Levels of Physical Activity That Predict Optimal Bone Mass in Adolescents
The HELENA Study

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Background: Physical activity is necessary for bone mass development in adolescence. There are few studies quantifying the associations between physical activity and bone mass in adolescents.

Purpose: To assess the relationship between moderate-to-vigorous physical activity (MVPA) and vigorous physical activity (VPA) and bone mass in adolescents.

Methods: Bone mass was measured by dual-energy X-ray absorptiometry and physical activity by accelerometers in 380 healthy Spanish adolescents (189 boys, aged 12.5–17.5 years) from the HELENA–CSS (2006–2007). Subjects were classified according to the recommended amount of MVPA (<60 minutes or ≥60 minutes of MVPA/day). Receiver operating characteristic curve analysis was applied to calculate the relationship between physical activity and bone mass.

Results: Less than 41 and 45 minutes of MVPA/day are associated with reduced bone mass at the trochanter and femoral neck. More than 78 minutes of MVPA/day is associated with increased bone mineral density (BMD) at the femoral neck. Regarding VPA, more than 28 minutes/day for the hip and intertrochanter and more than 32 minutes/day for the femoral neck are associated with increased BMD.

Conclusions: The recommended amount of physical activity (minutes/day) seems insufficient to guarantee increased bone mass. With some minutes of VPA/day, bone adaptations could be obtained at different bone sites.

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Introduction

Osteoporosis is a common health problem. In fact, about 2.7 million of European men and women suffer an osteoporotic fracture every year,[1] which is associated with high morbidity and mortality rates.[2] The economic burden of osteoporosis in Europe is higher than any kind of cancer (except lung cancer) or chronic cardiorespiratory diseases[2,3] and represents a direct annual cost of $48 billion.[1] To improve the outcome for osteoporosis sufferers, prevention remains the most important action in public health.

Acquiring a high bone mass during childhood and adolescence is a key determinant of adult skeletal health[4]

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and it may decrease the risk of osteoporotic fractures by 50%.[5,6] Exercise has been associated with bone accretion showing an important osteogenic effect, mainly when high-impact and weight-bearing physical activity occur.[7] Muscle mass is also a determinant of bone development.[8] Intensive physical activity, for example, participation in sport, is associated with increased development of muscle mass during growth.[8,9] Therefore, exercise may indirectly increase bone mass by increasing lean mass. In terms of bone health, it is not only the amount of physical activity that is important but also the type of physical activity.

Physical Activity Guidelines for children and adolescents recommend (1) that young people should accumulate at least 60 minutes (up to several hours) of moderate-to-vigorous physical activity (MVPA) per day; and (2) at least 3 days per week this should include activities to improve bone health and muscle strength.[10] To date, most studies assessed physical activity subjectively (i.e., using questionnaires), even when it has been shown that participants could under- or over-report physical activity in this population group,[11,12] which is an important issue. However, few studies have evaluated the association of objectively assessed physical activity and bone mass in adolescents. One study[13] showed a positive association between total hip BMC and the time spent (minutes/day) in vigorous and total physical activity in Swiss boys aged 6–13 years; although another study[14] of boys and girls aged 11 years from the United Kingdom showed a positive association between lower limbs' BMD and the time spent (minutes/day) in MVPA.

It is relevant to know whether current physical activity recommendations for adolescents are sufficient for healthy bone mass development, and this has not been studied yet. Therefore, the aim of this report is to analyze the relationships between MVPA and vigorous physical activity (VPA) and bone mass in different regions (whole body, pelvis, lumbar spine, and total hip) and subregions (trochanter, intertrochanter, and femoral neck).

Methods

Subjects

The HELENA (Healthy Lifestyle in Europe by Nutrition in Adolescence) project is funded by the European Union and includes a cross-sectional multicenter study (HELENA–CSS) that was performed in adolescents aged 12.5–17.5 years from ten European cities[15] in 2006–2007. The general characteristics of the HELENA–CSS have been described in detail elsewhere.[16] In this report, the only sample included is from the only city (Zaragoza) where bone mineral content (BMC) and bone mineral density (BMD) were measured by dual-energy X-ray absorptiometry (DXA). The total sample of adolescents with valid data (DXA and objectively measured physical activity) was 380 (189 boys and 191 girls). Ten subjects were excluded because they did not wear the accelerometer. Signed informed consent was obtained from parents and adolescents, and the protocol was approved by the Ethics Committee of Clinical Research from the Government of Aragón (CEICA, Spain).

