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Muscle volume is related to trabecular and cortical bone architecture in typically developing children

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ABSTRACT

Introduction: Muscle is strongly related to cortical bone architecture in children; however, the relationship between muscle volume and trabecular bone architecture is poorly studied. The aim of this study was to determine if muscle volume is related to trabecular bone architecture in children and if the relationship is different than the relationship between muscle volume and cortical bone architecture.

Materials and methods: Forty typically developing children (20 boys and 20 girls; 6 to 12 y) were included in the study. Measures of trabecular bone architecture [i.e., apparent trabecular bone volume to total volume (appBV/TV), trabecular number (appTb.N), trabecular thickness (appTb.Th) and trabecular separation (appTb.Sp)] in the distal femur, cortical bone architecture [cortical volume, total volume, section modulus (Z) and polar moment of inertia (J)] in the midfemur, muscle volume in the midthigh and femur length were assessed using magnetic resonance imaging. Total physical activity and moderate-to-vigorous physical activity were assessed using an accelerometer-based activity monitor worn around the waist for four days. Calcium intake was assessed using diet records. Relationships among the measures were tested using multiple linear regression analysis.

Results: Muscle volume was moderately-to-strongly related to measures of trabecular bone architecture [appBV/TV ($r = 0.81$), appTb.N ($r = 0.53$), appTb.Th ($r = 0.67$), appTb.Sp ($r = -0.71$); all $p < 0.001$] but more strongly related to measures of cortical bone architecture [cortical volume ($r = 0.96$), total volume ($r = 0.94$), Z ($r = 0.94$) and J ($r = 0.92$; all $p < 0.001$)]. Similar relationships were observed between femur length and measures of trabecular ($p < 0.01$) and cortical ($p < 0.001$) bone architecture. Sex, physical activity and calcium intake were not related to any measure of bone architecture ($p > 0.05$). Because muscle volume and femur length were strongly related ($r = 0.91$, $p < 0.001$), muscle volume was scaled for femur length (muscle volume/femur length$^{2.77}$). When muscle volume/femur length$^{2.77}$ was included in a regression model with femur length, sex, physical activity and calcium intake, muscle volume/femur length$^{2.77}$ was a significant predictor of appBV/TV, appTb.Th and appTb.Sp (*partial* $r = 0.44$ to 0.49, $p < 0.05$) and all measures of cortical bone architecture (*partial* $r =$ 0.47 to 0.54; $p < 0.01$).

Conclusions: The findings suggest that muscle volume in the midthigh is related to trabecular bone architecture in the distal femur of typically developing children. The relationship is weaker than the relationship between muscle volume in the midthigh and cortical bone architecture in the midfemur, but the discrepancy is driven, in large part, by the greater dependence of cortical bone architecture measures on femur length.

1. Introduction

Childhood is viewed as a critical time to maximize the mass, architecture and strength of bone and minimize fracture risk later in life [1,2]. Areal bone mineral density (aBMD), determined using dual-energy X-ray absorptiometry, is the single best surrogate of fracture risk widely available. However, there is a significant overlap in aBMD in those who have and have not fractured [3]. Moreover, using aBMD alone to make clinical decisions in children has been questioned [4,5]. The development of more sophisticated imaging techniques using magnetic resonance imaging (MRI) and computed tomography now allow for the separation of bone into different compartments and for the evaluation of different architectural features of trabecular and cortical bone. The architecture of bone is an important contributor to its biomechanical

Abbreviations: appBV/TV, apparent trabecular bone volume to total volume; appTb.N, apparent trabecular number; appTb.Th, apparent trabecular thickness; appTb.Sp, apparent trabecular separation; Z, section modulus; J, polar moment of inertia.

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strength [6]. Magnetic resonance imaging is particularly attractive for the study of bone in children because it does not expose them to ionizing radiation.

Due to the importance of bone architecture, identifying factors that contribute to its development could lead to an immediate and long-term reduction in fracture risk. Muscle clearly has a positive influence on bone which has led to the proposal of muscle-bone indexes that reflect the relationship between muscle and bone [7]. In theory, muscle-bone indexes can be used to identify those at greatest risk for fracture or if factors other than muscle are contributing to poor bone development [8]. Although the relationship between muscle and cortical bone architecture in children has been studied [9,10], the relationship between muscle and trabecular bone architecture remains unclear. Because other factors may influence the development of bone architecture, such as general growth, as indicated by bone length, sex, physical activity and dietary factors, such as calcium intake, these factors must be considered when evaluating the relationship between muscle and trabecular bone architecture.

