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Perspective Article

Lessons learned from school-based intervention trials: UBC Healthy Bones Studies

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The aim of this summary is, first, to outline the normal pattern of bone mineral accrual during childhood. From that foundation I review some intervention trials including those conducted at the University of British Columbia that evaluate the role of childhood physical activity on bone mass and bone structure.

Normal patterns of bone accrual during childhood

The normal pattern of bone mineral accrual was demonstrated in a 7-year longitudinal study conducted at the University of Saskatchewan in Canada[1]. We measured total BMC with DXA in approximately 200 children annually for 7 years. The findings are summarized for boys and girls in Figure 1.

The velocity curves illustrate the sex difference in the timing of peak bone mineral accrual, which, for the total body, occurs about 1.4 years earlier in girls (grey line) than in boys (black line) and is of a lesser magnitude (320 ± 58 g/y for girls vs. 400 ± 96 g/y for boys). Peak height velocity (PHV, maximum rate for linear growth) preceded the age of peak bone mineral accrual (maximum rate of increase in total body bone mineral) by more than half a year[1]. This is of clinical interest because the dissociation between accelerated linear growth and peak bone mineral accrual might constitute a period of relative bone fragility that could partly explain the increased fracture rate observed during adolescence[2].

What role does physical activity play in modulating the normal pattern of bone mineral accrual?

A number of excellent review articles[3] and chapters[4-6] and books[7] all conclude that appropriate physical activity augments bone health during childhood. Retrospective studies indicate that bone responds more favorably to mechanical loading during childhood and adolescence than it does in adulthood[8,9]. A study from Finland showed that racquet-players who had started playing before menarche had a 2–4 times greater dominant-nondominant side-to-side difference than those players who started playing their sport after menarche[10]. These findings launched a series of intervention trials that aimed to examine the components of exercise that were most effective for promoting bone health in childhood.

The interventions all involved running and/or jumping performed for 20–40 minutes, 2–3 times per week. They increased BMC, areal BMD (aBMD), and volumetric BMD (vBMD) across several sites in premenarcheal girls[11], aBMD and vBMD in prepubertal boys[12], trochanteric aBMD in a combined group of girls and boys[13], and lumbar spine and femoral neck BMC in both premenarcheal girls[14] and young prepubertal (5.9–9.8 years) girls and boys[15]. In other prospective trials, the magnitude of the augmented response generally varied from 1% at the trochanteric region of the femur in response to a moderate impact loading intervention implemented in elementary school physical education ($P < 0.05$) 13 (UBC Healthy Bones I) to about 3% at the femoral neck for a high-impact jumping intervention in which children performed drop-jumps from a 62-cm box ($p < 0.001$)[15].

Only 2 studies have assessed girls at different stages of maturity[14,16]. A 9-month study employed a step aerobics and jump program to determine the BMC response at the lumbar spine and proximal femur in 33 premenarcheal and 29 postmenarcheal girls[14]. The postmenarcheal girls showed no significant post-training intergroup differences in bone parameters. The premenarcheal girls' BMC, however, increased significantly more in the trainees than in the controls (lumbar spine 8.6% vs. 5.3; femoral neck 9.3% vs. 5.3%, both $p<0.02$).

UBC Healthy Bones Studies

To more specifically address the question of "timing" in the premenarcheal period, we conducted a randomized con-

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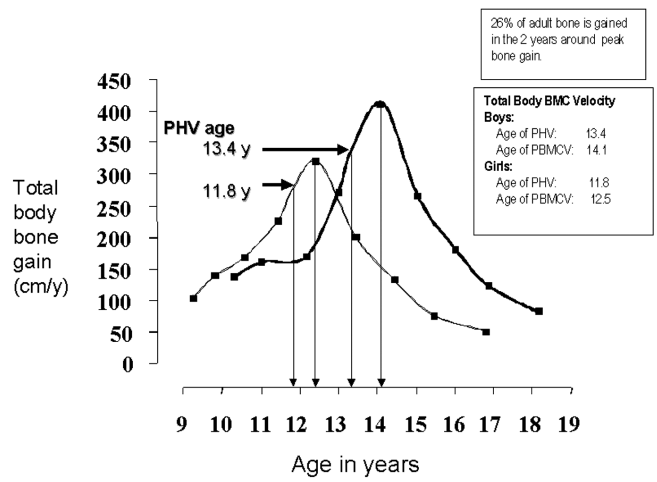

Figure 1.

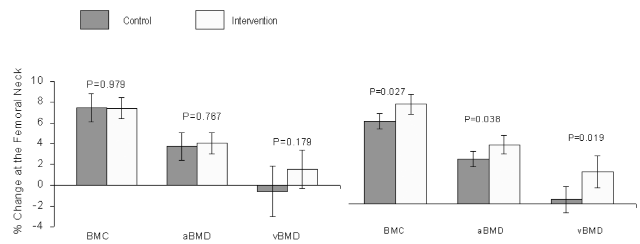

Figure 2. (left) Percent change in bone-mineral content (BMC), area bone mineral density (aBMD) and volumetric bone mineral density (vBMD) at the femoral neck in prepubertal girls (left) and early pubertal girls (right). (UBC Healthy Bones II)[16].

trolled exercise intervention in 177 girls to compare the effectiveness of a progressive loading program performed for 10 minutes during physical education classes in prepuberty (Tanner I) and early (Tanner II and III) puberty (UBC Healthy Bones II)[16]. Total body, lumbar spine (LS), proximal femur, femoral neck (FN) and trochanter BMC and aBMD were measured. The cohort was 45% White, 34% Asian, and 21% other or mixed ethnicities. Girls were between 8.7 and 11.7 years at baseline. There was no difference in the 8-month change in bone parameters in the prepubertal group. The early pubertal girls in the exercise classes gained 1.5% to 3.1% more bone at the femoral neck (FN) and lumbar spine (LS) than did participants of the same stage of maturity in the control classes ($p < .05$; Figure 2)[16]. Gains at other sites did not differ, and no ethnic effect was observed. By the end of the second school year of the study, girls attending intervention schools gained, on average, 3.7 and 4.6% more BMC at the LS and FN, respectively, than girls attending control schools[17].

