it is well documented that for women who undertake intense physical activity with loss of weight (gymnasts, ballerinas) the association is negative due to osteopenia.[33]

In the present study, neither calcium consumption nor vitamin D consumption showed a statistically significant association with either BMDa or BMDcorr at the spine or the femoral neck. Our results are consistent with other studies,[4,5,14,16] although it is well known that an adequate consumption of calcium is necessary for bone growth and probably for reaching PBM at the appropriate time, thus reducing the risk of osteoporosis.[37]

This is the first study to report BMDcorr in Mexican women, though it was faced with the inherent limitations of cross-sectional studies.

Conclusions

In order to lower costs and lower the dose of radiation in developing countries with little resources, BMDcorr measured using the method proposed by Kroger *et al* (1992) is an acceptable option to correct for the size of the bone.

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