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Relationships Between Legs Bone Mineral Density, Anthropometry and Jumping Height in Prepubertal Children

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A B S T R A C T

The aim of this study was to determine how the legs bone mineral density (BMD) is influenced by anthropometry and vertical jumping height in prepubertal children. In total, 64 8–11-year-old schoolchildren (27 boys and 37 girls) were studied. All children were at Tanner stage 1. The subjects' height and body mass were measured and BMI calculated. The following anthropometric parameters directly connected with leg were measured: skinfolds – front thigh and medial calf; girths – gluteal, thigh, mid-thigh, calf and ankle; lengths – iliospinale height, trochanterion height, trochanterion-tibiale laterale, tibiale-laterale height and tibiale mediale-spyrion tibiale; and breadths – biiliocristal, foot length and biepicondylar femur. Total body and legs fat mass and fat %, lean body mass (LBM) and both legs BMD were measured by DXA. Maximal jumping height was measured on the contact mat. Stepwise multiple regression analysis indicated that body height in boys (54.6%; R^2x100) and body mass in girls (57.3%) were the most important basic anthropometric parameters that influenced BMD in legs. From the measured skinfolds, that of the front thigh characterized legs BMD by 24.9–35.6%. From the girths, the most important parameter to characterize legs BMD was that of calf (50.0–59.1%). Tibiale laterale height was the only length parameter which was highly related with legs BMD (51.1–54.5%). Biepicondylar femur was the most important breadth parameter which characterized legs BMD (51.0–54.8%). Femur breadth and tibiale-laterale height were selected (68,7%) in boys, and tibiale-laterale height and front thigh skinfold thickness (66,0%) in girls when all measured leg anthropometric parameters were analyzed together. From the body composition parameters, the most important parameter to characterize legs BMD was legs LBM (48.9–59.5%). Jumping height did not correlate with legs BMD in any studied groups. In summary, the present study demonstrated that legs LBM together with tibiale-laterale height are the main predictors of legs BMD in prepubertal children.

***Key words**: legs bone mineral density, leg anthropometry, jumping height, prepubertal children*

Introduction

Several studies have investigated the influence of anthropometric parameters (such as body height, body mass and body mass index, BMI) on the bone parameters[1]. Low body mass has been found to be a significant risk factor in the development of osteoporosis. In contrast, obesity has been mentioned as a significant confounder of bone mineral density (BMD). The influence of specific leg anthropometrical of and body composition parameters to the legs BMD has not been studied in young children.

Skeletal loading during growth may increase bone mineral mass and BMD in early life. Ground reaction forces may provide a surrogate measure for the strain experienced by bone on landing and take off. The child is primarily more involved in short-term high-intensity exercise than in long-time activities[2]. Jumping represents one important type of human movement in everyday behaviour and different kinds of jumps are important per se for success in various athletic activities. The height of various types of vertical jumps could serve for the assess-

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ment of muscular strength and power[3], and even for the assessment of muscle fibre type composition[4]. The power of mechanical jumping has been found to be higher in subjects rich in fast-twitch muscle fibres than in subjects with high percentage of slow-twitch muscle fibres[5]. In children aged 11–13 years, the growth rate for vertical jump has been positively associated with increased body height but is unrelated to increased body mass. Boys have showed steeper growth rates than girls in jumping[6]. In multiple jumps, there is a correlation between mechanical power values and body mass and thigh circumference in young athletes[7].

