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A longitudinal study of the relationship of physical activity to bone mineral accrual from adolescence to young adulthood ☆

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ABSTRACT

Physical activity in adolescence is beneficial for increasing bone mineral accrual; however, it's unclear whether these benefits persist into adulthood. This prospective study investigated whether physically active adolescents maintained their higher bone mineral content (BMC) into the third decade of life when compared to their less active peers. Data were from 154 subjects (82 females and 72 males) who participated in the University of Saskatchewan's Pediatric Bone Mineral Accrual Study (1991–1997), entry age 8 to 15 years. Participants returned for follow-up as young adults (2002–2006), follow-up age 23 to 30 years. Dual energy X-ray absorptiometry was used to measure BMC of total body (TB), lumbar spine (LS), total hip (TH) and femoral neck (FN) annually from 1991 to 1997 and from 2002 to 2006. Peak height velocity (PHV) was determined for each child as a measure of maturity. Age and gender-specific activity *Z*-scores were calculated for each participant based on the mean physical activity scores obtained from bi-annual questionnaire data during childhood and adolescence. Subjects were ranked into three adolescent activity groups: active, average and inactive (top, middle two, and bottom quartiles, respectively). Analysis of covariance (ANCOVA) was used to compare adjusted TB, LS, TH and FN BMC across the three adolescent activity groups at 1 year post PHV and in young adulthood. When compared to the inactive group, active males had 8% greater adjusted BMC at the TB, 13% at the LS and 11% at the TH ($p<0.05$) in adolescence. Active females also had 8% and 15% more adjusted BMC ($p<0.05$) at the TB and LS, respectively, during adolescence. In young adulthood the male and female adolescent active groups were still significantly more active than their peers ($p>0.05$). It was found that active adolescent males had 8–10% more adjusted BMC at the TB, TH and FN ($p<0.05$) in young adulthood and that active adolescent females had 9% and 10% more adjusted BMC at the TH and FN. These results suggest that the skeletal benefits of physically activity in adolescents are maintained into young adulthood.

Introduction

Physical activity during childhood and adolescence enhances bone mass which subsequently may reduce the propensity of osteoporosis and related fractures if these changes persist later in life [1,2]. Observational studies have provided evidence of increased bone mineral content (BMC) in children and adolescents who have a more physically active lifestyle than their peers [3,4]. This evidence has been supported by exercise intervention trials showing a 2–4% greater BMC accrual in children randomized to intervention groups [5]. It remains inconclusive however, if the BMC benefit acquired during the growing years persists into adulthood.

To date, studies examining the effects of physical activity during childhood and adolescence on adult bone mass have been limited to retrospective assessment of physical activity [6] or earlier measured youth physical activity [7] to adult bone mineral status. Follow-up data in retired athletes have provided evidence of both sustained [8] and partially lost [9] bone mass benefit after a reduction or cessation of the activity. Whereas exercise-induced BMC gain have reported to persist 1–8 years after exercise intervention in pre- or early pubertal children [5,10].

Previous prospective data from our group showed a 9–17% greater bone mineral accrual in physically active adolescents when compared to their less active peers [11]. These data combined with other studies lend credence to the concept that physical activity in pre- and early puberty provides a unique opportunity to enhance bone accrual and peak bone mass; however, even if exercise during the growing years affects bone accrual, the importance of these effects from a clinical perspective depends on their permanence. The long-term implications of these benefits on adult bone mass can be only established with prospective longitudinal studies that follow subjects from childhood to adulthood. The present study incorporates longitudinally collected data from childhood, adolescence and into young adulthood; thus, our data provide an opportunity to determine prospectively

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whether the bone mass benefits of physical activity during adolescents are maintained into young adulthood. We hypothesized that physically active males and females during adolescence would have higher bone mineral content in their third decade of life when compared to their inactive adolescent peers.

Materials and methods

Study design

The Saskatchewan Pediatric Bone Mineral Accrual Study (PBMAS) used a mixed-longitudinal cohort design, with eight chronological age cohorts (entry ages 8 to 15 years). Individuals were repeatedly measured for up to seven consecutive years in adolescence (1991–1997) and for up to four consecutive years in young adulthood (2002–2006) (follow-up age 23 to 30 years).

