Low Vitamin D Status Has an Adverse Influence on Bone Mass, Bone Turnover, and Muscle Strength in Chinese Adolescent Girls

Leng Huat Foo, Qian Zhang, Kun Zhu, Guansheng Ma, Xiaoqi Hu, Heather Greenfield, and David R. Fraser

Abstract

Our goal in this cross-sectional study was to investigate the influence of low-vitamin D status on bone mass, bone turnover, and muscle strength in 301 healthy Chinese adolescent girls. Blood plasma 25-hydroxyvitamin D [25(OH)D] was measured by RIA and plasma and urine biomarkers of bone turnover were measured. Bone mineral content (BMC) and density and bone area for the whole body and the distal and proximal forearm were measured by dual energy X-ray absorptiometry. When vitamin D deficiency was defined as a serum 25(OH)D concentration of ≤50 nmol/L and severe deficiency as <25 nmol/L, 57.8% of subjects were vitamin D deficient and 31.2% were severely deficient. Multivariate analysis shows that girls with adequate vitamin D status had higher size-adjusted BMC for the whole body (P < 0.001), distal forearm (P < 0.001), and proximal forearm (P < 0.001) than those with poorer vitamin D status after adjusting for body size, handgrip strength, physical activity, and dietary intakes of calcium and vitamin D. Similar results were also found for handgrip muscle strength. Participants with adequate vitamin D status had significantly lower concentrations of bone alkaline phosphatase in plasma and deoxypyridinoline:creatinine ratio in urine compared with those of the vitamin D-deficient girls. Adolescent girls with adequate vitamin D status had significantly higher bone mass and muscle strength compared with those with poor vitamin D status. This may be attributed in part to a lower rate of bone remodeling with adequate vitamin D status. These findings suggest that adequate vitamin D status during adolescence is important for optimizing bone mass, which may lead to higher peak bone mass at maturity. Poor vitamin D status also compromises forearm muscle strength. J. Nutr. 139: 1002–1007, 2009.

Introduction

Vitamin D deficiency rickets has been reemerging as a public health problem in some developed and developing countries (1,2). Although persistent severe vitamin D deficiency causes rickets in children and osteomalacia in adults, mild hypovitaminosis D may also be associated with hyperparathyroidism and increased bone turnover. In postmenopausal women and in both elderly men and women, hypovitaminosis D may lead to bone loss and fractures (3,4).

The concentration of 25-hydroxyvitamin D [25(OH)D] in blood is regarded as the best indicator of vitamin D status, because it is quantitatively related to the supply of vitamin D over preceding weeks (5). There is as yet no consensus about the threshold level of 25(OH)D that indicates vitamin D deficiency in children. However, for adults, there is mounting evidence that vitamin D deficiency exists at a 25(OH)D concentration where parathyroid hormone (PTH) levels start to rise and where there is evidence of increased bone remodeling and a reduction in bone mass (6). Whether this threshold level applies to children and adolescents is still uncertain. It is generally agreed that plasma 25(OH)D concentrations <25 nmol/L indicate vitamin D deficiency in children (7–10) and it appears that normal calcium homeostasis is maintained in children and adolescents with plasma 25(OH)D ≥50 nmol/L (11). Therefore, adequate vitamin D status has been defined as a 25(OH)D concentration of >50 nmol/L. The term vitamin D insufficiency has been used in the literature when 25(OH)D is between 25 and 50 nmol/L (7,9). All these values may vary, depending on the assay method used to determine 25(OH)D concentrations (12).

A high prevalence of hypovitaminosis D has been reported in healthy growing children and adolescents in a number of...
countries (7,13–15). Most studies in Caucasian populations found that vitamin D deficiency was associated with an elevation of PTH concentration in blood (7,8) and an increase in the blood concentration of markers for bone turnover (14,16). Such changes in growing children and adolescents suggest that there may be suboptimal bone mass accretion (17), but the results from various studies have been conflicting. In Caucasian adolescent girls, a positive association has been reported between vitamin D status and bone mass measurements (8,16,18), whereas other studies did not find this relationship (19–21). Such discrepancies may be explained by the variable influence of confounding factors such as stage of sexual maturation and the rate of linear growth at the time of measurement (22,23). These biological variations may confound the relationship between vitamin D status and bone mass growth.

