South Dakota State University

Open PRAIRIE: Open Public Research Access Institutional Repository and Information Exchange

Ethel Austin Martin Program Publications

7-2008

Muscle-bone Relationships in the Lower Leg of Healthy Pre-pubertal Females and Males

Teresa L. Binkley
South Dakota State University, teresa.binkley@sdstate.edu

Bonny Specker
South Dakota State University, Bonny.Specker@sdstate.edu

Follow this and additional works at: https://openprairie.sdstate.edu/eam_pubs

Recommended Citation

Original Article

Muscle-bone relationships in the lower leg of healthy pre-pubertal females and males

T.L. Binkley and B.L. Specker

Ethel Austin Martin Program in Human Nutrition, South Dakota State University, Bookings, SD, USA

Abstract

Muscle-bone relationships in healthy pre-pubertal children were investigated using four muscle measures as predictors of tibial strength: 66% tibia cross-sectional muscle area (CSMA) by pQCT; leg lean mass (LLM) by DXA; and muscle power (Power) and force (Force) measured during a two-footed jump. Polar strength strain index (pSSI), a calculated surrogate for bone strength at the 20% distal tibia, was obtained on 105 (54 male) self-assessed pre-pubertal children. The amount of muscle (CSMA, LLM) may influence bone strength more than muscle strength (Power, Force) during periods of rapid growth. Correlations and multiple regression partial-R values from models controlling for age, sex, height and weight were obtained for each muscle predictor. CSMA, LLM, Power and Force were positively correlated with pSSI (R=0.84, 0.92, 0.85; 0.66, respectively, all $p<0.01$). Partial-R values were highest for LLM (partial-R=0.21), similar for CSMA and Power (0.14, 0.15, respectively) and lowest for Force (0.04) in predicting pSSI. Muscle predictors were associated with total and cortical area (R=0.59 to 0.90; $p<0.01$ for all), but not cortical vBMD at the 20% distal tibia site. These data support relationships between muscle predictors and bone parameters measured by pQCT in healthy pre-pubertal children.

Keywords: Muscle-bone, Pre-pubertal, pQCT, Cross-sectional Muscle Area, Bone Strength

Introduction

Bone research over the past decade has increasingly emphasized the importance of muscle development on bone development of the growing skeleton[1-3]. More and more evidence relating bone mass to bone size and muscle function is shifting the measurements used in bone research from bone mass to bone geometry or bone strength[4,5]. Studies by Schönau et al. have related bone strength and bone geometry of the forearm measured by peripheral quantitative computed tomography (pQCT) to muscle strength measured by grip dynamometer in healthy children and in children with cystic fibrosis and Ullrich Turner Syndrome[6-8]. Normal ranges and correlations of bone strength and muscle

strength lead to the perspective that bone diseases in childhood may be distinguished by comparing these measures[4,8]. Primary bone disorders are indicated by reduced bone strength with normal muscle strength. Secondary bone disorders occur when bone strength and muscle strength are reduced due to inactivity. Bone geometry of the radius such as total cross-sectional area and cortical area also has shown increases with increasing muscle strength, while trabecular and cortical volumetric bone mineral density (vBMD) do not[6]. Similar measurements of the lower leg have not been studied in children.

A longitudinal study in children from near birth through late adolescence[9] used radiograph films of the limbs to calculate polar section modulus as a surrogate measure for bone strength. The results showed that growth velocities in bone strength in the upper and lower limbs were correlated with changes in mechanical loads. The growth in bone strength velocity of the humerus was associated with changes in both body size (body weight • bone length) and muscular loads (muscle area). The influence of body size proved to be stronger on the weight-bearing femur. Growth in bone strength velocity of the femur was predominately influenced by body size (body weight • bone length), while the estimat-

ed cross-sectional area of muscle at the mid-thigh was not associated with femoral polar section modulus. From another perspective, muscle area and muscle mass add more to overall body weight, increasing loading and may predict bone strength of the weight-bearing tibia in growing children better than strength of the muscle measured as power or force.