Participants

The PBMAS has been described in detail elsewhere [12]. In brief, in 1991, of the 375 eligible students attending two elementary schools in the city of Saskatoon (population 200,000), the parents of 228 students (113 boys and 115 girls) provided written consent for their children to be involved in this study and 220 were DXA scanned. From 1992 to 1993 an additional 31 subjects were recruited and scanned. After 7 years of data collection, 109 males and 121 females had been measured on two or more occasions (median 6 scans). Between 2002 and 2006 one hundred and sixty nine of the subjects were measured on at least 1 or more occasions. For inclusion in the present analysis, participants required a determination of age at peak height velocity (PHV), at least two measures of BMC in young adulthood and continuous measures of adolescent and young adult physical activity. Eighty two females and 72 males fulfilled these requirements and these subjects represent the study population for the present investigation. Ethical approval was obtained from the University of Saskatchewan Biomedical Research Ethics Board and all participants provided written consent.

Anthropometry and somatic maturation

Anthropometric measurements were taken at six-month intervals by trained personnel following a standard protocol. Standing heights were recorded without shoes as stretch stature to 0.1 cm using a wall mounted stadiometer (Holtain Limited, Crymych, UK). Body mass was measured to 0.01 kg on a calibrated scale (Toledo Scale Company, Ontario, Canada).

To control for the well-documented maturational differences between adolescent boys or girls of the same chronological age, we calculated a biological maturity age for each individual [13]. The age of peak linear growth in stature (peak height velocity, PHV) was determined for each child and a continuous measure of biological maturity age (years from PHV) was generated by subtracting the chronological age at time of measurement from the chronological age at PHV [13].

Bone mineral measures

Bone mineral content (BMC, g) of the total body (TB), anterior–posterior lumbar spine (LS, L1–L4), total hip (TH) and the femoral neck (FN) was measured annually from 1991 to 1997 and 2002 to 2006 using the Hologic QDR 2000 (Hologic, Inc., Waltham, MA, U.S.A.). The array mode was employed for all scans and enhanced global software version 7.10 was utilized. Software version 5.67A analyzed the TB scans, while the scans of the TH, FN and LS were analyzed with software version 4.66A. The coefficient of variation for all sites was less than 1% and no scanner drift was observed during the follow-up.

Physical activity assessment

During childhood and adolescence general physical activity was assessed a minimum of three times per year for the first 3 years and two times per year thereafter. The questionnaires employed were the Physical Activity Questionnaire for Children (PAQ-C) and the Physical Activity Questionnaire for Adolescents (PAQ-A). The scores of the 2 or 3 assessments were averaged to create a single score to represent an individual's level of physical activity for the year. The PAQ-C/A assesses general levels of physical activity and is described in detail elsewhere [14]. In brief, the PAQ-C/A was designed for children and adolescents in grades three or greater to assess their level of moderate and vigorous physical activity. Physical activity was defined as “sports, games, or dance that make you breathe hard, make your legs feel tired or make you sweat”. In completing the PAQ-C/A, subjects were asked to rate their physical activity level during their spare time in the previous 7 days. Nine items scored on a five-point Likert-type scale, were averaged to derive an overall physical activity score ranging from one to five, with higher scores indicating higher levels of physical activity. The use of a five-point rating in the PAQ-C/A results in a normal distribution of physical activity scores. For high school students, the PAQ-C was modified to the PAQ-A by omitting one item regarding physical activity at recess.

The PAQ-C had favourable one-week test–retest reliability in a sample of 84 children from grades 4 to 8 with intraclass correlation coefficients of $r=0.75$ for boys and $r=0.82$ for girls [14]. Furthermore, the PAQ-C significantly correlated with other measures of physical activity in elementary [15] and secondary school students [16]. Convergent validity for the PAQ-C was demonstrated in 89 students in grades 4 to 8, through a moderate relationship to a peer-comparison activity rating ($r=0.63$), a one-week summation of 24-hour moderate to vigorous physical activity recalls ($r=0.53$) , and perceptions of athletic competence ($r=0.48$) [15]. Further convergent and construct validity were demonstrated in the results of 97 elementary school students, ages 9 to 14 years, through moderate relationships to a peer-comparison rating ($r=0.57$), the Leisure Time Exercise Questionnaire ($r=0.41$), a Caltrac motion sensor ($r=0.39$), a 7-day activity recall interview ($r=0.46$), and a step test of fitness ($r=0.28$) [15]. The Physical Activity Questionnaire for adolescents (PAQ-A) was also examined for convergent validity [16]. In 85 students from grades 8 through 12, the scores from the PAQ-A were moderately related to a peer-comparison rating ($r=0.73$), the Leisure Time Exercise Questionnaire ($r=0.57$), a Caltrac motion sensor ($r=0.33$), and the 7-day physical activity recall interview ($r=0.59$) [16].