Anthropometric Measurements

International guidelines for anthropometry in adolescents were applied.[17] Body weight (kg) and height (cm) were measured with an electronic scale (Type SECA 861, precision=100 g, range=0–150 kg) and a stadiometer (Type Seca 225, precision=0.1 cm, range=70–200 cm), respectively, while barefoot and wearing light indoor clothing.

Pubertal Development

Physical examination was performed by a physician aiming to classify the adolescents in one of the five stages of pubertal maturity defined by Tanner and Whitehouse.[18]

Bone, Lean, and Fat Mass

Adolescents were scanned using DXA (Hologic Explorer scanner, using a pediatric version of the software QDR-Explorer, version 12.4). Measurements were obtained from whole body, hip, and lumbar spine. The bone mass, fat mass, and lean mass [body mass – (fat mass + bone mass)] were measured. The DXA equipment was calibrated using a lumbar spine phantom as recommended by the manufacturer. For the whole body measurement, subjects were scanned in supine position and the scans were performed at a high resolution.[19] 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. Two additional examinations were conducted to estimate bone mass at the lumbar spine (mean L1–L4) and hip subregions (trochanter, intertrochanter, and femoral neck) as previously described.[20] Laboratory precision errors for regional analysis of the complete body scan, defined by the coefficient of variation (CV) for repeated measurements estimated in adolescent volunteers (n=49) with repositioning, were as follows: BMC=2.3%; BMD=1.3%; bone area=2.6%; and fat-free lean mass=1.9%.

Calcium Intake

Mean daily calcium intake was estimated from two nonconsecutive 24-hour recalls using the HELENA-DIAT (Dietary Assessment Tool) software.[21] For the assessment of calcium intake, the food composition tables published earlier[22] were used for the Spanish adolescents.

Physical Activity

A uniaxial accelerometer (Actigraph GT1M) was used to assess physical activity for 7 days, as described previously.[23] At least 3 days of recording with a minimum of 8 hours' registration per day was set as an inclusion criterion.

In this study, the interval of time (epoch) was set at 15 seconds. The time spent (minutes/day) at moderate physical activity (MPA; 3–6 METs) was calculated based on a cut-off of 2000–3999 counts per minute (cpm), which is approximately equivalent to an intensity of a brisk walk (4.5 km/h).[24] The time spent (minutes/day) at VPA (>6 METs) was calculated based on a cut-off of 4000 cpm. Further, MVPA (>3 METs) was calculated as the sum of moderate

and vigorous physical activity. The cut-offs to define the intensity categories are similar to those used in previous studies.[25]

Subjects were classified as non-active adolescents (<60 minutes/day of MVPA) and active adolescents (≥60 minutes/day of MVPA) according to the recent guidelines launched by the DHHS and other medical institutions.[10]

Statistics

All the variables showed normal distribution and the residuals showed a satisfactory pattern. Results are given separately by gender. Differences in bone mass–related variables by the time spent (minutes/day) in MVPA were established by one-way ANCOVA and Bonferroni post hoc. The dichotomized MVPA variable was entered as fixed factor, bone mass–related variables were entered as dependent variables, and height, pubertal status, lean mass, percentage of fat mass, and calcium intake were entered as covariates. Receiver operating characteristic (ROC) curve analysis was applied to calculate the relationship between MVPA and VPA and bone mass. BMC and BMD z-scores were calculated using a reference standard obtained by age and gender.[26] Once obtained, subjects were classified into four groups: less than M – 1 SD, less than M – 2 SD, more than M + 1 SD and more than M + 2 SD and considering each of them, they were entered in each model as a dichotomized variable (value of zero belongs to the group and value of one does not belong).

