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Short-term physical activity intervention decreases femoral bone marrow adipose tissue in young children: A pilot study☆,☆☆

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ABSTRACT

Mechanical stimulation is necessary for maximization of geometrical properties of bone mineralization contributing to long-term strength. The amount of mineralization in bones has been reciprocally related to volume of bone marrow adipose tissue and this relationship is suggested to be an independent predictor of fracture. Physical activity represents an extrinsic factor that impacts both mineralization and marrow volume exerting permissive capacity of the growing skeleton to achieve its full genetic potential. Because geometry- and shape-determining processes primarily manifest during the linear growth period, the accelerated structural changes accompanying early childhood (ages 3 to 6 y) may have profound impact on lifelong bone health. The objective of this pilot study was to determine if a short-term physical activity intervention in young children would result in augmentation of geometric properties of bone. Three days per week the intervention group (n = 10) participated in 30 min of moderate intensity physical activity, such as jumping, hopping and running, and stretching activities, whereas controls (n = 10) underwent usual activities during the 10-week intervention period. Femoral bone marrow adipose tissue volume and total body composition were assessed by magnetic resonance imaging and dual-energy X-ray absorptiometry, respectively, at baseline and after 10 weeks. Although after 10-weeks, intergroup differences were not observed, a significant decrease in femoral marrow adipose tissue volume was observed in those participating in physical activity intervention. Our findings suggest that physical activity may improve bone quality via antagonistic effects on femoral bone marrow adipose tissue and possibly long-term agonistic effects on bone mineralization.

Introduction

Long-term overall bone health is dependent upon cycles of site-specific bone morphology during maturation. Deposition of mineral on the periosteal surface influences the bone's external bone dimension and mass distribution underlying strength, whereas the extent of net mineral removal from its endocortical surface establishes the size of the marrow cavity, influencing stiffness (ability to withstand fracture) [1–3]. While net bone mineral deposition is critical for mass, resorption is not necessarily antagonistic, particularly during growth and development. The resorptive phase of the remodeling cycle at various sites enables replacement by new bone serving to optimize material composition, micro- and macro-architecture. However, as development progresses, bone remodeling begins to be “uncoupled” in that resorbed mineral is not completely replaced, resulting in a net bone loss and an increased size of the marrow compartment. Bone marrow, or more specifically, resident adipose tissue volume (BMAT), is reciprocally related to the amount of mineral in the long bones [4, 5] in adults and has been suggested to be an independent predictor of fracture [1, 4]. Assuming a constant age-associated rate of bone resorption, individuals with lower peak bone mass (and greater bone marrow adipose tissue volume) suffer greater fracture risk and reach an osteoporotic bone density more often and earlier than their counterparts.

Attributing 60–75% of the variance in peak bone mass to genetic heritability allows for the possibility that the remaining proportion may be amenable to “external factors” aimed at optimization of inherent capacity [1–3]. Mechanical stimulation (e.g., through weight-bearing physical activity) is necessary for maintaining a normal balance between selective mineral deposition and resorption from existing surfaces with the goal of maximization of geometrical properties contributing to long-term bone strength [6]. Mechanical stress which exceeds typical day-to-day threshold (in terms of intensity and strain) and/or conveys an unusual

Abbreviations: BMAT, Bone marrow adipose tissue; BMC, Bone mineral content; CBV, Cross-sectional bone volume measured in femur; CV, Coefficient of variation; DXA, Dual-energy X-ray absorptiometry; MR, Magnetic resonance; MRI, Magnetic resonance imaging; MSC, Mesenchymal stem cells; UAB, University of Alabama at Birmingham.

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loading pattern (e.g. jumping) has been shown to be most beneficial for anabolic bone maturation. Physical activity also increases blood supply to surrounding muscle, thereby promoting delivery of nutrients and chemical messengers. Because the geometry- and shape-determining processes primarily manifest during the linear growth period, the accelerated structural changes accompanying early childhood (~age 3 to 6 y) may have profound impact on lifelong bone health.

Interestingly, an estimated 20% increase in fracture prevalence among the pediatric population has been observed over the past decade [1–3]. Perturbation in the balance between deposition and resorption and consequential geometry, particularly during critical periods of growth, may compromise bone strength and stiffness. Accelerated infiltration of adipose tissue into the marrow cavity during this time may also lead to concessions in bone integrity. To our knowledge, no study has investigated the effect of BMAT changes in children in response to a physical activity program. Given the biomechanical advantage of optimizing cortical bone strength in early childhood, the objective of this study was to evaluate whether preschoolers participating in moderate-to-vigorous physical activity would have greater cross-sectional cortical bone volume and less bone marrow adipose tissue volume assessed via MRI segmentation in the femur compared to control counterparts.

