Osteoporos Int
DOI 10.1007/s00198-007-0459-0

ORIGINAL ARTICLE

Impact of maternal veiling during pregnancy and socioeconomic status on offspring's musculoskeletal health

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Received: 28 March 2007 / Accepted: 6 August 2007

Abstract
Summary The impact of maternal veiling during pregnancy and of socioeconomic status on offspring's bone mass was investigated in 326 healthy adolescents. Veiling during pregnancy was associated with decreased musculoskeletal parameters in the offspring boys, but not girls. SES was a significant predictor of bone mass in both genders.
Introduction This study investigates the effects of maternal veiling during pregnancy, a surrogate for low vitamin D level, and socioeconomic status (SES), a surrogate of nutritional status, on their offspring's bone mass at adolescence.
Methods Three hundred and twenty-six healthy adolescents aged 13.1(2.0) years and their mothers were studied. The impact of maternal veiling on offspring's bone mass was evaluated through regression analyses. Outcome variables were bone mineral density (BMD) and content (BMC) at the spine, hip, and total body of the children. Predictors were maternal veiling during pregnancy and SES. Covariates were height, body composition, Tanner staging, calcium intake, vitamin D and exercise in children.
Results In boys, adjusted analyses revealed that both maternal veiling during pregnancy and SES were significant predictors of bone mass, at multiple skeletal sites. In girls, SES but not maternal veiling during pregnancy was a significant predictor of bone mass at multiple sites.
Conclusion Maternal veiling during pregnancy was associated with decreased musculoskeletal parameters of boys, but not girls. SES was a significant predictor of bone mass in both genders. These findings may have profound implications on children's bone health.

Keywords Bone mass · Maternal veiling · Musculoskeletal · Offspring · Pregnancy · SES

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Introduction

Vitamin D is an important nutrient for bone metabolism [1, 2] and for optimal fetal calcium homeostasis and bone accretion. A growing body of evidence supports the importance of maternal nutrition and fetal hormonal milieu for neonatal and adult health, in general, and bone health, in particular, a phenomenon known as fetal programming [3, 4]. Morley et al. showed that maternal hypovitaminosis D in the third trimester of pregnancy was associated with reduced offspring's knee-heel length at birth [5]. Similarly, Javaid et al. demonstrated that maternal vitamin D insufficiency or deficiency in late pregnancy was associated with reduced whole body and spine bone mineral content (BMC) of their 9-year-old children [6].

Hypovitaminosis D in women of reproductive age is extremely common in Asia, in general, and Lebanon, in particular, especially in women whose culture dictates traditional concealment of clothes [7–13]. We hypothesized that maternal veiling; a surrogate of hypovitaminosis D, during pregnancy may negatively impact offspring's musculoskeletal health through fetal programming. Socioeconomic status (SES) reflects lifestyle and nutritional factors, variables known to affect maternal health in general and offspring's health, in particular. We therefore investigated the impact of maternal veiling during pregnancy and SES on children's musculoskeletal health during adolescence, a critical period for bone mineral accretion.

Methods

Subjects

Subjects were 326 healthy adolescents (170 boys and 156 girls) who had participated in vitamin D replacement clinical trial [14] and their 204 mothers. In the randomized trial, 363 healthy children and adolescents (184 boys and 179 girls) were recruited from four schools from the greater Beirut area, to ensure balanced representation geographically and socio-economically. The age group chosen was 10-17 years, a critical age for accretion of bone mass.

Subjects were included in the study if they were considered healthy, based on careful physical examination and absence of a history of any disorders or medications known to affect bone metabolism. At entry, all had normal serum, calcium, phosphorus and alkaline phosphatase levels for age. The study was approved by the institutional review board, and informed consent was obtained from all study subjects and their parents. Baseline data were used in the current analyses. The mean age of children was 13.1 (2.0) years. There were 53 siblings in this cohort: 27 boys and 26 girls.

Data collection

All children had a physical examination that included weight, height and Tanner stage assessment [14]. Pubertal status was determined by a physician (MN), using breast and pubic hair stages in girls, testicular and pubic hair stages in boys, according to the established criteria of Tanner [15]. In addition, age, calcium intake, exercise, and sun exposure were assessed through a questionnaire. Serum 25(OH)D was measured by a competitive protein binding assay using the Incstar Kit (Diasorin, Incstar, Sallugia, Italy) , with intra-and interassay CVs <13% at a serum concentration of 47 ng / ml. This assay measures both 25 OHD2 and 25 OHD3. The intra-assay CV% for measuring 25 OHD in our laboratory is 5% ±9, based on 124 specimens run as separate samples in the assay, with a mean 25 OHD level of 19±5 ng/ml.

