Randomized Trial of Physical Activity and Calcium Supplementation on Bone Mineral Content in 3- to 5-Year-Old Children

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ABSTRACT

A meta-analysis of adult exercise studies and an infant activity trial show a possible interaction between physical activity and calcium intake on bone. This randomized trial of activity and calcium supplementation was conducted in 239 children aged 3–5 years (178 completed). Children were randomized to participate in either gross motor or fine motor activities for 30 minutes/day, 5 days per week for 12 months. Within each group, children received either calcium (1000 mg/day) or placebo. Total body and regional bone mineral content by DXA and 20% distal tibia measurements by peripheral quantitative computed tomography (pQCT) were obtained at 0 and 12 months. Three-day diet records and 48-h accelerometer readings were obtained at 0, 6, and 12 months. Higher activity levels were observed in gross motor versus fine motor activity groups, and calcium intake was greater in calcium versus placebo (1354 ± 301 vs. 940 ± 258 mg/day, p < 0.001). Main effects of activity and calcium group were not significant for total body bone mineral content or leg bone mineral content by DXA. However, the difference in leg bone mineral content gain between gross motor and fine motor was more pronounced in children receiving calcium versus placebo (interaction, p = 0.05). Children in the gross motor group had greater tibia periosteal and endosteal circumferences by pQCT compared with children in the fine motor group at study completion (p < 0.05). There was a significant interaction (both p < 0.02) between supplement and activity groups in both cortical thickness and cortical area: among children receiving placebo, thickness and area were smaller with gross motor activity compared with fine motor activity, but among children receiving calcium, thickness and area were larger with gross motor activity. These findings indicate that calcium intake modifies the bone response to activity in young children. (J Bone Miner Res 2003;18:885–892)

Key words: bone, exercise, physical activity, calcium intake, children

INTRODUCTION

Peak bone mass attained early in life is considered a major factor in predicting osteoporotic risk. (1) Tracking of bone mass has been reported to occur from early adolescence to young adulthood, (2) and Huang et al. (3) reported that bone density measurements in postmenopausal women made up to 11 years earlier predicted fracture risk as well as more recent bone measurements. Studies identifying factors that influence peak bone mass have focused on older children, although some investigators suggest that environmental factors early in life also may be important in optimizing the genetic potential for bone gain. (4) Physical activity and calcium intake are considered the major environmental factors influencing bone mass.

Longitudinal studies show that high childhood activity is associated with high adult bone density, (5,6) and authors of a study on retired gymnasts suggest that the beneficial bone effect of activity early in life may persist beyond the period of increased activity. (7) A recent review of pediatric calcium supplementation trials indicates that bone mass at predominantly cortical bone sites is increased with additional calcium. (8) However, the long-term persistence of a bone benefit of a high calcium intake is not known. Most, but not all, (9) pediatric supplementation trials show that the bone benefit of increasing calcium intake occurs only as long as the high calcium intake occurs. (10–12)

We previously reported results of a randomized trial of gross motor versus fine motor activity in infants and found that the bone response to activity was dependent on the infant’s calcium intake. Infants consuming a low-to-moderate calcium intake who were randomized to receive...
daily bone loading activities had a lower bone mass accretion than infants randomized to fine motor activities.\textsuperscript{(13)} There was no difference in bone accretion between the two activity groups consuming moderately high to high calcium. A summary of adult exercise studies also showed that calcium intake may modify the bone response to activity.\textsuperscript{(14)} An interaction between physical activity and dietary calcium has significant public health implications. In the current study, we sought to determine whether calcium intake modifies the bone response to increased activity in young children.

\textbf{MATERIALS AND METHODS}

This 1-year, randomized, placebo-controlled, partially blinded trial of physical activity and calcium supplementation was conducted in 239 children aged 3–5 years who were enrolled in 11 participating childcare centers. None of the children were known to have any disorders that affected bone metabolism. Children were randomized to a calcium or placebo group and to a gross motor or fine motor activity group. Randomization was stratified according to childcare center and gender. The study was approved by the South Dakota State University Human Subjects Committee, and parental written informed consent was obtained.

