Original article

Physical activity is a prognostic factor for bone mineral density in Mexican children

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ABSTRACT

Background. Bone mass is similar in pre-pubertal girls and boys and double in both genders between the onset of puberty and early adult life. Exogenous factors such as nutrition and exercise contribute to the acquisition of bone mass. The objective of this project was to correlate calcium intake and level of physical activity with bone mineral density (BMD) in a sample of Mexican school-age children.
Methods. A validated questionnaire was applied. The questionnaire included the following dimensions: (a) sociodemographic information, (b) type of sports and games that involved physical activity and hours per week dedicated to them, (c) inactivity measured by hours expended watching TV or playing videogames per day and (d) dietary calcium. After completing the questionnaire, the children were invited to have a BMD and total body composition assessment using a dual-energy x-ray absorptiometry (DXA) (Prodigy LUNAR).
Results. In this cross-sectional study, 212 children were included, 48.6% were girls. The average total BMD in boys and girls was 0.8805 ± 0.056 g/cm^2 and 0.8788 ± 0.056g/cm^2, respectively, with significant differences in the groups of 10- and 12-year-old girls. An average of 10.9 ± 6.48 h of weekly physical activity was reported in boys and 10.6 ± 7.31 h in girls. Number of glasses of milk consumed was reported (1.7 ± 0.95 and 1.33 ± 0.91) per day in boys and girls, respectively. Differences in BMD in 10- and 12-year-old girls adjusted according to menarche were found. In the linear regression analysis, lean body mass was significantly associated with total, L2-L4, pelvis, and forearm BMD. Physical activity was significantly associated with leg BMD and age was associated with pelvis and forearm BMD.
Conclusions. High lean body mass, menarche and regular intense physical activity are predictors for a higher BMD in school-age children in Mexico City.
Key words: bone mineral density, children, nutrition, physical activity.

INTRODUCTION

Bone mass and skeletal size are similar in pre-pubertal girls and boys and double in both sexes between the onset of puberty and early adult life. Genetic predisposition is the main factor influencing bone mass. Exogenous factors such as nutrition, natural exercise, various diseases and medicines, as well as endogenous factors such as the GH-IGF-1 axis, sex steroids and the normality of menstruation contribute positively or negatively to the acquisition of bone mass.[1]

The ability of bone to adapt to mechanical loading is well accepted. Bone responds to increased mechanical stress by becoming stronger and to disuse by weakening and loss of bone mass.[2] Increasing evidence supports that exercise during growth has a high potential to reduce risk of osteoporosis in later life. Several studies have reported the positive effects of physical activity on the whole skeleton, lumbar spine, and hip in growing children.[2]

There are several modifiable risk factors associated with bone health; two of them are of particular interest in children and adolescents for their potential to enhance a positive effect on the skeleton: physical activity and adequate nutrition (where calcium intake is crucial). These factors have been associated with positive effects in bone and these changes have been reflected in bone architecture as well as in bone density measured by dual-energy x-ray absorptiometry (DXA).[3] Several local and systemic mechanisms have been proposed to explain these effects. Exercise is related with regional changes and may be due to two mechanisms: the stress response induced by local weight and the hormone regulated effects (estrogens and progesterone).[4,5]

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On the other hand, the systemic effects of calcium intake are associated with changes in bone remodeling and bone mineral density (BMD).[6] Physical activity and calcium intake in childhood are associated with bone health and increasing peak bone mass during growth which, in turn, may be helpful for prevention of osteoporosis in adulthood as reported in some studies.[5,7,8]

Because no data have been reported regarding the correlation between physical activity and dietary calcium in Mexican children, we designed the present study to determine the patterns of calcium intake, physical activity and inactivity and its correlation with BMD and lean body mass in a sample of school-age children in Mexico.

SUBJECTS AND METHODS

There were 212 children (6- to 12-years of age) who were evaluated and invited to participate in the study. All children came from a large public school in Mexico City. Children and their parents were invited to participate in the study from December 2003 to May 2004. Informed consent and assent was required for parents and children in all cases. A validated questionnaire was applied to all participants by a trained research assistant.[9] The questionnaire included the following dimensions: (a) sociodemographic information, (b) type of sports and games that involved physical activity and hours per week dedicated to them, (c) inactivity measured by hours expended watching TV or playing videogames per day and (d) dietary calcium.[10]

After completing the questionnaire, the children were invited to have a BMD and total body composition assessment using a dual-energy x-ray absorptiometry (*DXA*) (LUNAR Prodigy, GE Medical) using software for children that measured seven different regions including lean body mass and fat mass determination. Machine calibration was done daily, and weekly quality assurance tests were performed as recommended by the manufacturer of the DXA equipment (accuracy error <1%).[11,12] A review from LUNAR technicians was performed prior to study initiation. All scans were done by the same trained technician.