The purpose of this study is to investigate muscle-bone relationships of the lower leg in healthy pre-pubertal children using four different muscle measures as predictors to estimate bone strength of the tibia: cross-sectional muscle area (CSMA) measured in square millimeters from the 66% distal tibia slice by pQCT; leg lean mass (LLM) measured in grams by whole body DXA; and muscle power (Power) measured in Watts and muscle force (Force) measured in Newtons by ground reaction force from a two-footed jump. The polar strength strain index (pSSI), a surrogate for bone strength, was measured in cubic millimeters by pQCT at the 20% distal tibia site. We hypothesize that:

1) In growing children, muscle size and mass (CSMA, LLM) will have stronger correlations to bone strength (pSSI) than measures of muscle strength (Power, Force).
2) pSSI predicted by models controlling for age, sex, height and weight will have higher partial-R values for CSMA and LLM than for Power and Force.
3) Muscle predictors will be associated with the size of the bone but not with the volumetric density of the bone.

Methods

Participants were recruited from a convenience sample taken in a rural community and surrounding area in eastern South Dakota and from a nearby local elementary school with approximately 40 students per grade level. At the elementary school, notes describing the study and consent forms were sent home with all students in grades K-5. Without any further recruiting strategies, approximately 42% of the students returned a signed parental consent form and were included in the study. The South Dakota State University Human Subjects Committee approved the study for children 6 years of age and older, therefore some of the kindergarten students who were only 5 years old were not eligible. None of the children had conditions affecting bone development and therefore were considered healthy. Self-assessed Tanner Stage for pubertal development was obtained by interview with study personnel using sketched line drawings of breast and pubic hair development[10]. This method uses five sketches numbered 1 to 5 with a score of 5 being the most mature development. Females aged 7-15 years and males aged 9-16 years were asked which of the drawings looked most like them and the stage number recorded. Females were shown sketches for both breast and pubic hair development and when these scores did not match, the higher of the two was used. The final population included in analysis consisted of 105 (54 male) healthy, predominately Caucasian, pre-pubertal (Tanner score=1) children. Seventy six percent of this population was recruited

from the elementary school.

All densitometry measures were made using our mobile unit which houses bone densitometry equipment. The study was conducted at our office site with parents attending the visit with the child and at the elementary school site during the school day without the parent in attendance. Questionnaires completed by in-person interview with a parent or by phone interview with a parent of the elementary school children, were used to obtain information on date of birth, ethnicity and brief health history. Height without shoes was measured to the nearest 0.5 cm (Seca Model 225, Hanover, MD) and weight in light clothing was measured by digital scale to the nearest 0.1 kg (Seca Model 770, Hanover, MD).

Bone parameters, CSMA and pSSI were obtained by pQCT using the XCT2000 bone densitometer (Orthometrix Inc., White Plains, NY). Tibia length was measured using a segmometer (Rosscraft, Vancouver, Canada) as the total distance between the medial condyle and the medial malleolus of the tibia and used to locate image slices. A slice at 20% of the tibia length from the distal end was obtained after utilizing a scout view to place a reference line at the distal end of the tibia. A speed of 30 mm/sec and voxel size of 0.40 mm was used to acquire the 20% slice image. The 66% slice was acquired without the use of a scout view. This site is located by calculating 66% of the tibial length, measuring that length from the distal end and marking the leg. The scanner is then set over the mark and a slice image taken using a speed of 30 mm/sec and 0.60 mm voxel.

The 20% slice image was analyzed using manufacturer's software version 6.00B. Analysis settings were: Contour mode 2, Peel mode 2 with a threshold of 400 mg/cm^3 and Cort mode 1 and threshold of 710 mg/cm^3 for cortical bone with a threshold of 280 mg/cm^3 for pSSI. The 66% slice was analyzed for CSMA as suggested by the manufacturer[11]. Cortical vBMD at the 20% site was adjusted for partial volume effects as suggested by Rittweger[12]. Our institution's coefficients of variation (CVs) at the 20% distal tibia site for cortical density, total bone area and cortical bone area are less than 2% and the CV for pSSI is less than 5%. Precision for muscle area has not been measured at our institution. LLM was obtained using whole body DXA (Hologic, Inc., Bedford, MA). Images were analyzed using Discovery Pediatric Software version 12.3 provided by the manufacturer. Leg lean mass precision has only been measured in adults at our institution (CV<2%).

