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Abstract

BACKGROUND CONTEXT: In each specific habitual standing posture, gravitational forces determine the mechanical setting provided to skeletal structures. Bone quality and resistance to physical stress is highly determined by habitual mechanical stimulation. However, the relationship between bone properties and sagittal posture has never been studied in children.

PURPOSE: To investigate the association between bone physical properties and sagittal standing postural patterns in 7-year-old children. We also analyzed the relationship between fat/fat-free mass and postural patterns.

STUDY DESIGN: Cross-sectional evaluation.

PATIENT SAMPLE: This study was performed in a sample of 1138 girls and 1260 boys at 7 years of age participating in the Generation XXI study, a population-based cohort of children followed since birth (2005/6) and recruited in Porto, Portugal.

OUTCOME MEASURES: Sagittal standing posture was measured through photographs of the sagittal right view of children in the standing position. Three angles were considered to quantify the magnitude of major curves of the spine and an overall balance measure (trunk, lumbar and sway angles). Postural patterns were identified using latent profile analysis in Mplus.

METHODS: Weight and height were measured. Total body less head fat/fat-free mass and bone properties were estimated from whole body dual energy X-ray absorptiometry scans. The associations of fat/fat-free mass and bone physical properties with postural patterns were jointly estimate in latent profile analysis using multinomial logistic regressions.

RESULTS: The identified patterns were labelled as Sway, Flat and “Neutral to Hyperlordotic” (in girls) and “Sway to Neutral”, Flat and Hyperlordotic (in boys). In both genders, children in the Flat pattern showed the lowest body mass index and children with a rounded posture presented the highest: mean differences varying from -0.86kg/m^2 to 0.60kg/m^2 in girls and -0.70kg/m^2 to 0.62kg/m^2 in boys (vs. Sway/"Sway to Neutral"). Fat and fat-free mass were inversely associated with a Flat pattern and positively associated with a rounded posture: odds ratio (OR) of 0.23 per SD fat and 0.70 per SD fat-free mass for the Flat and 1.85 (fat) and 1.43 (fat-free) for the Hyperlordotic in boys; with similar findings in girls. The same direction of relationships was observed between bone physical properties and postural patterns. A positive association between bone (especially bone mineral density) and a rounded posture was robust to adjustment for age, height, and body composition (girls: OR=1.79, p=0.006 fat-adjusted, OR=2.00, p=0.014 fat-free mass adjusted; boys: OR=2.02, p=0.002 fat-adjusted, OR=2.42, p<0.001 fat-free mass adjusted).

CONCLUSIONS: In this population-based pediatric setting, there was an inverse association between bone physical properties and a Flat posture. Bone and posture were more strongly positively linked in a rounded posture. Our results support that both bone properties and posture mature in a shared and interrelated mechanical environment, probably modulated by pattern-specific anthropometrics and body composition.

Keywords: Sagittal standing posture; Spine; Bone density; Body composition; Body size; Child

Introduction

Sagittal standing posture refers to the way that people stand upright. Sagittal posture is commonly described by thoracic kyphosis and lumbar lordosis (outward and inward curves of the spine in the sagittal plane, respectively), complemented with sagittal balance, i.e. the positioning of the center of mass in the upright position [1]. In each specific habitual standing posture, gravitational forces determine the mechanical setting provided to skeletal structures. An anteriorly displaced center of mass, as frequently observed in osteoporotic patients due to thoracic hyperkyphosis, results in an increased forward bending moment of the upper body leading to higher compressive moments in thoraco-lumbar and lumbar regions [2]. This probably explains hyperkyphosis as a risk factor for new vertebral fractures independently of bone mineral density (BMD) or previous fracture [3, 4]. Stronger extensor trunk muscles are then needed to compensate for hyperkyphosis while keeping a stable upright posture, which increases spinal compressive [2, 5-7] and shear [5-7] loading that may promote spinal disorders and additional vertebral fractures in the long run. Thus, sagittal standing posture seems to be a key macrostructural factor in defining the amount of physical stimuli imposed on spino-pelvic bone tissue.

At the microstructural level, bone quality and resistance to physical stress is highly determined by habitual mechanical stimulation: the network of bone trabeculae is modeled in order to resist the specific stress to which it is usually exposed [8, 9]. Prepubertal years are a particularly sensitive stage for the attainment of optimal bone strength because the skeleton is especially responsive to mechanical loading and shows greater plasticity [10-13]. But despite the direct relationship between bone structure (size and architecture) and vertebrae shape and local alignment [7, 14, 15], the relationship between bone properties and sagittal posture has never been studied in children.

In addition, body size and composition contribute to the mechanical environment of spino-pelvic structures with fat and fat-free mass operating as extra-skeletal modulators of bone morphology. The skeleton has to support and deal with loading moments resulting from weight bearing [2, 7] and adiposity and muscles can also directly affect posture by changing the orientation of vertebral bodies towards increased lumbar lordosis [2, 16-19]. Thus, mechanical loading of the pediatric skeleton by extra-skeletal tissues seems to be a crucial factor to increase bone mineral accrual [10] and promote postural health [16, 20, 21]. Since both bone and posture are continuously matured in a shared and mutually interrelated mechanical environment, the influences of body size and composition need to be taken into account in evaluating the biological link between bone and posture.

Our primary goal was to investigate the association between bone physical properties and sagittal postural patterns among a large sample of 7-year-old children selected from the Generation XXI birth cohort. We also explored the roles of fat and fat-free mass in this association.