Food frequency was analyzed using the evaluation system for nutritional habits and food ingestion (SNUT) widely used and validated by the National Institute of Public Health of México (INSP).[10] Sample size was calculated expecting 15% of change in BMD per year for both genders, requiring the random assignment of 30 boys/girls for each age. In all cases, a p value of ≤ 0.05 was considered significant. The study was approved by the institutional Ethics and Research Committee.

RESULTS

Included in the study were 212 children of 6- to 12-years of age. Baseline characteristics are summarized in Table 1. Physical activity was reported to be 10.9 ± 6.48 h/week in boys and 10.6 ± 7.31 h/week in girls and inactivity was reported to be 20 ± 11.1 and 18.12 ± 9.8 h/week, respectively. Mean milk intake was 1.7 ± 0.95 and 1.33 ± 0.91 glasses/day in boys and girls, respectively, and intake of corn tortillas was 0.67 ± 0.78 and 0.69 ± 0.69 pieces/day reaching an approximate daily calcium ingestion of 466.6 and 527.9 mg/day respectively.

Figure 1 shows the linear and sustained increments in BMD per year of age in both genders in the pelvic and lumbar regions. The same effect was present in all regions. No significant effect was found according to gender in these measurements, with the exception of girls who showed a significant increment for every BMD measurement in the pubertal group. This difference is evident from 9 years of age and is seen earlier in the L2-L4 determination (Figure 2).

BMD showed significant differences according to age and gender: at 7 years of age, girls showed L2-L4, leg, pelvic and total BMD values higher than boys. At 9 years of age they still demonstrate higher values for leg BMD, at 10 years of age for L2-L4, leg and pelvic regions, at 11 years of age for pelvic region and at the age of 12 years, total BMD and forearm BMD remained higher than boys. On the other hand, at 7 years of age, boys had higher BMD values for the trunk area, from 7 to 10 years of age, forearm BMD remained higher than in girls and from 11- to 12-years of age, leg BMD values surpassed those for girls (data not shown).

According to Pearson's analysis, we observed a high correlation with total ($r^2 = 0.736$), pelvic ($r^2 = 0.809$), leg ($r^2 = 0.872$), forearm ($r^2 = 0.761$), L2-L4 ($r^2 = 0.664$) and spine ($r^2 = 0.529$) BMD when we included the following variables in the mode: gender, age, height, weight, body mass index, muscle, total fat mass, physical activity, sedentarism, milk and tortilla consumption (Table 2).

Table 1. Baseline characteristics of the studied population according to gender

Body measurements	*Girls (n = 109) Mean ± SD*	*Boys (n = 03) Mean ± SD*
Weight (kg)	34.4 ± 10.7	37.3 ± 13.1
Height (cm)	133.7 ± 13	134.6 ± 12.5
BMI (kg/m²)	18.7 ± 3.1	20 ± 4.2
Lean body mass (kg)	22.6 ± 5.8	24.7 ± 6.1
Fat mass (kg)	14.9 ± 17.6	18 ± 20.8
Bone Mineral Density (g/cm²)		
Spine	0.717 ± 0.13	0.704 ± 0.086
Lumbar Spine	0.771 ± 0.14	0.715 ± 0.10
Forearm	0.629 ± 0.07	0.641 ± 0.06
Legs	0.877 ± 0.14	0.897 ± 0.14
Pelvis	0.807 ± 0.12	0.792 ± 0.11
Total	0.875 ± 0.08	0.885 ± 0.08
Reproductive history		
Age at menarche	11 ± 0.8	
Physical activity (hours/week)		
Weight-bearing vigorous activity	10.1 ± 6.5	10.6 ± 7.3
Sedentarism	20 ± 11.1	18.1 ±9.8
Diet		
Milk consumption (glass/day)	1.7 ± 0.95	1.33 ± 0.91
Tortilla consumption (pieces/day)	0.68 ± 0.68	0.68 ± 0.8
Calcium (mg/day)	466.6	527.9

BMI, body mass index.