Maternal veiling status during pregnancy and socio-economic status (SES) were assessed by questionnaire. The questionnaire was administered to mothers once during the study period. The following question was asked: "Are you veiled: yes or no and if yes for how long?" Information on veiling status during pregnancy was unavailable for the mothers of nine boys who were excluded from the analyses. The mean duration of veiling was 25±8 years. SES assessment was based on children's school fees, identified as high if the children's school fees exceeded US $5,000/year and as low if they were less than US $700/year. The proportion of children receiving full scholarship in the high SES schools was less than 10% (information provided by the school administrators). The minimal wage in Lebanon is US $3,600/year.

Areal bone mineral density (BMD), bone mineral content (BMC) at the lumbar spine (LS), femur (total hip and femoral neck), total body, lean mass and fat mass were measured with a Hologic 4500 A densitometer (Hologic, Bedford, MA; software version 11.2:3). Because inclusion of the head in the calculation of total body BMD may lower the predictive value of some parameters for this variable, subtotal body measurements excluding the head were used [16]. In our center, the mean ± SD precision of BMD and BMC measurements, expressed as CV, for 122 serial duplicate scans performed during the study duration varied between 0.8±0.7% and 1.40±1.1%, depending on the skeletal site.

Statistical analyses

The main outcome measure was children's bone mass expressed as BMC and BMD. The skeletal sites of interest are the spine and total body, accepted sites for skeletal assessment in children. Although the hip is usually not recommended in children due to the lack of good delineation of its corresponding ROI in the very young (5–10 years), the hip was evaluated in this study due to the age group studied (>10 years) and the fact that it is a site rich in cortical bone that would be affected by vitamin D. Because of the significant effect of lean mass on BMD and BMC, the tight relationship between vitamin D and lean mass (LM), and the concept of bone-muscle unit, regression models were also run with BMD/LM or BMC/LM as outcome measures [17]. Predictors of interest were maternal veiling status during pregnancy or SES [17]. The kappa coefficient between veiling during pregnancy and SES was 0.351 ($p<0.001$). The kappa coefficient between current veiling and SES was 0.673 ($p<0.001$). Analyses using current veiling were implemented and the results were essentially similar to those when using SES, both for boys and girls, as reported herein. We therefore report results using veiling during pregnancy and SES as independent predictors, but not current veiling. Covariates adjusted for were the child's pubertal stage, height, calcium intake, 25 hydroy-vitamin D level, exercise, fat mass and lean mass. Vitamin D was entered in the model as a covariate because it is a predictor of bone mass in children in general [2] and in our study population in girls in particular, r=0.14–0.24 (p=0.02) [14].

Parametric tests were used to compare BMD or BMC in the various subgroups of children, and untransformed variables. Two multivariate linear regression models were built with maternal veiling during pregnancy or SES as predictors, and bone mass as outcome, adjusting for the above covariates. The impact of each predictor on the outcome was evaluated through examination of the respective R^2 derived from their respective models. An additional stepwise model was built that included both veiling status and SES as predictors, allowing the model to choose the most powerful predictor. The presence of siblings was adjusted for using multi-level models, siblings were considered the clusters and individuals were nested within the sibling variable (STATA version 8.2, College Station, TX, USA). Mean values were expressed as mean (SD). Significance was set at the 5% level, unadjusted for multiple testing. Analyses were implemented separately for boys and girls. SPSS version 15 (SPSS, Chicago, Illinois, USA) and STATA version 8.2 (College Station, TX, USA) were used.

Results

We studied 170 boys and 156 girls, mean ages (SD) of 13.0 (2.0) and 13.2 (2.1) years, respectively. Twenty-seven girls (17.3%) were veiled at presentation, and they were all daughters of mothers who were veiled. There were correlations between 25 OHD and bone mass at several sites in girls, r=0.14–0.24, p<0.02, but not boys. There was no correlation between vitamin D and subtotal lean mass in boys (r=-0.061, p=0.427) nor in girls (r=0.025, p=0.748).

