High Femoral Bone Mineral Density Accretion in Prepubertal Soccer Players

GERMAN VICENTE-RODRIGUEZ, IGNACIO ARA, JORGE PEREZ-GOMEZ, JOSE A. SERRANO-SANCHEZ, CECILIA DORADO, and JOSE A. L. CALBET

Department of Physical Education. University of Las Palmas de Gran Canaria, SPAIN

ABSTRACT

VICENTE-RODRIGUEZ, G., I. ARA, J. PEREZ-GOMEZ, J. A. SERRANO-SANCHEZ, C. DORADO, and J. A. L. CALBET. High Femoral Bone Mineral Density Accretion in Prepubertal Soccer Players. *Med. Sci. Sports Exerc.*, Vol. 36, No. 10, pp. 1789–1795, 2004. **Purpose:** To determine the effect of physical activity on bone mineral accrual during growth in prepuberal boys. **Methods**: Seventeen soccer players and 11 matched (physically active) control boys (Tanner 1–2, at the start of the study) were followed over a 3-yr period. Bone mineral content (BMC) and areal density (BMD) was measured by dual-energy x-ray absorptiometry. The maximal positive mechanical impulse (CJipos) and height jumped (Hj) during countermovement vertical jumps were assessed with a plate force. Additionally, 30-m running speed test (T_{30}), 300-m run test (AC), and 20-m shuttle run test (MAP) were performed. **Results**: The soccer players attained better results in MAP and AC than the controls ($P < 0.05$). At the end of the follow-up, the controls increased their percentage of body fat in 11 units ($P < 0.05$) whereas it remained unchanged in the soccer players. Lean body mass increased with growth but more in the soccer players than in the controls ($P < 0.05$). The soccer players exhibited greater BMC in the legs and greater BMD in all bone-loaded regions at the end of the study ($P < 0.05$). During these 3 yr, the soccer players gained twice as much femoral neck and intertrochanteric BMC than the control group ($P < 0.05$) and increased their femoral neck BMD by 10% and their mean hip BMD by a third more than the control group (both $P < 0.05$). Multiple regression analysis showed that the improvement in T_{30} and CJipos has predictive value for the enhancement of bone mass in growing boys. **Conclusion**: Long-term soccer participation, starting at a prepubertal age, results in greater improvement of physical fitness, greater acquisition of bone mass and a lower accumulation of body fat. **Key Words:** BONE MASS, PHYSICAL FITNESS, CHILDREN, EXERCISE

The accumulation of bone mass during childhood and adolescence may contribute more than half to the variability of bone mass with age (22). Extra gains in bone mass during growth could be crucial to achieve a high peak bone mass and to prevent osteoporotic fractures later in life. However, there is a lack of knowledge on the effects that common extracurricular physical activities, like soccer, might have on bone mass and density in prepuberal boys. This information is crucial to develop optimal exercise programs to enhanced bone acquisition during growth.

Cross-sectional studies suggest that physical activity promotes greater bone deposition in children than in adults (11,23,34). Weight-bearing activities increase bone mass more than nonweight-bearing activities in weight-loaded skeletal regions (8,29). Most of the studies relating to bone mass enhancement in pre- and peripubertal children have been carried out with female gymnasts, but there are some dealing also with boys (13,26). Ground reaction forces during gymnastic participations are close to 10 times body mass in prepubescent gymnast boys (13). This high-impact loading during gymnastic training has been associated with significantly greater bone mineral density (BMD) for the whole body (10), spine, and legs (28). Also, longitudinal case-control studies support the view that exercise increases bone mass (5,28). However, subjects participating in these studies were submitted to very high exercise volumes, which are far away from what is the usual day-to-day exercise practice of physically active children of the general population. In contrast, weight-supported activities associated with relatively low-magnitude ground-reaction forces do not have osteogenic effect on bone mass (14). Thus, it is needed to determine in ordinary children the influence on bone mass and density of ordinary physical activities like, for example, recreational out-of-school sport activities.

