INFLUENCE OF MECHANICAL LOADING AND SKELETON GEOMETRY IN BONE MASS AT THE PROXIMAL FEMUR IN 10-12 YEAR OLD CHILDREN - A LONGITUDINAL STUDY

Graça Cardadeiro[a], Fátima Baptista[a], Nicoletta Rosati[b], Vera Zymbal[a], Kathleen F. Janz[c], Luís B. Sardinha[a]

[a] Exercise and Health Lab, CIPER, Faculty of Human Movement, Technical University of Lisbon, Portugal
[b] CEMAPRE and Department of Mathematics, ISEG, Technical University of Lisbon, Portugal
[c] Department of Health and Human Physiology; Department of Epidemiology, University of Iowa, USA

g.cardadeiro@sapo.pt

INTRODUCTION

Osteoporosis is an underlying etiological factor in most hip fractures in elderly people [1, 2]. Sex distinction in hip fracture risk has been attributed largely to a lower peak adult bone mass in females and women's accelerated bone loss following the menopause [3]. However sex-specificities in bone morphology and mechanical competence may also contribute to rate differences in two main types of hip fracture [4, 5]. Geometric measures of the proximal femur and pelvis structure have been associated with hip fracture risk in adults [6-8]. These observations suggest the anatomy of the proximal femur and the pelvis are potential determinants of the type of hip fracture.

As clear sex differences in hip kinematics and muscle activity during walking and running have been observed [9, 10], and as physical activity (PA) is one of the determinants of the loads exerted on the proximal femur, it is reasonable to formulate the hypothesis that the geometry of the pelvis and the hip may be associated to sex-specific mineralization patterns of the proximal femur.

The aims of our study were: a) to analyse the effects of PA and pelvis - proximal femur geometry on bone mass distribution at the proximal femur; and b) to investigate whether sex distinctive geometric variables influence sex-specific bone mass distribution patterns.

We hypothesized that higher responsiveness might be an artefact of sex-related biomechanical differences that influence loading at different regions of the proximal femur.

METHODS

Subjects. 10 to 12 yrs children recruited from schools; all participants were healthy Caucasian students not taking any medication known to influence bone metabolism; all the participants evaluated twice at baseline and at the end of one-year follow-up.

Proximal femur analysis. BMDs of the left proximal femur evaluated using DXA (QDR Explorer, Hologic, Waltham, MA, USA); three BMD ratios were calculated as indicators of bone mass distribution of the proximal femur.

$$FN{:}PF = \frac{Femoral\ neck\ BMD}{Proximal\ femur\ BMD}\ ;\ TR{:}PF = \frac{Trochanter\ BMD}{Proximal\ femur\ BMD}\ ;\ IM{:}SL = \frac{Inferomedial\ femoral\ neck\ BMD}{Superolateral\ femoral\ neck\ BMD}$$

Inter-acetabular distance and abductor lever arm. Images of whole body and left hip obtained for all children using DXA to determine the inter-acetabular distance and abductor lever arm, respectively, using the CorelDRAW X6 software (Coral Corporation, Ottawa, Ontario, Canada); linear geometric **measures of the pelvis** included: the lower *inter-acetabular distance* (LIAD) (CD in Fig.1); the upper *inter-acetabular distance* (UIAD) (AB in Fig.1), and the *inter-acetabular distance* (IAD)(EF in Fig.1); the path of the **abductor muscles** represented by drawing a tangential line to the lateral margin of the greater trochanter which was parallel to the line between the highest point of great trochanter (point B in Fig.2) and the inferior limit of this subregion (point C in Fig.2); the abductor lever arm is represented by the perpendicular distance between that tangent of the greater trochanter and the center of rotation of the femoral head.