During young adulthood the Physical Activity Questionnaire for Adults (PAQ-AD), a 7-item version of the PAQ-C and PAQ-A, was used. The PAQ-AD questionnaire has established favourable validity with moderate relationships to an activity rating, leisure time activity scales, self-reported physical activity recall and motion sensors [17].

Adolescent activity groups were formed based on the PAQ-C/A scores. For each individual an age and sex-specific *Z*-score was determined for each test administration. The *Z*-score was based on the mean and SD for the entire sample of a similar chronological age. An average childhood and adolescent *Z*-score for all years was then calculated, with the median number of annual visits being 6 (minimum 3, maximum 7). Individuals were then ranked into quartiles according to their average activity *Z*-score. Those whose *Z*-score fell in the highest quartile were classified as active, those in the middle two quartiles were classified as average, and those whose score was in the lowest quartile were classified as inactive [11].

Dietary analysis

Intake was assessed via serial 24-hour recalls conducted both at the participation schools and at the time of the bone scans. All days of the week, except Friday and Saturday were included. Food intake from the 24-hour recalls was analyzed using a nutritional assessment software package (NUTS Nutritional Assessment System, version 3.7 Quilchena Consulting Ltd., Victoria, BC), which used the 1988 Canadian Nutrient File information. The same individual coded, checked all the forms and analyzed dietary intake data according to procedures described elsewhere [18].

General health and lifestyle

Tobacco use, alcohol consumption and oral contraceptive use was assessed via a general health and lifestyle questionnaire. Questions asked included current and previous cigarette consumption (number per day), exposure to second hand smoke (yes/no), alcohol consumption in the previous 12 month (daily or almost every day, 3 or 4 times a week, once or twice a week, once or twice a month, less than once a month, never) and oral contraceptive use (yes/no, brand name and time period used).

Statistical analysis

Analysis of variance (ANOVA) was used to compare anthropometric characteristics, nutritional data and physical activity levels and absolute body composition measures at 1 and 11 years after PHV, across the three adolescent activity groups within each sex. Analysis of covariance (ANCOVA) was performed to compare TB, TH, FN and LS BMC accrued at 1 year post PHV across adolescent activity groups (activity group entered as a fixed factor) with covariates (height and weight at 1 year post PHV) in both sexes. Similarly, ANCOVA was used to compare young adults TB, TH, FN and LS BMC across the three adolescent activity groups; controlling for 1 year post PHV BMC values and adult values of age, maturity age, height, weight, calcium intake and physical activity. Pearson correlation analysis was used to examine relationships between physical activity *Z*-scores at adolescence and young adulthood. All data were analyzed using SPSS for Windows, version 15.0 (SPSS, Inc., Chicago, IL, USA). Significance level is reported as $p<0.05$ and all statistical tests were two-tailed.

Results

1 year post PHV

Sample means (SD) for age, age at PHV, maturity age (years from PHV), height, weight, total body lean and fat mass, calcium intake and physical activity at 1 year after PHV by adolescent activity group are presented in Table 1. There were no statistically significant differences in age, age at PHV, maturity age (years from PHV), height, weight, total body lean and fat mass or calcium intake in males ($p>0.05$) between adolescent activity groups. However, the active adolescent males physical activity score was significantly higher than the average and inactive groups ($p<0.05$). In females, at 1 year post PHV, significant differences were found ($p<0.05$) among the adolescent activity groups, with the active females having significantly more total body lean mass and higher physical activity scores ($p<0.05$) (Table 1).