Materials and methods

Subjects

This study was conducted within Generation XXI, a population-based birth cohort of 8647 live born infants and their mothers [22, 23]. Participants were recruited between 2005 and 2006 at five public maternity units serving the six municipalities of the metropolitan area of Porto, North of Portugal. Initially, 91.4% of invited mothers agreed to participate. Seven years after birth, all Generation XXI children were invited to a follow-up evaluation based on their date of birth and 80% of the cohort's children were re-evaluated. The present study was based on an additional wave of assessment held for 2998 eligible children consecutively attending the 7 year-old follow-up (December 2012 to August 2013), and without a diagnosis of severe neurological impairment (n=7). This additional evaluation occurred between March 2013 and February 2014. Ethical approval was obtained from the Ethics Committee of São João Hospital/University of Porto Medical School.

Anthropometric variables

Weight was measured in light indoor clothing to the nearest 0.1kg using a digital scale (Xinyu Electronic Company, Limited) and height measured to the nearest 0.1cm using a wall stadiometer (SECA®). Body mass index was defined as weight in kg divided by height squared in m^2.

Dual energy X-ray absorptiometry

Whole body dual energy X-ray absorptiometry (DXA) scans were performed (Hologic Discovery QDR® 4500W, Bedford, MA, USA). Total body less head fat and fat-free mass were used. Fat and fat-free mass indices were then calculated by dividing fat mass and fat-free mass (kg) by height squared (m^2) [24]. Total body less head bone mineral content (BMC) was obtained and BMD was expressed as BMC (in g) per projected bone area (in cm^2). Area-adjusted BMC (aBMC) was derived as a measure of volumetric BMD by a regression of BMC on bone area and adding the residuals of the linear regression to mean BMC [25]. As recommended, total body less head rather than total body measurements were used because the head is less responsive to environmental stimuli [26]. The standard quality assurance tests using the calibration block were performed daily, and also each month using the spine phantom. DXA scans were removed from analysis due to anomalies caused by movement, artefacts or other logistic issues. Nine trained radiology technicians were involved in DXA evaluations. Two of the examiners performed 84% of all the scans.

Pediatric sagittal postural patterns

Sagittal standing posture evaluation was performed by quantitative assessment of photographs of the sagittal right view of children, which is documented as the safest method for epidemiological studies among children [27, 28]. Posture was assessed before DXA scans in order to facilitate the attainment of the usual upright position. Spherical retro-reflective markers were placed over anatomical landmarks on the right-side of the child's body by one of two qualified health professionals. Children assumed their habitual standing position with feet slightly apart and looking straight ahead [27, 29]. Full-body flash photographs of the sagittal right view of children were then acquired. Angular measures formed by the lines drawn from the anatomical landmarks were obtained using the postural assessment software PAS/SAPO [30]. Three angles were considered in order to quantify the magnitude of major curves of the spine (thoracic kyphosis and lumbar lordosis), and also an overall balance measure assessing body sway (as exemplified in the left panel of Figure 1).

Children were ranked regarding their distance to the average postural values within each examiner's distribution in order to eliminate potential systematic differences between examiners (i.e., individual residuals of mixed-effects models) [31] and residuals were used to define postural patterns through the R package Mclust [32]. Based on the interpretability of the patterns amongst the models with the smallest Bayesian Information Criterion [33], a final 3-pattern solution was obtained separately for girls and boys. The methods and results of pattern identification are thoroughly described elsewhere [34].

Statistical analysis

Since we wished to estimate the postural patterns and their associations with the exposures in a single step in order to minimise bias [35], we used the pediatric patterns described above as the basis for re-estimation of postural patterns within Mplus (version 6.12, Muthén & Muthén, Los Angeles, CA). Latent profile analysis was performed with multinomial logistic regressions simultaneously computed in the same models (i.e., including predictors of estimated postural latent profiles). Initially, five different parametrizations of variance-covariance matrices were tested, with a fixed 3-class solution for each gender based on our previous work on pediatric patterns [34]. Then, we selected the type of parametrization which optimized observed agreement of pattern assignment (based on the most likely class). Finally, latent postural classes were re-estimated using information provided by each different set of predictors included in the models and their associations were jointly quantified. This last step was used to account for uncertainty in the assignment of patterns and consequently to obtain unbiased estimates of associations [35]. Sensitivity analysis was carried out by considering regional measures of body composition (trunk, upper and lower limbs) derived from total body DXA scans.

Results

Pediatric postural patterns

A total of 1138 girls and 1260 boys accepted to participate and were included in the analysis (79% and 81% of eligible children, respectively). Compared to previous work on pattern assignment of Generation XXI children [34], final postural models obtained 68.5% concordance in girls and 79.7% in boys (detailed information provided in Supplemental Table 1). The average latent class assignment probabilities (for the most likely latent class membership) varied between 0.72-0.86 in girls and 0.68-0.69 in boys. Figure 1 (right panel) displays the average features of the three postural patterns and a typical child in each posture:

1) Sway (girls) and “Sway to Neutral” (boys): increased trunk angle with backward tilt of the spine over the hips;
2) Flat pattern in both genders: straight spine with forward trunk lean; and
3) “Neutral to Hyperlordotic” (girls) and Hyperlordotic (boys): relatively increased lumbar angle and intermediate body sway.

Gender-specific aggregation of the neutral labelling was based on different pattern prevalence between genders (see Figure 1).

Associations between DXA-derived parameters and postural patterns

Table 1 shows descriptive analyses of anthropometric variables and DXA-derived parameters according to participants’ most likely class assignment. Associations between DXA parameters and postural patterns are presented in Table 2 and Figure 2, using the Sway/”Sway to Neutral” pattern as reference given their intermediate overall profile of anthropometrics and parameters of body composition.