Effects of maternal veiling on boys' musculoskeletal health

Boys whose mothers were veiled during pregnancy tended to have lower BMC and BMD at several skeletal sites than boys of unveiled mothers. Differences in musculoskeletal parameters were significant at the LS BMC and BMD, total body and femoral neck BMD. However, these boys were also younger, had lower sun exposure, lower serum 25-OH vitamin D level, and belonged to the lower SES group, compared to boys of unveiled mothers (Table 1).

Maternal veiling during pregnancy was a significant predictor of child's BMD/LM at the spine, femoral neck and total body and of BMC/LM at the femoral neck; after adjusting for the child's pubertal stage, height, fat mass, calcium intake, vitamin D level and exercise. The proportion of variance in the outcome measure explained by maternal veiling ranged between 3% and 5%, depending on the skeletal site (Table 2, Model 1). Similarly, adjusted analyses revealed that maternal veiling during pregnancy was a predictor of BMD at the spine (p=0.04), femoral neck (p=0.031; Fig. 1a), and total body (p=0.06 Fig. 1b); and of femoral neck BMC (p=0.03).

Table 1 Baseline characteristics of sons by maternal veiling status

Variable	During pregnancy	
	Mother veiled (n=50)	Mother non-veiled (n=111)
No. of siblings	9	17
Early puberty/Late puberty	29/22	57/54
High SES / Low SES	2/49	56/55**
Age (years)	12.8 (1.7)	13.2 (2.0)*
Height (cm)	153.1 (12.6)	156.4 (13.6)
Weight (Kg)	50.1 (16.4)	53.5 (16.9)
Exercise (hr/week)	6.6 (6.2)	8.3 (7.0)
Calcium intake (mg/day)	739 (326)	802 (370)
Exposure to sun (min/week)	461 (259)	605 (348)*
Serum vitamin D (ng/ml)	14.9 (4.5)	17.5 (7.4)*
LS BMC (gm)	34.7 (10.3)	37.6 (13.4)*
LS BMD (g/cm^2)	0.673 (0.12)	0.720 (0.15)*
Tot. Hip BMC (gm)	26.6 (8.7)	28.6 (10.1)
Tot. Hip BMD (g/cm^2)	0.821 (0.14)	0.858 (0.15)
FN BMC (gm)	3.6 (0.8)	3.9 (1.0)
FN BMD (g/cm^2)	0.754 (0.11)	0.797 (0.13)*
Subtotal body BMC (gm)	11.5 (4.0)	12.5 (4.8)
Subtotal body BMD (g/cm^2)	0.818 (0.10)	0.854 (0.12)*
Subtotal lean mass (kg)	34.3 (10.4)	35.8 (10.7)
Subtotal fat mass (kg)	10.9 (6.9)	12.3 (7.3)

Values are expressed as means (SD)

Overall P-value by T-test between sons of veiled and sons of non-veiled mothers

**P* value ≤ 0.05; ***P* value ≤ 0.001

Effects of SES on musculoskeletal health in boys

SES was a significant predictor of BMD/LM at the hip, femoral neck, trochanter, radius and total body; after adjusting for relevant covariates. The proportion of variance in BMD/LM explained by SES ranged between 3% and 9% depending on the skeletal site (Table 2, Model 2).

Similarly, SES was a predictor of BMD at the spine (p=0.002), hip (p=0.038), femoral neck (p=0.002; Fig. 1a), total body (p<0.001; Fig. 1b); and of BMC at the spine (p=0.02) and total body (p=0.004) in the adjusted analyses.

Effects of SES versus maternal veiling on musculoskeletal health in boys

When veiling during pregnancy and SES were both entered in the stepwise model, SES was more consistently chosen by the

Table 2 β estimates and partial R^2 for the regression models evaluating the effects of maternal veiling during pregnancy and socioeconomic status (SES) on bone mass measures in their sons

Skeletal site	Veiling during pregnancy Model 1		SES model 2	
	β	R^2	β	R^2
LS BMD/LM	$1.0\times10^{-6*}$	3%	1.1×10^{-6}	5%
Hip BMD/LM	1.1×10^{-6}	3%	$1.6\times10^{-6**}$	4.5%
FN BMC/LM	$5.1\times10^{-6*}$	3.5%	NS	NA
FN BMD/LM	$1.3\times10^{-6*}$	4%	$1.9\times10^{-6**}$	7.8%
TB BMC/LM	NS	NA	0.01*	2.7%
TB BMD/LM	$1.0\times10^{-6**}$	5%	$1.6\times10^{-6**}$	9%

*0.01 ≤ *P* value ≤ 0.05; **0.05 < *P* value ≤ 0.001

Models estimates adjusted for child's height, fat mass, Tanner stage, 25 hydroxyvitamin D, calcium intake and exercise level

model as a predictor for BMD/LM and for BMC/LM at several skeletal sites, in the adjusted analyses (data not shown).