To investigate the relationship between physical activity and bone mineral content (BMC) at 1 year after PHV site specific values of BMC were analyzed by ANCOVA using a three group (inactive/average/active) design. To control for size differences, height and weight at 1 year after PHV were entered as covariates. In males, for TB, TH and LS, significant ($p<0.05$) physical activity group effects were observed (Fig. 1). At the FN there was no significant ($p>0.05$) effect of physical activity group. Pair-wise comparisons revealed significant differences between the active males and the average and inactive males groups for both TB and TH BMC, with active males having 7.6% and 10.5% more adjusted BMC than the inactive males at the TB and TH respectively; at the LS the active group had significantly ($p<0.05$) greater, 12.5%, more adjusted BMC than the inactive group ($p<0.05$). In females when BMC was controlled for height and weight, physical activity group effects were observed at 1 year post PHV at the TB and LS only; active females having 7.8% and 14.6% more adjusted BMC than their inactive counterparts at the TB and LS respectively (Fig. 1).

Young adulthood

In males, the average age at follow-up was 24.2±2.3 years (10.7±2.3 years from PHV) (Table 2), with the active males found to be significantly older ($p<0.05$). There were no statistically significant differences in maturity age (years from PHV), height, weight, total body lean and fat mass, calcium intake, alcohol consumption or percentage smokers in young adult males ($p>0.05$) However, the males who were classified as active in adolescence had significantly greater physical activity scores in young adulthood ($p<0.05$) (Table 2); the correlation between the *Z*-score activity score in adolescence and young adulthood was $r=0.34$ ($p<0.05$). In females, the average age in young adulthood was 23.1±2.2 years (11.3±2.2 years from PHV). Similar to males, active females in childhood were significantly more active in young adulthood ($p<0.05$); the correlation between *Z*-score activity score in adolescence and young adulthood was $r=0.33$

Table 1
Anthropometric, body composition, physical activity and calcium intake for each gender at 1 year after Peak Height Velocity by adolescent activity groups

Males		Inactive $n=18$	Average $n=36$	Active $n=18$
	Chronological age (year)	14.1 (1.2)	14.3 (0.9)	14.6 (0.8)
	Age at PHV	13.3 (1.2)	13.4 (0.9)	13.6 (0.8)
	Maturity age (year from PHV)	0.9 (0.8)	0.9 (0.4)	1.0 (0.2)
	Height (cm)	169.3 (8.5)	172.5 (5.8)	171.2 (6.5)
	Weight (kg)	56.4 (8.9)	60.6 (9.0)	59.7 (9.2)
	Total body lean mass (kg)	43.9 (6.0)	47.2 (5.3)	47.9 (6.2)
	Total body fat mass (kg)	9.5 (5.7)	10.3 (6.4)	8.6 (4.4)
	Calcium intake (mg/day)	1107 (481)	1347 (765)	1465 (681)
	Physical activity (score)	2.1 (0.4)	3.0 (0.3)	3.7 (0.3)*
Females		Inactive $n=20$	Average $n=42$	Active $n=20$
	Chronological age (year)	12.4 (1.3)	12.8 (0.8)	12.8 (0.8)
	Age at PHV	11.6 (1.2)	11.9 (0.8)	11.8 (0.7)
	Maturity age (year from PHV)	0.9 (0.3)	0.9 (0.4)	0.9 (0.3)
	Height (cm)	156.6 (9.9)	160.2 (5.8)	161.3 (8.1)
	Weight (kg)	46.0 (11.6)	51.4 (9.9)	49.9 (10.9)
	Total body lean mass (kg)	31.0 (5.2)	34.3 (4.7)	35.1 (6.4)*
	Total body fat mass (kg)	13.2 (6.8)	14.4 (6.9)	12.3 (5.3)
	Calcium intake (mg/day)	926 (377)	1117 (443)	885 (334)
	Physical activity (score)	2.0 (0.4)	2.8 (0.3)	3.6 (0.6)*

Values reported as mean (SD); ANOVA, between groups: *$p<0.05$.