Soccer is possibly the most widely practiced sport in the world by children. And this sport involves several sprints, which evoke high mechanical stress on lower-limb bones, particularly due to the high ground-reaction forces elicited during sprinting (18). The latter combined with the forces generated during jumping and kicking may confer excellent osteogenic properties to soccer, as suggested by some cross-sectional studies carried out with adult soccer players (8). Adult amateur soccer players have increased bone mineral content (BMC) and BMD at the lumbar spine, hip, and lower extremities compared with age-, height-, and weight-matched sedentary controls of the same Caucasian popula-

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Address for correspondence: J. A. L. Calbet, M.D., Ph.D., Department of Physical Education., University of Las Palmas de Gran Canaria, Campus Universitario de Tafira, 35017 Las Palmas de Gran Canaria, Canary Island, Spain; E-mail: lopezcalbet@terra.es.
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tion (8). Also in prepubertal children, we have seen that soccer players show higher lumbar spine and femoral BMD that their nonphysically active age-, weight-, and height-matched control counterparts (33). Despite these cross-sectional data, conclusive evidence on the effect of long-term soccer participation on the growing skeleton is lacking. This information is required to propose scientifically grounded guidelines for sport participation, specifically designed to promote bone acquisition in prepuberal children.

Therefore, this study was carried out to test the hypothesis that, playing soccer for at least 3 $h \cdot wk^{-1}$ for 3 yr, starting before puberty, has additional osteogenic benefits than those obtained from the compulsory physical activities included in the physical education program of primary schools during the same period of time. A secondary aim was to determine which physical fitness related variables are the best predictors of BMC and BMD acquisition during growth.

MATERIALS AND METHODS

Approach to the Problem

Longitudinal data about the effect of recreational sport participation on bone mass development in prepuberal boys are lacking. Therefore, this study was designed to test the effect of extracurricular physical activities (soccer) on BMC and BMD accrual. We have previously reported higher BMD in prepubescent soccer players (33). Thus, we expect bone mass increases in those skeletal regions that have been directly loaded by exercise even with a low volume of training. As a novelty, we also attempted to determine physical fitness related variables with predictive value for BMC and density acquisition. For those reasons we have collected body composition and physical fitness data twice over a 3.3-yr period. Additionally, percentage of increase of each variable have been calculated to show not only if soccer players have enhanced bone mass (33) but also what physical fitness variable may have a value to predict the response in the bone-related variables.

Subjects

A representative sample of Gran Canaria prepubescent children population was obtained by multi-age stratified sampling, using as a reference the database of the ISTAC (Instituto Canario de Estadística). In so doing, the initial sample was composed by 104 children (Tanner < 2) recruited from different schools and soccer clubs of Gran Canaria. Fifty-three were ascribed to the football group as they have been playing soccer for at least 1 yr (1.8 ± 0.2) and at least three times a week. The other 51, whose physical activities were limited to those included in the compulsory physical education curriculum (two weekly sessions of 45 min each), were assigned to the control group. Most of soccer players were recruited from sport clubs, whereas all the control group subjects were recruited from schools. The control group subjects did not participate in any kind of sport other than occasional children games, nor had they done so for at least 1 yr before the study as they answered during a personal interview. The boys answered a medical and physical activity questionnaire, and their parents gave additional medical information such as past injuries, medication, and known diseases. None of the subjects reported any excluding information. All children maintained their habitual physical activity over the follow-up period. Calcium intake was estimated from an analysis of habitual consumption of dairy products, as previously reported (33). Data were obtained from a personal interview where every boy answered a questionnaire about their usual daily intake of dairy products, that is, yogurt, different kind of cheese, milk, and so on.

These subjects were followed up over 3.3 yr. But at the end of the follow-up, only 28 boys (Tanner 3–4) kept in their initial status as soccer players (17) or controls (11) with the same criterions at the start of the follow-up. Therefore, at the end of the follow-up, the soccer players had been playing soccer for 5 yr and controls did not participate in any kind of sport during the previous 4 yr. Both parents and children were informed about the aims and procedures of the study, as well as the possible risks and benefits. The study was performed in accordance with the Helsinki Declaration of 1975 as regards the conduct of clinical research, being approved by the Ethical Committee of the University of Las Palmas de Gran Canaria. Written informed consent was obtained from subjects and their parents.

In general, soccer training sessions lasted for 1 h, including about 10 min of low-intensity games and stretching exercises, 10–25 min of technical soccer exercises (kicking actions, dribbling, jumping, and running with fast accelerations and decelerations) and 20–30 min of soccer match practice.

Pubertal Status Assessment

Tanner pubertal status was determined by auto-evaluation, a method of recognized validity and reliability (15).