The effect of maternal veiling during pregnancy and SES on BMD of boys at the femoral and total body BMD is shown in Fig. 1. The adjusted difference in femoral neck BMD between the two subgroups of boys by maternal veiling status and by SES, varied between 0.029 and .073 gm/cm^2 (Fig. 1a). Similarly, the adjusted difference in total body BMD between the two subgroups of boys by maternal veiling status and by SES varied between 0.019 and 0.073 gm/cm^2 (Fig. 1b).

To further dissect the impact of veiling on bone health, sub-group analyses were implemented in the group of boys of low SES, by maternal veiling status during pregnancy. Boys of veiled mothers showed a consistent trend for a lower bone mass, expressed either as BMC or BMD, at all skeletal sites, compared to boys of non-veiled mothers. The difference between the two sub-groups varied between 0.1–10.18 SD, depending on the skeletal site, but it did not, however, reach statistical significance. Similar analysis in boys of high SES was not done due to the small number of veiled mothers in this subgroup.

Post hoc calculations of power analyses were implemented using the change in R^2 obtained by adding SES or veiling to a model that already contained height, fat mass, Tanner stage, 25 hydroxyvitamin D, calcium intake and exercise level. The change in R^2 ranged between 0.01 and 0.02, at the various skeletal sites. Accordingly, with 161 boys, the power of the study to detect an impact of these predictors varied between 64% and 89%, assuming a 10% significance level.

Effects of maternal veiling on girls' musculoskeletal health

Girls of mothers who wore the veil during pregnancy tended to have lower BMD and BMC at several skeletal sites, as compared to girls of unveiled mothers. The differences were statistically significant for BMD at the radius and total body and for BMC at the spine and total body. However, these girls were also younger, shorter, more likely to be premenarcheal, exercised less, had lower sun exposure, lower vitamin D levels, and were of the lower SES group (Table 3).

