ARTICLE ORIGINAL / ORIGINAL ARTICLE

RELATIONS BETWEEN BIRTH WEIGHT AND HIP BONE STRENGTH INDICES IN A GROUP OF ADOLESCENT GIRLS

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El Hage R. Relations between birth weight and hip bone strength indices in a group of adolescent girls. J Med Liban 2013 ; 61 (3) : 138-143.

ABSTRACT • OBJECTIVE : The aim of this study was to explore the relations between birth weight and hip bone strength indices in a group of adolescent girls.

METHODS AND RESULTS : This study included 26 adolescent girls (15.3 ± 2.9 years old). Weight and height were measured and body mass index (BMI) was calculated. Birth weights were obtained from obstetric records. Body composition and BMD were assessed by dual-energy X-ray absorptiometry (DXA). To evaluate bone geometry, DXA scans were analyzed at the femoral neck (FN), the intertrochanteric (IT) region and the femoral shaft (FS) by the Hip Structure Analysis (HSA) program. Cross sectional area (CSA), an index of axial compression strength, cross sectional moment of inertia (CSMI), an index of structural rigidity and section modulus (Z), an index of bending strength, were measured from bone mass profiles. Birth weight was positively correlated to CSA, CSMI and Z of the three sites (FN, IT and FS). However, the positive associations between birth weight and HSA variables disappeared after controlling for body weight.

CONCLUSION : In this population, the positive associations between birth weight and hip bone strength indices disappear after controlling for body weight.

Keywords : bone mineral density, hip structural analysis, menarche, paediatrics, body weight

El Hage R. Relations entre le poids de naissance et les indices de résistance osseuse de la hanche chez un groupe d'adolescentes. J Med Liban 2013 ; 61 (3) : 138-143.

RÉSUMÉ • OBJECTIF : Le but de cette étude était d'explorer les relations entre le poids de naissance et les indices de résistance osseuse de la hanche chez un groupe d'adolescentes.

MÉTHODES ET RÉSULTATS : Vingt-six adolescentes (âgées en moyenne de 15,3 ± 2,9 ans) ont participé à cette étude. Le poids et la taille ont été mesurés et l'indice de masse corporelle (IMC) a été calculé. La composition corporelle et la densité minérale osseuse (DMO) ont été mesurées par absorptiométrie biphotonique à rayons-X (DXA). Afin d'évaluer la géométrie osseuse, les scans au niveau du col fémoral (CF), de la région intertrochantérienne (IT) et de la diaphyse fémorale (DF) ont été analysés par le logiciel *Hip Structure Analysis* (HSA). La surface de la section transversale (CSA), le moment d'inertie de la surface transversale (CSMI) et le module de section (Z) ont ainsi été mesurés par le logiciel HSA. Le poids de naissance était positivement corrélé à la CSA, au CSMI et au Z des trois régions étudiées (CF, IT et DF). Cependant, les corrélations positives entre le poids de naissance et les indices de résistance osseuse de la hanche disparaissaient après ajustement pour le poids corporel.

CONCLUSION : Dans cette population, les corrélations positives entre le poids de naissance et les indices de résistance osseuse de la hanche disparaissent après ajustement pour le poids corporel.

Mots-clés : densité minérale osseuse, *Hip Structure Analysis*, ménarche, pédiatrie, poids corporel

INTRODUCTION

Osteoporosis is an important global health problem which is associated with morbidity and mortality [1-4]. It is known to mainly affect elderly women [1-3]. The World Health Organization (WHO) definition of osteoporosis is based on a bone mineral density value 2.5 standard deviation or more below the mean for young normal subjects [1-4]. BMD measurements using DXA have been recognized as the "gold standard" for the diagnostic of osteoporosis [1-4]. DXA has been validated in adolescents and adults [5-8]. It is well established that BMD acquisition is mainly limited to the first two decades of life [9]. Accordingly, Hernandez *et al.* [10] underlined that peak BMD, attained by the end of the second decade of life, could be the single most important factor for the prevention of osteoporosis later in life. Peak BMD is influenced by several factors such as genetics, race, gender, dietary intakes, endocrine factors, mechanical factors, or the exposure to deleterious influences [2, 9]. In addition, several studies from around the world have shown positive associations between birth weight and adult BMD [11-17]. However, BMD is not a measure of bone strength; it is a surrogate of bone strength [18-19]. In reality, bone strength derives from many components which include BMD, cortical porosity, micro-architecture, and geometry [18-19]. Interestingly, Beck *et al.* [20]

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developed a computer program to derive hip geometry from bone mineral data for an estimate of hip strength. The program, called Hip Structure Analysis (HSA), was developed originally to improve the predictive value of hip bone mineral data for osteoporosis fracture risk assessment [20-21]. Later on, many researchers used this program to detect the effects of ageing [22-25], gender [26], body mass index [27], and physical activity [28] on hip bone strength indices. Bone strength may be better represented by HSA variables such as cross sectional area (CSA), an index of axial compression and section modulus (Z), an index of bending strength, than BMD or bone mineral content [20-21, 29]. The aim of this study was to explore the relation between birth weight and hip bone strength indices, evaluated by the HSA software, in a group of Lebanese adolescent girls.