Materials and methods

Ten children (40% European American, 60% African American) participated in a school-based physical activity intervention and an additional ten children (40% European American, 40% African American, 20% Hispanic American) were recruited to serve as controls. All measures were performed at the UAB/Nutrition Obesity Research Center Core Metabolism Laboratory and except the MRI was obtained at the UAB Division of Cardiology. Baseline measurements were obtained between February and March 2010, and follow-up measurements were obtained within 2 weeks of the 10-wk intervention period from March to May 2010.

Intervention

Since the intervention was conducted during typical school hours, all children in the participating classrooms engaged in the physical activity program. However, data were only collected from the first 10 children whose parent or guardian agreed to attend pre- and post-body composition assessment at UAB. In addition, parents of participating classrooms were notified of their child's participation and allowed for the opportunity to opt-out. Up to two children per family were eligible to participate.

The research-based SPARK-Early Childhood curriculum was used to guide the supervised physical activity program [7–9]. Three days per week over a ten-week period a certified exercise physiologist engaged the children in 20 min of moderate intensity physical activity. The activities primarily focused on locomotive skills such as jumping, hopping and running. The general format for each exercise session included a five-minute warm-up activity, two 10-minute jumping activities, and a five-minute cool down activity. Children were introduced to the program and progressively trained to be active for the full 20-minute locomotive activity portion. All activities required minimal equipment (e.g. cones) and could be performed in the classroom. To monitor compliance, attendance logs were completed each day by the teacher. From records, the average student attendance was >90% across all weeks of the study.

Anthropometric assessment

Height and weight were measured using a portable stadiometer and digital scale. Waist circumference was measured at the narrowest apparent part of the torso between the ribs and iliac crest as described by Lohman et al. [10]. Waist circumference measures were obtained using a flexible tape measure (Gulick II; Country Technology, Inc., Gays Mills, WI) and recorded to the nearest 0.1 cm.

Body Composition

Adipose tissue distribution in the femur and whole-body body composition was assessed by magnetic resonance imaging (MRI) and dual-energy X-ray absorptiometry (DXA), respectively. Whereas DXA measures total tissue content based upon an areal estimate, magnetic resonance through delineation and simple signal thresholding allows contrast between tissue compartments, thus providing a more sensitive quantification of fat and bone.

MRI imaging and analysis

Measures for cross-sectional cortical bone volume and bone marrow adipose tissue volume assessed in the femur were acquired using MRI. MRI which involves no ionizing radiation is emerging as a comprehensive tool for fat quantification. For MRI, children were scanned using a Philips 3T system in the UAB Division of Cardiology [5]. A series of T1-weighted slices (allowing for rapid scans with strong fat-water tissue contrast) were acquired at the upper-leg regions with data acquisition beginning at the iliac crest and continuing to the knee (superior border of the patella). These slices included the ilium, sacrum, ischium, pubis, coccyx, femoral heads, and femur; however, to ensure consistency, only the volumes of tissue in the femur were included in the analysis. A standard commercial 3D inversion-prepared gradient-echo pulse sequence was used (e.g. MP-RAGE). Imaging parameters included repetition time (TR) = 6.4 ms, echo time (TE) = 3.2 ms, inversion time (TI) = 801 ms, 5 mm slices with 0 mm gap, bandwidth (BW) = 241 kHz, and one signal average. A 6 receiver array was used. The participant rested in either a prone position during the procedure with the iliac crest as the point of origin.

Following acquisition, the bone marrow and cortical bone compartments were segmented and analyzed off-site in the laboratory of Houchun Hu at the University of Southern California using SliceOMatic (Tomovision, Inc.) software. The technique used for analysis has been described elsewhere [11, 12]. Briefly, the procedure involves the transfer of images to an offline workstation, followed by the use of SliceOMatic. All tissue segmentation was performed using the “Region Growing” toolbox and the “Paint” function. As the DICOM images from each MRI exam were not normalized, the threshold for each subject's data was determined individually based on histogram, in a manual fashion. Since BMAT exhibited bright signal intensities due to its large fat content and is surround by bone with dark signal intensity, SliceOmatic segmentation was straightforward. Performance of the chosen threshold in segmenting the BMAT was visually inspected by the segmenter. BMAT in pelvis was not included because of the difficulty in differentiating this component from adjacent intramuscular or subcutaneous adipose tissue.

DXA imaging

Total body composition (body fat mass and bone mineral content) was measured by DXA using a GE Lunar Prodigy densitometer (GE LUNAR Radiation Corp., Madison, WI). Participants were scanned in light clothing, while lying flat on their backs with arms at their sides. DXA scans were performed and analyzed using pediatric software (enCORE 2002 Version 6.10.029). In our laboratory, the coefficient of variation (CV) for repeated measures of total body fat mass is 6.55%.

Statistical analysis

Measures were conducted at baseline and at 11 weeks. All data were analyzed using SAS 9.1 software (SAS institute Inc. Cary, NC). Student's t-tests for paired data were used to compare mean values