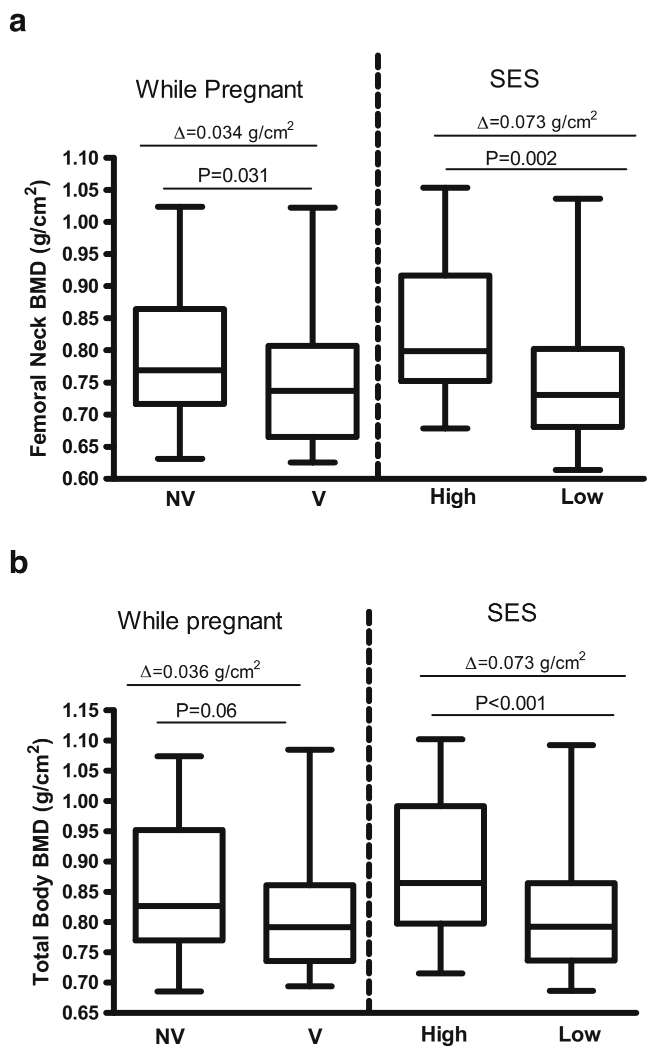

Fig. 1 Box plots showing femoral neck BMD (panel **a**) and a total body BMD (panel **b**) in boys by veiling status of their mothers during pregnancy, and by socio-economic status (SES). Veiling status: non-veiled (NV) or veiled (V). The box plots depict derived values from the model adjusted for child's height, Tanner stage, calcium intake, exercise level, lean mass, fat mass and 25 hydroxy-vitamin D levels. The *p* values are those of the β estimates derived from the model. The box plot shows the median BMD (50th percentile) as a line and the first (25th percentile) and third quartile (75th percentile) of the BMD distribution as the lower and upper parts of the box. The whiskers shown above and below the boxes represent the largest and smallest observed BMD values that are less than 1.5 box lengths from the end of the box

Table 3 Baseline characteristics of daughters by maternal veiling status

Variable	During pregnancy	
	Mother veiled (n=35)	Mother non-veiled (n=121)
No. of siblings	5	21
Pre/Post menarcheal	12/33	22/99*
High SES/Low SES	4/31	71/50**
Age (year)	12.1 (1.6)	13.4 (2.1)**
Height (cm)	147.7 (8.4)	153.6 (10.2)**
Weight (Kg)	45.3 (12.8)	47.8 (11.5)
Exercise (hr/week)	2.0 (2.6)	4.4 (5.3)**
Calcium intake (mg/day)	718 (400)	674 (369)
Exposure to sun (min/week)	284 (279)	484 (327)**
Serum vitamin D (ng/ml)	9.1 (3.5)	15.5 (8.2)**
LS BMC (gm)	35.2 (10.1)	39.6 (12.2)*
LS BMD (g/cm^2)	0.740 (0.14)	0.792 (0.16)
Tot. Hip BMC (gm)	21.5 (5.5)	23.3 (5.6)
Tot. Hip BMD (g/cm^2)	0.746 (0.12)	0.789 (0.13)
FN BMC (gm)	3.1 (0.7)	3.3 (0.7)
FN BMD (g/cm^2)	0.686 (0.10)	0.726 (0.12)
Subtotal body BMC (gm)	10.1 (2.9)	11.6 (3.3)*
Subtotal body BMD (g/cm^2)	0.784 (0.08)	0.835 (0.09)*
Subtotal lean mass (kg)	28.4 (6.4)	30.1 (6.0)
Subtotal fat mass (kg)	12.3 (6.7)	13.0 (6.0)

Values are expressed as means (SD)
Overall P-value by T-test between daughters of veiled and those of non-veiled mothers
**P* value ≤ 0.05; ***P* value ≤ 0.001

In the adjusted analyses, there was no effect of maternal veiling during pregnancy on any of the musculoskeletal parameters of their daughters, expressed as BMD or BMC/LM (model 1, Table 4). However, maternal veiling was a predictor of BMD at the spine only (p=0.025). Entering the veiling status of the daughters (n=27 veiled girls) as a covariate in the regression model did not change the above mentioned findings (data not shown).

Effects of SES versus maternal veiling on girls' musculoskeletal health

SES was a significant predictor of BMD/LM at the spine, total hip, femoral neck, trochanter, radius, and total body; and of BMC/LM at the femoral neck and total body. SES accounted for 3–12% of the variance in the outcome measure, depending on the skeletal site (Table 4, Model 2). Similarly, SES was a predictor of BMD at the spine (p= 0.033), femoral neck (p<0.001; Fig. 2a), trochanter (p= 0.05), total body (p<0.001; Fig. 2b); and of BMC at the femoral neck (p=0.05) and total body (p=0.008) in the adjusted analyses.

Effects of SES versus maternal veiling on girls' musculoskeletal health

When both veiling during pregnancy and SES were entered in the adjusted model, SES was exclusively chosen by the model as the predictor for BMD/LM at the spine, hip, femoral neck, trochanter, radius and subtotal body. Similarly, SES was picked up by the model as the predictor for BMC/LM at the femoral neck, radius and sub-total body, in the adjusted analyses (data not shown).