MATERIAL AND METHODS

Subjects and study design

The study participants (n = 26) were recruited from three private schools in Beirut, Lebanon. Inclusion criteria were being post-menarchal (at least one year of regular menstrual cycles), adolescent, sedentary (practising less than two hours of physical activity per week and not involved in impact sports) girls from 12 to 20 years of age with no diagnosis of comorbidities and no history of fracture. The girls were nonsmokers and had no history of major orthopaedic problems or other disorders known to affect bone metabolism. Moreover, girls participating in this study were not pregnant and had not taken hormonal contraceptives for the past six months.

In this study, the number of years since menarche was considered as a maturation index (MI) [30]. Birth weights were obtained from obstetric records. This study did not include extremely lean (BMI < 16 kg/m^2) girls or extremely obese (BMI > 40 kg/m^2) girls. Informed written consents were obtained from the children and their parents. This study was approved by the University of Balamand Ethics Committee.

Anthropometric measurements

Height (cm) was measured in the upright position to the nearest 1 mm with a Seca standard stadiometer. Body weight (kg) was measured on a Taurus mechanic scale with a precision of 100 g. The girls were weighed wearing only underclothes. BMI was calculated as body weight divided by height squared (kg/m^2). Body composition (lean mass, fat mass, body fat percentage) was assessed by dual-energy DXA (Hologic QDR-4500W; Waltham, MA).

Bone mass measurements

Bone mineral content (BMC, in g) and density (BMD, in g/cm^2) were determined for each individual. The DXA measurements were completed at the whole body (WB), the total hip (TH) and at the femoral neck (FN) using the instrument previously described (Hologic QDR-4500W; Waltham, MA). The Hologic APEX software, version 2 (1986-2007, Hologic Inc.) was used to analyze the DXA scans on the Hologic machine. In our laboratory, the coefficients of variation were < 1.5% for BMD in adolescents [31]. The same certified technician performed all analyses using the same technique for all measurements.

Hip structure analysis (HSA)

The proximal femur densitometry scans were analyzed for geometric properties of bone structure using the Hip Structure Analysis (HSA) software program developed by Beck *et al.* [20]. The HSA technique calculates dimensions of bone cross-sections at specific locations across the proximal femur using bone mass images generated by absorptiometry scanners [20-21]. In brief, the HSA program measures bone mineral density and geometry of cross-sections using distributions of mineral mass traversing the bone axis, averaged for precision over five parallel lines (5 mm) across the bone axis [20-21]. The femoral neck, the intertrochanteric and the femoral shaft regions were analyzed in this study. Bone cross-sectional area (CSA; cm^2) and section modulus (Z; cm^3) were determined directly from the bone profile at the intertrochanteric and the femoral shaft regions using algorithms described previously [20-21]. CSA is equivalent to the amount of bone surface area in the cross-section after excluding soft tissue space and is proportional to conventional bone mineral content in the corresponding cross-section [20-24]. In mechanical terms, CSA is an indicator of resistance to loads directed along the bone axis [20-24]. Section modulus (Z) is an indicator of strength of the bone to resist bending and torsion [20-24]. CSMI (cm^2)^2 is the cross-sectional moment of inertia and is derived from the integral of the bone mass weighed by the square of distance from the center of mass. The CSMI is relevant to bending in the plane of the DXA image [20-24]. Cortical thickness and buckling ratio were not calculated in this study because they are less useful in children and adolescents. All HSA analyses were completed by a single technician at Balamand University. In our laboratory, the coefficients of variation for CSA and Z of the three regions (FN, IT and FS) evaluated by duplicate measurements in 10 adolescents were < 3%.

Daily calcium intake

The estimation of the daily calcium intake was based on a frequency questionnaire [32-33].

The selection of items was based on the food composition diet, frequency of use, and relative importance of food items as a calcium source. A total of 30 food items was selected.