To our knowledge, there are no data concerning the influence of vitamin D status on the growth of bone mass and on the biomarkers of bone turnover in adolescent girls, especially in Chinese populations. Most studies have been with Caucasian children and adolescents. Therefore, because we and others found a high prevalence of vitamin D deficiency in adolescent girls in China (13,24), we investigated the influence of variable vitamin D status on bone mineral content (BMC) of the whole body and forearm, handgrip muscle strength, and the biomarker values for bone turnover in 301 healthy Chinese adolescent girls aged 15 y in Beijing, China (40°N).

Materials and Methods

Study design. A cross-sectional analysis was performed on data collected in 2004 on a random subset of 350 Chinese girls aged 15 y from a larger group of 504 participants, who were the participants of a 5-y prospective study described previously (25). That 5-y study investigated the relationships between genetic, pubertal, nutritional, and lifestyle factors on bone mass accretion, following a randomized double-blind controlled milk supplementation trial in adolescent girls in Beijing over 2 y from 1999 to 2001 (26). A subsequent 3-y follow-up study that investigated whether the effects on bone growth and development from the milk supplementation had been maintained found that all the benefits for vitamin D status, body size, and bone mass had disappeared after supplementation had ceased (25). Three years after the end of the supplementation trial, the intervention and control groups did not differ in plasma 25(OH)D, intact-PTH (iPTH) concentrations (25), and biochemical markers of bone metabolism assessed (L. H. Foo, unpublished data). Thus, the data for all 3 groups were pooled for comprehensive statistical analyses. Forty-nine of these participants were excluded, because the data were incomplete for 1 or more of the measured variables. The included and excluded participants did not differ in plasma 25(OH)D, iPTH, and body composition values. None of the 301 participants included in the analysis had clinical signs of bone disease that could potentially prevent them from being physically active, nor were they taking any medications known to influence bone metabolism. The study was approved jointly by the Human Ethics Review Committee of the University of Sydney and that of the National Institute for Nutrition and Food Safety, China Center of Disease Control and Prevention. Written informed consent was obtained from participants and their parents or guardians prior to participation in this study.

Anthropometry and pubertal Tanner measurements. Anthropometric measurements including body weight, height, and sitting height were performed using standardized procedures and the details of these measurements were reported elsewhere (24). Breast and pubic hair development were assessed during hospital visit by the research officer (K. Zhu) according to Tanner's definitions of the 5 stages of puberty (27). When there were discrepancies between breast and pubic hair development stages, breast development alone was used to define the stage of pubertal development. Age at menarche was also recorded.

Bone mass and handgrip muscle strength assessments. Bone age was determined using the Greulich and Pyle Atlas method (28). Radiological examination of the left hand and wrist of each subject was carried out using a standard protocol at the Department of Radiology, 304 Hospital of Beijing, China. Skeletal age, to the nearest 3 mo, was determined from the stage of growth of the metacarpals, phalanges, and carpal bones in reference to a set of CHN method-China Population Skeletal Development Standard photographs. Bone mass measurements of the whole body, the distal and proximal forearm were made using dual-energy X-ray absorptiometry (XR-36, Norland Medical Systems). All bone measurements were performed by the same 2 trained technicians who were unaware of the treatment groups throughout the trial periods. To minimize technical variation, the same technician analyzed all the data, using Norland enhanced software version 3.9.4. Quality control scans were performed each day. Prior to each scan, the densitometer was calibrated according to the manufacturer's recommendations. During the course of the study (2–6 mo), the CV of repeated measurements using a manufacturer-supplied phantom was <1%, indicating satisfactory long-term stability of the instrument with no sign of drift. For ethical reasons, we did not perform repeat scans on the same child after repositioning. In the present study, BMC and bone area (BA) of the total body and the distal and proximal forearm were not used as primary dependent variables, because there is now widespread agreement that areal bone mineral density (aBMD) should not be used as a measure of bone mineral status during growth (29,30). Handgrip strength was measured on both nondominant and dominant hands using a hand-held dynamometer (Lafayette Instrument, model 78010) with adjustable widths. The CV for repeated measurements (n = 10) was 1.7%.