Physical Fitness

Dynamic and maximal isometric force. The forces generated during vertical jumps were measured with a force plate (Kistler, Winterthur, Switzerland). Each boy performed a maximal counter movement jump (CMJ), starting from a standing position allowing for counter movement, with the intention of reaching knee bending angles of around 90° just before impulsion. The knee angle was measured with a digital goniometer (Lafayette Instrument Company, Lafayette, IN). The jumping height (Hj), peak force (Fp, or maximal force-body mass), positive impulse, and mean power (Mp) generated were determined in the best of three trials.

The maximal isometric force (MIF) during leg extension in the squat position (knees bent at 90°) was also measured with the same force plate, described previously (9). Briefly, during 5 s, subjects were encouraged to exert the highest strength in the lowest time. The best of three attempts, with a 1-min rest period in between, was recorded.

Anaerobic capacity. A 300-m running test was used to estimate the anaerobic capacity because the anaerobic capacity is the first determinant of performance in maximal all-out efforts eliciting exhaustion between 30 and 60 s (6,7). The test was performed on a 400-m track, and timings were measured manually. The boys were asked to run the 300 m as fast as possible.

Running speed test. The time needed to cover 30 m (T_{30}) was measured with photoelectric cells (General ASDE, Valencia, Spain). The timer is automatically activated when the subject crosses the first cell, every 5 m thereafter. The boys were motivated to run as fast as they could, and the best performance achieved in three trials separated by at least a 1-min rest period was taken as the representative value of this test.

Aerobic maximal power. The maximal oxygen uptake ($\dot{V}O_{2max}$) was estimated using a reliable maximal multistage 20-m shuttle run test as it is described elsewhere (33). Subjects were required to run back and forth on a 20-m course and be on the 20-m line at the same time that a beep is emitted from a tape. The frequency of the sound signals increases in such a way that running speed starts at 8.5 km·h^{-1} and is increased by 0.5 km·h^{-1} each minute. The length of time the subjects were able to run for was recorded to calculate the $\dot{V}O_{2max}$.

Bone and lean mass. Bone mass and lean mass (body mass − [fat mass + bone mass]) were measured using dual-energy x-ray absorptiometry (DXA) (QDR-1500, Hologic Corp., Software version 7.10, Waltham, MA). DXA equipment was calibrated using a lumbar spine phantom and following the Hologic guidelines. Subjects were scanned in supine position and the scans were performed in high resolution. Lean mass (g), fat mass (g), total area (cm^2), and BMC (g) were calculated from total and regional analysis of the whole body scan. BMD (g·cm^{-2}) was calculated using the formula BMD = BMC·area^{-1}. The regional analysis was performed as described elsewhere (8). Lean mass of the limbs was assumed to be equivalent to the muscle mass.

Two additional examinations were conducted to estimate bone mass at the lumbar spine and proximal region of the femur. BMC and density values of the femoral neck, greater trochanter, inter-trochanteric, and Ward‘s triangle subregions are also reported.

Statistical Analysis

Mean and SEM are given as descriptive statistics. Differences between groups were established using Student's unpaired *t*-test. ANCOVA were performed to evaluate differences in bone mass, entering the increment in height, body mass, age, and final age as covariates. The reason for using these covariates is based on evidence identifying height, age, and body mass as influential factors on the growing skeleton (17,31). Additionally, bivariate correlation and linear stepwise multiple regression analysis was applied to identify the relationships between physical fitness and bone mass variables. SPSS package (SPSS Inc, Chicago, IL) for Personal Computer was used for the statistical analysis. A P value less than 0.05 was considered significant.

RESULTS

Physical Characteristics and Physical Fitness

The subjects' age, calcium intake, and anthropometrics were comparable at base line and 3.3 yr later (Table 1). Calcium intake decreased by approximately 40% ($P < 0.05$) in both groups with growth, due to a lower consumption of dairy products with growth. Increases in physical fitness were similar in both groups, although the soccer players tended to augment their aerobic maximal power ($P = 0.07$) and increased their anaerobic capacity by 7% more than the control group ($P < 0.05$).

Body Composition

Although the percentage of body fat (%BF) did not change during the 3.3 yr in the soccer players, it increased by 11 units in the control group ($P < 0.05$). Total lean body mass increased 6% more in the soccer players than in the control group ($P < 0.05$).