Peak jump force (Force) and peak jump power (Power) from a two-footed counter movement jump were obtained using a ground reaction force platform and software (Novotec Medical, Pforzheim, Germany). Children were instructed to jump as high as possible in a similar manner to previous studies using jumping mechanography[13,14]. The mechanics of the force platform have been described in detail previously[13]. In brief, detectors in the plate sense deformations from an applied force causing changes in electrical resistance that are proportional to the force. The voltage changes from the detectors are amplified and recorded by computer software over

	Group	Female	Male	p-value
N	105	51	54	
Age (yr)	8.5 (1.5)	8.3 (1.5)	8.7 (1.5)	NS
Height (cm)	131.5 (10.3)	128.8 (10.0)	134.0 (10.0)	<0.01
Weight (kg)	30.8 (7.8)	29.8 (8.2)	31.6 (7.4)	NS
CSMA (mm^2)	3583 (742)	3479 (791)	3680 (686)	NS
LLM (g)	7219 (1820)	6782 (1864)	7634 (1693)	0.02
Power (Watts)	1064 (327)	1017 (320)	1108 (330)	NS
Force (N)	1547 (514)	1371 (440)	1712 (527)	<0.001
Bone Area: Muscle Area 66%	5.0 (0.7)	4.8 (0.7)	5.1 (0.7)	NS
WB Bone mass: WB Lean Mass	4.5 (0.4)	4.6 (0.5)	4.5 (0.3)	NS
Data are mean (SD).				

Table 1. Population characteristics.

Outcome Variable	Muscle Predictor Correlation Coefficients			
	CSMA	LLM	Power	Force
Bone Strength (pSSI) 20% (mm^3)	0.84 *	0.92*	0.85*	0.66*
Adjusted Cortical vBMD 20% (mg/cm^3)	-0.08	-0.16	-0.09	-0.08
Total Area 20% (mm^2)	0.77*	0.86*	0.79*	0.59*
Cortical Area 20% (mm^2)	0.81*	0.90*	0.84*	0.65*
*p<0.0001				

Table 2. Correlation coefficients between outcome variables and muscle predictors.

time during a jump. The body weight of the jumper is recorded by the software and an associated power is calculated. The force and power utilized in this study are the force from the upward part of the jump and corresponding calculated power. The highest force reading and corresponding power out of three jumps was recorded from the computer software and used in the analysis. Short-term error for jumping mechanography has been measured by Rittweger et al.[14] and reported as 3.6% for power (W/kg) for the two-footed counter movement jump in an adult population.

Statistical analysis was performed using JMP IN 5.1 software (SAS Institute Inc., Cary, NC). Correlations from linear regression models and partial-R values from multiple regression models controlling for age, sex, height and weight were obtained for each of the muscle predictors. Partial-R values were calculated as

$$\text{Partial R} = \frac{\sqrt{SSM^* - SSM,}}{SSE}$$

where,
SSM*=Sum of Squares Model – error explained by age, sex, height and weight plus the muscle predictor included in the model.

SSM=Sum of Squares Model – error explained by age, sex, height and weight included in the model.
SSE=Sum of Squares Error – total error in model.

Results

Participant characteristics are shown for the full group, females and males (Table 1). There were no differences between females and males in age, weight, CSMA or Power but males were taller, had greater leg lean mass and created higher ground reaction forces than females. Bone area to muscle area was approximately 5%. The manufacturer has estimated bone area to muscle area ratios to be approximately 5% in healthy individuals at the 66% distal tibia site[11]. This ratio and the ratio of whole body bone mass to whole body lean mass are presented in Table 1.

Correlations between outcome variables and muscle predictors using simple linear regression methods are shown in Table 2. The muscle predictors were positively associated with bone strength, total and cortical area of the bone at the 20% site. Leg lean mass had the highest and Force had the lowest correlation coefficient for all outcomes with CSMA

and Power having similar R-values for the variables tested. None of the muscle predictors was associated with cortical vBMD at the 20% distal tibia site. Scatter plots showing the associations between bone strength measured as pSSI and power (Figure 1, top) and cortical density (vBMD) and power (Figure 1, bottom) are shown.