Two calcium (500 mg elemental calcium as calcium carbonate/tablet, TUMS; Smith-Kline-Beecham, Parsippany, NJ, USA) or placebo (lactose) chewable supplements were given daily, 5 days per week, by study personnel. One tablet was offered both before and after the activity intervention. Children in the fine motor group received 30 minutes/day of activities designed to keep them sitting quietly. Children in the gross motor group received 30 minutes/day of activities; the first 5 minutes were spent in warm-up, followed by 20 minutes of jumping, hopping, and skipping activities, followed by 5 minutes of cool-down. Both activity programs were theme-based with 17 different weekly programs. Children, parents, childcare providers, and study personnel administering the supplements were blinded to the child’s assignment. Study personnel recorded compliance with supplements and activity programs daily.

Three-day diet records and 48-h accelerometer readings were obtained at baseline, 6 months, and study completion. A registered dietitian reviewed diet records, and nutrient intake was determined using Nutritionist V (First DataBank, Inc., San Bruno, CA, USA). Because of the relatively high baseline calcium intake (946 mg/day), we formed calcium intake (diet + supplement) quartiles (≤870, 871-1099, 1100–1413, and >1413 mg/day), and these quartiles were used to compare differences between fine motor and gross motor groups and to further describe the interaction between activity and calcium intake. Accelerometers were worn only on days that children were present in the childcare center, and their use is described elsewhere.\textsuperscript{(15,16)} Accelerometer readings were used to determine whether there were baseline differences among groups in spontaneous activity levels and to determine to what extent the activity intervention increased 24-h activity levels. Information on medical history, including history of preterm birth, was obtained by questionnaire from the parents at enrollment. Height and weight were measured at the beginning and end of the study using standardized procedures.

Total body bone mineral content (BMC) and area were measured at enrollment and on study completion by DXA (model QDR-4500A; Hologic, Waltham, MA, USA) using the Experimental Pediatric Whole Body Version 8.2 software. Regional measures of arm and leg BMC and bone area were obtained from the total body scan using the manufacturer’s definition. Total body fat and lean mass, as well as total body percent fat, were obtained from the total body DXA scan. Periosteal and endosteal circumferences, cortical thickness, and cortical area of the 20% distal tibia were measured by peripheral quantitative computed tomography (pQCT; XCT 2000; Norland/Stratec, Madison, WI, USA) as previously described.\textsuperscript{(17)} Scans that showed any sign of movement were omitted from all analyses. CV for total body BMC supplied by the manufacturer is less than 1%. Our CVs for pQCT in young children, without the use of a scout view, are 3.6% and 5.4% for periosteal circumference and cortical bone area, respectively.

Difficulties with movement using pQCT were noted early in the study and ultimately led to the development of a pediatric leg-stabilizing device (Norland/Stratec). We also conducted the pQCT measurements without a scout view, which identifies the end of the tibia, to minimize the amount of time the children were required to hold still. Although this may have increased the CV for our measurements, we felt that it was necessary to obtain a scan without significant movement. Because scan quality was poor on a large percent of the baseline measurements (51%), the final mean pQCT measurements were compared among groups using a general linear model approach.

Descriptive statistics were compared among groups by ANOVA. Analysis of covariance was used to test for an interaction of calcium supplementation and activity group on absolute changes in BMC and bone geometry at 12 months. If the interaction was not significant, the main effects of calcium supplementation and activity group were tested. Bone mineral density (BMD) using DXA is expressed as an areal density, or BMC per projected bone area. Bone size may theoretically influence areal density measurements, and a variety of mathematical methods have been suggested to adjust areal BMD. The approach suggested by Molgaard et al.\textsuperscript{(18)} was used in the current analyses. Other covariates included were gender, age, history of preterm birth, childcare center, and changes in weight, height, and percent total body fat. We previously found these variables to be associated with either the bone measurements used in the current study\textsuperscript{(19)} or activity levels of these children.\textsuperscript{(16)} In addition, measures of compliance with the activity program (days of full or partial participation) and supplements (number supplements taken) also were included. To illustrate where group differences existed, individual pairwise comparison of least-squares means was performed using Student’s t-tests. Data presented are mean ± SD unless otherwise noted, and two-tailed tests were used in all analyses.
RESULTS

A total of 178 (74%) of the 239 children enrolled completed at least 38 weeks (overall average of 50 weeks of intervention) and were present in the center at least 50% of the total days. Fifty-four completed less than 38 weeks and were excluded (46 withdrawn from participating center, 7 withdrawn by investigator because of center or parental noncompliance, 1 withdrawn by parent because of scheduling conflicts); 1 child withdrew after 38 weeks but was unable to schedule an exit exam; and 6 children were excluded because they were present in the center less than 50% of the intervention days. There were no baseline differences among groups (Table 1) or between those children who were excluded and those who completed.

