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Sustained effects of physical activity on bone health: Iowa Bone Development Study

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ABSTRACT

Studies of youth athletics and interventions have shown some maintenance of bone mineral content (BMC; g) after cessation of training, but less is known about sustained effects of everyday physical activity (PA). Using a prospective cohort, this report examined potential effects of childhood PA on adolescent BMC. Participants (N = 156 boys, 170 girls) had exams at ages 5, 13, and 15. Body size and maturity were determined using anthropometry. Moderate-to-vigorous-intensity PA (MVPA) and vigorous-intensity PA (Vigorous PA) were measured using accelerometry. BMC of the spine and hip was measured using dual-energy X-ray absorptiometry. Mixed regression models tested whether PA at age 5 affected BMC at ages 13 and 15 after adjustment for age (year), height (cm), weight (kg), maturity (pre-peak height velocity or post), and activity level (min/day). Analysis was repeated to control for age 5 BMC. On average, boys participated in 59, 52, and 38 min of MVPA and 13, 17, and 11 min of Vigorous PA at ages 5, 13, and 15, respectively. MVPA ($\beta = 0.799$) and Vigorous PA ($\beta = 1.338$) at age 5 predicted later spine BMC ($p < 0.05$). MVPA ($\beta = 0.480$) at age 5 predicted hip BMC. Girls participated in 47, 33, and 26 min of MVPA and 10, 9 and 7 min of Vigorous PA at ages 5, 13, and 15, respectively. Neither MVPA nor Vigorous PA predicted later spine BMC. MVPA ($\beta = 0.302$) at age 5 predicted hip BMC. After controlling for BMC at age 5 as well as the other covariates, the effect of MVPA ($\beta = 0.695$) and Vigorous PA ($\beta = 1.079$) at age 5 remained significant for boys at the spine. For girls, neither MVPA nor Vigorous PA at age 5 predicted spine or hip BMC. Children's early PA appears to have a modest effect on adolescent BMC at the critical regions of spine and hip; benefits may be greater for geometric changes, which future studies should include.

Introduction

Mechanical loading via physical activity (PA) places strains on bone greater than those needed for steady state remodeling, leading to a response that increases bone mass and improves its overall strength via changes in geometry and micro-architecture [1–4]. The potential of PA to increase bone mass depends on the magnitude of the load, the rate at which the load is applied, the duration of the loading bout, and the novelty of the load [5]. Loads of greater force that are delivered quickly, such as jumping, appear to provide the greatest opportunity for bone mineralization, or bone mineral content (BMC) accrual [6].

Loads necessary for bone accrual have been found in activities ranging from competitive sport to exercise interventions to self-selected activity. Previous research on competitive sport found that 9- to 12-year-old female gymnasts had 15.5% higher bone mineral density (BMD) at the mid-radius, 33% at the distal radius, 11.0% at the L2–L4 vertebrae, 15.0% at the femoral neck, and 15.0% at Ward's triangle than controls of the same age [7,8]. A study examining the playing versus non-playing arms of 16- to 50-year-old female tennis and squash athletes found that the athletes had greater between-arm BMC differences when compared to controls (15.5% at the proximal humerus, 16.2% at the humeral shaft, 8.5% at the radial shaft, and 12.5% at the distal radius) [9]. Exercise interventions have also provided evidence of skeletal benefits from targeted impact activities. Gunter et al. [6] and Fuchs et al. [10] found BMC gains in prepubescent boys and girls of 3.5%–8.0% at the hip and lumbar spine resulting from a targeted, high-impact jumping intervention. Higher levels of everyday PA, examined by a prospective observational study, showed that highly active 8- to 14-year-olds had 18.0% greater BMC at the lumbar spine in both boys and girls, 7.0% greater BMC at the femoral neck in boys, and 11.0% greater BMC at the femoral neck in girls compared to the least active group [11].

Cross-sectional, longitudinal, and randomized controlled trials demonstrate the benefits of PA on bone health in children [12–15]. However, as children progress into and through adolescence, they tend to reduce their activity levels and it is less clear if the BMC benefits obtained from early PA can be sustained into adolescence despite this reduction in activity [16–18]. A previous report from the Iowa Bone Development Study found that, even though PA levels decreased as children aged,

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those who were most active at age 5 had greater BMC at ages 8 and 11 than those were less active. After adjusting for concurrent age, height, weight, and MVPA, boys in the highest MVPA quartile at age 5 had 14.0% more BMC at the spine and 11.0% more BMC at the hip at age 8 than those in the lowest MVPA quartile. Girls in the highest MVPA quartile at age 5 had 8.0% more spine and hip BMC at age 8 than those in the lowest MVPA quartile. These values decreased to 7.0% for the spine and hip in boys at age 11. For girls, the values decreased to 6.0% for the spine and 5.0% for the hip at age 11 [19]. Baxter-Jones and colleagues [20] also examined the sustainability of BMC over time and reported that active adolescent males had 8.0% more hip BMC as adults than their inactive or moderately-active peers after adjustment for age, maturity age, height, weight, adult PA, calcium intake, and BMC one year after peak height velocity (PHV). These males also had 9.0% greater adjusted femoral neck BMC. The active adolescent females in the study had 9.0% and 10.0% greater BMC at the hip and femoral neck, respectively [20].

These studies provide some evidence that increased BMC associated with PA can be maintained into the future. Using objective PA monitors, dual-energy X-ray absorptiometry (DXA), and a ten-year, longitudinal design, this report extends the previous Iowa Bone Development Study results to examine whether childhood PA is associated with greater BMC during adolescence.