Partial-R values followed the same pattern as correlation coefficients and were highest for LLM (partial-R=0.21), lowest for Force (partial-R=0.04) and similar for CSMA and Power (0.14 and 0.15, respectively). In a model controlling for age, sex, height and weight, the partial-R value reflects an increase of about 4% in the R-squared value for the model if LLM is added, an increase of about 2% if CSMA or Power are added, and relatively no increase in the R-squared value for the model when Force is added.

Discussion

These results are similar to previous findings of relationships between muscle strength and bone strength in the forearm of children[6,15]. It has been suggested that muscle strength by grip dynamometer may be a stronger determinant of bone strength in the radius of adults compared to cross-sectional muscle area of the forearm[5]. We hypothesized that the amount of muscle in children predicted by leg lean mass or cross-sectional muscle area would better determine bone strength during growth than muscle strength predicted by power or force from a two-footed jump. Our results show that both the amount of muscle and the strength of muscle are associated with bone strength in growing children.

Leg lean mass added more to the R-squared values of models controlling for age, sex, height and weight than cross-sectional muscle area and power, while force did not add to the predictions. Forces created from a two-footed jump are random submaximal forces and it is possible that these forces are dissipated throughout both legs and therefore are not solely associated with the tibia. A group of pQCT users (2007 Black Forest Forum, Bad Liebenzell, Germany) has discussed the type of jump that should be used in conjunction with ground reaction plate force measures. Functional muscle-bone relationships need to evaluate the maximal force that can be produced by the muscles that act on the bone in question. A one-footed jump landing on the ball of the foot has been suggested as the most appropriate type of jump to obtain force readings because it mimics the direction of the load placed on the tibia (Hans Schiessl, personal communication). To obtain an accurate force reading using this type of jump, several jumps in repetition are needed. This is a challenging physical task for children and for most people in general. It may be that one-footed force measures of this type are limited to use in studies involving athletes or in people of a certain level of physical conditioning. Our data confirm that the force from the two-footed jump does not reveal functional muscle-bone relationships in the tibia, but that leg lean mass, cross-sectional muscle area and power add to the prediction of tibia bone outcomes.
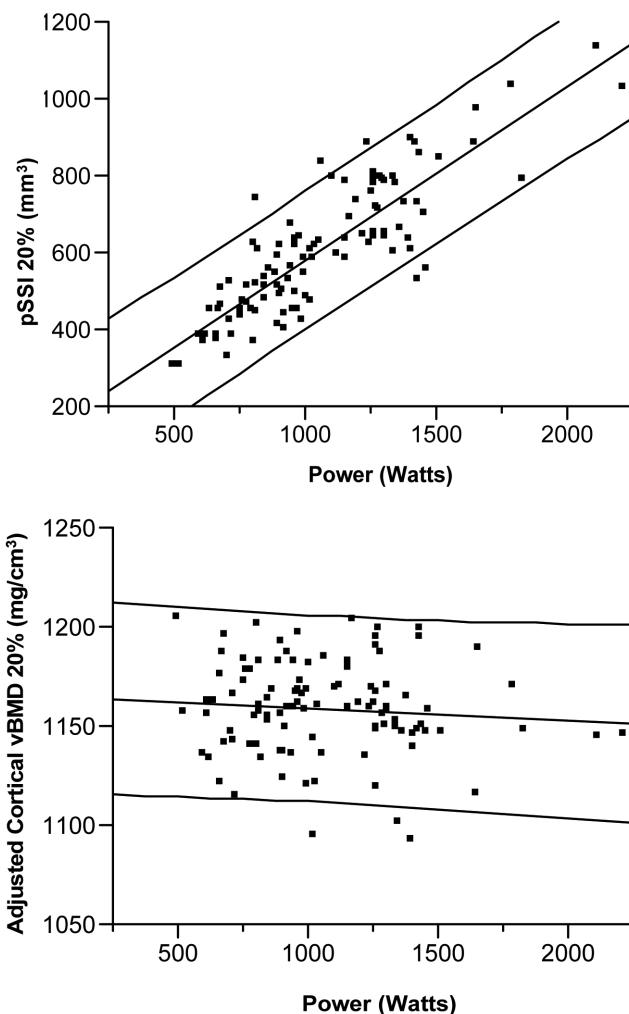

Figure 1. Top: significant association between bone strength (pSSI) and power. R = 0.85, p < 0.0001. Bottom: No association was found between cortical volumetric bone density (vBMD) and power.

