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Adolescence physical activity is associated with higher tibial pQCT bone values in adulthood after 28-years of follow-up — The Cardiovascular Risk in Young Finns Study

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ABSTRACT

High peak bone mass and strong bone phenotype are known to be partly explained by physical activity during growth but there are few prospective studies on this topic. In this 28-year follow-up of Cardiovascular Risk in Young Finns Study cohort, we assessed whether habitual childhood and adolescence physical activity or inactivity at the age of 3–18 years were associated with adult phenotype of weight-bearing tibia and the risk of low-energy fractures. Baseline physical activity and data on clinical, nutritional and lifestyle factors were assessed separately for females and males aged 3–6-years (N = 395–421) and 9–18-years (N = 923–965). At the age of 31–46-years, the prevalence of low-energy fractures was assessed with a questionnaire and several tibial traits were measured with pQCT (bone mineral content (BMC; mg), total and cortical cross-sectional areas (mm^2), trabecular (for the distal site only) and cortical (for the shaft only) bone densities (mg/cm^3), stress–strain index (SSI; mm^3, for the shaft only), bone strength index (BSI; mg^2/cm^4, for the distal site only) and the cortical strength index (CSI, for the shaft only)). For the statistical analysis, each bone trait was categorized as below the cohort median or the median and above and the adjusted odds ratios (OR) were determined. In females, frequent physical activity at the age of 9–18-years was associated with higher adulthood values of BSI, total and cortical areas, BMC, CSI and SSI at the tibia independently of many health and lifestyle factors (ORs 0.33–0.53, $P \leq 0.05$; P-values for trend 0.002–0.05). Cortical density at the tibial shaft showed the opposite trend (P-value for trend 0.03). Similarly in males, frequent physical activity was associated with higher values of adult total and cortical areas and CSI at the tibia (ORs 0.48–0.53, $P \leq 0.05$; P-values for trend 0.01–0.02). However, there was no evidence that childhood or adolescence physical activity was associated with lower risk of low energy fractures during the follow-up. In conclusion, frequent habitual physical activity in adolescence seems to confer benefits on tibial bone size and geometry in adulthood.

Introduction

Bone mass in adulthood is determined by peak bone mass attained by the early adulthood and the subsequent rate of bone loss during the lifespan. In children who are either pre-pubertal or in the early stages of puberty, muscular contractions during weight-bearing activities can site-specifically increase bone mass and strength [1,2]. Greater relative side-to-side differences in bone mineral content (BMC) measured with dual-energy X-ray absorptiometry (DXA) or in geometry of humeral diaphysis measured with peripheral quantitative computed tomography (pQCT) has been observed in the playing arm of tennis and squash players when the playing was started at or before menarche compared with those who started the playing after menarche age [3,4]. In a large population-based cross-sectional study using objective measures of physical activity, the highest impact levels of physical activity were positively associated with the periosteal bone mineral

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accrual at the femoral neck and other hip sites [5]. In a recent review and meta-analysis of 10 at least 12 month long randomized controlled trials on the effects of supervised exercise on estimated bone strength, prepubertal boys had stronger bones than habitually active or sedentary controls [6], whereas in other age groups or in females no significant effect on estimated bone strength was observed. In another review of weight-bearing exercise interventions, 16 out of 22 trials found that exercise enhanced bone mineral accrual in prepubertal, early pubertal and pubertal children and adolescents compared to controls [7]. The most significant increases in DXA-measured bone mass were found at the femoral neck in early pubertal children. There are also some prospective studies with longer follow-up time (duration from 6 to 15 years) suggesting long-term skeletal benefits of childhood physical activity [8–10].

Bone mineral density (BMD) is routinely assessed with DXA, which cannot distinguish between cortical and trabecular bone or actual cross-sectional geometry. This can be done with pQCT. However, there are only few longitudinal studies on childhood or adolescence physical activity that have used pQCT measured bone traits as endpoints. In a follow-up study of healthy females and males, physically active adolescents had 10–13% greater bone strength, cortical content, total and cortical area at the tibia diaphysis later in young adulthood than their inactive peers [11]. A recent controlled 6-year intervention of 6–9 years old children using both DXA and pQCT showed that increasing the amount of physical education within the school curriculum from the standard weekly 60 min to 40 min every school day increased children's bone mass and size and in girls also skeletal architecture [12]. In another intervention, daily jumping program plus 15 min of physical activity for 5 days a week increased prepubertal boys' bone strength at the distal tibia compared with the control group during a 14 month median follow-up time [13], whereas no group differences were found in females or early pubertal boys. A 9-month high-impact exercise intervention of adolescent girls did not improve the pQCT-derived tibial cortical geometry in pre- or postmenarcheal girls [14], but premenarcheal girls gained more bone mineral at the lumbar spine and femoral neck compared with the controls. In addition to abovementioned pQCT-studies, retrospectively assessed regular exercise at the competitive level during growth and young adulthood has been associated with greater cortical bone size at the tibial diaphysis and higher estimated bone strength at the metaphysis in 80-year old men [15]. In 24 years old men, years spent in physical activity during adolescent growth were positively associated with cortical cross-sectional area and thickness at the tibia [16]. In another study of the same young adult male population, currently inactive men who had participated in sports during childhood and adolescence had larger cortical cross-sectional area and thicker cortical bone at the tibia than men who had never participated in any sport activity prior to study inclusion indicating remaining benefits of physical activity during growth [17].