Whole body. Whole body BMC increased similarly in both groups with growth, but at the end of the study, lower-extremity BMC was higher in the soccer players than in the controls (333.1 ± 9.1 g vs 296.3 ± 12.6 g, $P < 0.05$; size = 0.42, power = 0.96). Likewise, whole body BMD increased with growth in both groups ($P < 0.05$) but more in the soccer players than in the controls ($P < 0.05$; size = 0.18, power = 0.52). In fact, soccer players gained 6% ($P < 0.05$; size = 0.36, power = 0.89) more leg BMD and a third more total BMD ($P < 0.05$; size = 0.18, power = 0.52) than the control group (Fig. 1). Consequently, whole body and regional BMD were greater in the soccer players at the end of the study ($P < 0.05$; size = 0.28–35, power = 0.76–0.89).

Spine regions. Lumbar spine (measured with the specific lumbar scan) and thoracic spine (obtained from the whole body scan) BMC and BMD increased similarly with growth. However, at the end of the follow-up, the lumbar spine BMC was 13% greater in soccer players than in the control group ($P < 0.05$; size = 0.20, power = 0.57).

TABLE 1. Subjects' age, calcium intake and anthropometrics results (mean ± SEM).

	1st		2nd	
	Soccer Players	Controls	Soccer Players	Controls
Age (yr)	8.7 ± 0.4	9.4 ± 0.3	12.0 ± 0.4	12.7 ± 0.3
Height (cm)	133.3 ± 2.4	134.8 ± 1.6	152.6 ± 3.1	155.6 ± 2.1
Body mass (kg)	30.4 ± 1.9	30.9 ± 1.6	44.0 ± 3.0	47.2 ± 3.1
Ca^{2+} (mg)	1525.2 ± 127.0	1531.8 ± 175.6	802.1 ± 93.2	872.0 ± 112.2

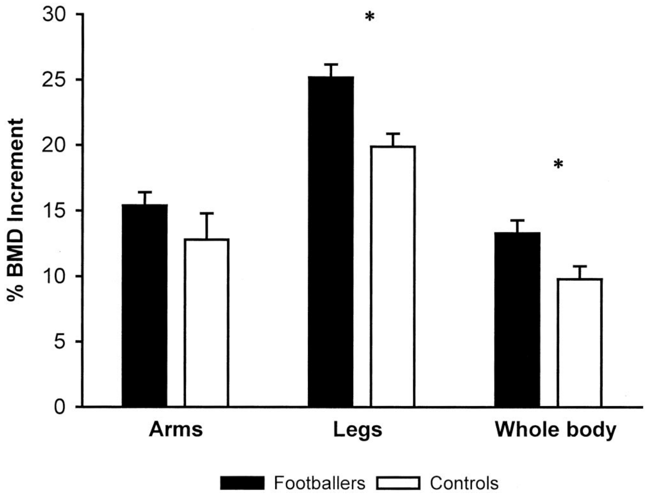

FIGURE 1—Bone mineral density (BMD) increments in whole body, legs, and arms in soccer players and controls; $^*P < 0.05$.

Likewise, lumbar and thoracic spine BMD was 10 and 6% greater ($P < 0.05$; size = 0.36 and 0.24, power = 0.89 and 0.67) in the soccer players at the end of the study.

Hip regions. Femoral neck and intertrochanteric BMC increased twice more in the soccer players than in the control group, which resulted in two times higher increment of the soccer players' mean hip BMC (all, $P < 0.05$; size = 0.23, power = 0.63–65; Fig. 2). Femoral neck BMD increased by 10% and the mean hip BMD by a third more in the soccer players than in the controls (both $P < 0.05$; size = 0.32, power = 0.83 and size = 0.30, power = 0.79; Fig. 2). Nevertheless, mean hip and subregional femoral BMC were similar in both groups except the femoral neck BMC that was higher in the soccer players ($P < 0.05$; size = 0.34, power = 0.86). Additionally, mean hip and subregional femoral BMD were 8–16% higher in the soccer group compared with the control group at the end of the follow-up ($P < 0.05$; size = 0.31 and 0.23–0.33, power = 0.81 and 0.66–85).