As we hypothesized, all four muscle predictors tested were associated with total and cortical bone area at the 20% site. These results are similar to previous findings[6] and support the bone and muscle relationships proposed by Frost[16,17], that greater muscle mass and muscle strength cause bones to adapt and become larger in size. Cortical vBMD at the 20% distal tibia site was not associated with any of the muscle predictors, indicating that higher bone strength measures at this age must be associated with changes in geometry and size of the bone rather than material properties (cortical vBMD) of the bone.

These data support relationships between muscle predictors and bone parameters measured by pQCT in healthy prepubertal children. Cross-sectional muscle area, leg muscle mass, muscle power and force measured from a two-footed jump all predict bone strength (measured as pSSI) in cortical bone of the tibia in pre-pubertal children. In multiple

regression models controlling for age, sex, height and weight in pre-pubertal children, the partial-R value for leg lean mass was highest. Muscle predictors were positively associated with cross-sectional bone area but not cortical vBMD.

References

1. Hogler W, Briody JN, Woodhead HJ, Chan A, Cowell CT. Importance of lean mass in the interpretation of total body densitometry in children and adolescents. J Pediatr 2003;143:81-8.
2. Rauch F, Bailey DA, Baxter-Jones A, Mirwald RL, Faulkner R. The 'muscle-bone unit' during the pubertal growth spurt. Bone 2004;34:771-5.
3. Schönau E, Neu CM, Manz F. Muscle mass during childhood-relationship to skeletal development. J Musculoskelet Neuronal Interact 2004;4:105-8.
4. Schönau E. From mechanostat theory to development of the "Functional Muscle-Bone Unit". J Musculoskelet Neuronal Interact 2005;5:232-8.
5. Hasegawa Y, Schneider P, Reiners C. Age, sex, and grip strength determine architectural bone parameters assessed by peripheral quantitative computed tomography (pQCT) at the human radius. J Biomech 2001;34:497-503.
6. Schönau E. The development of the skeletal system in children and the influence of muscular strength. Horm Res 1998;49:27-31.
7. Schönau E, Neu CM, Mokov E, Wassmer G, Manz F. Influence of puberty on muscle area and cortical bone area of the forearm in boys and girls. J Clin Endocrinol Metab 2000;85:1095-8.
8. Schönau E, Werhahn E, Schiedermaier U, Mokow E, Schiessl H, Scheidhauer K, Michalk D. Influence of muscle strength on bone strength during childhood and adolescence. Horm Res 1996;45(Suppl.1):63-6.
9. Ruff C. Growth in bone strength, body size, and muscle size in a juvenile longitudinal sample. Bone 2003;33:317-29.
10. Morris N, Udry J. Validation of a self-administered instrument to assess stage of adolescent development. J Youth Adolesc 1980;9:271-81.
11. Anonymous. XCT 2000 Operator's Guide. White Plains, NY: Norland Medical (Orthometrix, Inc.); 2000.
12. Rittweger J, Michaelis I, Giehl M, Wusecke P, Felsenberg D. Adjusting for the partial volume effect in cortical bone analyses of pQCT images. J Musculoskelet Neuronal Interact 2004;4:436-41.
13. Fricke O, Weilder J, Tutlewski B, Schönau E. Mechanography - a new device for the assessment of muscle function in pediatrics. Pediatr Res 2006;59:46-9.
14. Rittweger J, Schiessl H, Felsenberg D, Runge M. Reproducibility of the jumping mechanography as a test of mechanical power output in physically competent adult and elderly subjects. JAGS 2004;52:128-31.
15. Rauch F, Schönau E. Peripheral quantitative computed tomography of the distal radius in young subjects - new reference data and interpretation of results. J Musculoskelet Neuronal Interact 2005;5:119-26.
16. Frost HM. Bone "mass" and the "mechanostat": A proposal. Anat Rec 1987;219:1-9.
17. Frost HM, Schönau E. The "muscle-bone unit' in children and adolescents: A 2000 overview. J Pediatr Endocrinol Metabol 2000;13:571-90.