Flat posture

In both genders, children in the Flat pattern showed the lowest body mass index with mean differences of 0.86kg/m^2 in girls and 0.70kg/m^2 in boys, comparing to the Sway/“Sway to Neutral” pattern. Fat and fat-free mass were inversely associated with a Flat pattern: odds ratio (OR) of 0.36 per fat standard deviation (SD) and 0.60 per fat-free SD in girls (both $p<0.01$) and, in boys, ORs were 0.23 per fat SD ($p=0.001$) and 0.70 per fat-free SD ($p=0.023$). However, when adjusted for age and height (model 1), these associations remained statistically significant only for fat mass, and were independent of fat-free mass [model 2b: girls OR=0.34, 95% confidence interval (CI):0.21-0.55; boys OR=0.22, 95% CI:0.06-0.81]. Even though children in the Flat pattern had lower bone properties in crude analysis (especially in girls: ORs ranging from 0.66, 95% CI:0.46-0.94 per BMD SD to 0.72, 95% CI:0.53-0.99 per aBMC SD), those associations did not remain in adjusted models. Moreover, when adjusting for fat mass (model 2a), the Flat pattern was associated with increased bone properties, especially in girls (ORs varying from 1.17, 95% CI:0.86-1.61 per aBMC SD to 1.60, 95% CI:1.03-2.49 per BMC SD).

“Neutral to Hyperlordotic”/Hyperlordotic posture

Children with a rounded posture presented the highest body mass index: mean differences of 0.60kg/m^2 in girls and 0.62kg/m^2 in boys (vs. Sway/“Sway to Neutral”). The likelihood of having a “Neutral to Hyperlordotic”/Hyperlordotic pattern increased per SD of fat mass and fat-free mass, and the relationships of posture with each component of body size were independent of each other (model 2b and 2a), although not significantly in girls. When adjusted for fat-free mass, ORs for fat mass were increased by 29% in girls ($p=0.370$) and 77% in boys ($p=0.012$) and when adjusted for fat mass, ORs for fat-free mass were increased by 50% in girls (p=0.113) and 118% in boys (p=0.016). Additionally, a rounded posture was associated with higher bone mineral density and content (stronger for BMD than BMC) independently of fat/fat-free mass. In girls, across models 2a and 2b, ORs varied from 1.35 (95% CI:0.85-2.17) per BMC SD to 2.00 (95% CI:1.15-3.46) per BMD SD; and in boys from 1.23 (95%CI:0.73-2.08) per BMC SD and 2.42 (95%CI:1.48-3.95) per BMD SD.

Sensitivity analysis

Similar results to the main analysis were obtained in the analysis of regional parameters from trunk, upper limbs, and lower limbs regions. No clear differences were observed between regions in respect to associations of fat/fat-free mass and bone parameters with postural patterns.

Discussion

In both genders, lower adiposity was associated with a flattened spine, and concordantly, higher fat and fat-free mass with a rounded posture type. There was an inverse association between bone physical properties and a Flat posture, but this relationship did not remain after accounting for differences in body composition across postural morphotypes. However, in a rounded posture, bone and posture were more strongly linked, possibly as the result of a shared accumulation of increased mechanical forces: children in the postural pattern characterized by higher lumbar angle ("Neutral to Hyperlordotic" in girls and Hyperlordotic in boys) presented higher bone mineral density, independently of anthropometrics and body composition.

Sagittal postural patterns in this work showed a plausible association with body size and composition among the pediatric population. For instance, both girls and boys with a hypercurved spine were heavier, taller, exhibited higher fat and fat-free mass, and increased bone mass and density. Since compressive forces on spino-pelvic structures are the sum of superincumbent fat and muscle loads acting on vertebral bodies in the axial plane, this implies specific weight-loading profiles for each postural morphotype even if not attributable to its sagittal configuration. In a rounded spine, higher forces are applied to bone structures because the skeleton has more weight to support and needs higher muscle moments to regulate amplified oscillations of the upper body over the hips [2, 7]. Our characterization of postural patterns reinforces that children with a flattened spine can keep an anteriorly displaced balance (increased sway angle) because they are lighter, while children with a rounded spine need to activate stronger extensor back muscles to avoid falling anteriorly and to reestablish balance in an intermediate range.

Numerous studies showed that low body mass index/weight is associated with a flattened posture and that increased body size is associated with a hypercurved spine [16, 21]. However, we showed, for the first time, that both fat mass and fat-free mass contribute to the associations of body size with sagittal posture. After adjustment for height, only fat mass was inversely associated with a Flat posture while both components of non-skeletal body mass were positively and independently related with a rounded posture type. The effect of adiposity on spino-pelvic alignment is mainly derived from biomechanical constraints during posture development, potentially causing plastic deformation of bones and intervertebral discs [16, 20, 21]. Adiposity also displaces balance forwardly which increases lumbar lordosis as the most efficient compensation to restore a stable basis of support [2, 16, 17]. On the other hand, stronger back extensor muscles lead to an increase in lumbar lordosis [18, 19] and a hyperlordotic posture, through its sagittal organization alone, also requires higher muscle moments than all other postures; especially during more demanding tasks [36]. These mechanical pathways are congruent with our findings, but the robust and exclusive association (after adiposity adjustment) between fat-free mass and a hyperlordotic posture probably implies a biological threshold for adiposity, above which muscles predominantly control upright balance. This threshold is likely related with balance instability caused by adiposity, which would explain why fat-free mass was not associated with a Flat pattern.