Mechanical loading during childhood plays a critical role in normal growth and development of the skeleton. It is well documented that sport events which are connected with skeletal loading (e.g. gymnastics) have an increased bone mineral mass and density compared with nonloading sporting activities (e.g. swimming, biking)[8–10]. Childhood is a critical period when bones may be particularly responsive to weight-bearing exercises[11]. Different jumping exercises are one of the main activities in prepubertal children. Recent investigations confirm that even short bouts of jumping exercises (a few minutes every day) enhance bone mineral mass at the weight bearing proximal femur in early pubertal children[12]. Jumping exercises for 7 months (3 times per week, 10 minutes per session) augment bone mineral accrual at several regions equally in prepubertal boys with average or low BMI and intervention effects on bone mineral were undetectable in prepubertal boys with high BMI values[13]. Prepubertal period is the most sensitive time for the maximal influence of high-impact exercises[14,15]. This is understandable because recent evidence confirms that simple jumps can produce ground reaction forces of 3.5–5.0 times body weight and force rates of around 500 times of body weight in prepubertal children[12]. There are discussions about the threshold of the minimal number of jumps which are needed to increase BMD. Probably the threshold in children is around 25 jumps per day for 12 weeks[16] or, according to the recently presented programme 10 counter-movement jumps 3 times per day (in total about 3 min/day) during 8 months in early pubertal children[17]. However, there is no information about the possible relationships between maximal single vertical jump height and bone parameters in prepubertal children. Secondly, there is few information about the influence of basic anthropometry and especially legs anthropometry on the bone parameters of legs and jumping height in children. Therefore, we examined a group of prepubertal children to determine how the legs BMD is influenced by anthropometry and vertical jumping height. We hypothesized that jumping height is highly related to legs BMD value.

Methods

Subjects

In total, 64 8–11-year-old prepubertal schoolchildren (27 boys and 37 girls) were studied. They were all healthy and did not suffer from any pain or disability in lower limbs. The children participated in two compulsory physical education lessons per week at school. Additionally, 16 boys and 22 girls took part 2–3 times per week in different sport club activities. All the children were at Tanner stage 1 using self-assessment illustrated questionnaire of pubertal stages[18]. All children, parents and teachers were thoroughly informed about the purposes and contents of the study and written consent was obtained from the parents or adult probands. This study was approved by the Medical Ethics Committee of the University of Tartu (Estonia). All measurements were performed before the lunch time at school.

Anthropometry

Body height and body mass of the children were measured by the Martin metal anthropometer (±0.1 cm) and medical electronic scales (A&D Instruments, UK, ±0.05 kg), respectively. Body mass index (BMI) was calculated (kg/m^2). All anthropometric parameters were measured according to the protocol recommended by the International Society for the Advancement of Kinanthropometry[19]. Three series of anthropometric measurements were taken and the means were used. All measurements were made on the right side of the body. Anthropometric parameters were measured using the Centurion Kit instrumentation (Rosscraft, Surrey, BC, Canada). Calibration of all equipment was conducted prior to and at regular intervals during the data collection period. The tester had a Level 1 certificate from the International Society for the Advancement of Kinanthropometry[19]. In our study only those anthropometric parameters were used which are directly connected with leg. From the skinfolds, front thigh and medial calf were measured. The following girths were measured: gluteal, thigh, mid-thigh, calf and ankle. From the length parameters, iliospinale height, trochanterion height, trochanterion-tibiale laterale, tibiale-laterale height and tibiale mediale-spyrion tibiale were measured. Finally, biiliocristal breadth, foot length and biepicondylar femur were measured (all named as breadths).

Body composition

Total body and both legs fat mass and fat % and lean mass (LBM) were measured by dual-energy X-ray absorptiometry (DXA) using a DPX-IQ densitometer (Lunar Corp. Madison, USA). In addition both legs BMD was also measured by DXA.

Jumping height

Maximal jumping height was measured on the contact mat (Newtest OY, Finland). Three jumps performed with the subjects', hands on the hips, were used. The best result of three jumps was used. Children were required to jump vertically as high as they possibly could. The test was preceded by a short standard stretching and warming-up procedure. Vertical jumping tests in children are valid and reliable[19].

Statistical analysis

Data analysis was performed using SPSS 10.0 for Windows (Chicago, IL). Standard statistical methods were used to calculate mean () and standard deviation (±SD). An unpaired, two tailed t-test was used to assess differences between groups. Spearman correlation coefficient was used to express bivariate relationships. The effect of different anthropometric and body composition parameters and jumping height to the legs BMD was analyzed by stepwise multiple regression analysis. Significance was set at $p<0.05$.

Results

Basic anthropometric, body composition, bone and jumping height parameters in children are presented in Table 1. There were no differences in mean age, body height, body mass and BMI between boys and girls. Total body and legs fat % was significantly ($p<0.05$) higher in girls. There were no differences in other measured anthropometric parameters between boys and girls. The difference in legs BMD was also not significant between boys and girls. Mean jumping height was higher in boys, but the difference with girls was not significant (Table 1).