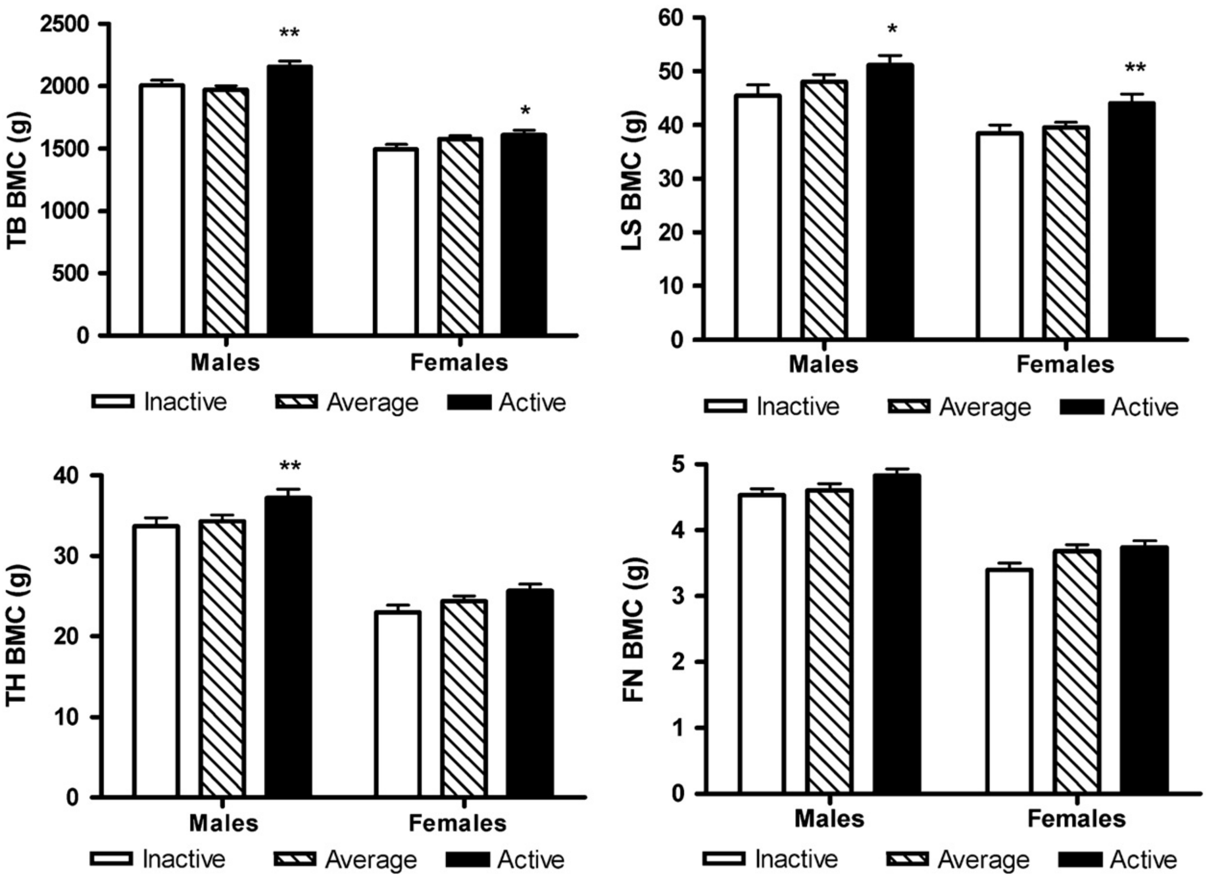

Fig. 1. Adjusted total body (TB), lumbar spine (LS), total hip (TH) and femoral neck (FN) bone mineral content (BMC) by inactive, average and active adolescent activity groups at 1 year after peak height velocity (PHV). Adjusted Means (SE) (height and weight covariates); ** significantly greater ($p<0.05$) than inactive and average groups, * significantly greater ($p<0.05$) than inactive group.

($p<0.05$). The adolescent active female group also had been taking oral contraception on average for a significantly longer time period in young adulthood ($p<0.05$) (Table 2).