An ROC curve provides the whole spectrum of specificity/sensitivity values for all the possible cut-offs. The area under the curve (AUC) is determined from plotting sensitivity versus 1 – specificity of a test as the threshold varies over its entire range. Taking into account the suggested cut-off points, the test can be non-informative/test equal to chance (AUC=0.5); less accurate (0.5<AUC≤0.7); moderately accurate (0.7<AUC≤0.9); highly accurate (0.9<AUC≤ 1.0); and perfect discriminatory tests (AUC=1.0).[27] Cut-off points were selected for those scores optimizing sensibility–specificity relationship. In addition, ROC curve indexes of each cut-off point were calculated through the determination of positive and negative predictive values, overall misclassification rate, positive and negative likelihood ratios, and Youden Index.[28] Those indexes were calculated with EPIDAT software, version 3.1. SPSS, version 15.0, was used for the analysis. The probability value for the significance level was fixed at 0.05.

Results

Table 1 shows descriptive characteristics (M±SD) of the study sample. For boys, active adolescents had a significantly higher calcium intake and calcium intake/lean mass ratio and they spent more minutes on MVPA and VPA than non-active ones (all $p<0.05$). For girls, active adolescents were significantly taller and spent more minutes on MVPA and VPA, and they had significantly lower body mass and BMI than non-active ones (all $p<0.05$). Except for lumbar spine BMD in girls ($p<0.05$; Table 2), adjusted results showed no differences in BMC and BMD between MVPA groups.

As ROC curves showed only significant results for M – 1 SD and M + 2 SD, they appear throughout the paper as reduced and increased bone mass groups, respectively. ROC curves showed less-accurate specific thresholds ($p<0.05$) of MVPA (sensitivity range=0.797–0.880,

Table 1. Descriptive characteristics of the studied adolescents by MVPA recommended levels

	Boys		Girls	
	MVPA (minutes/day)		MVPA (minutes/day)	
	<60 minutes (n=85)	≥60 minutes (n=104)	<60 minutes (n=148)	≥60 minutes (n=43)
Age (years)	14.9 ± 1.2	14.6 ± 1.3	14.7 ± 1.1	15.1 ± 1.2
Sexual maturation (I/II/III/IV/V) (%)	(0/4/8/18/70)	(0/3/12/22/63)	(0/1/6/4/89)	(0/0/3/12/85)
Height (cm)	166.5 ± 21.2	166.2 ± 26.3	153.8 ± 33.5*	159.9 ± 6.6
Body mass (kg)	62.7 ± 12.7	61.6 ± 17.3	55.2 ± 9.6*	51.9 ± 6.2
Lean mass (kg)	45.3 ± 8	45.5 ± 9.4	35.5 ± 4.9	35.2 ± 3.9
Fat mass (%)	23.4 ± 6.4	25.7 ± 7.7	26.4 ± 7.7	27.7 ± 8.3
BMI	22.6 ± 3.8	22.3 ± 3.2	23.3 ± 3.4*	20.3 ± 2.2
Calcium intake (mg/day)	803.9 ± 310*	949.9 ± 420.1	702 ± 304.8	663.2 ± 277.4
Calcium intake/lean mass ratio (mg/kg)	0.018 ± 0.007*	0.021 ± 0.01	0.02 ± 0.01	0.019 ± 0.008
MVPA minutes	45 ± 11*	82 ± 20	40 ± 11*	77 ± 15
VPA minutes	14 ± 7*	33 ± 13	10 ± 6*	27 ± 12

Note: Results are given as M±SD.
*$p<0.05$ (between MVPA groups)
MVPA, moderate-to-vigorous physical activity; VPA, vigorous physical activity

Table 2. BMC and BMD by MVPA recommended levels adjusted for height, pubertal status, lean mass, percentage of fat mass, and calcium intake