Physical activity and dietary intake assessments. Physical activity levels were collected from a validated detailed questionnaire over the previous 12 mo, whereas dietary intakes were assessed from 2 3-d food records (including 2 weekdays and 1 weekend day, as described previously in detail (31). Because the vitamin D content of foods is not given in the food composition database for China (32), the presumed concentrations of vitamin D were obtained from the United Kingdom food composition tables (33). An adjustment was made to the UK values for vitamin D in eggs (which local analyses have shown to be lower than in the UK) and in fresh milk, which is fortified with vitamin D in China (13,34). None of the participants reported taking any vitamin supplements.

Blood vitamin D, PTH, and biomarkers of bone turnover analyses. One 5-mL overnight fasting venous blood sample was collected between 0630 and 0900 during the period March to April at the end of winter. Urine samples were also collected from the second morning void on the day of blood collection. The urine and blood plasma samples were stored at –80°C prior to analysis. Details of blood and urine biochemical analyses were previously described (24,25). In brief, plasma 25(OH)D concentration was determined by 125I-RIA kits (Diasorin), and iPTH (1–84) was analyzed by immunometric assay (Immulite intact PTH; Diagnostic Products). The intra- and interassay CV were 4.2 and 6.6% for 2.9 and 5.0%, respectively, for 25(OH)D and iPTH. Plasma calcium and urinary creatinine (Cr) were assessed by atomic absorption spectrophotometry (Model Hitachi 7060 Automatic Chemistry Analyzer, Hitachi). Plasma osteocalcin (OC) and bone-specific alkaline phosphatase (BAP) were both measured using a commercial ELISA kit method (N-MID Osteocalcin, Osteometer BioTech, and Metra, Quidel, respectively). The intra- and interassay CV were 4.0 and 4.8% to 8.7%, and 6.5 and 5.4% to 7.9%, respectively, for OC and BAP levels, whereas urinary deoxyxypyrindoline (Dpd) was determined using a commercially available immunoassay kit method (ImmuLite Pyrilinks-D; Diagnostic Products Corporation). The intra-assay CV was 5.7%. The result of Dpd levels were normalized to the urine Cr concentration and expressed as a ratio to urine Cr excretion (nmol Dpd/mmol Cr) to correct for the day-to-day variation in urine volume. All samples from different schools and groups were analyzed at the same time and assayed in duplicate and, to reduce interassay variation, all plasma samples were also analyzed in single batch assays.
Classification of vitamin D status. Although there is as yet no agreed consensus for the threshold level of 25(OH)D to define vitamin D deficiency in children and adolescents, for the present analysis, vitamin D deficiency is defined as a 25(OH)D concentration of ≤50 nmol/L and severe vitamin D deficiency as a plasma 25(OH)D concentration of <25 nmol/L.