In the linear regression analysis, lean body mass was significantly associated with total (0.006, 95% CI: 0.002-0.01, p = 0.004), L2-L4 (0.007, 95% CI: 0.000-0.014), pelvis (0.0103, 95% CI: 0.004-0.016, p = 0.0007), and forearm (0.005, 95% CI: 0.0017-0.008, p = 0.0028) BMD. Physical activity was significantly associated with leg BMD (0.0014, 95% CI: 0.0002-0.002, p = 0.0207). Finally, age was directly associated with pelvis (0.007, 95% CI: 0.000-0.015, p = 0.007) and forearm (0.007, 95% CI: 0.002-0.012, p = 0.007) BMD (data not shown).

DISCUSSION

The present study is the first to assess the effect of dietary calcium and exercise on bone mineral density in Mexican children. Among the many variables evaluated, physical activity, lean body mass and puberty were strongly associated with total and regional BMD.

We observed a clear correlation between physical activity and increased BMD. This increment was directly related with the number of hours and the intensity of physical activity reported by the children. Until 10 years of age, this variable was different between genders due to sexual maturation. It is also remarkable that boys and girls reported a similar amount of exercise per week; however, later in life; men tend to exercise more, possibly due to cultural or social factors.

Other studies reported that physical exercise, especially weight bearing activity, has beneficial effects on the skeleton in both children and adolescents as well as in postmenopausal women and elderly subjects.[2,13,14] It is clear that the higher BMD is associated with a higher lean body mass (muscle), which can only be attained through

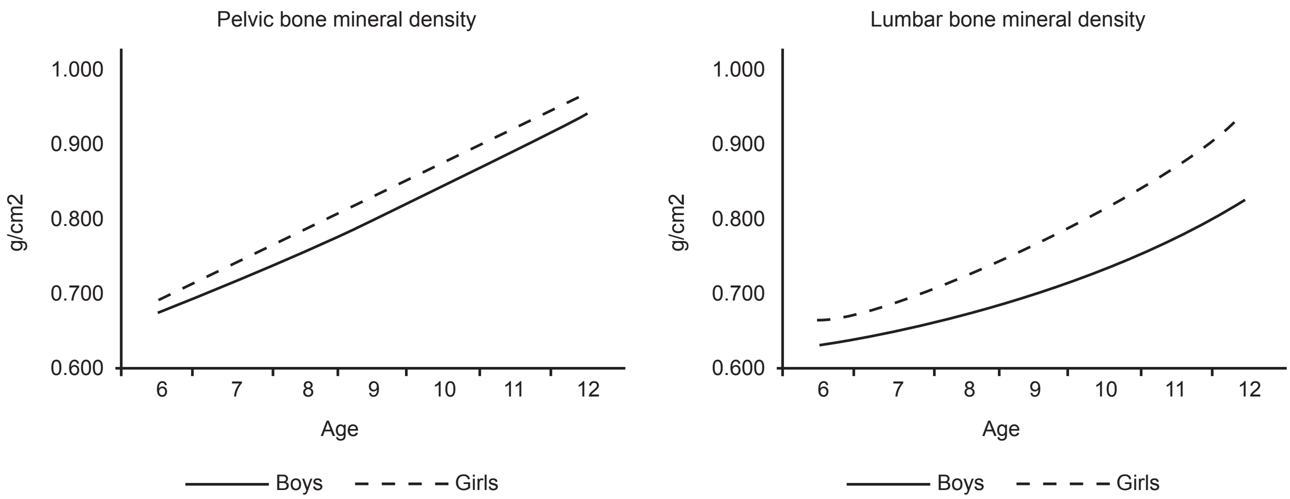

Figure 1. Pelvic and lumbar bone mineral density according to gender.