The present study was performed to investigate the associations of 3 to 18 years old children's and adolescents' physical activity on pQCT-measured tibial bone traits in adulthood 28 years later in a population-based cohort setting. We hypothesized that frequent physical activity level in childhood and adolescence would result in increased tibia outcomes in adulthood.

Materials and methods

The Cardiovascular Risk in Young Finns Study

The Cardiovascular Risk in Young Finns Study is an ongoing multicenter follow-up of atherosclerosis risk factors in Young Finns [18]. In the present study, childhood data were obtained from the first cross-sectional survey conducted in 1980 (n = 3596 subjects, 83% of those invited) when subjects were 3, 6, 9, 12, 15, or 18 years old. The subjects had been randomly selected from the national population register from five university cities in Finland (Helsinki, Turku, Tampere, Kuopio and Oulu) and the rural municipalities in their vicinity. In 2008, subjects (n = 3386) in the original register of the Young Finns Cohort were invited to pQCT measurements. Altogether 1884 individuals (1058 females and 826 males) aged 31–46 years attended the pQCT measurements organized in five study centers between February and December 2008. The reasons for non-participation have been described in detail previously [18,19]. Briefly, those who dropped out were more often men and represented the younger age groups than the present participants. Otherwise, no statistically significant differences were found in health related factors except smoking prevalence between eastern and western Finland.

The invitation letter to the pQCT measurements included two questionnaires on diseases, medications, and lifestyle factors relevant to bone health. Pregnant women were excluded. The study was approved by the local ethics committees of the Universities of Helsinki, Turku, Tampere, Kuopio, and Oulu. Written informed consent was obtained from all participants, and the study was conducted in compliance with the World Medical Association Declaration of Helsinki — Ethical Principles for Medical Research Involving Human Subjects.

Bone measurements and fractures

Two trained research assistants in each study center performed the pQCT measurements from the distal and shaft sites of the tibia. The same pQCT device was used in all five study centers (XCT 2000R, Stratec, Medizintechnik GmbH, Pforzheim, Germany). Distal tibia was scanned at the 5% site of the measured bone length, and tibial shaft at the 30% site from the distal endplate on the left leg, except in case of metal implants or previous fractures, when measurements were done on the right leg. Altogether 61 tibia scans were excluded due to interrupted protocol, inability to fit the leg into the gantry, inaccurate positioning of the extremity or serious movement artifacts during scanning. The precision of the pQCT method was evaluated in a subgroup with in vivo coefficients of variation (CV%) varying between 0.5% and 2.6% for the tibial traits [20].

For the distal site, peel and counter modes 2 were used according to standard procedures [21]. For the shaft a density threshold of 710 mg/cm^3 was applied to separate the cortical bone from other tissues. The following bone traits were obtained: bone mineral content (BMC; mg), total and cortical cross-sectional areas (mm^2), and trabecular (for the distal site only) and cortical (for the shaft only) bone densities (mg/cm^3). In addition, three different bone strength indices were estimated. The conventional stress–strain index (SSI; mm^3), representing the resistance of the bone against torsional load, was calculated for the shaft only. For the distal site, bone strength index (BSI; mg^2/cm^4), representing bone strength against compressive loading, was calculated as a product of the total density squared and total cross-sectional area (TotD^2 $*$ TotA) [4,22]. For both distal and shaft sites, the cortical strength index (CSI), indicating cortical stability, was calculated as a ratio of cortical area to total cross-sectional area (CoA/ToA) [23].

Information on all fractures during the entire follow-up period and oral corticosteroid medication for at least one month (yes/no) was collected with a questionnaire in 2008 [20]. Bone fracture type, how the fracture occurred, site of the fracture and age when fracture occurred were reported separately. Fractures were classified as low-energy fractures if sustained as a result of a fall from no more than the standing height. Fractures caused by a fall from greater heights, sport injuries involving other people, collisions or accidents involving vehicles or high velocities such as cycling, skiing, skating or motorized vehicles were excluded from the analysis.

Assessment of physical activity

The sum indices of total physical activity based on physical activity index (PAI) collated in 1980 were chosen to describe habitual physical