The inverse relation between bone physical properties and a Flat pattern observed in our work may be explained by the profile of anthropometric and body composition characteristics featured by this typology. However, in the case of a rounded posture, an association between bone quality and posture remains after those adjustments. A specific shape and design of the spine establishes the morphological configuration for the action of gravity and muscles. A Sway posture minimizes muscle work and stresses in the resting standing position [36]. As lumbar lordosis increases up to a hyperlordotic posture mechanical loads also increase. Flattened or neutral spines are better suited to minimize muscle work and stress in weight-bearing activities [36] and the extremely pronounced thoracic kyphosis in the Sway type can be expected to contribute to higher mechanical stress compared to the Flat pattern [2, 5, 6]. Conversely, fat and lean mass positively affect bone structure through mechanical and endocrine effects [37, 38] with a more important contribution of lean than fat mass during childhood [38, 39]. Therefore, both adiposity and muscles can lead to changes in the morphology of vertebral bodies, namely by changing their antero-posterior height ratios [40]. These changes modify vertebral tilt and define local alignment [7, 14, 15], and consequently overall postural patterns due to adaptation of adjacent anatomical regions [1]. As examples, longitudinal vertebral growth in children may increase lumbar lordosis [15], and both higher thoracic kyphosis [14, 41, 42] as well as higher lumbar lordosis [42] seem to have an osteoporotic origin (decreased BMD) at more advanced ages.

Our population-based finding of bone-posture potentiation in a hypercurved spine suggests that a bidirectional mechanisms exist – i.e. hyperlordosis promotes mechanical stress but bone growth changes vertebrae tilting – in a pattern-specific dynamic environment also defined by anthropometrics and body composition. This was also supported by regional analysis of body composition, with no clear differences of bone-posture associations between load bearing regions and the upper limbs. Increased loads and endocrine adaptations in the hyperlordotic posture probably culminate in stronger biological relations of fat, muscle, and bone with sagittal alignment. Probably due to weaker mechanical forces, maturational processes of bone and posture do not seem more closely linked in a Flat than in a Sway posture. Furthermore, associations between bone and posture were stronger for boys than for girls. This may result from different aggregations of postural morphologies in the present classifications (“Neutral to Hyperlordotic” in girls and “Sway to Neutral” in boys), or represent a true gender-specific bone response to mechanical stimuli [43, 44].

One of the limitations of this work is the lack of direct measurement of mechanical stimuli imposed by anthropometrics, adiposity and muscle contractions. Our analyses assumed that mechanical influences are captured by lean mass and reflected in bone physical properties, both quantifiable by DXA measurements. The population-based nature of our work constrained these assessments, but it ensured a wide representation of naturally occurring anthropometrics, body composition, bone physical properties and postural angles in the pediatric population. Furthermore, it has been previously shown that children participating in this wave of assessment (posture and DXA measurements) were similar to the general Generation XXI cohort at birth regarding anthropometrics, although maternal education was higher for included children [34]. The external validity of our findings is a key advantage because previous evidence had relied mainly on biomechanical model simulations without any empirical measurements of bone quality [2, 5, 6, 36]. Furthermore, it is essential to study posture morphotypes instead of isolated parameters because patterns add the effect of different combinations of regional alignment on health, and consequently, allow a more comprehensive mechanical characterization of the upright posture [2, 16, 29, 36]. Our associations between DXA-derived parameters and postural patterns may be biased due to the use of posture classification not completely overlapping with the initial Mclust grouping, especially in the Flat pattern (Supplemental Table 1). However, given the direction of differences between classifications, this would bias results towards the null hypothesis and not create spurious associations. Further, latent profile analysis in Mplus enables using information provided from model predictors (i.e., DXA-derived parameters) to re-estimate patterns and jointly quantify unbiased associations [35], which probably surpasses limitations resulting from the use of two different software. Since variables considered in this study have high physiological correlation, differentiating effects of posture from body size/composition on bone may be unrealistic. Moreover, given the observational nature of our study, the causal nature of relationships between body composition, bone and posture should be seen in the context of homeostatic feedback mechanisms rather than as a set of unidirectional effects.

This study evaluated for the first time the relations between bone physical properties and sagittal posture in 7-year-old children recruited from a population-based birth cohort. There was an inverse association between bone physical properties and a Flat posture, and bone and posture were more strongly positively linked in a rounded posture. As initially hypothesized, our results support that both bone and posture mature in a shared and interrelated mechanical environment modulated by pattern-specific anthropometrics and body composition.