Again, to investigate the relationship between physical activity and BMC in young adulthood site specific values of BMC were analyzed by ANCOVA using a three group (inactive/average/active)

Table 2
Anthropometric, body composition, physical activity, calcium intake and other lifestyle factors for each gender in young adulthood by adolescent activity groups

Males		Inactive ($n=18$)	Average ($n=36$)	Active ($n=18$)
	Chronological age (year)	23.1 (2.2)	24.3 (2.0)	25.0 (2.5)*
	Maturity age (year from PHV)	9.8 (2.6)	10.9 (1.9)	11.4 (2.4)
	Height (cm)	177.8 (6.6)	180.5 (7.5)	178.5 (6.5)
	Weight (kg)	79.6 (12.9)	84.7 (12.0)	83.6 (13.8)
	Total body lean mass (kg)	57.8 (7.2)	61.1 (8.6)	61.9 (8.6)
	Total body fat mass (kg)	17.6 (8.4)	19.2 (9.1)	17.1 (7.6)
	Calcium intake (mg/day)	1390 (516)	1381 (673)	1412 (856)
	Physical activity (score)	1.9 (0.5)	2.3 (0.6)	2.7 (0.5)*
	Smokers (%)	22.2%	30.6%	11.1%
	Alcohol consumption	3.5 (0.9)	3.3 (1.0)	3.5 (1.0)
Females		Inactive ($n=20$)	Average ($n=42$)	Active ($n=20$)
	Chronological age (year)	22.7 (2.2)	23.5 (2.23)	22.6 (3.3)
	Maturity age (year from PHV)	11.1 (2.4)	11.7 (2.2)	10.8 (2.1)
	Height (cm)	164.2 (6.0)	167.1 (6.1)	168.3 (7.3)
	Weight (kg)	65.3 (14.5)	69.7 (17.8)	68.9 (13.1)
	Total body lean mass (kg)	38.1 (5.4)	40.5 (5.8)	41.5 (6.4)
	Total body fat mass (kg)	23.8 (9.6)	25.4 (13.5)	23.7 (8.9)
	Calcium intake (mg/day)	857 (408)	959 (447)	881 (345)
	Physical activity (score)	1.8 (0.7)	2.1 (0.6)	2.5 (0.7)*
	Smokers (%)	20.0%	40.5%	30.0%
	Alcohol consumption[a]	3.9 (0.9)	3.9 (0.9)	3.6 (0.9)
	Oral contraception (%)	70.0%	66.7%	60.0%
	Oral contraception (years)	2.7 (1.5)	5.1 (3.3)	5.3 (2.9)*
	Children 1 or more (%)	20.0%	26.2%	5.0%

Values reported as mean (SD); ANOVA between groups: *$p<0.05$.
[a] Alcohol consumption in the previous 12 months; 1 = daily, 2 = 3–4 per week, 3 = 1 or 2 per week, 4 = 1 or 2 per month, 5 ≤ 1 per month, and 6 = never.