The effect of maternal veiling during pregnancy and SES on BMD of girls at the femoral and total body is shown in Fig. 2. Girls of lower SES had a significantly lower femoral neck and total body BMD compared to girls of higher SES (Fig. 2a and b).

Post hoc calculations of power analyses were implemented using the change in R^2 obtained by adding SES or veiling to a model that already contained height, fat mass, Tanner stage, 25 hydroxyvitamin D, calcium intake and exercise level. The change in R^2 ranged between 0.005 and 0.01, at the various skeletal sites. Accordingly, with a total of 156 girls, the power of the study to detect an impact of these predictors varied between 40% and 63%, assuming a 10% significance level.

Discussion

Maternal veiling during pregnancy was associated with lower bone mass of mothers' adolescent sons but not daughters. Socio-economic status was a significant predictor of these parameters in both genders.

In view of the abundant literature from Lebanon and the region that confirmed low 25-OH vitamin D levels in veiled women [7–9], ranging between 5–15 ng/ml, we considered maternal veiling during pregnancy a good surrogate for low

Table 4 β estimates and partial R^2 for the two regression models evaluating the effect of maternal veiling during pregnancy and socioeconomic status (SES) on bone mass measures in their daughters

Skeletal site	Veiling during pregnancy model 1		SES model 2	
	β	R^2	β	R^2
LS BMD/LM	NS	NA	$1.5\times10^{-6*}$	4.5%
Hip BMD/LM	NS	NA	$1.4\times10^{-6*}$	4.0%
FN BMC/LM	NS	NA	$5.3\times10^{-6*}$	3%
FN BMD/LM	NS	NA	$2.0\times10^{-6**}$	9%
TB BMC/LM	NS	NA	0.02**	4.7%
TB BMD/LM	NS	NA	$1.6\times10^{-6**}$	11.8%

*0.01 ≤ *P* value ≤ 0.05; **0.05 <*P* value ≤ 0.001
Models estimates adjusted for child's height, fat mass, Tanner stage, 25 hydroxyvitamin D, calcium intake and exercise level