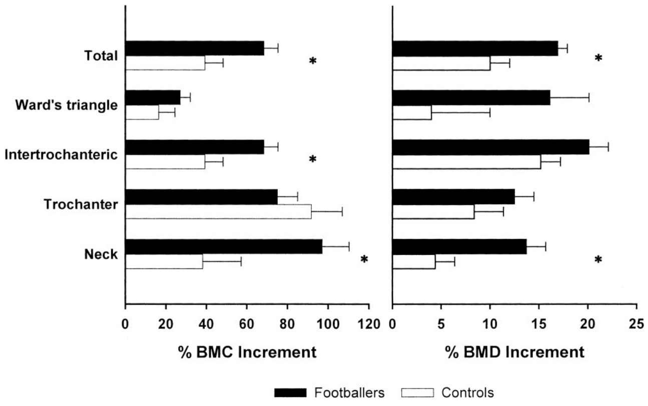

FIGURE 2—Increments in BMC and density (BMD) in the total femoral and the femoral zones; $^*P < 0.05$.

Relationship between Physical Fitness and Bone Mass and Density

Among all physical fitness variables, the increment of the positive mechanical impulse generated during the CMJ (CJipos) showed the highest correlation with the increment of mean hip and lumbar BMC and BMD (Fig. 3). The increment in running speed (T_{30}) showed a weak relationship with the increment in lumbar BMD ($P < 0.05$). Likewise, the increment in anaerobic capacity (T_{300}) also directly correlated with lumbar and femoral bone variables ($P < 0.05$).

Multiple regression analysis showed that the increment in height, CJipos, and T_{30} were the variables with the highest predictive value for BMC and BMD (mean hip BMC (BMCh) and BMD (BMDh)) increments in growing boys in different regions, as reflected in the following equations: Δ BMCh (g) = $2.087 \cdot \Delta$ CJipos (kp·s) $- 1.733 \cdot \Delta$ Body mass (kg) $- 3.847 \cdot \Delta T_{300}$ (s) $- 0.613$ (R = 0.89, $P < 0.001$; SEE = 0.04); Δ BMDh (g) = $1.635 \cdot \Delta$ height (m) $- 0.649 \cdot \Delta T_{30}$ (s) $- 0.142$ (R = 0.85, $P < 0.001$; SEE = 0.04); Δ lumbar BMC = $7.369 \cdot \Delta$ height (m) $- 0.749 \cdot \Delta T_{30}$ (s) $- 0.606$ (R = 0.96, $P < 0.001$; SEE = 0.07); and Δ lumbar BMD = $0.316 \cdot \Delta$ CJipos (kp·s) $- 0.606 \cdot \Delta T_{30}$ (s) $- 0.0516$ (R = 0.88, $P < 0.001$; SEE = 0.04).

DISCUSSION

The present study reports an osteogenic effect on regional BMC and total and regional BMD in early pubertal boys who played soccer for 3 $\text{h} \cdot \text{wk}^{-1}$ over a 3-yr period. Moreover, as expected, soccer players maintained their fat mass and improved their lean mass and their physical fitness, whereas their nonphysically active age-, weight-, and height-matched control counterparts increased their %BF (11 units) and did not change their lean mass.

The beneficial effect of soccer practice on bone development is well documented in adults (1,8). Increases in whole body, hip, and lumbar spine bone mass in female (1,16) and male (8) soccer players have been observed. Previous cross-sectional studies in our laboratory demonstrated that recreational soccer players who started soccer practice during their prepuberal years have between 13 and 24% greater regional BMC than the control subjects (8). In agreement, in the present study the soccer players with Tanner 3–4 showed 12% higher leg BMC compared with the control group. In addition, a recent cross-sectional study suggested that the beneficial effect of soccer participation on bone mass and density is already present in prepubertal boys (33). Interestingly, it has been reported that the femoral neck area appears to be especially sensitive to the mechanical stress elicited by soccer actions in children, inasmuch as the prepubertal boys playing soccer for at least 1.8 yr show 7% greater femoral neck BMD than their physically active counterparts (33). Additionally, the trochanteric area was 10% larger in the prepubertal soccer players than in the control group (33), as previously observed in adult soccer players (8). What this study adds to previous knowledge is