Statistical analysis. Descriptive statistics are reported as mean ± SD and differences as mean ± SEM for all variables, unless otherwise indicated. Where variables were not normally distributed, the mean and 95% CI ranges of the untransformed values were presented for ease of interpretation. Because the profiles of plasma 25(OH)D, iPTH concentration, biomarkers of bone turnover, and dietary intakes in the study group were skewed, all these values were log-transformed prior to analysis. Partial correlation coefficients analysis was used to examine the direction and magnitude of the relation between the plasma 25(OH)D level and either bone mass or muscle strength after adjusting for body size, pubertal Tanner breast stage, physical activity status, and dietary calcium and vitamin D intakes. We used ANCOVA, with post hoc Bonferroni’s correction for multiple comparisons to assess the difference in bone mass according to 3 vitamin D status ranges, after adjusting for known potential confounding factors such as body size, bone size, pubertal breast development stage, physical activity, and dietary calcium and vitamin D intakes. Because body weight and height and BA are strongly associated with BMC, these factors were given higher priority to minimize the size-artifacts on bone mass when included into the model in growing children and adolescents (30). A similar approach was also used to determine the association between vitamin D status and forearm handgrip muscle strength and biochemical markers of bone turnover, after controlling for known potential confounders. Statistical analysis was carried out using SPSS version 12.0 for Windows and significance for all the tests was defined by a P-value < 0.05.

Results

Participant characteristics. The age of the participants was 15.0 ± 0.5 y and most of them had reached Tanner pubertal breast stages of IV and V (Table 1). Their bone age was ~1 y higher than the mean chronological age, implying that skeletal maturity was somewhat more advanced than their chronological age would indicate, in agreement with a study in Caucasian girls (35). Daily intakes of calcium and vitamin D were 457 ± 199 mg/d and 0.6 ± 0.5 μg/d, respectively, with almost all participants consuming less than the Recommended Nutrient Intake for both calcium (99%) and vitamin D (100%) for Chinese adolescent girls aged 15 y (32). The physical activity profiles showed that most physical activity was obtained from leisure-based activities (68.5%) compared with 31.5% for school-based activities. Most of these studies have been conducted in Caucasian children and adolescents and none have been reported in Chinese adolescent girls.

Relationships between vitamin D status groups, bone mass, and biomarkers of bone turnover. After further adjustments for body size, BA, and other lifestyle confounding factors, we found that those who had an adequate vitamin D status had higher size-adjusted BMC for the total body (P < 0.01) and distal forearm (P < 0.05) than did those who were severely vitamin D deficient, but the differences for size-adjusted BMC at the proximal forearm between those who were vitamin D deficient and those who were severely vitamin D deficient were not significant (P = 0.09).

Severely vitamin D-deficient participants had significantly higher concentrations of iPTH, BAP, and urinary Dpd/Cr ratio than those who had a higher vitamin D status. On the other hand, the concentrations of plasma calcium and OC and the urine calcium excretion relative to Cr did not differ among the 3 groups.

Relationships between vitamin D status groups and muscle strength. Girls with adequate vitamin D status had a greater handgrip muscle strength than those who were deficient or severely deficient in vitamin C after adjusting for body size, pubertal stage, dietary calcium and vitamin D intakes, organized sports status, and total physical activity levels (P = 0.014) (Table 2).

Discussion

In postmenopausal and elderly women, low vitamin D status is associated with secondary hyperparathyroidism, bone loss, and increased risk of osteoporotic fractures (3,4,36). However, because of conflicting reports, it has not been clearly demonstrated whether vitamin D status has a significant influence on bone mass growth in children and adolescents because it has yielded conflicting results. Some studies have found a positive relationship between vitamin D status and bone mass in healthy adolescents (8,37), using aBMD assessed by dual-energy X-ray absorptiometry as the endpoint bone variable. This is now regarded as an inaccurate measure of bone mass accretion during growth, because it depends on bone size and body growth factors (29,30). The increase in aBMD reported in these studies may have been related to differences in bone size between individuals rather than to vitamin D status. To confound matters, other studies did not find such an association (19,21). Most of these studies have been conducted in Caucasian children and adolescents and none have been reported in Chinese adolescent girls.