Pelvic and Proximal Femur DXA Image

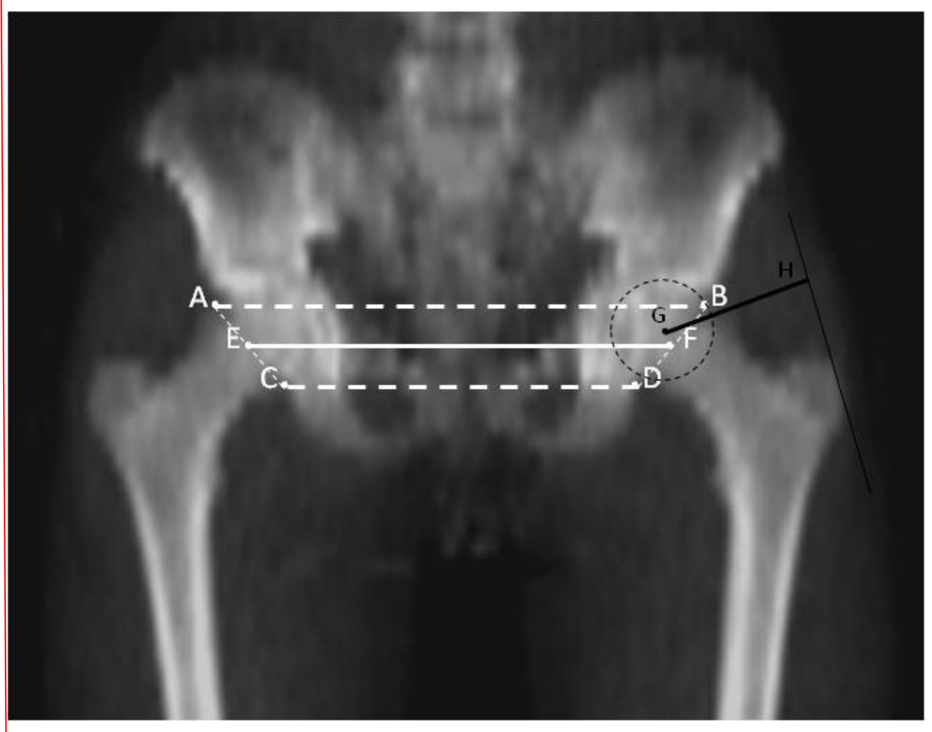

Fig.1 Geometric measures of the pelvic bone: [AB] – upper inter-acetabular distance (UIAD); [CD] - lower inter-acetabular distance (LIAD); [EF] – inter-acetabular distance (IAD); [GH] – abductor lever arm.

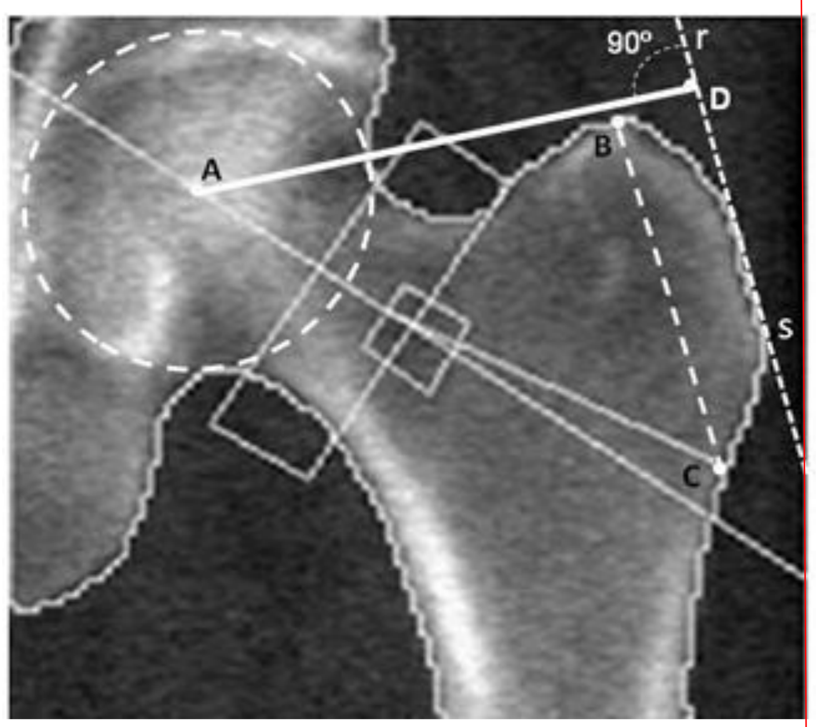

Fig.2 DXA image illustrating the abductor lever arm determination: [AD] – abdutor lever arm (ALA); [BC] - line between the higher point of great trochanter and the inferior limit of this sub-region; rs – Line tangential to the lateral margin of the greater trochanter.

Habitual physical activity. PA assessed with the Actigraph accelerometer (model GT1M); intensity of PA was defined according to the counts per minute (cpm) as follows: sedentary activity, up to 100 cpm; light-intensity (LPA) from 101 to 2295 cpm; moderate-intensity (MPA) from 2296 to 4011 cpm; and vigorous-intensity (VPA) over 4012 cpm [50]. **Current and historical physical activity participation relevant to the musculoskeletal system** quantified with the Bone-Specific Physical Activity Questionnaire (BPAQ).

Body size and body composition. Standing and sitting height measured with a stadiometer (Secca 770, Hamburg, Germany) with children in underwear and barefoot; body mass (kg), total fat (kg), and total lean mass without bone (kg) determined from a total-body scan using DXA with children in a fasting state; body mass index (BMI) calculated as body mass in kilograms divided by height (in meters) squared.