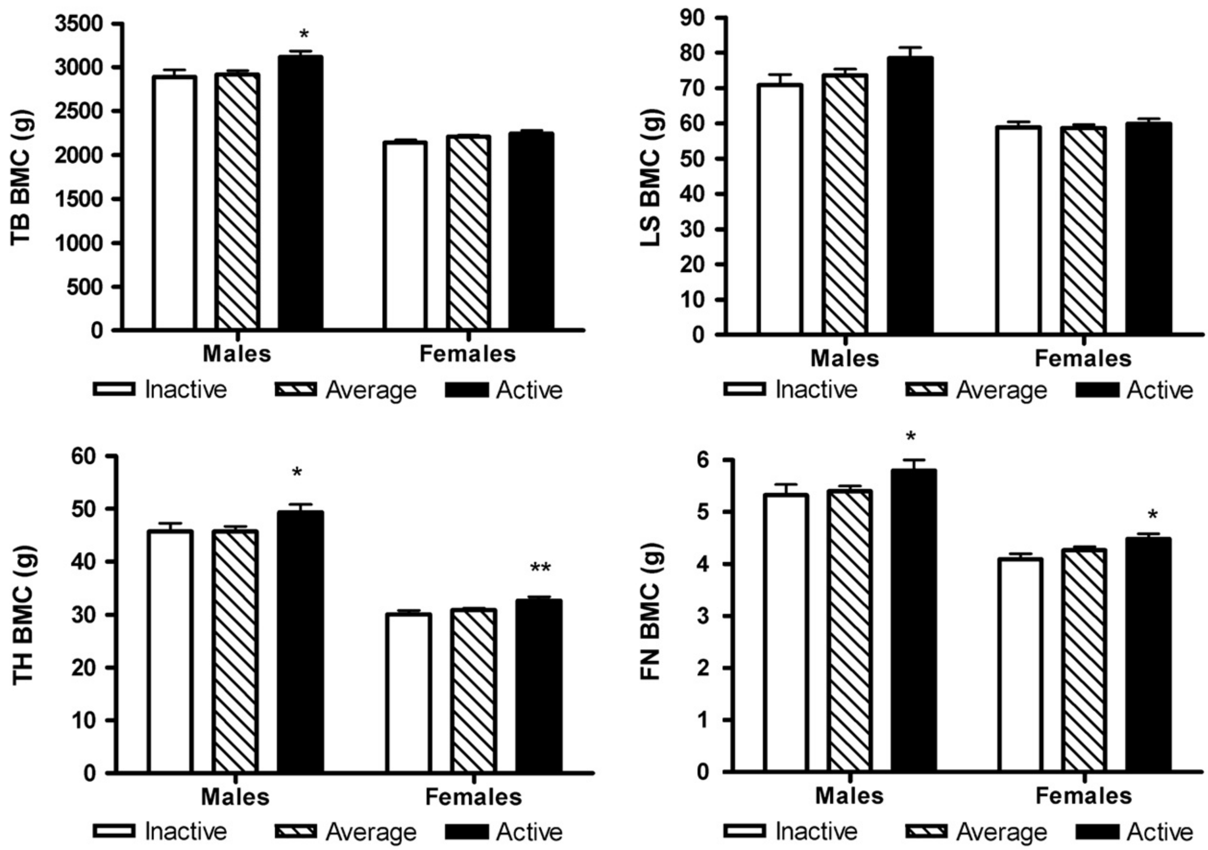

Fig. 2. Adjusted total body (TB), lumbar spine (LS), total hip (TH) and femoral neck (FN) bone mineral content (BMC) by inactive, average and active adolescent activity groups in young adulthood. Adjusted Means (SE) (age, maturity age, height, weight, adult physical activity, calcium intake and BMC at 1 year after PHV covariates); ** significantly greater ($p<0.05$) than inactive and average groups, * significantly greater ($p<0.05$) than inactive group.

design; controlling in young adulthood for size and lifestyle differences and BMC in adolescence: age, maturity age, height, weight, physical activity, calcium intake, and BMC at 1 year after PHV were entered as covariates.

In males, significant ($p<0.05$) TB, TH and FN differences between adolescent physical activity groups were observed (Fig. 2). At the LS there was no significant ($p>0.05$) effect of adolescent physical activity grouping. Pair-wise comparisons revealed significant differences between the active males and the inactive males, with active males having 7.6%, 7.8% and 8.9% more adjusted BMC than the inactive males at the TB, TH and FN respectively. In females (Fig. 2) when BMC was controlled for age, maturity age, height, weight, physical activity, calcium intake, and BMC at 1 year after PHV, significant adolescent activity group effects were observed at the TH and FN only; active females having 8.6% and 9.5% more adjusted BMC than their inactive counterparts at the TH and FN respectively. No adolescent activity group differences were found for adjusted young adulthood TB or LS BMC ($p>0.05$) in females (Fig. 2).

Discussion

The results support the conjecture that the positive effects of childhood physical activity during the time of peak bone mineral accrual persist into young adulthood. When controlling for maturational and size differences among the groups, active males had an average of 8% greater adjusted total body (TB) and 11% greater adjusted total hip (TH) BMC than their inactive or moderately active peers at 1 year after PHV. The active males maintained this benefit into adulthood, as their adjusted TB and TH hip BMC was 8% greater when compared to their peers who had been inactive or moderately active in adolescence. Furthermore it was found that the active adolescent males had 9% more adjusted femoral neck (FN) BMC. Active adolescence females had 8% greater adjusted TB and 15% greater adjusted LS BMC during adolescence, however no significant differences were found at these sites in young adulthood. Young adult females, who were active adolescents, had 9% and 10% greater TH and FN BMC respectively. Although our results suggest that the effects of adolescent physical activity are greater than or mask the effects of current adult physical activity, it also was interesting to note that physical activity scores during adolescence were positively correlated with adult physical activity scores. This is in accordance with studies reporting that physical activity and sports participation tends to track moderately from childhood to adolescence [19,20]. These results support the notion that adolescent physical activity may pertain to adult lifestyle, and thus, provide justified target for osteoporosis prevention.