The primary aim of this study was to determine if muscle volume is related to measures of trabecular bone architecture in typically developing children and if the relationship is different than the relationship between muscle volume and cortical bone architecture. We hypothesized that thigh muscle volume would be related to measures of trabecular and cortical bone architecture in the distal femur of typically developing children while controlling for femur length, sex, physical activity and calcium intake.

2. Methods

2.1. Subjects

Typically developing children 6 to 12 years of age, between the 5th and 95th percentile for height and body mass, with no history of lower extremity fracture, no intramedullary fixation in the femur or tibia, no use of chronic medications known to affect bone or muscle development and not participating in > 3 h of organized physical activity per week were recruited from the Newark, DE, USA community by distributing flyers. The procedures followed were in accordance with the ethical standards of the institutions on human experimentation. The Institutional Review Boards at the University of Delaware and the AI duPont Hospital for Children approved the study. Written consent from parents and written assent from children, if able, were given before testing.

2.2. Protocol

For each participant, height, body mass, sexual maturity, physical activity, calcium intake, measures of trabecular and cortical bone architecture, muscle volume and femur length were assessed and recorded within a two week period.

2.3. Anthropometrics

Children wore shorts, a t-shirt and no shoes during anthropometric assessment. Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (Seca model 222, Novel products, Rockton, IL). Body mass was measured to the nearest 0.2 kg using a digital scale (Detecto 6550, Cardinal Scale, MO). Height, body mass and body mass index (BMI) percentiles were calculated from the normative graphs published by the Centers for Disease Control and Prevention [11].

2.4. Tanner staging

Sexual maturity was assessed by a physician assistant using the Tanner staging technique [12]. Signs of pubic hair growth were assessed along with testicular/penile development in boys, and breast development in girls. The Tanner stages range from 1 to 5, with 1 indicating no signs of sexual development (pre-pubertal), 2 indicating early sexual development and 5 indicating full sexual development.

2.5. Physical activity

Physical activity was assessed using an accelerometer-based activity monitor (Actical; Philips Respironics, Sunriver, OR) that was worn on the non-dominant hip for four days (three weekdays and one weekend day). Four days of data collection was chosen because it yields accurate and reliable estimates of physical activity [13]. The children were asked not to remove the activity monitor at any time (including sleep) except while swimming at a depth greater than three feet or while bathing/showering. Activity counts were registered in 15 second epochs. Total physical activity was reported in average counts/d. Moderate-to-vigorous physical activity was reported in average counts/d, average minutes/d and average counts/min/d. Physical activity was divided into moderate and vigorous levels based on the work of Puyau et al. [14] with 1500–6500 counts per minute classified as moderate activity and >6500 counts per minute classified as vigorous activity. Only participants who wore the activity monitors for at least three complete days were included in the final analysis. This was confirmed by reviewing physical activity logs that were kept by the child with the assistance from the parent and by reviewing the graphical output generated by the activity monitor software.

2.6. Calcium intake

Children, with the aid of a parent, completed a diet record for two days during the week and one day on the weekend. To facilitate accurate quantification of foods, each participant and their parent received a list of serving size estimates based on comparisons to everyday objects (e.g., 3 oz of meat or poultry is approximately the size of a deck of cards). Calcium intake was estimated using the diet records and the USDA Food and Nutrient Database for Dietary Studies, v. 1.0, as previously done [15]. Only participants who recorded diet for three complete days were included in the final analysis.

2.7. Magnetic resonance imaging

Trabecular bone architecture at the distal femur, cortical bone architecture and muscle volume at the level of the middle-third of the femur, and femur length on the non-dominant side were estimated using MRI (GE 1.5 T; Milwaukee, WI). Children were immobilized from the waist down using the BodyFIX (Medical Intelligence, Inc., Schwabműnchen, GER), as previously described [16]. Different imaging protocols were used to collect images needed for the assessment of trabecular bone architecture and for the assessment of cortical bone architecture, muscle volume and femur length.

2.7.1. Trabecular bone architecture

A phased array coil (USA Instruments; Aurora, OH) was secured to the lateral portion of the distal femur using a VacFIX system (PAR Scientific A/S; Sivlandvaenge, Denmark). The lateral distal femur was identified using a three-plane localizer. Then 26 high resolution axial images were collected immediately above the growth plate in the metaphysis using a 3D fast gradient echo sequence with a partial echo acquisition (30 ms repetition time; 4.5 ms echo time; 30° flip angle; 13.89 kHz bandwidth; 9 cm field of view) and an imaging matrix of 512 × 384 reconstructed to a $175 \times 175 \times 700\ \mu m^3$ voxel size. Measures of trabecular bone architecture [i.e., apparent trabecular bone volume to total volume (appBV/TV), trabecular number (appTb.N), trabecular thickness (appTb.Th), and trabecular separation (appTb.Sp)] in the 20 most