### Table 1 General characteristics of the participants

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>15.0 ± 0.4</td>
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<tr>
<td>Bone age, y</td>
<td>16.0 ± 0.8</td>
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<tr>
<td>Body weight, kg</td>
<td>55.1 ± 9.9</td>
</tr>
<tr>
<td>Height, m</td>
<td>1.8 ± 0.1</td>
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<tr>
<td>BMI, kg/m²</td>
<td>21.1 ± 3.4</td>
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<tr>
<td>Tanner breast stage</td>
<td></td>
</tr>
<tr>
<td>–2 – 3</td>
<td>2.0</td>
</tr>
<tr>
<td>–4</td>
<td>47.5</td>
</tr>
<tr>
<td>–5</td>
<td>50.5</td>
</tr>
<tr>
<td>Calcium intake, mg/d</td>
<td>457.0 ± 198.7</td>
</tr>
<tr>
<td>Vitamin D intake, μg/d</td>
<td>0.6 ± 0.5</td>
</tr>
<tr>
<td>Total physical activity (PA), h/wk</td>
<td>10.2 ± 7.5</td>
</tr>
<tr>
<td>School-based PA</td>
<td>2.6 ± 1.9</td>
</tr>
<tr>
<td>Leisure-based PA</td>
<td>7.0 ± 5.5</td>
</tr>
<tr>
<td>Organized sports status</td>
<td>15.6</td>
</tr>
<tr>
<td>Plasma PTH, pmol/L</td>
<td>364.4 (343.7–385.0)</td>
</tr>
<tr>
<td>Plasma 25(OH)D, nmol/L</td>
<td>34.0 (32.1–35.9)</td>
</tr>
</tbody>
</table>

1 Values are means ± SD, means (95% CI), or %, n = 301.
In the present study, we found that adolescent girls with adequate vitamin D status had significantly higher size-adjusted BMC for the whole body and distal and proximal forearm compared with those of poor vitamin D status, even when adjusted for bone size and body size. BA did not differ at the skeletal sites measured between the 3 groups of vitamin D status. The present results are similar to 2 previous studies of Caucasian girls (18,19). A study of Icelandic adolescent girls aged 16 to 20 y also found significant positive associations between 25(OH)D concentration and forearm BMD and BMC when it was analyzed in adolescent girls aged 16 y old (19). In contrast, a study of Caucasian adolescent boys and girls aged 16 and 18 y found no significant association between vitamin D status and any bone mass measurements, after adjusting for bone and body size, although univariate correlation analysis showed a positive association with BMC of the proximal femur (21). This discrepancy between the present findings and those of Caucasian adolescents might be related to differences in subject characteristics, their sexual maturity, the techniques for bone measurements, and the skeletal sites measured.

Interpretation of the effects of vitamin D status and bone mass accretion in growing children and adolescents is always complicated by factors such as the degree of sexual maturation and the rate of linear growth. The interaction between these variables is complex during this rapid growth period (22,23). For instance, there is a strong confounding effect of puberty on skeletal remodeling and remodeling, where plasma calcium and phosphate concentrations may be affected by factors other than vitamin D status (19,23). This suggests that these biological variations may confound the independent influence of vitamin D on bone mass accretion. In the present study, the significant association between vitamin D status and bone mass remained unchanged, even after adjusting for pubertal stage. This is not surprising, because most of the participants were at a postpubertal stage of development, when changes in sex hormone levels are less pronounced compared with those in participants at an earlier stage of puberty (23,38). Another explanation for inconsistency in findings may be the differences in study design, subject characteristics, skeletal measurement techniques, data interpretation, and/or baseline vitamin D status. However, the significance of the present findings is strengthened by the homogeneity in age and sex of the participants studied. Any differences in the bone mass parameters caused by differences in vitamin D status were thus more likely to be detected. Furthermore, the present results were remarkably similar to those of 2 previous studies of Caucasian adolescent girls when analysis was stratified according to individual age group (18,19).