Energy and calcium intake calculated from a semi-quantitative Food Frequency Questionnaire, assessing regular intake of a wide set of a typical Portuguese foods.

Maturity estimated as the years of distance positive or negative from the age of peak height velocity using sex-specific prediction equations [11].

Age, Maturity, Body Composition and Physical Activity

	Baseline				One-year follow-up			
	Girls		Boys		Girls		Boys	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Age, y	10.7	(0.4)	10.7	(0.3)	11.8	(0.4)	11.8	(0.3)
Maturity Offset, y	-1.26	(0.5)	-2.87	(0.5)^{a,b}	-0.03	(0.5)	-1.88	(0.6)^{a,b}
Peak High Velocity, y	11.5	(0.5)	13.1	(0.7)^{a,b}	11.8	(0.5)	13.6	(0.7)^{a}
Height, cm	145.1	(6.8)	143.5	(6.8)	152.4	(6.9)	149.9	(8.1)
Weight, kg	39.9	(8.1)	38.2	(8.6)	45.8	(8.9)	43.0	(9.8)^{a,b}
Body Mass Index, kg/m^2	18.9	(3.3)	18.4	(3.2)	19.6	(3.0)	19.0	(3.2)
Body Fat, kg	11.8	(4.7)	9.92	(5.1)^{a,b}	13.53	(5.2)	11.0	(5.3)^{a,b}
Body Lean Mass, kg	26.88	(4.2)	27.12	(4.1)	30.7	(4.9)	30.58	(5.5)
Body Fat, %	28.8	(6.8)	24.73	(7.3)^{c}	28.9	(6.6)	24.7	(6.8)^{a}
Moderate PA, min/d	32.5	(11.5)	31.0	(10.9)	28.5	(11.3)	39.7	(11.2)^{a,b}
Vigorous PA, min/d	13.7	(8.5)	13.3	(7.5)	11.6	(7.4)	18.9	(9.7)^{a,b}
Moderate and Vigorous PA, min/d	46.1	(18.3)	44.3	(17.5)	40.1	(17.2)	58.6	(19.2)^{a,b}
PA Average Intensity, count/min/d	441.1	(109.2)	419.6	(111.0)	387.9	(117.2)	481.3	(118.6)^{a,b}
Past BPAQ	9.0	(14.1)	6.6	(14.2)	12.8	(19.2)	8.1	(15.4)
Current BPAQ	18.6	(34.2)	16.1	(20.4)	17.1	(28.5)	17.2	(18.8)
Total BPAQ	27.7	(41.2)	22.7	(31.8)	29.9	(42.7)	25.3	(25.5)
Proximal Femur BMD, g/cm^2	0.729	(0.86)	0.774	(0.78)^{a}	0.801	(0.11)	0.807	(0.09)
Neck BMD, g/cm^2	0.699	(0.09)	0.744	(0.08)^{a}	0.754	(0.103)	0.771	(0.09)
Trochanter BMD, g/cm^2	0.592	(0.08)	0.609	(0.07)	0.655	(0.09)	0.638	(0.08)
Neck / Proximal Femur BMD	0.96	(0.05)	0.96	(0.05)	0.94	(0.05)	0.95	(0.04)
Trochanter / Proximal Femur BMD	0.81	(0.04)	0.79	(0.04)^{a,b}	0.82	(0.04)	0.79	(0.03)^{a,b}
SL Neck BMD, g/cm^2	0.602	(0.09)	0.638	(0.08)^{a}	0.665	(0.11)	0.678	(0.10)
IM Neck BMD, g/cm^2	0.775	(0.09)	0.831	(0.09)^{a}	0.825	(0.11)	0.845	(0.10)
IM Neck BMD / SL Neck BMD	1.297	(0.13)	1.308	(0.10)	1.253	(0.13)	1.255	(0.11)
Inter-Acetabulum Distance, cm	12.59	(0.8)	12.31	(0.6)^{a}	13.49	(1.0)	12.77	(0.8)^{a,b}
Abdutor Lever Arm, cm	4.20	(0.4)	3.68	(0.5)^{a,b}	4.66	(0.3)	4.22	(0.5)^{a}

PA, physical activity; BPAQ, bone physical activity questionnaire; BMD, bone mineral density, SL, superolateral, IM, inferomedial; ^{a} p < 0.05 difference between boys and girls within each examination ; ^{b} Non parametric test ; ^{c} Parametric T-Test for proportions