Mean leg anthropometric parameters (skinfolds, girths, lengths and breadths) are presented in Table 2. There were not any differences between boys and girls in any measured parameter.

The results of the stepwise multiple regression analysis are presented in Table 3. Different basic anthropometric parameters were related to legs BMD in children. The most important anthropometric parameters were body height (54.6%, $R^2 \times 100$) and body mass (57.3%, $R^2 \times 100$) in boys and girls, respectively, while body height and body mass together were selected (58.5%, $R^2 \times 100$) in total group. From total body and legs composition parameters, the most important was LBM (48.9–59.5%, $R^2 \times 100$). From the skinfold thicknesses, front thigh was significantly related to legs BMD (24.9–35.6%, $R^2 \times 100$). From the leg girths, the most important parameter to characterize legs BMD was calf girth (50.0–59.1%, $R^2 \times 100$). Tibiale laterale was the only significant leg length parameter which was highly related to legs BMD (51.1–54.5%, $R^2 \times 100$). Femur was the most important breadth parameter which related with legs BMD (51.0–54.8%, $R^2 \times 100$). When all measured leg anthropometric parameters were analysed together then femur breadth and tibiale laterale length were selected (68.7%, $R^2 \times 100$) in boys and tibiale laterale length and front thigh skinfold (66.0%, $R^2 \times 100$) in girls. In total group, femur breadth and tibiale laterale length were selected (63.6%, $R^2 \times 100$). Surprisingly, jumping height did not relate to legs BMD in any studied groups.

Discussion

To our knowledge, this is the first study to report that single vertical jumping height does not appear to be a significant predictor of legs BMD in prepubertal children. This was rather surprising as it is a well known fact that different jumping exercises highly increase legs BMD[11,21,22]. On the other hand, jumping height depends on the muscle fibre type composition[5], muscular strength and power[3] and/or some specific anthropometric parameters[7]. Finally, the jumping height also depends on the angle of legs bent in knee joints[23] which was not checked in our study.

TABLE 1
BASIC ANTHROPOMETRIC, BODY COMPOSITION, BONE PARAMETERS AND JUMPING HEIGHT IN CHILDREN (X±SD)

	Boys (n=27)	Girls (n=37)	Total group (n=64)
Age (yrs)	10.3±1.0	10.3±1.0	10.3±1.0
Body height (cm)	143.4±8.5	143.9±8.8	143.7±8.6
Body mass (kg)	38.8±10.5	38.8±9.1	38.8±9.6
BMI (kg/m^2)	18.6±3.6	18.5±3.0	18.6±3.2
Total body composition (DXA)			
Body fat %	22.6±9.6	28.5±9.4*	25.9±9.5
Fat mass (kg)	9.1±6.0	11.1±6.0	10.2±6.0
Lean mass (kg)	27.9±5.2	25.7±4.7	26.7±5.0
Legs composition (DXA)			
Fat %	10.6±4.0	12.9±4.2*	11.6±4.1
Fat mass (kg)	4.1±2.6	5.0±2.5	4.6±2.6
Lean mass (kg)	9.9±2.1	9.2±1.9	9.5±2.0
Legs bone parameters			
BMD (g/cm^2)	0.940±0.101	0.926±0.119	0.932±0.111
Jum ping height (cm)	20.4±5.2	18.0±3.9	19.0±4.6

*p<0.05, BMI – body mass index, DXA – dual-energy X-ray absorptiometry, BMD – bone mineral density

TABLE 2
LEG ANTHROPOMETRIC PARAMETERS IN CHILDREN (X±SD)