	Boys		Girls	
	MVPA (minutes/day)		MVPA (minutes/day)	
	<60 minutes (n=85)	≥60 minutes (n=104)	<60 minutes (n=148)	≥60 minutes (n=43)
BMC (g)				
Whole body	2145.86 ± 23.66	2112.68 ± 21.41	1881.24 ± 16.21	1842.96 ± 31.56
Hip	36.52 ± 0.84	37.09 ± 0.75	26.25 ± 0.31	26.33 ± 0.60
Lumbar spine	52.60 ± 0.96	50.95 ± 0.87	50.23 ± 0.65	48.12 ± 1.26
Hip scan				
Trochanter	8.88 ± 0.21	8.64 ± 0.19	6.41 ± 0.11	6.48 ± 0.22
Intertrochanter	22.98 ± 0.80	23.85 ± 0.72	16.00 ± 0.22	16.04 ± 0.44
Femoral neck	4.66 ± 0.08	4.59 ± 0.07	3.83 ± 0.04	3.82 ± 0.07
BMD (g/cm^2)				
Whole body	1.073 ± 0.009	1.059 ± 0.008	1.044 ± 0.007	1.029 ± 0.014
Hip	10001 ± 0.013	0.993 ± 0.012	0.901 ± 0.008	0.892 ± 0.015
Lumbar spine	0.892 ± 0.011	0.865 ± 0.010	0.942 ± 0.009*	0.900 ± 0.016
Hip scan				
Trochanter	0.798 ± 0.015	0.794 ± 0.013	0.707 ± 0.007	0.704 ± 0.013
Intertrochanter	1.135 ± 0.015	1.113 ± 0.013	1.032 ± 0.010	1.018 ± 0.019
Femoral neck	0.916 ± 0.015	0.908 ± 0.013	0.843 ± 0.008	0.839 ± 0.015

Note: Results are given as M±SE.
*p<0.05 (between MVPA groups)
BMC, bone mineral content; BMD, bone mineral density; MVPA, moderate-to-vigorous physical activity; VPA, vigorous physical activity

specificity range=0.712–0.820) or VPA (sensitivity range=0.716–0.878, specificity range=0.730–0.927) for reduced bone mass groups in the femoral neck and trochanter subregion (Table 3) and less-accurate to moderately accurate specific thresholds (p<0.05) of MVPA (sensitivity=0.643, specificity=0.586) or VPA (sensitivity range=0.556–0.667, specificity range=0.608–0.846) for increased bone mass groups in the hip and intertrochanter and femoral neck subregions (Table 4), as the latter is of great importance because of its clinical relevance to osteoporosis. For all the significant cut-off points, the ROC curve indexes showed satisfactory results (Tables 3 and 4).

Discussion

The findings of the present study indicate that (1) there are no BMC and BMD differences in most body regions among adolescents regardless of whether they meet the current physical activity recommendations or not, and (2) specific thresholds of physical activity are associated with reduced or increased bone mass groups.

This is the first study analyzing, in adolescents, whether meeting the current physical activity recommendations (60 minutes/day of MVPA) or not has any effect on BMC and BMD at different body regions and subregions. In addition, there are no studies quantifying the amount of MVPA and VPA necessary to predict bone mass in such a critical period as adolescence.

Results showed no differences between active/nonactive adolescents (in both genders) in all analyzed body regions, except for the lumbar spine BMD in girls. Further analyses were made changing the MVPA cut-offs to tertiles. Results comparing adolescents in the different tertiles of MVPA showed no differences in most of the analyzed regions, except for trochanter BMC in boys (tertil 1 – tertil 2; p<0.05; data not shown). It has been reported that the effect of physical activity on bone mass could be mediated more by the kind of physical activity than by the total amount.[7] In a recent study[29] with prepubertal tennis players, the authors showed that the human skeleton has a great potential to adapt in response to