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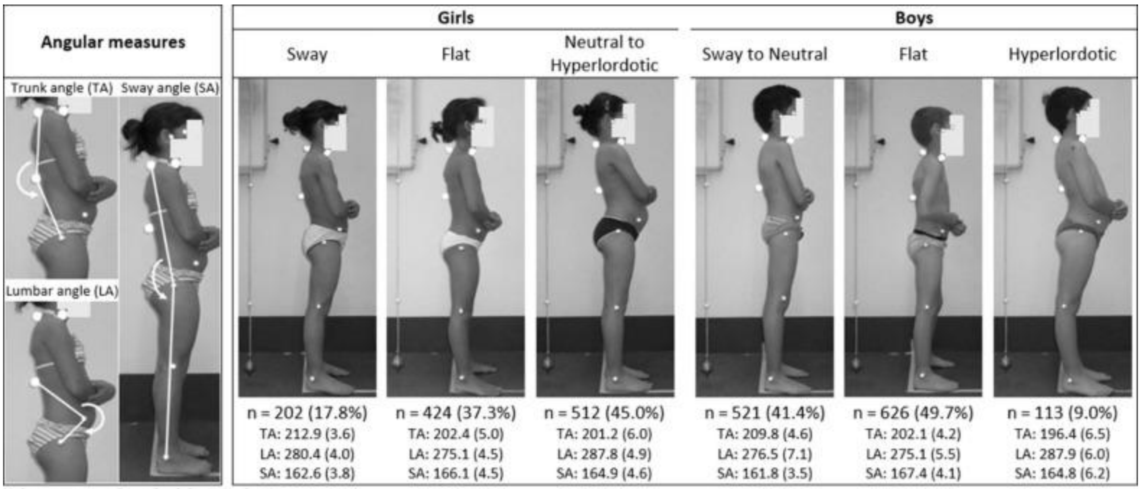
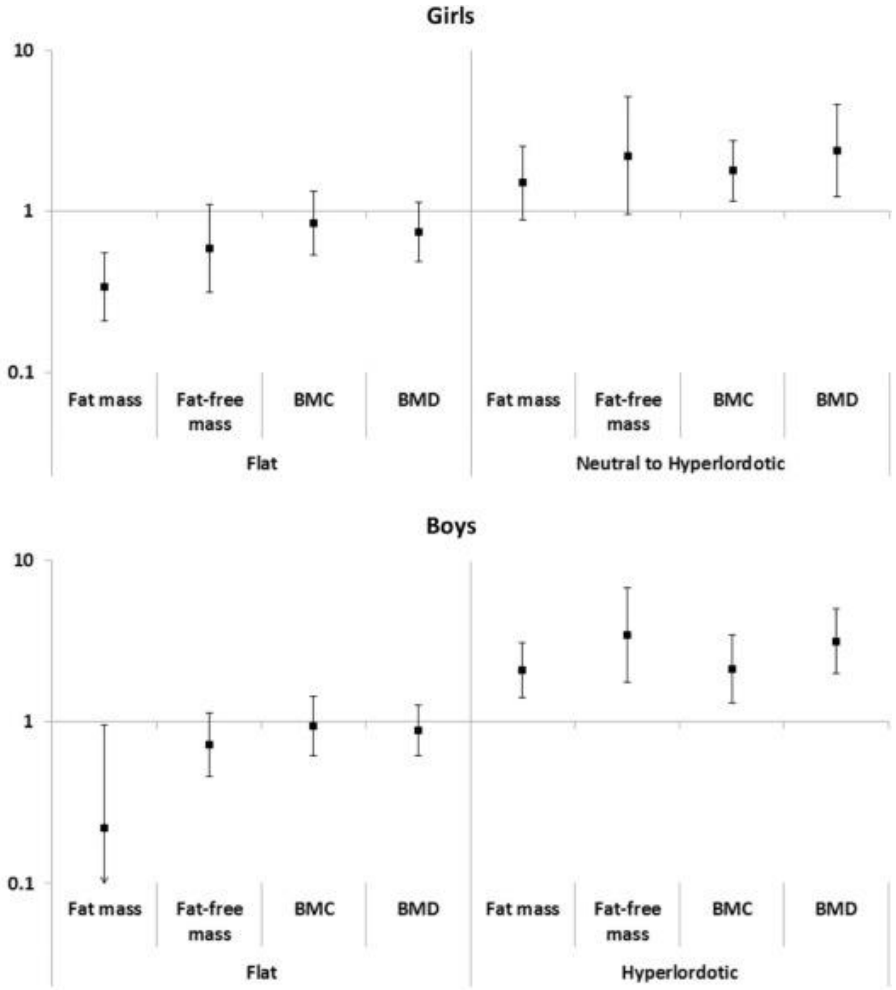
Figure legends



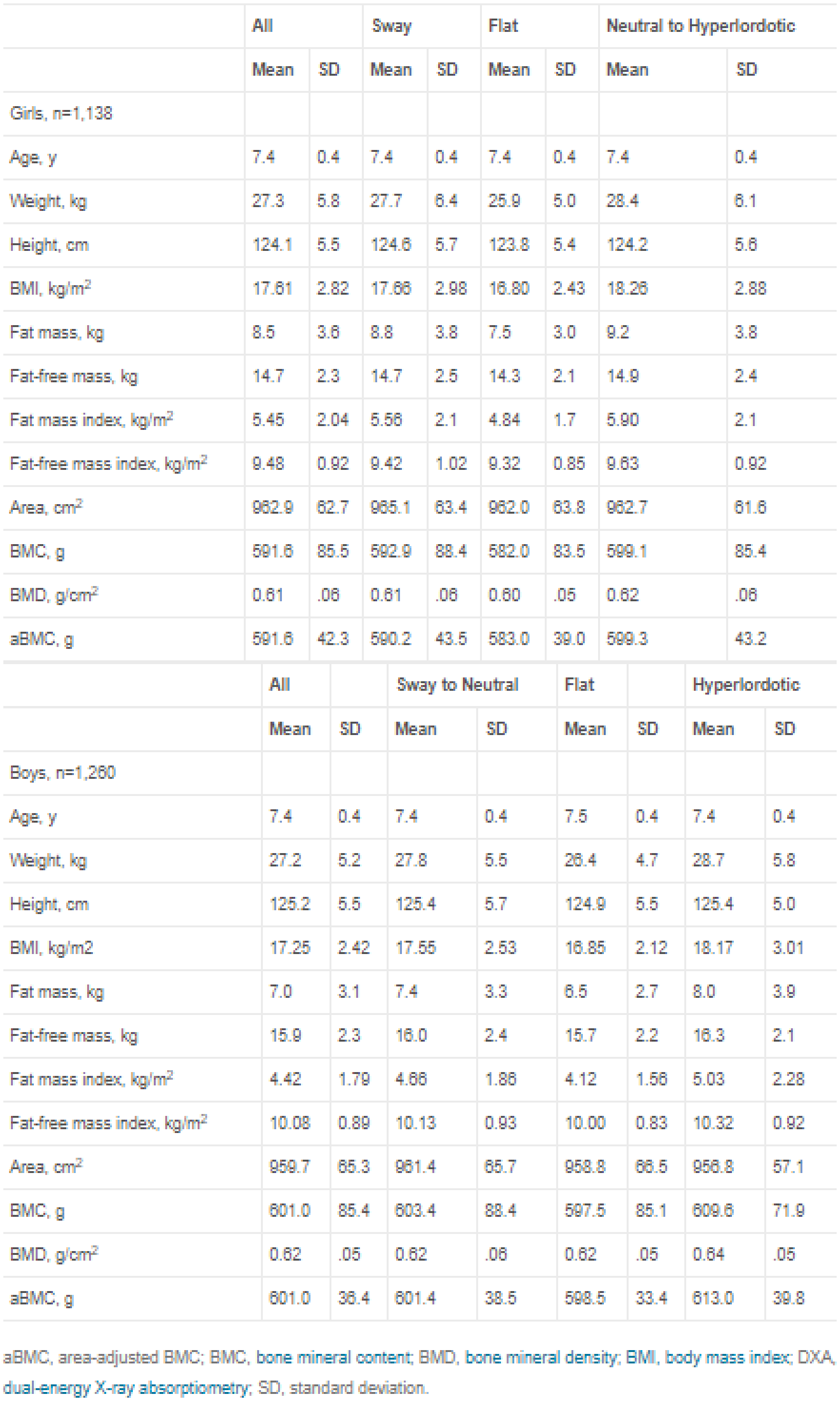
Values are mean (standard deviation)