	Boys (n=27)	Girls (n=37)	Total group (n=64)
Skinfolds (mm)			
Front thigh	19.0±8.6	23.2±7.4	21.4±8.1
Medial calf	13.9±7.4	16.7±6.6	15.5±7.0
Girths (cm)			
Gluteal	76.3±7.6	77.7±7.7	77.1±7.6
Thigh	44.9±6.3	46.2±5.7	45.6±6.0
Mid-thigh	40.4±5.3	41.4±5.0	41.0±5.1
Calf	29.5±3.6	30.2±3.1	29.9±3.2
Ankle	20.5±1.8	20.5±1.9	20.5±1.8
Lengths (cm)			
Iliospinale height	82.2±5.8	82.3±5.7	82.2±5.7
Trochanterion height	75.9±5.4	75.9±5.3	75.9±5.3
Trochanterion-tibiale-laterale	36.4±2.7	36.3±3.0	36.4±2.9
Tibiale-laterale	39.4±4.1	39.4±3.0	39.4±3.5
Tibiale mediale sphyrion tibiale	33.9±2.9	34.1±2.7	34.0±2.8
Breadths (cm)			
Biiliocristal	23.9±2.4	24.2±2.3	24.1±2.3
Foot lengths	22.5±1.8	22.2±1.5	22.3±1.6
Biepicondylar femur	8.8±0.6	8.5±0.6	8.6±0.6

Thus, in prepubertal children the continuous loading of the legs more important than the absolute height of the single jump to influence legs BMD. In contrast, there is few information available whether the different training programme, which successfully increase BMD have also increased jumping height or increased muscle mass of the legs. Exercise programme using 10 duck jumps 3 times per week increased significantly jumping height[13]. However, recent bone intervention study by McKay et al.[12] indicated that during 8-month training programme the jumping height did not increase in early pubertal children. In these studies, the relationship between jumping height and bone parameters was not presented.

There are limitations in our study. Firstly, we did not measure BMD on the traditional sites of lumbar spine or femoral neck but used only the total BMD of legs. Femur may experience greater mechanical loading during high-impact activities than other skeletal sites (including lumbar spine)[24]. Secondly, we did not check the calcium intake of our children. On the other hand, other studies[15] have not found relationships between calcium intake and any of the bone variables in children. Thirdly, we did not consider the influence of additional physical activity in sport clubs on the jumping height and legs BMD. Finally, our sample size was relatively small.

As a rule, there are negative effects of excessive body mass and fatness on motor items involving the movement of the entire body, and positive effects of body size, especially weight on strength development[25]. It is interesting that from the basic anthropometric parameters, the body height in boys and body mass in girls influenced legs BMD in our study and jumping height was only moderately related to BMI in children (12.9% in boys and 8.9% in girls). Historical study by Clarke[26] concluded that the relationship between basic anthropometry and vertical jump height was almost zero. From the total body composition parameters, LBM was the most important component which directly correlated with legs BMD (Table 3). Physical activity, including jumping exercises, increases LBM. LBM stimulates osteogenesis via forces on bone[27] whereas muscle forces impose the largest voluntary bone loads and strains and significantly related to bone strength and mass[28].

From the two measured leg skinfold thicknesses, only thigh skinfold was moderately related to legs BMD (24.9–25.6%, $R^2 \times 100$). Clarke[26] reported a negative correlation between skinfold thicknesses and the height of vertical jump. However, total body fat % and fat mass were not related to legs BMD or jumping height in our study. Calf girth was highly related with legs BMD (Table 3). The relationship with jumping height was not significant. This is in line with the study by Lefevre et al.[29] in adult men. This relatively high relationship can be explained with the fact that bone is also included in girth and LBM measurements. From the leg anthropometric parameters, the most important one for characterizing legs BMD was tibiale laterale length (Table 3). This parameter was selected when we also analysed together all the measured leg anthropometric parameters. Tibiale laterale lengths correlated significantly with calf girths (r=0.389–0.408)

TABLE 3
STEPWISE MULTIPLE REGRESSION ANALYSES WHERE DEPENDENT VARIABLE WAS LEGS BMD AND INDEPENDENT VARIABLES WERE BASIC AND LEG ANTHROPOMETRIC, AND BODY COMPOSITION PARAMETERS