Table 3. Time of MVPA and VPA to predict low (–1 SD) BMC and BMD

	Minutes/day	AUC (CI)	Sensitivity	Specificity	OMR (%)[a]	PPV (%)[a]	NPV (%)[a]	PLR[a]	NLR[a]	A[a]
MVPA										
BMC										
Whole body	41	0.512 (0.428, 0.596)	0.736	0.344	—	—	—	—	—	—
Hip	46	0.538 (0.459, 0.618)	0.648	0.468	—	—	—	—	—	—
Lumbar spine	32	0.550 (0.406, 0.693)	0.879	0.294	—	—	—	—	—	—
Hip scan										
Trochanter	**41**	**0.579* (0.500, 0.659)**	**0.880**	**0.712**	**82.31**	**85.66**	**75.20**	**3.06**	**0.17**	**0.59**
Intertrochanter	32	0.534 (0.451, 0.616)	0.885	0.793	—	—	—	—	—	—
Femoral neck	**45**	**0.618** (0.540, 0.695)**	**0.797**	**0.820**	**82.05**	**87.66**	**73.55**	**4.11**	**0.21**	**0.63**
BMD										
Whole body	41	0.498 (0.416, 0.579)	0.742	0.323	—	—	—	—	—	—
Hip	46	0.536 (0.451, 0.621)	0.649	0.483	—	—	—	—	—	—
Lumbar spine	32	0.548 (0.429, 0.667)	0.879	0.261	—	—	—	—	—	—
Hip scan										
Trochanter	41	0.550 (0.464, 0.636)	0.761	0.397	—	—	—	—	—	—
Intertrochanter	47	0.534 (0.456, 0.612)	0.649	0.478	—	—	—	—	—	—
Femoral neck	41	0.568 (0.484, 0.652)	0.756	0.400	—	—	—	—	—	—
VPA										
BMC										
Whole body	15	0.516 (0.437, 0.596)	0.538	0.547	—	—	—	—	—	—
Hip	9	0.524 (0.444, 0.605)	0.757	0.323	—	—	—	—	—	—
Lumbar spine	7	0.557 (0.453, 0.614)	0.843	0.254	—	—	—	—	—	—
Hip scan										
Trochanter	**10**	**0.590* (0.513, 0.666)**	**0.878**	**0.730**	**82.43**	**85.04**	**77.44**	**0.17**	**3.26**	**0.61**
Intertrochanter	8	0.533 (0.451, 0.616)	0.793	0.293	—	—	—	—	—	—
Femoral neck	**19**	**0.624** (0.551, 0.697)**	**0.716**	**0.927**	**82.05**	**90.97**	**76.17**	**9.87**	**0.31**	**0.64**
BMD										
Whole body	15	0.511 (0.430, 0.591)	0.537	0.539	—	—	—	—	—	—
Hip	21	0.541 (0.460, 0.622)	0.423	0.741	—	—	—	—	—	—
Lumbar spine	6	0.560 (0.428, 0.692)	0.847	0.348	—	—	—	—	—	—
Hip scan										
Trochanter	21	0.552 (0.469, 0.634)	0.400	0.742	—	—	—	—	—	—
Intertrochanter	20	0.540 (0.464, 0.617)	0.419	0.702	—	—	—	—	—	—
Femoral neck	**20**	**0.581* (0.503, 0.660)**	**0.722**	**0.923**	**82.99**	**89.04**	**79.34**	**9.39**	**0.30**	**0.65**

Note: Boldface indicates significance.
[a]Only significant results are shown.
*$p<0.05$, **$p\leq0.01$
A, Youden index; AUC, area under the curve (ROC analysis); BMC, bone mineral content; BMD, bone mineral density; MVPA, moderate-to-vigorous physical activity; NLR, negative likelihood ratio; NPV, negative predictive value; OMR, overall misclassification rate; PLR, positive likelihood ratio; PPV, positive predictive value; VPA, vigorous physical activity