The questionnaire included the following: milk and dairy products, including calcium-enriched items such as yoghurt, cheese and chocolate. Items such as eggs, meat, fish, cereals, bread, vegetables and fruits were also included. Adequacy of calcium in the subjects was assessed using the adequate intake guidelines of 1300 mg of calcium [32].

TABLE I
CLINICAL CHARACTERISTICS and BONE MINERAL DENSITY of the STUDY POPULATION

	Mean ± SD	Range
Age (years)	15.3 ± 2.9	12 - 20
MI (years)	3.6 ± 3.0	1 - 10
Birth weight (kg)	3.25 ± 0.59	2 - 4.5
Weight (kg)	64.5 ± 13.7	38 - 97
Height (cm)	160.8 ± 5.2	152 - 172
BMI (kg/m^2)	24.8 ± 4.6	16.1 - 35.6
Lean mass (kg)	39.4 ± 5.6	29.3 - 53.8
Fat mass (kg)	23.2 ± 8.0	8.9 - 40.2
Fat mass (%)	34.5 ± 6.6	21 - 41.8
WB BMC (g)	1857 ± 279	1436 - 2555
WB BMD (g/cm^2)	1.01 ± 0.08	0.855 - 1.225
DCI (mg/d)	729 ± 270	221 - 1410
TH BMD (g/cm^2)	0.853 ± 0.100	0.687 - 1.124
FN BMD (g/cm^2)	0.799 ± 0.122	0.576 - 1.145

MI: maturation index (years since menarche) **BMI**: body mass index
WB: whole body **BMC**: bone mineral content **BMD**: bone mineral density
DCI: daily calcium intake **TH**: total hip **FN**: femoral neck

Statistical analysis

The means and standard deviations were calculated for all clinical data and for the bone measurements. Associations between clinical and bone data and between birth weight and clinical characteristics were given as Pearson correlation coefficients (for normally distributed variables) or Spearman correlation coefficients (for non-normally distributed variables). Multiple linear regression analysis models were used to test the relationship between HSA variables with body weight and birth weight, and between weight, BMI, lean mass, fat mass and body fat percentage with age and birth weight, and between birth weight with bone mass (BMC/BMD) and HSA variables. Data were analyzed with Number Cruncher Statistical System 2001 (NCSS, Kaysville, UT). A level of significance of $p < 0.05$ was used.

TABLE II
HIP STRUCTURE ANALYSIS VARIABLES of the STUDY POPULATION

	Mean ± SD	Range
FN CSA (cm^2)	2.95 ± 0.62	2.07 - 4.90
FN CSMI $(cm^2)^2$	2.43 ± 0.69	1.48 - 2.28
FN Z (cm^3)	1.42 ± 0.33	0.920 - 2.12
IT CSA (cm^2)	4.24 ± 0.69	3.16 - 5.97
IT CSMI $(cm^2)^2$	9.50 ± 2.20	6.09 - 13.76
IT Z (cm^3)	3.34 ± 0.70	2.32 - 4.76
FS CSA (cm^2)	3.55 ± 0.45	2.81 - 4.59
FS CSMI $(cm^2)^2$	2.60 ± 0.58	1.73 - 3.95
FS Z (cm^3)	1.79 ± 0.29	1.38 - 2.47

FN: femoral neck **IT**: intertrochanteric **FS**: femoral shaft
CSA: cross sectional area **CSMI**: cross sectional moment of inertia
Z: section modulus **SD**: standard deviation

RESULTS

Clinical characteristics and bone mineral density of the subjects

Age, birth weight, anthropometric characteristics, daily calcium intake and BMD of the whole body, the total hip and the femoral neck are displayed in Table I.

HSA variables (CSA, CSMI and Z) of the three sites (FN, IT and FS) are shown in Table II.

Associations between birth weight and anthropometric characteristics

Birth weight was positively correlated to • body weight ($r = 0.62$; $p < 0.001$) • BMI ($r = 0.40$; $p < 0.05$) • lean mass ($r = 0.68$; $p < 0.001$) • fat mass ($r = 0.60$; $p < 0.01$) and • fat mass percentage ($r = 0.36$; $p < 0.05$).

After controlling for age, birth weight remained significantly correlated to body weight, BMI, lean mass, fat mass and fat mass percentage.