Fig. 1. Individual angular measures used to identify pediatric sagittal postural patterns using Mplus latent profile analysis (left panel) and a typical member of each pattern shown separately for girls and boys (right panel).



BMC = bone mineral content; BMD = bone mineral density.

Fig. 2. Graphs showing associations (odds ratio and 95% confidence interval) between standardized DXA parameters and pediatric sagittal postural pattern, shown separately for girls (reference = Sway) and boys (reference = Sway to Neutral). Odds ratios are per standard deviation higher DXA parameter, adjusted for age and height.

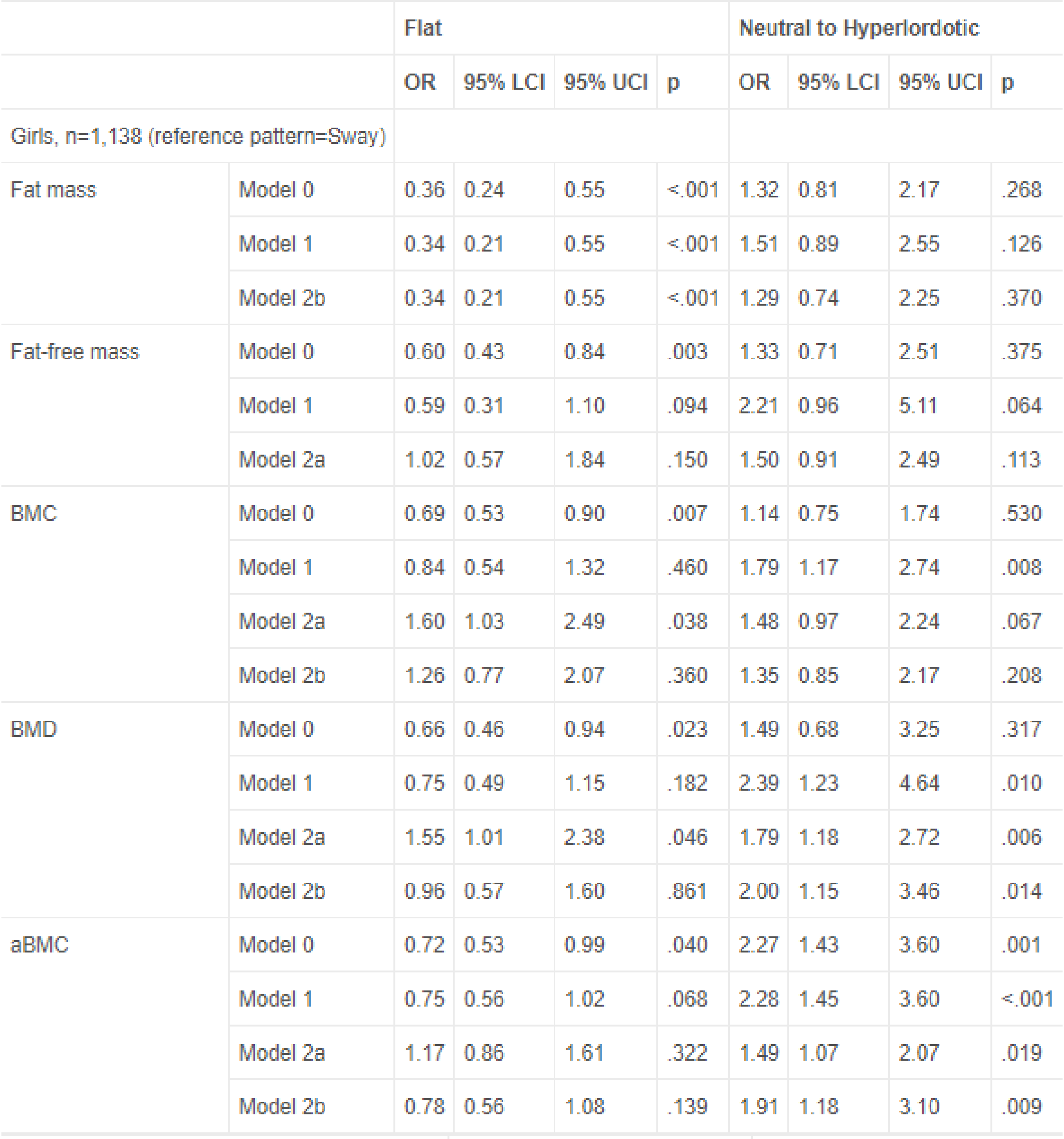


	All		Sway		Flat		Neutral to Hyperlordotic	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Girls, n=1,138								
Age, y	7.4	0.4	7.4	0.4	7.4	0.4	7.4	0.4
Weight, kg	27.3	5.8	27.7	6.4	25.9	5.0	28.4	6.1
Height, cm	124.1	5.5	124.6	5.7	123.8	5.4	124.2	5.6
BMI, kg/m^2	17.61	2.82	17.66	2.98	16.80	2.43	18.26	2.88
Fat mass, kg	8.5	3.6	8.8	3.8	7.5	3.0	9.2	3.8
Fat-free mass, kg	14.7	2.3	14.7	2.5	14.3	2.1	14.9	2.4