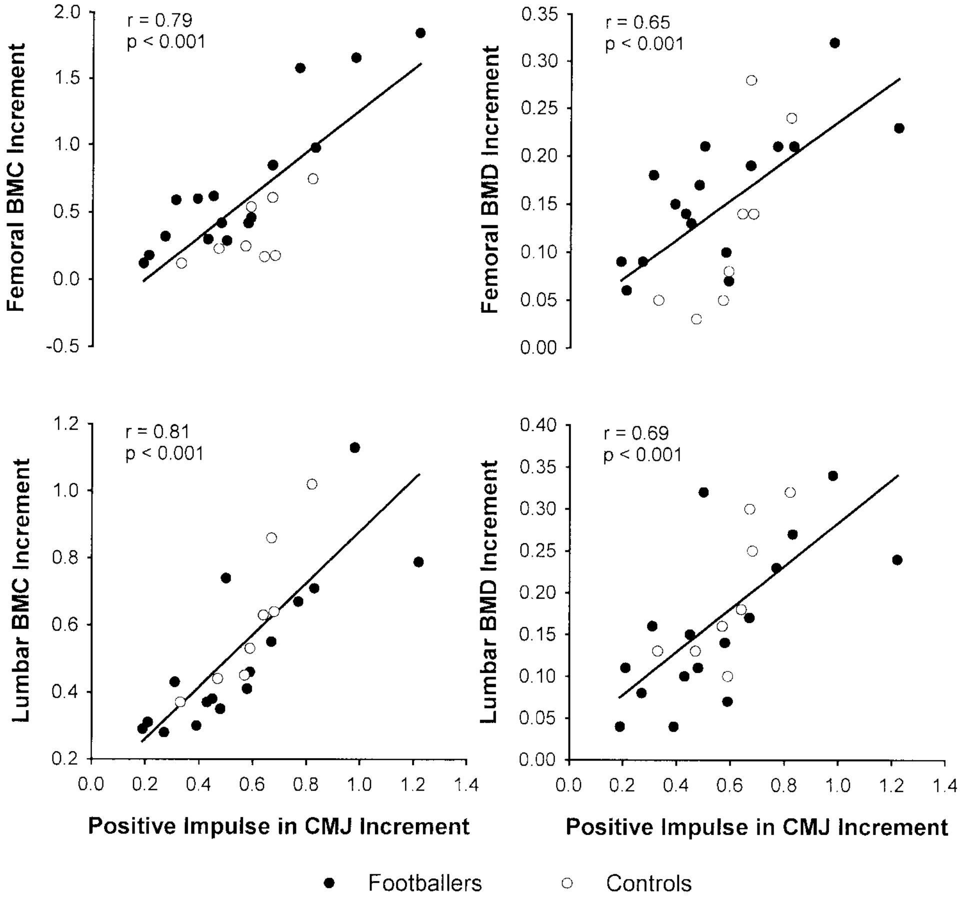

FIGURE 3—Relationship between the increment in femoral and lumbar BMC and density (BMD) with the anaerobic power increment.

that, despite the small number of subjects who did not vary their pattern of physical activity during the 3.3 yr of follow-up, it shows clearly that soccer participation stimulates bone acquisition in prepuberal children. Moreover, the present study has demonstrated a site specific effect of soccer participation, as there was no significant difference between the soccer group and the control group with regards to the BMD in the unloaded, nonweight-bearing bones, that is, arm and head bones. It should be emphasized that our results do not appear to be under the influence of a selection bias. If only subjects with naturally enhanced BMC and BMD were "selected" to practice soccer then, in contrast with our experimental observations, all skeletal sites, which include unloaded sites, should have had higher BMC and BMD in the soccer players than in the controls. Also, although individual dietary calcium intakes varied, both groups on average consumed similar amounts of calcium.

Even when no adjustments were done (for differences in increment in height, body mass, age, and final age), the soccer players still had a significantly higher increase in total and intertrochanteric femoral BMC than the controls. Some authors have suggested that BMC adjusted for differences in bone and body size is more comparable to the true volumetric bone density than the areal BMD (27). Because both groups had similar body mass, height, and bone area, this difference in BMC increase likely reflects a real difference in volumetric bone density increase.

Lean mass development may play an important role in the acquisition of a higher bone mineral peak (26). However, after adjusting for total lean mass, differences in bone variables remained statistically significant. The latter implies that additional factors apart from muscle mass development account for differences encountered in BMC and BMD.