Intervention weeks were similar among groups and averaged 50 weeks (range, 38–58 weeks; Table 2). Children were present in the centers on an average of 78% of the 5-day workweek. Children randomized to receive calcium consumed less supplement on days they were present compared with children randomized to receive placebo. Overall compliance rates with the supplement, taking into account the number of days present in the center, were 56 ± 25% and 74 ± 12% in the calcium and placebo groups, respectively (p < 0.01). Average dietary calcium intakes were similar among groups, and total average calcium intake (diet + supplement) was greater in the calcium (1354 ± 301 mg/day) versus placebo group (940 ± 258 mg/day; p < 0.01).

Children randomized to gross motor activities participated on average in 92% of the days they were present versus 95% for children randomized to fine motor activities. Overall compliance rates with the gross motor and fine motor programs, taking into account the number of days the children were present, were 72% and 75%, respectively. Percent time in moderate plus vigorous activity, percent of time in vigorous activity, and total average daily accelerometer counts were similar at baseline but higher in gross motor versus fine motor groups at 6 and 12 months (Table 2). Percent of total daily counts that occurred during the activity programs also differed between gross motor and fine motor groups at both 6 and 12 months.

The height increase was different between calcium and placebo groups (Table 3). Least-square means ± SE for changes in height were 6.9 ± 0.2 and 7.4 ± 0.2 cm in the calcium and placebo groups, respectively. There was no relationship between the height gain per week and compliance with the supplement (number of supplements taken per supplements offered, r = 0.08, p = 0.5) or number of supplements received (r = 0.13, p = 0.2) among children who received calcium. Therefore, children who consumed
more of the supplements did not have less height gain than children consuming less.

There was a significant interaction between the activity and supplement groups in leg BMC gain (Fig. 1): the difference in BMC gain between gross motor and fine motor groups was more pronounced in children receiving calcium versus placebo. Among children receiving placebo, leg BMC gain was similar in the gross motor and fine motor groups. However, among children receiving calcium, those in the gross motor group had 9.7% greater increase in leg BMC than those in the fine motor group. Because of the high calcium intake among this population, we also analyzed calcium intake as quartiles. Similar results were obtained except for the relationship between change in height and calcium intake, which was not significant (p = 0.13, changes in height with increasing calcium quartiles of 7.1 ± 0.2, 7.5 ± 0.2, 6.9 ± 0.2, and 7.4 ± 0.2 cm). The interaction between activity group and quartile of calcium intake on leg BMC change was significant (Fig. 2, p = 0.05). Similar results were obtained when the 11 non-white children were excluded from the analyses. We also investigated the relationship between change in leg BMC per change in bone