Fat mass index, kg/m^2	5.45	2.04	5.56	2.1	4.84	1.7	5.90	2.1
Fat-free mass index, kg/m^2	9.48	0.92	9.42	1.02	9.32	0.85	9.63	0.92
Area, cm^2	962.9	62.7	965.1	63.4	962.0	63.8	962.7	61.6
BMC, g	591.6	85.5	592.9	88.4	582.0	83.5	599.1	85.4
BMD, g/cm^2	0.61	.06	0.61	.06	0.60	.05	0.62	.06
aBMC, g	591.6	42.3	590.2	43.5	583.0	39.0	599.3	43.2

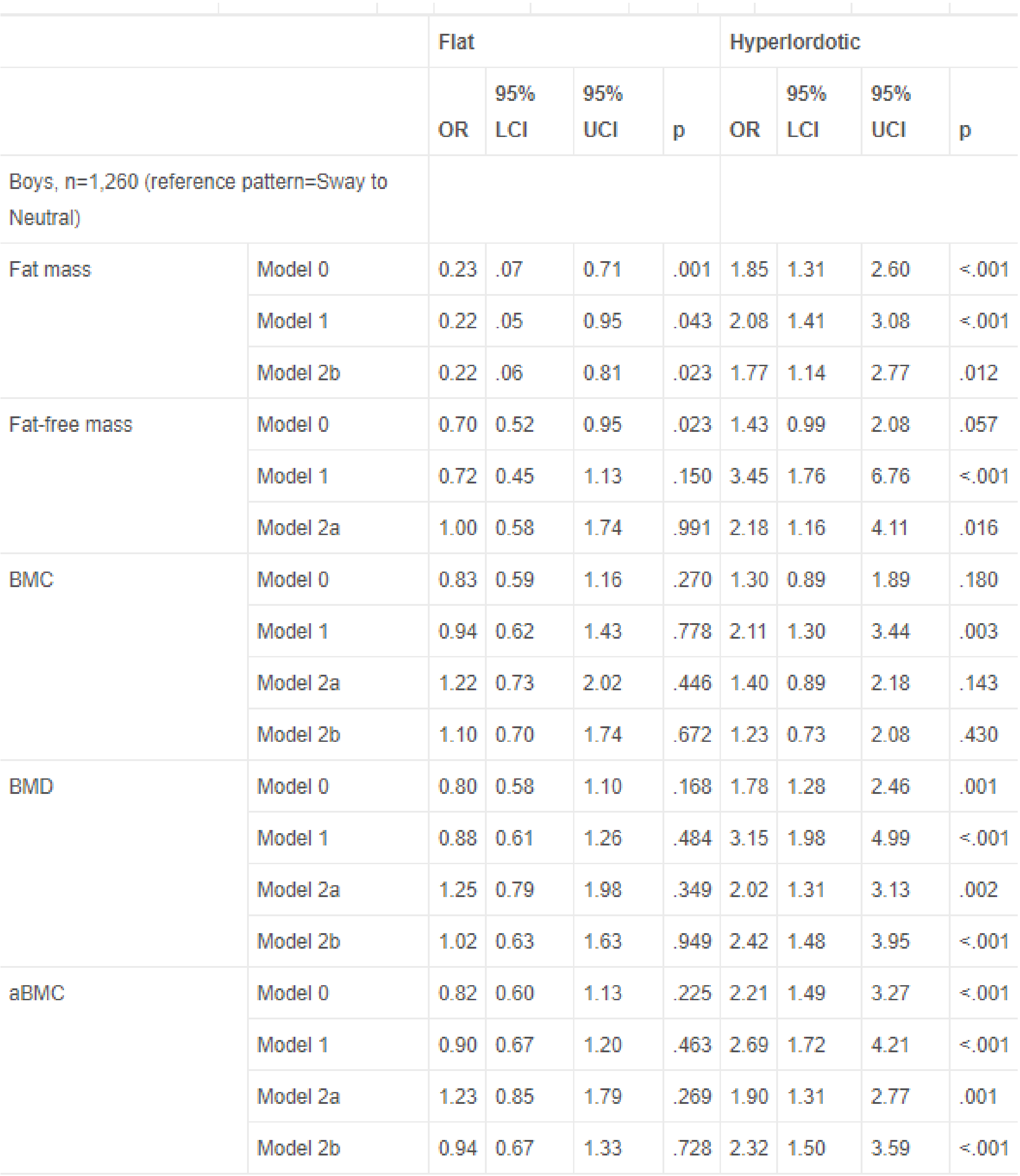
	All		Sway to Neutral		Flat		Hyperlordotic	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Boys, n=1,260								
Age, y	7.4	0.4	7.4	0.4	7.5	0.4	7.4	0.4
Weight, kg	27.2	5.2	27.8	5.5	26.4	4.7	28.7	5.8
Height, cm	125.2	5.5	125.4	5.7	124.9	5.5	125.4	5.0
BMI, kg/m2	17.25	2.42	17.55	2.53	16.85	2.12	18.17	3.01
Fat mass, kg	7.0	3.1	7.4	3.3	6.5	2.7	8.0	3.9
Fat-free mass, kg	15.9	2.3	16.0	2.4	15.7	2.2	16.3	2.1
Fat mass index, kg/m^2	4.42	1.79	4.66	1.86	4.12	1.56	5.03	2.28
Fat-free mass index, kg/m^2	10.08	0.89	10.13	0.93	10.00	0.83	10.32	0.92
Area, cm^2	959.7	65.3	961.4	65.7	958.8	66.5	956.8	57.1
BMC, g	601.0	85.4	603.4	88.4	597.5	85.1	609.6	71.9
BMD, g/cm^2	0.62	.05	0.62	.06	0.62	.05	0.64	.05
aBMC, g	601.0	36.4	601.4	38.5	598.5	33.4	613.0	39.8