It is known that one SD enhancement in femoral neck BMD would be expected to result in 50% or greater reduction of proximal femur fractures in adults (12). After 3 yr of extracurricular soccer participation, the soccer group enhanced their femoral neck BMD by two thirds and their total femoral BMD by twice that of the sedentary boys, resulting in a 9.5% higher femoral neck and 8% higher total femoral BMD. These increments in femoral bone might translate into reduced risk of bone fractures later in adult life. These findings provide further evidence, which indicates that exercise should be continued throughout the pubertal years in order to benefit from the increased responsiveness to load that immature bone has (4).

Prospective case-control studies have demonstrated beneficial effects in bone mass (5). Also, studies in other sports, like artistic gymnastics (13,25) or skipping (30), have shown osteogenic properties in the growing skeleton, similar to those observed in the present study. But, these kinds of activities and the time devoted to training in most of these studies are far away from the usual patterns of physical activity freely chosen by kids. Our study shows that just 3 h of soccer participation a week elicits a marked osteogenic effect on clinically relevant zones. This is why we think soccer may be considered as a low-cost and effective option to improve bone acquisition in growing children. School physical education is the primary program responsible for training the children and young people to be physically active and to motivate students to be engaged in moderate-to-vigorous physical activity. It is rather important to highlight that an increasing number of children exclusively performed the physical activity included in the school physical education sessions (Serrano Sanchez, personal communication), which are insufficient and inadequate to produce the required osteogenic effect to achieve the full potential for bone development.

There are three important questions to be answered: when should sport practice begin? For how long should people be active? When exercise participation is stopped, is the benefit achieved lost? Our data indicate that sport participation should start before the pubertal growth spurt (33) when bone tissue is more responsive to exercise. The latter could be due to the internal hormonal environment in children at the start of puberty (Tanner 1–2). Growth hormone, IGF-1, and testosterone increase during this period (2), enhancing bone growth and turnover through osteoblastic stimulation (21). In regard to the second question, our cross-sectional data suggest that it should be possible to elicit a greater increase in bone mass and density through a longer period of soccer participation (3,8,19,33). In fact, more than a quarter of adult total body bone mineral is accrued during a 2-yr period of fast bone mineral accrual during growth, approximately between 13 and 15 yr in boys (3). Our follow-up was finished when our subjects were under 13 yr old, so according to Bailey et al. (3) and Gustavsson et al. (19), they could potentially benefit from further enhancements of bone mass with soccer participation compared with that solely expected from the compulsory 80- to 90-min physical education school activities. The third question remains unanswered.

The present study also shows that the increment attained in some of the physical fitness related variables, particularly the increments in anaerobic power, positive mechanical impulse in CMJ, and 30-m running test, strongly correlated with mean hip and lumbar bone mass accretion. However, as happened in prepubertal boys (33), 30-m running speed test has the highest predictive value for bone mass accumulation in early puberal boys independently of the sport practice. Performance in a 30-m running test depends on muscle power (P), which in turn results from the optimal combination of force (F) and velocity (V) ($P = F \times V$) (24). Muscle mass is the main determinant of force (32) and bone mass (17) in children. Thus, part of the relationship between BMC and 30-m running test could be explained through the relationship between muscle mass and both BMC and 30-m running performance. The second factor in this equation, velocity, is related to muscle fiber phenotype (24). For a given muscle mass, the performance in the 30-m speed test is higher in subjects with a greater proportion of Type II fibers in the vastus lateralis (Vicente-Rodriguez, unpublished). Skeletal muscle Type II fibers contract faster and are capable to generate faster and higher forces than Type I fibers (24). Because muscle fibers exert its action on bones, in theory, subjects with a greater proportion of Type II fibers could potentially generate greater stress and strain on the bone where it inserts (20). Therefore, the performance on the 30-m running test depends on several factors, which, in turn, are associated with BMC and BMD.

CONCLUSIONS

Soccer participation entails benefits in cardiovascular physical fitness and soft tissue body composition as it counteracts the sociocultural tendency to accumulate body fat and improves lean mass. But the most important finding is that it has marked osteogenic effects in children, which may facilitate the acquisition of a higher bone mineral peak, which can translate into a reduction in the risk of bone fractures throughout life. In addition, this study proposes predictive equations to estimate the potential benefit elicited by soccer participation on bone mass and density depending on the improvements observed in some physical fitness variables.

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