### Table 2. Compliance With Activity and Supplement Interventions (Mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>Fine motor + calcium (n = 45)</th>
<th>Fine motor + placebo (n = 45)</th>
<th>Gross motor + calcium (n = 43)</th>
<th>Gross motor + placebo (n = 43)</th>
<th>p Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weeks of intervention (range)</td>
<td>50.6 (38–55)</td>
<td>49.9 (39–54)</td>
<td>50.8 (39–58)</td>
<td>49.9 (39–54)</td>
<td>0.95</td>
</tr>
<tr>
<td>Time between scans (weeks)</td>
<td>51.8 ± 4.1</td>
<td>51.3 ± 4.3</td>
<td>52.0 ± 3.3</td>
<td>50.9 ± 4.5</td>
<td>0.90</td>
</tr>
<tr>
<td>Percent days present</td>
<td>78 ± 9</td>
<td>79 ± 9</td>
<td>77 ± 9</td>
<td>79 ± 9</td>
<td>0.97</td>
</tr>
<tr>
<td>Supplement compliance (when present)</td>
<td>71 ± 32</td>
<td>94 ± 13</td>
<td>75 ± 29</td>
<td>93 ± 10</td>
<td>0.67</td>
</tr>
<tr>
<td>Overall compliance with supplement</td>
<td>55 ± 26</td>
<td>74 ± 13</td>
<td>58 ± 24</td>
<td>74 ± 12</td>
<td>0.62</td>
</tr>
<tr>
<td>Average dietary calcium intake (mg/d)</td>
<td>951 ± 286</td>
<td>904 ± 273</td>
<td>955 ± 242</td>
<td>977 ± 240</td>
<td>0.33</td>
</tr>
<tr>
<td>Average calcium intake (diet + supplement, mg/d)</td>
<td>1340 ± 337</td>
<td>904 ± 273</td>
<td>1367 ± 266</td>
<td>977 ± 240</td>
<td>0.30</td>
</tr>
<tr>
<td>Compliance with activity program (when present)</td>
<td>96 ± 6</td>
<td>95 ± 12</td>
<td>90 ± 10</td>
<td>93 ± 10</td>
<td>0.13</td>
</tr>
<tr>
<td>Overall compliance with activity program</td>
<td>75 ± 10</td>
<td>75 ± 13</td>
<td>70 ± 12</td>
<td>74 ± 12</td>
<td>0.13</td>
</tr>
<tr>
<td>Mean percent time in moderate + vigorous activity</td>
<td>12.6 ± 4.4</td>
<td>12.8 ± 4.5</td>
<td>14.6 ± 5.6</td>
<td>14.6 ± 4.5</td>
<td>0.01</td>
</tr>
<tr>
<td>6 Months</td>
<td>11.8 ± 4.1</td>
<td>11.1 ± 3.4</td>
<td>13.1 ± 4.0</td>
<td>12.9 ± 3.8</td>
<td>0.01</td>
</tr>
<tr>
<td>Mean percent time in vigorous activity</td>
<td>5.1 ± 2.5</td>
<td>4.8 ± 2.5</td>
<td>6.1 ± 3.5</td>
<td>5.7 ± 2.4</td>
<td>0.04</td>
</tr>
<tr>
<td>6 Months</td>
<td>4.6 ± 2.5</td>
<td>4.0 ± 1.9</td>
<td>5.3 ± 2.2</td>
<td>5.0 ± 2.1</td>
<td>0.02</td>
</tr>
<tr>
<td>Average daily sensor counts (×10,000)</td>
<td>28.1 ± 8.5</td>
<td>27.7 ± 8.8</td>
<td>30.9 ± 11.3</td>
<td>31.0 ± 8.4</td>
<td>0.03</td>
</tr>
<tr>
<td>6 Months</td>
<td>26.4 ± 8.5</td>
<td>24.6 ± 6.8</td>
<td>28.1 ± 7.4</td>
<td>27.8 ± 7.1</td>
<td>0.04</td>
</tr>
<tr>
<td>Percent daily counts during activity program</td>
<td>3.1 ± 2.1</td>
<td>2.9 ± 1.2</td>
<td>8.6 ± 4.2</td>
<td>9.1 ± 3.8</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>6 Months</td>
<td>3.0 ± 1.4</td>
<td>3.5 ± 1.5</td>
<td>8.9 ± 3.8</td>
<td>8.7 ± 3.0</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

* Analyzed using Student’s t-test.
Data are mean ± SD.

<table>
<thead>
<tr>
<th></th>
<th>Activity</th>
<th>Supplement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p Value</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>0.23</td>
<td>0.41</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.53</td>
<td>0.02</td>
</tr>
<tr>
<td>TB lean (kg)</td>
<td>0.55</td>
<td>0.11</td>
</tr>
<tr>
<td>TB fat (kg)</td>
<td>0.97</td>
<td>0.78</td>
</tr>
<tr>
<td>TB BMC (g)</td>
<td>0.01</td>
<td>0.95</td>
</tr>
<tr>
<td>Arm BMC (g)</td>
<td>0.18</td>
<td>0.54</td>
</tr>
<tr>
<td>Leg BMC (g)</td>
<td>0.42</td>
<td>0.90</td>
</tr>
<tr>
<td>TB BA (cm²)</td>
<td>0.27</td>
<td>0.93</td>
</tr>
<tr>
<td>Arm BA (cm²)</td>
<td>0.09</td>
<td>0.25</td>
</tr>
<tr>
<td>Leg BA (cm²)</td>
<td>0.20</td>
<td>0.74</td>
</tr>
</tbody>
</table>

TB, total body; BMC, bone mineral content; BA, bone area.
* Covariates included in all models were time between scans, number of supplements taken, days of participation, age, gender, childcare center, and history of preterm birth. For BMC and bone area measurements, change in weight, height, and percent body fat also were included.
† Analyzed using analysis of covariance. Data are least-square means ± SEM.
area by total calcium intake for each activity group. Change in leg BMC per change in bone area was not correlated with calcium intake among children in the fine motor group ($r = -0.09, p = 0.42$) but was correlated with intake among children in the gross motor group ($r = 0.30, p = 0.005$).