Results differed somewhat for boys[18]. Intervention boys (n=47) gained significantly more TB BMC (9.6 vs. 7.7%, $p<0.01$, PF aBMD (3.2 vs. 1.8 %, $p<0.05$), and TR aBMD (3.4 vs. 1.4 %, $P<0.01$) compared with controls (n=45) (Figure 3). The bone mineral advantage in the intervention group was 4.4% at the proximal femur after 20 months (Figure 3).

Some of the circuit-training activities that these children undertook as a part of this intervention included 3 levels of drop jump from a 10-, 30-, and 50-cm platform; a 2-legged side-to-side jump; an alternating foot jump; and a tuck jump. The ground-reaction forces of between 2.5 and 5 times body weight were associated with these jumps (assessed in the University of British Columbia biomechanics laboratory in a subset of 70 boys and girls)[19].

Novel modalities to assess structural changes in bone

An understanding of bone's response to mechanical loading in children and adolescents has been limited by the inability of DXA technologies to distinguish geometry from areal density and to assess the bone structure changes that underpin bone densitometric changes[20]. Thus, researchers have sought novel ways to characterize the structural adaptation of growing bone to exercise.

To this end, we analyzed the proximal femur scans of girls in the Healthy Bones II Study using a hip structural analysis program[6] to directly assess subperiosteal width and cross-sectional moment of inertia and to estimate cortical thickness and section modulus at the FN, intertrochanteric, and femoral shaft regions[21]. There were no significant differences for change in bone structure variables in the prepubertal girls. The more mature girls in the intervention group showed significantly greater gains in FN (+ 2.6%, $P = .03$) and intertrochanteric (+ 1.7%, $p = .02$) BMD. Underpinning these changes were increased bone cross-sectional area and reduced endosteal expansion. Changes in subperiosteal dimensions did not differ. Structural changes improved in section modulus at the FN (+ 4.0%, $p = .04$).

We also examined differences in bone structure by pQCT at the tibia between girls who completed the 20-month HBS II exercise intervention and controls[22]. There was no difference in cortical area (cm^2), cortical thickness (cm), periosteal and endosteal circumferences (cm) and cross-sectional moment of inertia (cm^4) at the midshaft (50%) between groups. Similarly, there were no differences for trabecular area (cm^2), total bone area (cm^2), and total density (TotD, mg/cm^3) at the distal (10%) site between groups.

In summary, the studies referred to, and others, provide convincing evidence that both moderate and high impact physical activity can augment bone mass in children. Data suggest that the response is sex-, site-, and maturity-specific. Also, bone appears to respond to childhood exercise by changing bone structure as well as by altering material properties.

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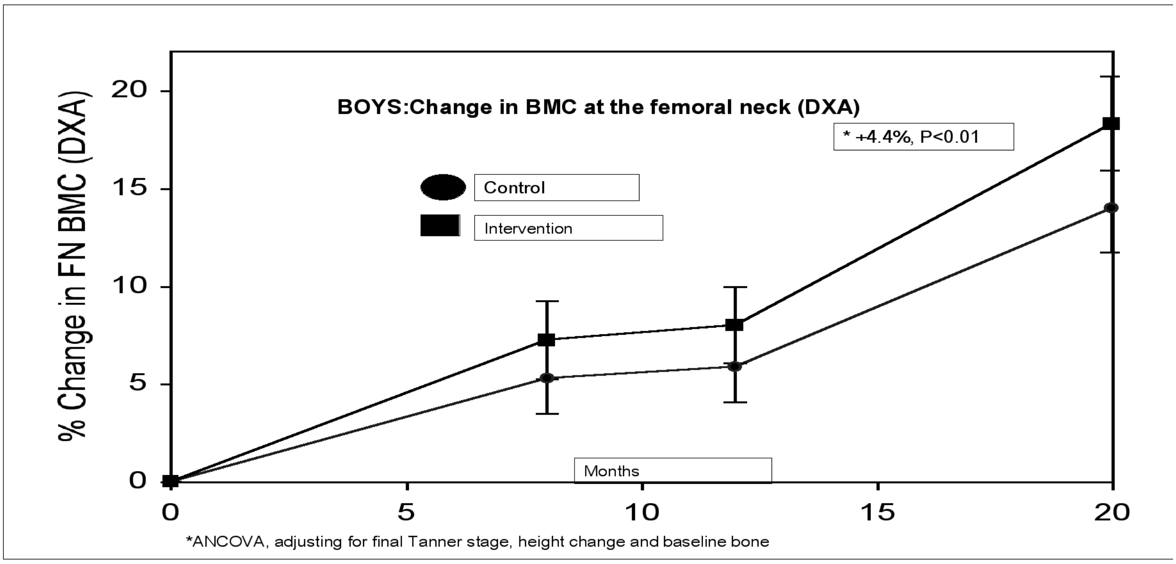

Figure 3. Percent change in femoral neck BMC in exercise and control boys across 20 months.

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