	Groups	Independent variable	R^2	F	SEE	p
Basic anthropometry (body height, mass, BMI)	M	Height	0.546	30.1	0.069	<0.000
	F	Body mass	0.573	43.0	0.079	<0.000
	Total	Body mass Height	0.585	40.8	0.073	<0.000
Total body composition (fat, LBM)	M	LBM	0.558	31.6	0.069	<0.000
	F	LBM	0.534	36.7	0.082	<0.000
	Total	LBM	0.497	58.4	0.079	<0.000
Leg composition (fat, LBM)	M	LBM	0.489	40.2	0.087	<0.007
	F	LBM	0.577	43.7	0.089	<0.000
	Total	LBM	0.595	86.8	0.071	<0.000
Leg skinfolds	M	Front thigh	0.256	8.6	0.089	<0.007
	F	Front thigh	0.356	17.7	0.097	<0.000
	Total	Front thigh	0.249	19.5	0.097	<0.000
Leg girths	M	Calf	0.591	36.1	0.066	<0.000
	F	Calf	0.531	36.3	0.083	<0.000
	Total	Calf	0.500	59.0	0.079	<0.000
Leg lengths	M	Tibiale laterale	0.545	29.9	0.070	<0.000
	F	Tibiale laterale	0.539	37.4	0.082	<0.000
	Total	Tibiale laterale	0.511	61.5	0.078	<0.000
Leg breadths	M	Femur	0.548	30.2	0.069	<0.000
	F	Femur	0.510	33.3	0.085	<0.000
	Total	Femur	0.523	52.8	0.078	<0.000
Total leg anthropometry	M	Femur Tibiale laterale	0.687	26.3	0.059	<0.000
	F	Tibiale laterale Front thigh	0.660	37.4	0.072	<0.000
	Total	Femur Tibiale laterale	0.636	61.6	0.068	<0.000

M – male, F – female, LBM – lean body mass

and biepicondylar femur breadths (r=0.607–0.707). Legs BMD relationship with leg skinfold thicknesses was not significant.

In summary, the present study demonstrated that legs LBM together with tibiale-laterale length are the main predictors of legs BMD in prepubertal children.

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REFERENCES

1. LIN YC, LYLE RM, WEAVER CM, MCCABE LD, MCCABE GP, JOHNSTON TEEGARDEN D, Bone, 32 (2003) 546. — 2. COOPER DM, New horizons in pediatric exercise research. In: BLIMKIE CR, BAR-OR O (Eds) (Champaign, IL. Human Kinetics, 1995). — 3. VANDEWALLE H, PERES G, MONOD H, Sports Med, 4 (1987) 268. — 4. BOSCO C, KOMI PV, TIHANYI J, FEKETE G, APOR P, Eur J Appl Physiol, 51 (1983) 129. — 5. BOSCO C, TIHANYI J, LATTERI F, FEKETE G, APOR P, RUSKO H, Acta Physiol Scand, 128 (1986) 109. — 6. BUTTERFIELD SA, LEHNHARD R, LEE J, COLADARD T, Perc Motor Skills, 99 (2004) 225. — 7. VIITASALO JT, ÖSTERBACK L, ALEN M, RAHKILA P, HAVAS E, Acta Physiol Scand, 131 (1987) 139. — 8. DYSON K, BLIMKIE CJ, DAVISON KS, WEBBER CE, ADACHI JD, Med Sci Sports Exerc, 29 (1997) 443. — 9. HEINONEN A, OJA P, KANNUS P, SIEVANEN H, HAAPASALO H, MANTTARI A, VUORI I, Bone, 17 (1995) 197. — 10. CASSELL C, BENEDICT M, SPECKER B, Med Sci Sports Exerc, 25 (1996) 1243. — 11. BAILEY DA, MCKAY HA, MIRWALD RL, CROCKER RPE, FAULKNER RA, J Bone Min Res, 14 (1999) 1672. — 12. MCKAY HA, MACLEAN L, PETIT M, MACKELVIE-O'BRIEN K, JANSSEN P, BECK T, KHAN KM, Br J Sports Med, 39 (2005) 521. — 13. MCKAY HA, PETIT MA, SCHUTZ RW, PRION JC, BARR SI, KHAN KM, J Pediatr, 136 (2002) 156. — 14. HEINONEN A, SIEVANEN H, KANNUS P, OJA L, PASANEN M, VUORI I, Osteopor Int, 11 (2000) 1010. — 15. FUCHS RK, BAUER JJ, SNOW CM, J Bone Min Res, 16 (2001) 148. — 16. JOHANNSEN N, BINKLEY T, ENGLERT V, NEIDERAVE RG, SPECKER B, Bone, 33 (2003) 533. — 17. MCKAY H, TSANG G, HEINONEN A, MACKELVIE K, SANDERSON D, KHAN KM, Br J Sports Med, 39 (2006) 10.