TABLE III
CORRELATIONS BETWEEN PHYSICAL CHARACTERISTICS and HIP STRUCTURE ANALYSIS VARIABLES

	FN CSA (cm^2)	FN CSMI $(cm^2)^2$	FN Z (cm^3)	IT CSA (cm^2)	IT CSMI $(cm^2)^2$	IT Z (cm^3)	FS CSA (cm^2)	FS CSMI $(cm^2)^2$	FS Z (cm^3)
Birth weight (kg)	0.63 ***	0.57 **	0.59 **	0.44 *	0.48 *	0.44 *	0.51 **	0.38 *	0.39 *
Weight (kg)	0.84 ***	0.69 ***	0.76 ***	0.83 ***	0.81 ***	0.79 ***	0.71 ***	0.63 ***	0.65 ***
Height (cm)	0.70 ***	0.52 **	0.55 **	0.49 *	0.68 ***	0.53 **	0.65 ***	0.74 ***	0.71 ***
BMI (kg/m^2)	0.59 **	0.56 **	0.63 ***	0.72 ***	0.61 ***	0.66 ***	0.51 **	0.36	0.40 *
Lean mass (kg)	0.82 ***	0.59 **	0.65 ***	0.79 ***	0.86 ***	0.84 ***	0.66 ***	0.57 **	0.61 **
Fat mass (kg)	0.74 ***	0.67 ***	0.71 ***	0.72 ***	0.67 ***	0.66 ***	0.64 ***	0.49 *	0.54 **
Fat mass (%)	0.48 *	0.48 *	0.51 **	0.52 **	0.40 *	0.44 *	0.48 *	0.32	0.38 *

FN: femoral neck **IT**: intertrochanteric **FS**: femoral shaft **CSA**: cross sectional area **CSMI**: cross sectional moment of inertia **Z**: section modulus
BMI: body mass index * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

Associations between birth weight and bone variables

Birth weight was positively correlated to • WB BMC ($r = 0.51$; $p < 0.05$) • WB BMD ($r = 0.51$; $p < 0.05$) • CSA, CSMI and Z of the three sites (FN, IT and FS) (Table III). Birth weight explained 33%, 35% and 30% of FN CSA, FN Z and FS CSA variances respectively (Figures 1-3). After controlling for body weight, birth weight was not correlated to HSA variables. FN CSA was positively correlated to birth weight after controlling for WB BMC or WB BMD. FN CSMI, FN Z, IT CSA, IT CSMI, IT Z, FS CSA, FS CSMI and FS Z were not significantly correlated to birth weight after controlling for WB BMC or WB BMD.

Associations between physical characteristics and HSA variables

Maturation index and DCI were not significantly correlated to HSA variables. Body weight, height, lean mass and fat mass were positively correlated to CSA, CSMI and Z of the three sites (Table III).

DISCUSSION

In the present study, we have demonstrated that birth weight was a positive determinant of hip bone strength indices evaluated by the HSA program in a group of adolescent girls. However, the associations between birth weight and HSA variables disappeared after controlling for body weight which was one of the strongest predictors of HSA variables in the studied population.

Weight at birth was positively associated to body weight, lean mass, fat mass, fat mass percentage and BMI even after controlling for age. These results are in line with those reported by several studies [34-38]. Thus, this study reinforces the hypothesis which states that birth weight is associated with subsequent higher body weight and fat mass values.

Birth weight has been shown to be a positive determinant of whole body, lumbar spine and femoral neck BMC in adults [35-36]. Schlüssel *et al.* [36] reviewed sixteen articles which were aimed at exploring the relation between birth weight and adult bone mass. They underlined that the association of birth weight with bone parameters was much more evident for BMC rather than BMD [36]. In fact, the majority of the studies reviewed by Schlüssel *et al.* [36] reported a positive correlation between birth weight and adult BMC even after adjustment for adult bone size. In contrast, the relation between birth weight and adult BMD seems to disappear after adjustment for adult bone size [36]. A potential explanatory mechanism consists of the fact that prenatal growth sets the growth trajectory and hence predicts bone size (in terms of length and width), which is more strongly related to BMC than BMD [36].

In our study, weight at birth was positively correlated to CSA, CSMI and Z of the FN, IT and FS. This result is clinically important because HSA variables are strongly

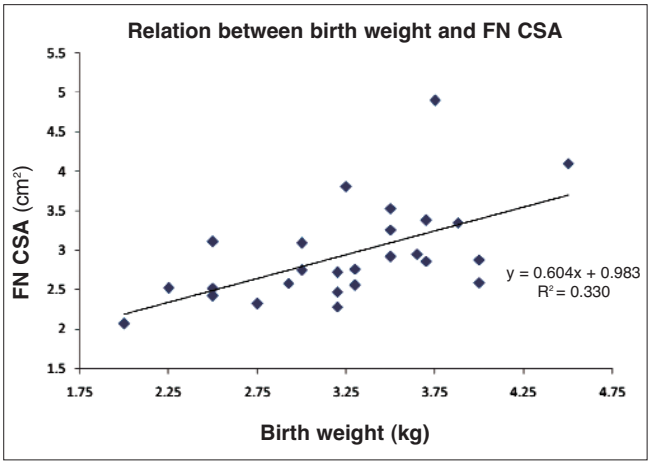

Figure 1
Relation between birth weight and femoral neck cross-sectional area.