Table 4. Time of MVPA and VPA to predict high (+2 SD) BMC and BMD

	Minutes/day	AUC (CI)	Sensitivity	Specificity	OMR (%)[a]	PPV (%)[a]	NPV (%)[a]	PLR[a]	NLR[a]	A[a]
MVPA										
BMC										
Whole body	41	0.562 (0.419, 0.705)	0.909	0.270	—	—	—	—	—	—
Hip	57	0.643 (0.501, 0.786)	0.778	0.537	—	—	—	—	—	—
Lumbar spine	73	0.581 (0.392, 0.770)	0.545	0.759	—	—	—	—	—	—
Hip scan										
Trochanter	41	0.591 (0.45, 0.732)	0.909	0.290	—	—	—	—	—	—
Intertrochanter	57	0.541 (0.369, 0.714)	0.667	0.534	—	—	—	—	—	—
Femoral neck	78	0.544 (0.340, 0.747)	0.444	0.825	—	—	—	—	—	—
BMD										
Whole body	44	0.566 (0.373, 0.76)	0.889	0.331	—	—	—	—	—	—
Hip	78	0.673 (0.497, 0.848)	0.500	0.824	—	—	—	—	—	—
Lumbar spine	82	0.442 (0.168, 0.717)	0.333	0.849	—	—	—	—	—	—
Hip scan										
Trochanter	53	0.475 (0.293, 0.657)	0.600	0.479	—	—	—	—	—	—
Intertrochanter	46	0.664 (0.509, 0.818)	0.889	0.263	—	—	—	—	—	—
Femoral neck	**78**	**0.835** (0.735, 0.936)**	**0.643**	**0.586**	**63.33**	**87.66**	**26.45**	**1.55**	**0.61**	**0.23**
VPA										
BMC										
Whole body	23	0.609 (0.447, 0.771)	0.545	0.668	—	—	—	—	—	—
Hip	**19**	**0.692* (0.557, 0.828)**	**0.583**	**0.608**	**60.77**	**4.52**	**97.87**	**1.49**	**0.68**	**0.19**
Lumbar spine	22	0.632 (0.435, 0.829)	0.727	0.648	—	—	—	—	—	—
Hip scan										
Trochanter	28	0.665 (0.513, 0.818)	0.545	0.778	—	—	—	—	—	—
Intertrochanter	19	0.576 (0.411, 0.741)	0.777	0.574	—	—	—	—	—	—
Femoral neck	27	0.608 (0.408, 0.809)	0.555	0.757	—	—	—	—	—	—
BMD										
Whole body	38	0.567 (0.349, 0.786)	0.333	0.898	—	—	—	—	—	—
Hip	**28**	**0.802** (0.666, 0.937)**	**0.667**	**0.794**	**79.23**	**4.82**	**99.35**	**3.24**	**0.42**	**0.46**
Lumbar spine	38	0.477 (0.188, 0.765)	0.333	0.896	—	—	—	—	—	—
Hip scan										
Trochanter	24	0.514 (0.309, 0.719)	0.500	0.683	—	—	—	—	—	—
Intertrochanter	**28**	**0.741** (0.578, 0.908)**	**0.556**	**0.795**	**78.97**	**6.02**	**98.70**	**2.71**	**0.56**	**0.35**
Femoral neck	**32**	**0.889** (0.813, 0.964)**	**0.667**	**0.846**	**84.36**	**6.35**	**99.39**	**4.34**	**0.39**	**0.51**

Note: Boldface indicates significance.
[a]Only significant results are shown.
*$p<0.05$; **$p\leq0.01$
A, Youden index; AUC, area under the curve (ROC analysis); BMC, bone mineral content; BMD, bone mineral density; MVPA, moderate-to-vigorous physical activity; NLR, negative likelihood ratio; NPV, negative predictive value; OMR; overall misclassification rate; PLR, positive likelihood ratio; PPV, positive predictive value; VPA, vigorous physical activity

mechanical loading, even in tennis players who trained only 2 days/week. Tennis participation before puberty is associated with increased lean mass and bone mass in the playing arm.[30]

It is necessary to take into account the mechanical stress that bone must support, which depends on both the intensity and the type of exercise more than the amount of physical activity. Therefore, actions in sport that involves tensile, compressive, shear, bending, and torsion stresses that can elicit mechanostat-related mechanisms during growth have an osteogenic potential.[31] Although the use of accelerometers presents an interesting option for measuring physical activity, mainly because of their objective measurement, it is not possible to know the kind of physical activity that was accumulated during the suggested 60 minutes (e.g., bone-strengthening activities). Direct observation of physical activity behavior would be needed. In addition, some activities without impact (e.g., cycling or swimming), known to be associated with lower bone mass, are not registered with the Actigraph MTI (model GT1M) accelerometer. Similarly, bouts of short time but high-intensity weight-bearing activities, such as jumps, are also not registered.

It is known that adolescence is a key period for bone acquisition and also that it is determinant for future skeletal health.[4] In this regard, all the efforts focusing on physical activity and exercise, mainly intense, high-impact and weight-bearing activities, may be positively related to the development of bone mass during adolescence.[7] Although genetics plays the most important role, physical activity and exercise should be also taken into account in order to prevent the development of osteopenia, or at least to delay the appearance of any bone fragility–related problem as long as possible. This is especially important in girls, as they are at higher risk than boys of developing osteoporosis in adulthood.[32] Therefore, it is of considerable interest that the adequate MVPA thresholds that permit the identification of adolescents within reduced or increased bone mass groups be found. With this aim, ROC curves were used. Additional analyses were also made using VPA because adolescents have been shown to be engaged in high-intensity extracurricular sports activities.[33]

In order to define those physical activity levels that could prevent the development of osteopenia, it was observed that periods of less than 41 and 45 minutes/day of MVPA were associated with reduced BMC at the trochanter and femoral neck, and less than 20 minutes/day of VPA were also associated with reduced BMD at the femoral neck. These recommendations should be considered taking into account that accelerometers measure the amount of physical activity but not the type. Therefore, the minutes suggested might change if adolescents were doing osteogenic activities (i.e., jumps), which it is not possible to register with accelerometers. It could be useful for future studies to determine not only the amount of physical activity but also the type.