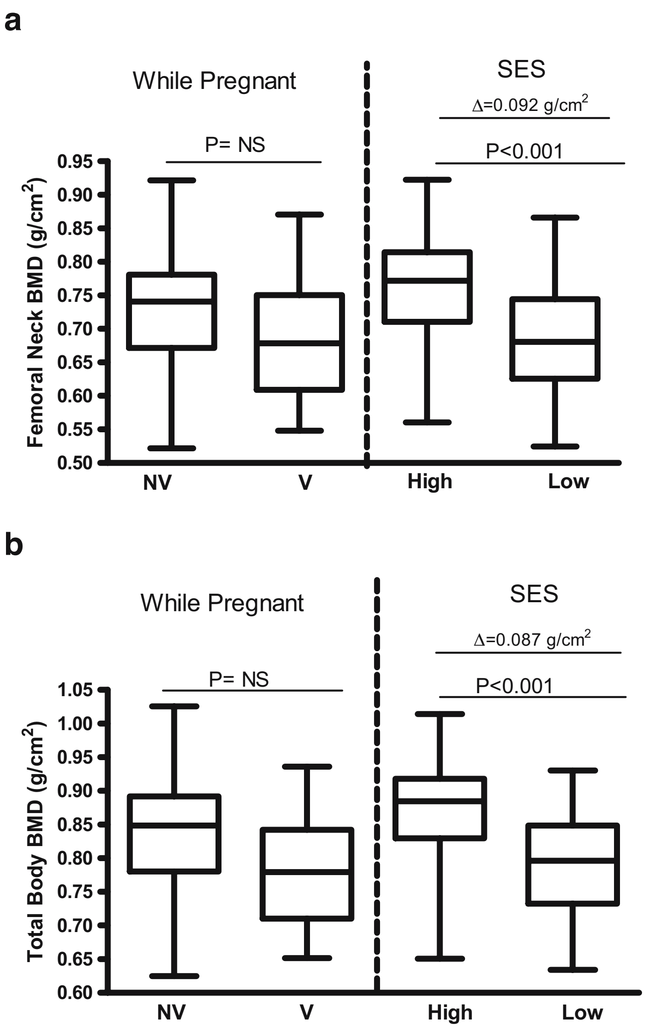

Fig. 2 Box plots showing femoral neck BMD (panel **a**) and a total body BMD (panel **b**) in girls by veiling status of their mothers during pregnancy, and by socio-economic status (SES). Veiling status: non-veiled (NV) or veiled (V). The box plots depict derived values from the model adjusted for child's height, Tanner stage, calcium intake, exercise level, lean mass, fat mass and 25 hydroxy-vitamin D levels. The *p* values are those of the β estimates derived from the model. The box plot shows the median BMD (50th percentile) as a line and the first (25th percentile) and third quartile (75th percentile) of the BMD distribution as the lower and upper parts of the box. The whiskers shown above and below the boxes represent the largest and smallest observed BMD values that are less than 1.5 box lengths from the end of the box

maternal vitamin D levels. In a population-based cohort study, Javaid et al. demonstrated that maternal hypovitaminosis D during the third term of pregnancy was associated with reduced bone mineral density in children at age 9 years [6]. Similarly, Morley, et al. showed that low maternal vitamin D during late pregnancy was associated with reduced intrauterine long bone growth, assessed by knee-heel length at birth [5]. The lowest parameters were observed in children of mothers with 25-hydroxyvitamin D levels <28 nmol/L (<11 ng/ml) [5, 6], levels well within the range noted in veiling women [7–9]. Maternal hypovitaminosis D during pregnancy may, therefore, alter fetal bone growth through fetal programming, with permanent long-term effects on offspring's musculoskeletal health [3, 4]. The lower bone mass at multiple skeletal sites in adolescent boys whose mothers veiled during pregnancy is consistent with the genetic programming theory hypothesized in the above studies. However, mothers who veiled during pregnancy were also veiled afterwards, and we, therefore, cannot rule out an effect of maternal veiling post-pregnancy on childhood's bone mass. In order to filter out this effect, comparison to a group of children whose mothers wore the veil only during pregnancy would have been ideal and desirable. However, such a group was not available. Veiling during pregnancy may have also reflected other predictors, such as nutrition or SES.

Maternal veiling during pregnancy had a significant effect on musculoskeletal outcomes in boys, findings in sharp contrast to those in girls. The sexual dimorphism for the impact of presumed maternal hypovitaminosis D during pregnancy on offspring's bone health is consistent with age and gender differences in vitamin D effect on musculoskeletal parameters observed in other studies. Gender differences in changes in height and weight by VDR polymorphisms were noted in healthy infants in one study [18]. Gender differences in bone mass response to vitamin D replacement have also been noted in two trials [2, 14, 19], and by VDR polymorphisms in one study [20]. In the first study, increments in bone mass were noted in girls but not in boys in response to vitamin D replacement [2, 14]. In contrast, larger and more consistent increments were observed in elderly men, as compared to elderly women, in the second study [19]. Finally, duodenal expression of a calcium transporter, TRPV6, was noted to be vitamin D dependant in older men but not in women [21], possibly explaining the above-noted gender differences in the elderly vitamin D trial [19]. Although the lack of significant findings in girls may have been due to a relatively low power of the study (40–68%), the smaller magnitude of the impact of maternal veiling in girls detailed in the power analyses is also consistent with gender differences. The basis for these putative gender differences is unclear and deserves further investigation.

Ample evidence in the literature supports the central role of lifestyle factors on musculoskeletal health, especially during growth and adolescence [2, 22–24]. Maternal social position during pregnancy and SES of children have both been associated with bone mass of children in two recent studies [16, 24]. Mediators of such effect include nutritional factors, weight, height, and body composition that may affect appositional and longitudinal bone growth [25]. We used school fees as a surrogate of SES in view of the wide discrepancies in school fees between high and low SES schools, the low proportion of students receiving full financial aid in the high SES schools, and the information on the minimal wage in Lebanon, allowing little room for misclassification.