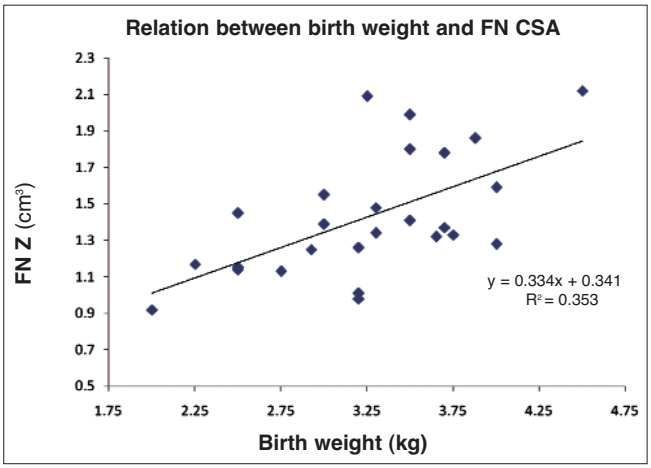

Figure 2
Relation between birth weight and femoral neck section modulus.

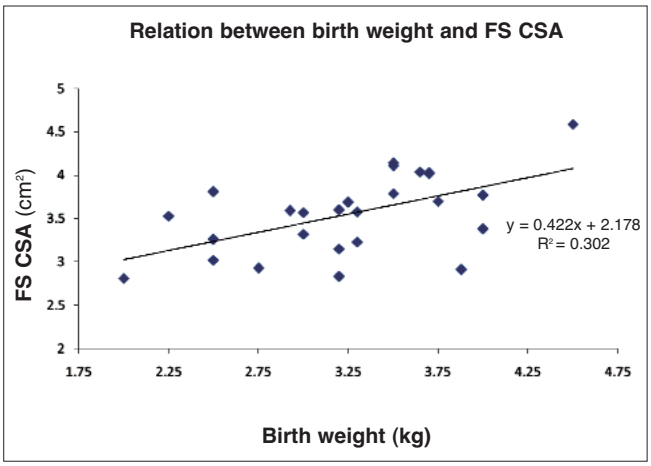

Figure 3
Relation between birth weight and femoral shaft cross-sectional area.

correlated to bone mechanical resistance and are predictors of fracture risk in elderly women [18-25].

We have previously shown that the relation between birth weight and BMD in adolescence may be influenced by gender [34, 37]. This may be explained by the fact that birth weight is a positive determinant of fat mass, which is a positive determinant of BMD in girls but not in boys [39-40].

In our report, body weight, height, lean mass and fat mass were positively correlated to CSA, CSMI and Z of the three sites (FN, IT and FS). In fact, the hip is a weight-bearing site which is strongly influenced by mechanical factors [2, 9].

The lack of correlation between daily calcium intake and HSA variables may be due to the cross-sectional area nature of our study.

Some limitations of this study deserve comment. First, the cross-sectional nature of the study would not allow for proper evaluation of causal relationship between birth weight and hip bone strength. Second, our small sample size may have prevented us from reaching statistical significance for some variables. The third limitation is the two-dimensional nature of DXA [18-19, 29]. Additionally, there are well-known difficulties in assessing diet using self-reported questionnaires [41]. For instance, food-frequency questionnaires provide a limited list of foods and do not allow specific ingredients to be entered for analysis [41]. Furthermore, the hip (including total hip and proximal femur) is not an ideal site for measurement of BMD in growing children due to significant variability in skeletal development and lack of reproducible regions of interest [42]. Finally, one assumption in the HSA algorithm is that bones are fully mineralized, which may not be the case in adolescents [18-19]. The effect of an overestimate of mineralization can influence "true" CSA and Z values [18-19, 43-44]. However, up to our knowledge, it is the first study to assess the relations between birth weight and HSA variables in adolescent girls.

In conclusion, the positive associations between birth weight and hip bone strength indices disappear after controlling for body weight in this group of adolescent girls. Future larger studies are needed to confirm the relations between birth weight and hip structure analysis variables in adolescents and young adults.

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