In order to guarantee optimal bone health, it was found that more than 78 minutes/day of MVPA was associated with increased BMD at the femoral neck, more than 19 minutes/day of VPA with increased BMC at the hip and more than 28 and 32 minutes/day of VPA with increased BMD at the intertrochanter and femoral neck. At the opposite end, as has been mentioned, about 20 minutes/day of VPA is needed to ensure at least normal bone mass in the femoral neck, which is one of the most important regions in terms of clinical relevance.

Taking into account that an important number of regions and subregions have been analyzed, it might be thought that these tests are capitalizing on chance. However, even being stricter with the level of significance ($p \leq 0.01$), significant associations were found in an important number of bone sites, especially at the femoral neck subregion. The minutes proposed as cut-offs have shown satisfactory ROC curve indexes, which suggests a good classification of the subjects into the groups of reduced or increased bone mass. Vigorous physical activity includes activities with intensities greater than 6 METs, most of which are sports similar to those previously associated with increased bone mass (e.g., football, handball, artistic gymnastics, and hockey).[7,8,34] One study[35] also showed that participation in high-impact activities for 1 hour or more a day was associated with greater BMC, especially at the hip. Those results are consistent with those of the current study, which might be explained by the relationship between VPA and sports.

Although 33% of Spanish adolescents aged 12.5–18.5 years asserted that they did not play any extracurricular sport,[33] the sports that are most practiced among the rest of the adolescents are considered high-intensity sports.[36] Participation in extracurricular sports can be considered the main source of at least moderate physical activity.[37] Thus, a useful strategy to increase their physical activity (moderate–vigorous or vigorous) should be oriented toward encouraging adolescents to engage in extracurricular sporting activities. In addition, a few minutes of VPA has been found to be associated with increased bone mass at the total hip and subregions (trochanter, intertrochanter, and femoral neck), which are precisely those considered as regions/subregions of clinical relevance to osteoporosis. Participation in sport and VPA practice should be encouraged because of its important role in developing healthy bones.

Strengths and Limitations

The use of sophisticated methods, such as DXA, to assess bone mass and the use of accelerometers with a short

epoch (15 seconds) to assess physical activity in a relatively large sample of adolescents are the strengths of the current study. Although with the use of accelerometers, an objective measurement of adolescents' physical activity can be obtained, it is not possible to know the kind of activity the subjects are engaged in, which would be of great interest for analyzing if the current physical activity recommendations are good enough for bone mass–recommended physical sports activities.

It could be interesting to analyze these data according to sexual maturation because of its association with physical activity levels. However, with the present sample it was not possible to check if the effect of physical activity on bone mass is different at prepubertal ages because of a too limited number of individuals in some categories. To minimize this limitation, sexual maturation was used as a confounder in the analyses. It is also noteworthy as a limitation that the present cross-sectional study provides only suggestive evidence concerning causal relationships between physical activity variables and bone mineral content and density. In this specific case, it is feasible that the amount of physical activity (or even the sports practiced) has an effect on BMC and BMD and it does not seem feasible that bone mass determines the amount of physical activity.

Conclusion

The recommended levels of physical activity seem to be insufficient stimulus to guarantee increased bone mass. With some minutes/day of VPA, bone adaptations could be obtained at the hip. Specifically, BMD adaptations are obtained with just 32 minutes/day of VPA at the femoral neck, which is of great importance because of its clinical relevance to osteoporosis. It could be of interest if future studies aim to measure not only the amount of physical activity but also the type and, therefore, get a clearer picture of the current status of adolescents' physical activity and its influence on bone mass.

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Appendix

Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.amepre.2011.03.001.