Funded by Portuguese Science and Technology Foundation (SFRH/BD/38671/2007, PTDC/DES/115607/2009) and program POCI, partially funded by FEDER

Regression Analysis - BMD

	FN BMD		SLFN BMD		IMFN BMD		TR BMD	
	Coef. estimate	Robust SE	Coef. estimate	Robust SE	Coef. estimate	Robust SE	Coef. estimate	Robust SE
Boys and Girls								
Sex	0.0327	0.0102^{b}	0.0293	0.0121^{c}	0.0389	0.0108^{a}		
Height, cm	-0.0016	0.0005^{b}						
Lean mass, kg	0.0139	0.0011^{a}	0.0129	0.0008^{a}	0.0140	0.0013^{a}	0.0105	0.0010^{a}
Maturity, yrs					-0.0244	0.0076^{b}	0.0129	0.0045^{b}
Total BPAQ	0.0003	0.0001^{b}	0.0004	0.0002^{c}	0.0002	0.0001^{b}		
Constant	0.5547	0.0566^{a}	0.2503	0.0224^{a}	0.3192	0.0545^{a}	0.3527	0.0394^{a}
Model R^2								
within	0.65		0.67		0.46		0.75	
between	0.46		0.32		0.48		0.30	
overall	0.48		0.36		0.48		0.38	
Girls								
Height, cm	-0.0017	0.0006^{b}			-0.0030	0.0010^{b}		
Lean mass, kg	0.0170	0.0016^{a}	0.0154	0.001^{a}	0.0185	0.002^{a}	0.0125	0.0012^{a}
Maturity, yrs							0.0207	0.0052^{a}
Total BPAQ	0.0003	0.0001^{c}	0.0004	0.0002^{c}	0.0001	0.0001^{c}		
Constant	0.4790	0.0616^{a}	0.1776	0.0294^{a}	0.6983	0.1059^{a}	0.3182	0.0455^{a}
Model R^2								
within	0.74		0.73		0.61		0.87	
between	0.59		0.48		0.56		0.56	
overall	0.61		0.51		0.56		0.61	
Boys								
Lean mass, kg	0.0081	0.0009^{a}	0.0101	0.0011^{a}	0.0113	0.0021^{a}	0.0133	0.0020^{a}
Moderate PA							0.0005	0.0002^{c}
Total BPAQ							0.0003	0.0001^{b}
Constant	0.5241	0.0274^{a}	0.3665	0.0328^{a}	0.9732	0.1460^{a}	0.7131	0.1076^{a}
Model R^2								
within	0.56		0.59		0.30		0.67	
between	0.23		0.11		0.32		0.24	
overall	0.25		0.15		0.31		0.28	

(FN) femoral neck; (SLFN) superolateral femoral neck; (IMFN) inferomedial femoral neck; (BMD) bone mineral density; (TR) trochanter; (SE) standard error; (BPAQ), bone physical activity questionnaire; (PA) physical activity. ^{a} p < 0.001 ; ^{b} p < 0.01 ; ^{c} p < 0.05

Regression Analysis – BMD RATIOS

	FN:PF BMD		IM:SL FN BMD		TR:PF BMD	
	Coef. estimate	Robust SE	Coef. estimate	Robust SE	Coef. estimate	Robust SE
Boys and Girls						
Sex					-0.0347	0.0107^{b}
Lean mass, kg	0.0020	0.0009^{c}			0.0014	0.0004^{b}
Maturity, yrs	-0.0218	0.0058^{a}				
Total BPAQ	0.0002	0.0001^{c}				
IAD, cm	0.0198	0.0098^{c}				
ALA, cm	-0.0753	0.0282^{b}	-0.0740	0.0090^{a}		
IAD.ALA^{-1}	-0.0863	0.0335^{b}				
Constant	1.1581	0.1271^{a}	1.5888	0.0385^{a}	0.7741	0.0134^{a}
Model R^2						
within	0.28		0.31		0.05	
between	0.03		0.01		0.07	
overall	0.05		0.03		0.08	
Girls						
Lean mass, kg	0.0022	0.0010^{c}	-0.0071	0.0015^{a}		
Total BPAQ	0.0002	0.0001^{b}				
IAD, cm					0.0089	0.0023^{a}
ALA, cm	-0.0563	0.0094^{a}				
IAD.ALA^{-1}			0.1157	0.0369^{b}		
Constant	1.1299	0.0306^{a}	1.1365	0.1271^{a}	0.6979	0.0301^{a}
Model R^2						
within	0.39		0.25		0.04	
between	0.06		0.06		0.18	
overall	0.11		0.09		0.15	
Boys						
Maturity, yrs	-0.0213	0.0055^{a}			--	--
IAD, cm	0.0161	0.0062^{b}	0.0531	0.0217^{c}	--	--
ALA, cm			-0.2007	0.0463^{a}	--	--
IAD.ALA^{-1}			-0.1361	0.0500^{b}	--	--
Constant	0.6932	0.0905^{a}	1.8461	0.2134^{a}	--	--
Model R^2						
within	0.14		0.39		--	
between	0.01		0.01		--	
overall	0.02		0.04		--	