None of these studies have addressed the differences in bone growth in response to changes in vitamin D status. In the present study, there was a significant difference only in size-adjusted BMC at the skeletal sites measured between the 3 different groups of vitamin D status but not in bone size at any of the skeletal sites. This significant difference in bone mass rather than in bone size might be explained by the increased remodeling of bone induced by vitamin D deficiency, suggesting that an adequate vitamin D status may enhance the amount of mineral present within a given bone volume by minimizing bone remodeling rather than by promoting bone growth and increasing bone size.

The biochemical markers of bone formation, OC, and BAP and the urine Dpd:Cr ratio as a marker of bone resorption were used to examine the possible effect of vitamin D status on skeletal remodeling. In the present study, those girls with a higher vitamin D status had significantly lower concentrations of BAP and lower urinary Dpd:Cr ratio compared with those in the vitamin D-deficient group, suggesting that low vitamin D status is associated with greater rates of bone remodeling. Although there is little published data on a relationship between vitamin D status and bone turnover in healthy children and adolescents, the present findings are in agreement with a study in Caucasian adolescents, where a significant inverse correlation was found between 25(OH)D concentration and urinary Dpd:Cr ratio and increased BAP levels in participants with vitamin D insufficiency (<55 nmol/L) in Caucasian adolescent boys aged 16 and 18 y

### TABLE 2

<table>
<thead>
<tr>
<th></th>
<th>Severely vitamin D deficient</th>
<th>Vitamin D deficient</th>
<th>Vitamin D sufficient</th>
<th>P-trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>94</td>
<td>174</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Size-adjusted BMC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total body, g</td>
<td>2230.2 ± 14.7</td>
<td>2291.4 ± 10.8**</td>
<td>2416.6 ± 24.7***</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Proximal forearm, g</td>
<td>1.44 ± 0.01</td>
<td>1.47 ± 0.01</td>
<td>1.53 ± 0.02***</td>
<td>0.001</td>
</tr>
<tr>
<td>Distal forearm, g</td>
<td>1.10 ± 0.02</td>
<td>1.52 ± 0.01*</td>
<td>1.86 ± 0.03*</td>
<td>0.007</td>
</tr>
<tr>
<td>Biochemical markers of bone turnover</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Plasma Ca, mmol/L</td>
<td>2.69 ± 1.04</td>
<td>2.57 ± 1.03</td>
<td>2.61 ± 1.06</td>
<td>0.410</td>
</tr>
<tr>
<td>Urinary Ca:Cr, mmol/L</td>
<td>9.65 ± 1.02</td>
<td>9.06 ± 0.80</td>
<td>10.27 ± 1.79</td>
<td>0.290</td>
</tr>
<tr>
<td>PTH, pmol/L</td>
<td>354.2 ± 1.5</td>
<td>314.2 ± 1.0*</td>
<td>319.9 ± 1.1</td>
<td>0.040</td>
</tr>
<tr>
<td>Osteocalcin, μg/L</td>
<td>25.6 ± 1.0</td>
<td>23.2 ± 1.0</td>
<td>22.1 ± 1.1</td>
<td>0.166</td>
</tr>
<tr>
<td>BAP, μmol/L</td>
<td>43.1 ± 1.0</td>
<td>55.2 ± 1.0*</td>
<td>45.0 ± 1.1***</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Dpd:Cr, mmol/mmol</td>
<td>6.00 ± 1.06</td>
<td>5.42 ± 1.03</td>
<td>4.96 ± 1.06</td>
<td>0.024</td>
</tr>
<tr>
<td>Handgrip muscle strength, kg</td>
<td>22.9 ± 0.4#</td>
<td>23.3 ± 0.39*</td>
<td>25.1 ± 0.6</td>
<td>0.014</td>
</tr>
</tbody>
</table>