aBMC, area-adjusted BMC; BMC, bone mineral content; BMD, bone mineral density; BMI, body mass index; DXA, dual-energy X-ray absorptiometry; SD, standard deviation.

Table 1. Descriptive data for anthropometric variables and DXA parameters according to pediatric sagittal postural patterns, shown separately for girls and boys



		Flat				Neutral to Hyperlordotic			
		OR	95% LCI	95% UCI	p	OR	95% LCI	95% UCI	p
Girls, n=1,138 (reference pattern=Sway)									
Fat mass	Model 0	0.36	0.24	0.55	<.001	1.32	0.81	2.17	.268
	Model 1	0.34	0.21	0.55	<.001	1.51	0.89	2.55	.126
	Model 2b	0.34	0.21	0.55	<.001	1.29	0.74	2.25	.370
Fat-free mass	Model 0	0.60	0.43	0.84	.003	1.33	0.71	2.51	.375
	Model 1	0.59	0.31	1.10	.094	2.21	0.96	5.11	.064
	Model 2a	1.02	0.57	1.84	.150	1.50	0.91	2.49	.113
BMC	Model 0	0.69	0.53	0.90	.007	1.14	0.75	1.74	.530
	Model 1	0.84	0.54	1.32	.460	1.79	1.17	2.74	.008
	Model 2a	1.60	1.03	2.49	.038	1.48	0.97	2.24	.067
	Model 2b	1.26	0.77	2.07	.360	1.35	0.85	2.17	.208
BMD	Model 0	0.66	0.46	0.94	.023	1.49	0.68	3.25	.317
	Model 1	0.75	0.49	1.15	.182	2.39	1.23	4.64	.010
	Model 2a	1.55	1.01	2.38	.046	1.79	1.18	2.72	.006
	Model 2b	0.96	0.57	1.60	.861	2.00	1.15	3.46	.014
aBMC	Model 0	0.72	0.53	0.99	.040	2.27	1.43	3.60	.001
	Model 1	0.75	0.56	1.02	.068	2.28	1.45	3.60	<.001
	Model 2a	1.17	0.86	1.61	.322	1.49	1.07	2.07	.019
	Model 2b	0.78	0.56	1.08	.139	1.91	1.18	3.10	.009



		Flat				Hyperlordotic			
		OR	95% LCI	95% UCI	p	OR	95% LCI	95% UCI	p
Boys, n=1,260 (reference pattern=Sway to Neutral)									
Fat mass	Model 0	0.23	.07	0.71	.001	1.85	1.31	2.60	<.001
	Model 1	0.22	.05	0.95	.043	2.08	1.41	3.08	<.001
	Model 2b	0.22	.06	0.81	.023	1.77	1.14	2.77	.012
Fat-free mass	Model 0	0.70	0.52	0.95	.023	1.43	0.99	2.08	.057
	Model 1	0.72	0.45	1.13	.150	3.45	1.76	6.76	<.001
	Model 2a	1.00	0.58	1.74	.991	2.18	1.16	4.11	.016
BMC	Model 0	0.83	0.59	1.16	.270	1.30	0.89	1.89	.180
	Model 1	0.94	0.62	1.43	.778	2.11	1.30	3.44	.003
	Model 2a	1.22	0.73	2.02	.446	1.40	0.89	2.18	.143
	Model 2b	1.10	0.70	1.74	.672	1.23	0.73	2.08	.430
BMD	Model 0	0.80	0.58	1.10	.168	1.78	1.28	2.46	.001
	Model 1	0.88	0.61	1.26	.484	3.15	1.98	4.99	<.001
	Model 2a	1.25	0.79	1.98	.349	2.02	1.31	3.13	.002
	Model 2b	1.02	0.63	1.63	.949	2.42	1.48	3.95	<.001
aBMC	Model 0	0.82	0.60	1.13	.225	2.21	1.49	3.27	<.001
	Model 1	0.90	0.67	1.20	.463	2.69	1.72	4.21	<.001
	Model 2a	1.23	0.85	1.79	.269	1.90	1.31	2.77	.001
	Model 2b	0.94	0.67	1.33	.728	2.32	1.50	3.59	<.001

aBMC, area-adjusted BMC; BMC, bone mineral content; BMD, bone mineral density; DXA, dual-energy X-ray absorptiometry; LCI, lower confidence interval; OR, odds ratio; UCI, upper confidence interval.
Model 0=crude associations; Model 1=adjusted for age and height; Model 2a=additionally adjusted for fat mass; Model 2b=as model 1 plus adjustment for fat-free mass.

Odds ratios are per one standard deviation higher DXA-derived parameter.

Table 2. Associations between standardized DXA parameters and pediatric sagittal postural patterns, shown separately for girls and boys