There were no baseline differences in mean periosteal and endosteal circumferences and cortical area and thicknesses among groups (Table 4). Overall means at baseline for periosteal circumference, endosteal circumference, cortical area, and cortical thickness were 46.7 ± 3.5 mm, 38.5 ± 4.4 mm, 54.8 ± 9.3 mm$^2$, and 1.30 ± 0.25 mm, respectively. After the intervention, children in the gross motor group had greater periosteal and endosteal circumferences than children in the fine motor group (Fig. 3). Neither circumference differed by calcium group. The interaction between activity and supplement groups was significant for both cortical area and thickness. Figure 4 is a diagrammatic illustration of the effects of activity and calcium on periosteal and endosteal circumferences and cortical thickness.

### DISCUSSION

In this randomized trial, we tested the hypothesis that calcium intake modifies the bone response to physical activity in young children. We found no positive effect of physical activity on changes in leg bone mass unless the children were consuming high calcium intakes (≥1100 mg/day). However, physical activity led to increases in both periosteal and endosteal tibia circumferences independent of calcium intake. These results indicate that physical activity stimulates bone growth in diameter, but the amount of mineralized bone is dependent on both physical activity and calcium intake.

The finding of a bone benefit with physical activity is consistent with cross-sectional studies showing that physically active children have greater bone mass or density than sedentary children. However, cross-sectional studies are difficult to interpret because of potential selection bias. Physically active children are likely to have other characteristics, such as greater lean mass, that also may contribute to high bone density. Conducting randomized activity trials minimizes potential biases. However, not all trials have shown a bone benefit from physical activity. Our finding of an interaction between physical activity and calcium intake may explain some of the previous inconsistent findings on the role of activity on bone health.

There are several reviews of adult trials on the effects of activity on bone mass. As reported by these authors, study results are not consistent. Inconsistent findings also are observed with calcium supplementation trials. Reported percent contributions of environmental and genetic factors in explaining observed variance in bone density sum to greater than 100%, illustrating that it is unlikely these factors contribute to bone density independent of each other. Physical activity and calcium intake each are found to contribute to explaining up to 40% of the variance in bone density, whereas genetic factors are estimated to explain around 80%.

It has been proposed that calcium intake may have a potentiating effect in allowing physical activity or genetic characteristics to exert effects on bone density. When adult activity trials were summarized based on the mean calcium intake for each study population, a positive relationship between spine BMD change and calcium intake was observed only among the groups randomized to an exercise program. There was no relationship between spine BMD change and calcium intake among control groups. Thus, physical activity had a beneficial bone effect only at higher calcium intakes. In the current study, we found a similar interaction between physical activity and calcium intake among young children, consistent with the results of the meta-analysis of adult activity trials.

Results of the six activity trials in either infants or children reported to date have been inconsistent. The majority of studies that measured predominantly trabecular bone sites, such as the spine, find a greater increase in bone density with activity compared with controls. These findings are compatible with animal studies showing that mechanical stimulation increases both trabeculae number and size. Reports on activity effects at predominantly cortical bone sites are not seen in all studies. Although we did not
measure a trabecular bone site, we did find that gross motor activity alters bone shape at 20% distal tibia shaft.

Bone responds locally to loading by increasing modeling and remodeling to give a stronger structure. Animal studies show that skeletal loading with minimal bone strain can result in increased bone remodeling in a short time period. Expanded periosteal circumference and cortical thickness with increased activity indicate that skeletal loading leads to a greater combination of compression, torsion, and bending forces among children randomized to gross motor activities. Whether the dissimilar finding of greater periosteal circumference by pQCT than children in the fine motor activity group is consistent with animal studies, which used DXA scans to estimate femoral shaft periosteal and endosteal diameters, reported no activity effect on periosteal expansion, but did report a decrease in endosteal diameter in children assigned to physical activity.