1 Values are means ± SEM. *Different from vitamin D-sufficient, P < 0.05. Asterisks indicate different from severely vitamin D deficient: **P < 0.01; ***P < 0.001. #P < 0.05; **P < 0.01; ***P < 0.001.
2 Adjusted for pubertal breast stage, handgrip muscle strength, organized sports status, total physical activity levels, and dietary vitamin D and calcium intakes.
3 All analyzed were based on log-transformed data.
4 Adjusted for pubertal Tanner breast stage and age at menarche.
5 Adjusted for body size, pubertal breast stage, handgrip muscle strength, organized sports status, total physical activity levels, and dietary vitamin D and calcium intakes.
Tasmania, Australia, at a similar latitude to Beijing (14). The bone resorption marker, serum tartrate-resistant acid phosphatase isofrom 5b, was increased in blood in vitamin D-deficient prepubertal girls aged 10–12 y in Finland compared with those who had a higher vitamin D status (16). In contrast, El-Hajj Fuleihan et al. (9) did not find any significant association between vitamin D status and bone formation markers in adolescent boys and girls in Lebanon.

A comparison of 25(OH)D concentration in blood with handgrip muscle strength showed that participants with adequate 25(OH)D levels of ≥50 nmol/L had significantly greater handgrip muscle strength compared with those of lower vitamin D status. This relationship was independent of body size, level of physical activity, and dietary intakes of calcium and vitamin D. This is the first study, to our knowledge, to investigate whether there is any relationship between vitamin D status and muscle strength in adolescents. The findings are comparable to those where vitamin D status was correlated with muscle strength (39). Several studies in elderly participants also found that higher serum 25(OH)D levels were significantly associated with increased muscle strength and improved lower extremity muscle function (40,41). In the elderly, this improved muscle strength may lower the risk of falls and osteoporotic fractures. The mechanism for the greater handgrip muscle strength in participants with better vitamin D status was not explored in the present study. However, several explanations of this phenomenon can be suggested. One possible mechanism may involve a direct role of vitamin D (either as 1,25(OH)2D or 25(OH)D) in muscle action. Although such an effect has not been well defined, there has been much research on the molecular action of vitamin D in muscle (42,43). It may be that vitamin D has a role in modifying the transport of calcium in muscle or it may have a role quite independent of that. For instance, low vitamin D status may result in fatigue and diminished muscle oxygenation and consequently may affect muscle strength and function and give rise to muscle weakness (42,44). On the other hand, a separate observation that 25(OH)D is apparently stored in muscle in newborn rats may indicate a special role of muscle in vitamin D homeostasis, which is quite independent of any role of vitamin D in muscle function (45).

The present study has some limitations. The study population may not be representative of the general adolescent population in China. However, most of the anthropometric and socioeconomic characteristics of the present participants were within the expected norms of the age group for urban adolescent girls from a recent national representative survey (46). Hence, it is reasonable to apply the results to girls of comparable age from urban areas of China. In addition, because of the cross-sectional nature of the present study in determining factors associated with vitamin D status and bone mass development and forearm muscle strength, a cause of any effect cannot be established. However, the strengths of the present study are that a larger population sample was studied than in any other investigation of vitamin D status, bone mass status, and blood and urine biochemical markers of bone turnover in Chinese adolescents at 15 y of age. This study was more comprehensive than earlier research and collected data on body composition components, muscle strength, physical activity, PTH, and biomarkers of bone formation and resorption in relation to vitamin D status that were not previously evaluated. Hence, data obtained in the present study gives a comprehensive insight into the influence of vitamin D status, bone mass status, and biochemical markers of bone turnover in Chinese adolescent girls, after taking into consideration other known factors such as body composition and lifestyle-related factors. A longitudinal study with a large sample size would be required to establish any causal mechanisms in Chinese adolescent girls.

In conclusion, the results of the present study suggest that adequate vitamin D status is important in enhancing muscle strength and in attaining higher peak bone mass. This effect on bone may in part be attributed to lower rates of bone remodeling when vitamin D status is adequate. Further longitudinal population studies would help in defining the mechanisms of these relationships.

Literature Cited


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