The magnitude of the decrements in BMD between children of mothers who veiled during pregnancy and those who did not was 1/3 of a SD at both the femoral neck and total body, and the magnitude of such decrements between children of low and high SES was 0.8 SD. These decrements, adjusted for powerful covariates, are clinically relevant and may translate into increased fracture risk, assuming that such differences are carried into older life [26]. The correlation between maternal veiling during pregnancy and SES did not allow the dissection of the individual contribution of each of these variables to offspring's musculoskeletal parameters. Indeed, veiling during pregnancy and SES were significantly correlated, kappa = 0.3. However, the separate predictive model and different R^2 provided by each predictor suggest differences in the impact of each on bone outcomes. Furthermore, the comprehensive model that chose SES over maternal veiling during pregnancy, also suggests that SES is a more encompassing predictor that includes other variables over and above veiling such as poor nutrition, lower education or poor exercise. In a recent study from India, girls from upper socio-economic classes had significantly higher BMD at the distal forearm and calcaneum as compared to girls of lower SES. Since both groups had similar serum vitamin D levels, the effect on BMD was attributed to the significantly better nutrition, heights and weights observed in girls of higher SES [27]. The role of exercise in promoting musculoskeletal health in children and adolescents has been reviewed in a systematic review by Hind & Burrows [28]. Weight-bearing exercise seems to enhance bone mineral accrual in children, especially during early puberty and more so if coupled with adequate calcium intake [28]. Finally, the above does not negate the consistent, significant, and substantial negative impact of maternal veiling and SES on children's bone health, albeit with some gender differences. Furthermore, sub-group analyses in boys of low SES suggest an independent effect of maternal veiling on bone mass of their sons, with differences that would be anticipated to have an impact on fracture risk if carried into adulthood.

Our study is limited by the fact that it is observational, used DXA measures in a growing skeleton, although both BMC and BMD were used. The study did not have any information on maternal breast feeding and gestational age that are potential predictors of child's bone mass. Maternal veiling status during pregnancy could be subject to recall bias; however women usually recall to the month the date they started wearing the veil because this is an important landmark in their religious life. We assumed that SES at the time of study reflected SES during pregnancy. Nevertheless, it also reflects SES of the children which itself may affect musculoskeletal parameters, independent of maternal factors. Veiling status during pregnancy was used as a surrogate marker of maternal hypovitaminosis D. Since vitamin D levels were not measured during pregnancy, it may be argued that veiled mothers may have had normal vitamin D levels during pregnancy due to routine prenatal vitamin supplementation. The proportion of Lebanese pregnant veiled mothers who use prenatal supplements was estimated to be 13–16% in a previous study [29]. Moreover, the dose of vitamin D in prenatal vitamins usually does not exceed 200 IU/day, which is insufficient for raising maternal vitamin D levels to a replete range.

The effect of maternal veiling during pregnancy on the offspring's musculoskeletal health is being captured 13 years later. However, epidemiologic studies have linked anthropometric measures at birth to cardiovascular outcomes and to the risk of hip fractures decades later, underscoring the substantial impact of pre-natal or early post-natal environmental stimuli on structure and function manifesting several years later [4]. Furthermore, infancy and adolescence are periods of accelerated musculoskeletal growth that are particularly suited to examine the expression of imprinting phenomena [1, 3].

In conclusion, maternal veiling during pregnancy was associated with lower musculoskeletal parameters of adolescent boys, but not girls. In contrast, lower SES was associated with lower bone mass in both genders. The effect of SES on musculoskeletal parameters may capture lifestyle factors during pregnancy or thereafter common to both mothers and children, while the impact of maternal veiling during pregnancy may reflect the effect of hypovitaminosis D on fetal programming as it relates to musculoskeletal health. Our observations may have substantial impact on public health in view of the increasing prevalence of veiling worldwide.

Acknowledgments The study was supported in large part by an educational grant from Nestle Foundation and by a grant from Merck KGaA. The authors thank the administrators, school nurses, parents and students from the American Community School, the International College, Amlieh School and Ashbal Al Sahel School for their support in making the study possible. The authors thank Mrs S. Mroueh for her expert technical assistance in the acquisition and analyses of the bone mineral density scans and Mrs Hajj Shahine for her tireless efforts in running the hormonal assays.

Conflict of interest statement None

Authors' contributions All authors participated in the writing of the manuscript and have seen and approved the final version. MN did the literature review, participated in data collection, analysis and manuscript write-up. ZM participated in statistical analysis. JM did the data collection, analysis and participated in drafting of the manuscript. AA participated in patient evaluation, examination and data collection.

GEHF was the lead investigator who designed the study protocol, secured funding for the study, oversaw data collection, analysis and contributed substantially to manuscript write-up.

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