The type of force applied to bone also may determine the type of bone response. Petit et al. suggested that the reason an endosteal circumference decrease, and not a periosteal increase, was observed in their study was because of the higher axial compression forces that resulted from jumping. Axial compression forces are considered to be more likely to induce bone formation on the endosteal surface, while torsion or bending forces are more likely to induce bone formation on the periosteal surface. Our study provided a wide range in daily gross motor activities that would lead to a greater combination of compression, torsion, and bending forces among children randomized to gross motor versus fine motor activities. Whether the dissimilar finding on periosteal adaptation to bone loading between us and

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**Table 4. Tibia Measurements by Activity and Supplement Group**

<table>
<thead>
<tr>
<th>Activity Group</th>
<th>Supplement</th>
<th>Periosteal Circumference (mm)</th>
<th>Endosteal Circumference (mm)</th>
<th>Cortical Area (mm²)</th>
<th>Cortical Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine Motor</td>
<td>Calcium</td>
<td>N = 23</td>
<td>48.2 ± 0.8</td>
<td>52.5 ± 2.0</td>
<td>1.20 ± 0.06</td>
</tr>
<tr>
<td>Fine Motor</td>
<td>Placebo</td>
<td>N = 21</td>
<td>48.3 ± 0.8</td>
<td>52.4 ± 2.1</td>
<td>1.24 ± 0.05</td>
</tr>
<tr>
<td>Gross Motor</td>
<td>Calcium</td>
<td>N = 16</td>
<td>48.3 ± 0.8</td>
<td>53.1 ± 2.1</td>
<td>1.21 ± 0.06</td>
</tr>
<tr>
<td>Gross Motor</td>
<td>Placebo</td>
<td>N = 16</td>
<td>48.3 ± 0.8</td>
<td>53.1 ± 2.1</td>
<td>1.21 ± 0.06</td>
</tr>
</tbody>
</table>

Analyzed using analysis of covariance. Data are least-square means ± SEM.

* Covariates included were age, gender, history of preterm birth, weight, height, and percent body fat.

† Covariates included were time between scans, number of supplements taken, days of participation, age, gender, childcare center, history of preterm birth, weight, height, and percent body fat.
other investigators is caused by the differences in the ages of the children studied, measurement methods, bone sites measured, or in the types of bone loading forces that were applied is not known. We found that the bone response to physical activity was modified by the child’s calcium intake. There seems to be no benefit of gross motor activity on changes in leg BMC measured by DXA among children randomized to placebo, but there does seem to be a benefit, in terms of change in leg BMC, of gross motor activity on those children randomized to calcium. However, using pQCT, we found that children participating in the gross motor activities had greater periosteal and endosteal circumferences than children participating in the fine motor activities regardless of their calcium intake. The relatively smaller cortical thickness and cortical area among children randomized to placebo and gross motor activity compared with placebo and fine motor activity could explain why similar BMC was observed by DXA despite differences in bone geometry. Our finding of an interaction between supplement and activity groups on leg BMC was confirmed by the observation of a positive relationship between change in leg bone mass and calcium intake among children in the gross motor group. No such relationship was apparent within the fine motor group.

Although some of the trials report beneficial bone effects of activity in prepubertal children,30,32,34 others find beneficial effects in pubertal, but not prepubertal, children.31 It is speculated that estrogen augments the bone response to activity,42 and the positive findings in pubertal, but not prepubertal, children would support this hypothesis. However, others have speculated that increased activity may enhance bone formation during the prepubertal years by acting synergistically with growth hormone.43 Based on the studies completed to date and the lack of preponderance of positive findings in one pubertal group versus the other, it currently is unclear whether pubertal status modifies the bone response to physical activity.

To our knowledge, this is the first report of a randomized trial using a factorial design to determine whether calcium intake modifies the bone response to physical activity in young children. Our findings indicate that physical activity increases bone circumference, and when combined with higher calcium intake, there is greater cortical thickness and area that we speculate is because of less endosteal expansion. It is unclear whether increases in cortical thickness among the group randomized to gross motor activities and placebo occur later in time compared with the gross motor plus calcium group. Ongoing follow-up visits among these children will allow us to clarify this issue.

ACKNOWLEDGMENTS

The authors are indebted to the parents, children, and childcare centers who participated in this study; Glaxo-SmithKline Beecham for providing the supplements; Dr Lianne Mulligan and Julie Wermers (study coordinator) for developing the activity programs; Dr Kevin Finn for validation of the accelerometers; Dr Kendra Kattelmann for overseeing the dietary analyses; the graduate nutrition students who analyzed dietary intake data; Drs Richard Horning and Timothy Wittig for reviewing the statistical analyses; Karen Woje for reviewing the manuscript; Neil Johannsen, Corey Wulf, Karen Finn, and Tami Hogg-Lorenzen for coordinating study procedures; and the numerous activity specialists who diligently lead the children through these programs. This work was supported by National Institutes of Health Grant R01 AR45310.

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Received in original form August 20, 2002; in revised form October 15, 2002; accepted November 15, 2002.