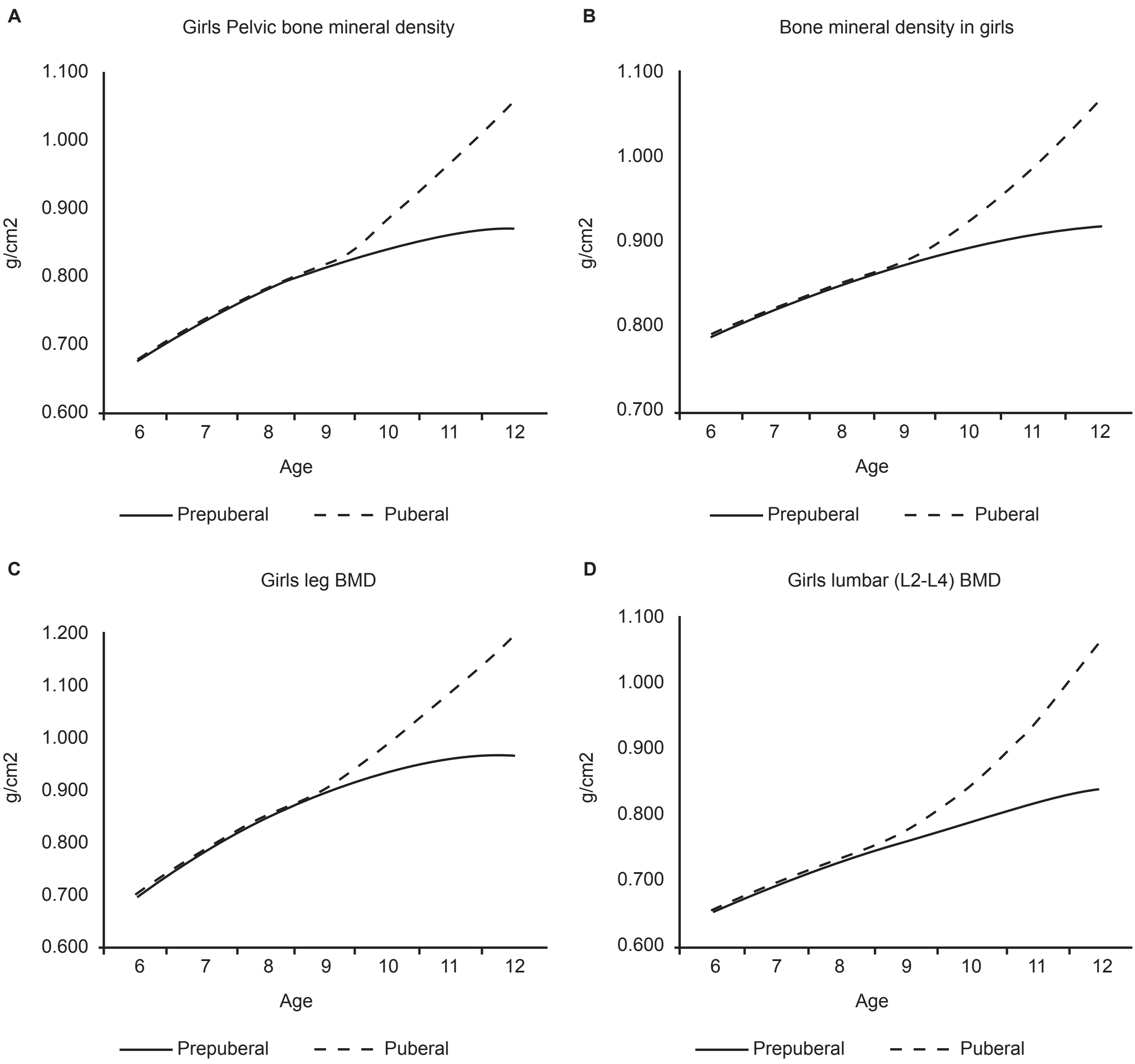

Figure 2. Sectional bone mineral density by puberal development in girls in (A) pelvic bone, (B) total BMD, (C) legs, and (D) lumbar spine (L2-L4).

regular weight-bearing exercise. This association revisited importance because both are determinants for better bone health. Vicente-Rodriguez and colleagues reported that pre-pubertal boys involved in weight-bearing activity had higher BMD than age- and weight-matched non-physically active counterparts. These authors also stated that the enhancement of lean mass appeared to be the best predictor for the accumulation of bone mass in children.[15] Gunter et al. assessed hip BMD in pre-pubertal children who participated in a 7-month jumping intervention with control subjects who participated in a stretching program of equal duration. After 7 months, children who completed the high-impact jumping exercises had 3.6% more hip BMD than control subjects.[2] Similar results were reported in clinical trials of different activities like jumping and compulsory physical education sessions, among others.[2,13-15] The study

Table 2. Linear regression analysis for BMD

Bone mineral density	R^2
Total	0.7368
Pelvis	0.809
Leg	0.872
Forearm	0.761
Spine	0.529
L2-L4	0.664

Adjusted for gender, age, height, weight, body mass index, lean body mass, total fat mass, physical activity, sedentarism, milk and tortilla ingestion.

by Markou et al. mentions that up to 30% of peak BMD is accrued in the 3 years surrounding puberty. The authors also underlined the importance of regular activity during these years as well as into adolescence by showing that recreationally active boys and girls achieved 9% and 17% greater total body BMD, respectively, as compared to inactive children.[1] The mechanism by which mechanical stimulation of bone induces new bone formation is through bending forces that cause formation of osteocytes and generation of pressure gradients that drive through the bone, providing nutrients and flow-related shear stresses on the cell membranes which, along with several enzymes activated in osteoblasts and osteocytes, increase bone mass.[1] We were able to demonstrate similar results in our group. There was a sustained increment of BMD with age, exercise and pubertal stage in both genders.