Previous studies lend support to the theory that physical activity related bone mass gains during growth are associated with greater adult bone mass [21,22]. There is also some evidence from (young) athletic groups that areal bone mineral density (aBMD) or BMC can be retained for many years after an athlete retires from sports training [8,23,24]. There is also data showing that the initial effects of mechanical loading during adolescence on bone mass and aBMD, decline with the removal or decline of the physical activity [9,25]. Most of these previous studies, both supportive and non-supportive, are based on cross-sectional, short term intervention or retrospective study designs. The strength of our results is that they are based on prospective longitudinal data from the same subjects followed from adolescence into young adulthood; providing convincing evidence for the hypothesis that physical activity during adolescents affects bone health in (at least) young adulthood.

Despite the 15-year follow-up (1991–2006), high participant retention (67%) and careful control of possible confounding factors such as sexual maturity and size differences, our study has limitations. Observational studies, such as the present one, are limited due to the inherent susceptibility of observational associations related to uncontrolled factors, selection bias, and reverse causality. We followed a small cohort of Caucasian adolescents, and thus, results may not be generalized to other populations. Since we used a mixed-longitudinal cohort design, entry age 8 to 15 years, subjects had been in the study for varying lengths of time when they reached 1 year post PHV. It is therefore impossible to identify whether the active adolescents already had higher BMC values when they entered the study. It could be argued that males and females with a well-developed musculoskeletal system are naturally more physically active because of their greater bone mineralization. Although it may be true that adolescents with greater BMC are more active, we also know that studies of young children (4 to 6 years of age) have shown positive relationships between activity and bone accrual [4] and that physical activity tracks across the lifespan [19]. These two observations would add weight to the argument that PA increases bone mass and our observations concur with this argument. The subjective measure of PA used in this study is also problematic. Although the used physical activity groups were formed by utilizing cumulative childhood and adolescence activity data and both questionnaires (PAQ-C and PAC-A) have shown a good internal consistency and acceptable validity [14–16] physical activity assessment by questionnaires is prone to various degrees of inaccuracy [26].

Extensive follow-ups after randomized, controlled exercise trials are needed to confirm our observations; but, some confirming evidence already exists. Increased hip BMC from high-impact exercise in growing children was sustained following 7 years of detraining [10]. Other follow-ups have been shorter but shown similar residual benefits in the exercise-induced BMC in pre- or early pubertal children [27]. Factors such as the type, amount, frequency, duration and history of physical activity and the maturity of the bones when exercise is started, reduced or ceased may be related to the skeleton's ability to preserve benefits from childhood activity [27]. Throughout the growing years, particularly early in puberty, the ability of bone to adapt to mechanical loading seems to be better than after puberty [28]. Whether the exercise-induced gain in bone mass and alterations in bone structure are more permanent if obtained during growth than after skeletal maturity is poorly known.

Unilateral loading studies have suggested that structural changes such as cortical bone size and shape affected by exercise may be retained with age despite reduced training [29]. Enlarged bone size and altered geometry may persist even to a greater degree than factors such as bone mineral content per se which may partly explain the observed lower fracture risk, especially at the weight bearing skeletal sites in physically active individuals [30].

In conclusion there is increasing evidence that physical activity during the growing years affects components of bone strength such as bone mineral accrual in young adulthood; however, the importance of this observation for long-term skeletal health is not yet clear. We are continuing to follow these subjects into their adult years and perhaps will able to use this cohort to address this critical question. Although our results are not definitive they do support the conjecture that physical activity and sports participation during the growing years may increase bone accrual and contribute to reduced fracture risk in later life [31]. Thus, the results of the present study suggest that the promotion of physical activity during adolescence and young adulthood is well advised as a strategy to reduce lifetime risk of osteoporosis and related fractures.

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