(FNPF) Femoral neck to proximal femur BMD ratio; (SLFN) superolateral femoral neck; (IMFN) inferomedial femoral neck; (TR:PF) trochanter to proximal femur BMD ratio; (SD) standard deviations; (BPAQ) bone physical activity questionnaire; (IAD) inter-acetabular distance; (ALA) abductor lever arm; (IAD.ALA^{-1}); inter-acetabular distance to abductor lever arm ratio; ^{a} p < 0.001; ^{b} p < 0.01 ; ^{c} p <0.05

CONCLUSIONS

- **BPAQ** was a significant positive predictor for all BMD variables (p<0.05) except TR BMD in girls and FN BMDs in boys (>0.05).
- At least one **geometric variable** was significant in the estimated models for the BMD ratios: in girls, the IAD was a positive predictor of TR:PF (p<0.001) and ALA was a negative predictor of FN:PF; in boys, the IAD was a positive predictor of FN:PF (p<0.01) and IM:SL (p<0.05); also in boys, ALA was a negative predictor of the IM:SL (p< 0.001).
- The **interaction of IAD*ALA** predicted IM:SL positively in girls and negatively in boys (p<0.01).
- ✓ The **IAD and the ALA**, as indicators of the main lever arms of the biomechanics of the hip, **may play a role in the relative mineralization of the proximal femur in peripubertal boys and girls**, as was theoretically expected..
- ✓ However unlike total lean body mass and PA, the same **geometric variables don't seem to influence the absolute BMD levels** at the proximal femur neck and trochanter..
- ✓ Further research is needed to better understand the effects of geometric variables on the relative mineralization of the proximal femur regions including the development of **a specific biomechanical model to simulate the vector forces exerted on these regions**.

REFERENCES

1. Burge R, Dawson-Hughes B, Solomon DH, Wong JB, King A, Tosteson A 2007 Incidence and economic burden of osteoporosis-related fractures in the United States, 2005– 2025. J Bone Miner Res 22:465–475.
2. Orsini LS, Rousculp MD, Long SR, Wang S 2005 Health care utilization and expenditures in the United States: a study of osteoporosis-related fractures. Osteoporos Int 16:359–371.
3. Bonjour JP, Theintz G, Buchs B, Slosman D, Rizzoli R 1991 Critical years and stages of puberty for spinal and femoral bone mass accumulation during adolescence. J Clin Endocrinol Metab 73:555-563.
4. Karagas MR, Lu-Yao GL, Barrett JA, Beach ML, Baron JA 1996 Heterogeneity of hip fracture: Age, race, sex, and geographic patterns of femoral neck and trochanteric fractures among the US elderly. Am J Epidemiol 143(7):677-682.
5. Lo¨fman O, Berglund K, Larsson L, Toss G 2002 Changes in hip fracture epidemiology: redistribution between ages, genders and fracture types. Osteoporos Int 13:18–25.
6. Faulkner KG, Cummings SR, Black D, Palermo L, Glüer CC 1993 Simple measurement of femoral geometry predicts hip fracture: The study of osteoporotic fractures. J Bone Miner Res 8:1211–1217.
7. Partanen J, Jämsä T, Jalovaara P 2001 Influence of the Upper Femur and Pelvic Geometry on the Risk and Type of Hip Fractures. J Bone Miner Res 16 (8):1540-1546.
8. Mautalen CA, Vega EM, Einhorn TA 1996 Are the etiologies of cervical and trochanteric hip fractures different? Bone 18:S133–7.
9. Ferber R, Davis IM, Williams DS 2003. Gender differences in lower extremity mechanics during running. Clin. Biomech 18:350– 357.
10. Malinzak RA, Colby SM, Kirkendall DT, Yu B, Garrett WE 2001 A comparison of knee joint motion patterns between men and women in selected athletic tasks. Clin. Biomech. 16, 438–445.
11. Mirwald RL, Baxter-Jones AD, Bailey DA, Beunen GP 2002 An assessment of maturity from anthropometric measurements. Med Sci Sports Exer 34: 689-694

European Calcified Tissue Society - Annual Congress 2013 , Lisbon, PORTUGAL, 18 - 21 May 2013