Materials and methods

Participants

Study participants were members of the Iowa Bone Development Study – a longitudinal study of bone health during childhood, adolescence, and young adulthood – recruited from 1998 to 2001 from a cohort of families participating in the Iowa Fluoride Study. Additional information about the study design and demographic characteristics of the participants has been described elsewhere [21–24]. Baseline measures were assessed at age 5 (N = 156 boys, 170 girls) and follow-up measures were assessed at ages 13 (N = 143 boys, 160 girls) and 15 (N = 114 boys, 117 girls). For inclusion in these analyses, participants were required to have one measurement at age either 13 or 15; however, 56% of boys and 63% of girls had both. Approval for this study was obtained from the University of Iowa Institutional Review Board (human subjects). Parents provided written informed consent and children provided assent.

Physical activity

ActiGraph activity monitor model number 7164 was worn by participants at ages 5 and 13 year. Due to the unavailability of this model at the 15 year measurement, model GT1M was used. Previous research has shown a high correlation in movement counts between the two monitors (r = 0.99) [25]. Movement counts were collected in one-minute epochs for ages 5 and 13 and five-second epochs for age 15. The five-second epochs for age 15 were re-integrated to one-minute epochs to maintain consistency with the earlier measurements. Procedures for PA measurement using the ActiGraph and validation of these monitors have been described elsewhere [26–28]. Children at age 5 were asked to wear the monitor all day during waking hours for four consecutive days, including one weekend day. The number of wear days for children at ages 13 and 15 was increased to five consecutive days, including both weekend days, to account for increased day-to-day variability in accelerometry-measured PA in older children when compared to younger children [27]. To be included in the analyses, participants were required to have three valid days of monitor wear for each measurement period. A day was considered valid if the monitor was worn for at least 8 h per day. Using the Spearman–Brown prophecy formula, this corresponds to a 60% reliability coefficient [29]. To reduce seasonal effects, PA was only monitored during the autumn months.

The PA variables of interest were time spent in moderate through vigorous-intensity physical activity (MVPA) (minutes) and time spent in vigorous-intensity PA (Vigorous PA) (minutes). Mean values were obtained from all minutes of all valid days of wear. As specified by Evenson and colleagues (in a sample of 5- to 8-year-olds) [30], cut-points were defined as <100 counts per minute for sedentary, ≥2296 counts per minute for MVPA, and ≥4012 counts per minute for Vigorous PA. The moderate-intensity and vigorous-intensity PA cut-points have been evaluated using area-under-the-receiver operating characteristic curve (ROC-AUC) and have been shown to exhibit fair (ROC-AUC = 0.74) to good (ROC-AUC = 0.84) classification accuracy, respectively. When combined (MVPA), the cut-points exhibited excellent classification accuracy (ROC-AUC = 0.90). Based on a comparison of five independently developed sets of cut-points (in samples ranging from 5- to 18-year-olds), Trost and colleagues recommended that researchers use the Evenson cut-points [31].

Bone mineral content

At age 5, left hip scans were obtained using a Hologic QDR 2000 DXA (Hologic, Inc., Bedford, MA) with software version 7.20B, using the pencil-beam mode. At ages 13 and 15, the Hologic QDR 4500 DXA (Delphi upgrade) with software version 12.3 and the fan-beam mode were used. All scans were reanalyzed using Hologic software version 12.6, and BMC (g) was derived from these scanned images. Software-specific global regions of interest were used to designate the general boundaries of the images. A review of the bone within the region of interest box was confirmed by the operator and edited to ensure appropriate bone-edge detection. Quality control scans were performed daily using the Hologic spine phantom. To minimize operator-related variability, all measurements were conducted by one of three experienced technicians. Translational equations for 4500 DXA measures to 2000 DXA measures were used to adjust for the differences between the two DXA machines. A separate study where 60 children (32 boys and 28 girls) aged 9.9 to 12.4 were scanned on each machine in random order during one clinic visit was conducted. The actual observations were closely aligned around the translational equation regression line, and the coefficient of determination (R^2) for the 4500 DXA regressed on to the 2000 DXA data was 0.99 (unpublished observation).

Height, weight, and somatic maturity

Research-trained nurses measured the participants' height (cm) using a Harpenden stadiometer (Holtain, Crymych, UK) and body mass (kg) using a Healthometer physician's scale (Continental, Bridgeview, IL) at each visit. At ages 13 and 15, sitting height was used to estimate maturity offset (year from PHV) using predictive equations established by Mirwald and colleagues [32]. These equations include age, sex, weight, height, sitting height, and leg length as predictors of years from PHV, or somatic maturity. The method of Mirwald [32] has been validated in white Canadian children and adolescents (R^2 = 0.91–0.92, SEE = 0.49–0.50). The maturity offset variable was dichotomized as 0 (before PHV, or premature) or 1 (after PHV, or mature).

Statistical analysis

Descriptive statistics (means, standard deviations) were calculated for the anthropometric, BMC, and PA characteristics of the participants. Student's t-tests were used to examine sex differences. Longitudinal linear mixed regression models were used to determine whether age 5 PA could predict age 13 or 15 spine or hip BMC after adjusting for age (13/15 year), height (cm), weight (kg), maturity (0 = pre-PHV/1 = post; boys, age 13 only), and concurrent (age 13/15) MVPA/Vigorous PA (as relevant) activity level (min/day). The residual observations within children were correlated through the within-person variance–covariance