In the U.S., the main objectives for physical activity in children include increasing the proportion of adolescents who engage in moderate physical activity for at least 30 min on 5 or more days a week and vigorous physical activity that promotes cardiorespiratory fitness 3 or more days a week, among others.[16] According to these recommendations, our population reported a sufficient amount (about 90 min/day) of weight-bearing vigorous activity, similar in both genders. Unfortunately, this behavior changes throughout life because after puberty men usually report more physical activity than women.

It has been previously published that from the onset of puberty, sexual dimorphism in bone growth and development leads to bigger bones in males than in females. In both genders there is a significant age-dependent increase in BMD.[1] The notion that pubertal timing is related to the risk of osteoporosis during adult life has so far been primarily documented in females. Puberty is characterized by rapid bone growth and appearance of secondary sexual characteristics. Bone is elongated via endochondral ossification at the epiphyseal plate and broadened by periosteal apposition at the diaphysis. Sexual maturation and bone growth are driven by progressively elevated exposure to sex steroids. In the long bone shaft, it has been postulated that androgens promote periosteal bone formation, whereas estrogens acts as inhibitors as well as for endosteal resorption.[17]

Several epidemiological studies have documented a relationship between age at menarche and risk of osteoporosis. Later age at menarche is associated with lower area bone mineral density in the spine and proximal femur and higher risk of vertebral and hip fracture.[18,19] Our results agree with Chevalley and colleagues who found that the gain in BMD between 7.9 and 16.4 years of age was inversely related to age at menarche at both the axial and appendicular skeletal sites in an 8-year follow-up cohort of girls 8 ± 5 years of age. The absolute values of BMD measured at 16.4 years of age were also significantly greater in girls comparing early with late menarche.[19] As an explanation for these results, in the follow-up study of Wang et al. (258 girls), serum levels of 17-estradiol and testosterone increased progressively up to menarche, and serum 17-estradiol was a positive predictor for total BMD and cortical thickness.[17] These authors also reported that, at the endocortical surface, serum 17-estradiol inhibits bone resorption during rapid pubertal growth, and later (after menarche) the higher concentration promotes bone formation. This can be related to the maturation of the female because it is necessary to develop the ability to store calcium in preparation for the high calcium demand during pregnancy.[17] Kontulainen and colleages prospectively assessed cortical bone density development and radial distribution of bone mineral density across the axial plane of the tibial diaphysis in 68 early and peri- and postpubertal girls and 59 boys. During a 20-month period, girls had a 2–3% greater increase in cortical bone density (CBD) than boys in each maturity group. Peripubertal girls, who reached menarche during the follow-up, showed the greatest increase in average CBD and consolidation in the subcortical region.[20] Change in CBD and its distribution were related to maturation and gender. Postpubertal girls had greater CBD at baseline than both early and peripubertal girls and postpubertal boys.[20]

On the other hand, it has been demonstrated in prospective randomized, double-blind, placebo-controlled intervention trials that a higher calcium intake during childhood and adolescence increases bone mass gain, and this may result in higher peak bone mass.[18] Even though our group of children reported an ingestion of <75% of the recommended dietary allowance for milk (490 mg for boys and 385 mg for girls), we were not able to detect an association between calcium intake and BMD values. This may be due to sample size and/or food frequency measurements, which is not a very precise method for the determination of micronutrients. However, with these results, we should make the recommendation of increasing the daily dietary calcium intake in Mexican children to achieve the recommended dietary calcium intake in this age group.

The main strengths of our study are the bone assessment method, which is the gold standard for BMD determination and the homogeneous population regarding age and ethnicity.

Our study has certain limitations. The food frequency information used to evaluate calcium intake is not the best method to assess micronutrient ingestion. It has been published that 7-day dietary recall has more precision and validity. Due to sample size, these results are not a reflection of Mexican children.

In conclusion, our findings establish muscle mass, menarche and regular intense physical activity as important predictors of BMD. Because lean mass is composed primarily of skeletal muscle, participation in sports during puberty may not only have a direct osteogenic effect by impact loading but also an indirect effect in increasing muscle mass.

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