— 18. TANNER J, Growth at Adolescence, 2nd ed. (Oxford, Blackwell Scientific Publications, 1962). — 19. NORTON K, OLDS T, Anthropometrica (UNSW Press, Sydney, 1996). — 20. VAN PRAAGH E, Anaerobic fitness tests: what are we measuring. In: TOMKINSON GR, OLDS TS (Eds) Pediatric Fitness. Secular Trends and Geographic Variability (Karger, Basel, 2007). — 21. KATO T, TERASHIMA T, YAMASHITA T, HATANAKA Y, HONDA A, UMEMURA Y, J Appl Physiol, 100 (2006) 839. — 22. MACKELVIE KJ, MCKAY HA, PETIT MA, MORAN O, KHAN KM, J Bone Min Res, 17 (2002) 834. — 23. HARLEY RA, DOUST JH, J Sports Sci, 12 (1994) 139. — 24. GREENE DA, NAUGHTON GA, Sports Med, 36 (2006) 723. — 25. MALINA RM, Ex Sports Sci Rev, 3 (1975) 249. — 26. CLARKE HH, Res Quart, 28 (1957) 229. — 27. ILICH-ERNST J, BROWNBILL RA, LUDEMANN MA, FU R, Medscape Wom Health, 7 (2002) 2. — 28. FROST H, Med Sci Sports Exerc, 32 (2000) 911. — 29. LEFEVRE J, DUFOUR AB, BEUNEN G, CLAESSENS A, Am J Hum Biol, 5 (1993) 351.

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POVEZANOST IZMEĐU MINERALNE GUSTOĆE KOSTIJU NOGU, ANTROPOMETRIJE I SKAKANJA U VIS KOD DJECE U PREDPUBERTETU

S A Ž E T A K

Cilj ove studije bio je otkriti kako mineralna gustoća kostiju nogu (Bone mineral density – BMD) utječe na antropometriju i vertikalno skakanje u vis kod pretpubertetne djece. U ukupnom uzorku bilo je 64 u djece (27 dječaka i 37 djevojčica) u dobi od 8–11 godina. Sva djeca bila su na Tannerovom stupnju 1. Izmjerene su visine i mase tijela te je izračunavat indeks tjelesne mase. Također su mjereni antropometrijski parametri direktno povezani sa nogama; kožni nabori – prednjeg bedra i srednji lista noge; opsezi – bedra, srednjeg bedra, lista, zgloba; dužine – iliospinalne visine, trohanteriorne visine, trohanteriorna kost – tibia – laterala, dužine noge bipikondilarnog femura. Totalne tjelesne i nožne masnoće mjerene su u postotku indeksa mršavosti i debljinu obiju nogu (BMD) prema DXA. Mjerena je maksimalna visina skoka. Multiplom regresijom utvrđeno je da su visine dječaka (54,6 %; R2 x 100) i djevojčica (57,3 %) bile najvažniji bazični antropometrijski parametri koji su utjecali na BMD. Mjere kožnih nabora prednjeg bedra karakterizirali su BMD od 24,9–35,6 %. Od opsega najznačajniji parametar koji karakterizira BMD (50–59,1 %) bio je opseg lista. Tibialno lateralna visina bio je parametar visoko povezan sa BMD (51,1–54,5 %). Biepikondilarni femur bio je najvažniji parametar širine koji je karakterizirao BMD (51–54,8 %). Širina femura i tibio – lateralna visina bili su kod dječaka (68,7 %) i tibio – lateralna visina i kožni nabor prednjeg bedra kod djevojčica (66 %) bili su analizirani zajedno. Od kompozicije tijela, najznačajniji parametar koji je karakterizirao BMD bio je LBM (48,9–59,5 %). Visina skoka nije korelirala sa BMD nogu.