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Original Article

Geometric indices of hip bone strength in young female football players

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Abstract

Objective: The aim of this study was to compare geometric indices of hip bone strength in female football players and controls. **Methods:** 18 adult female football players and 18 adult sedentary females participated in this study. The two groups were paired for age, weight and body mass index (BMI). Daily calcium intake (DCI) and daily protein intake (DPI) were evaluated by questionnaires. Total hip bone mineral density (BMD) and femoral neck BMD were measured by DXA. Cross-sectional area (CSA), an index of axial compression strength, section modulus (Z), an index of bending strength and cortical thickness (CT) were evaluated at the femoral neck (FN), the intertrochanteric (IT) and the femoral shaft (FS) regions by the hip structure analysis (HSA) program. **Results:** Age, weight, height, BMI, DCI and DPI were not different between the two groups. TH BMD, FN BMD, FN CSA, FN Z, FN CT, IT CSA, IT Z, IT CT, FS CSA and FS Z were significantly higher in football players compared to controls (crude percentage differences between the two groups varied between 8 and 19%; P<0.05). After adjusting for body weight using a one-way analysis of covariance (ANCOVA), TH BMD, FN BMD, FN CSA, FN Z, FN CT, IT CSA, IT Z, IT CT, FS CSA and FS Z remained significantly higher in football players compared to controls (adjusted percentage differences between the two groups varied between 7 and 17%; P<0.05). **Conclusion:** This study suggests that, in adult females, football practice is associated with greater geometric indices of hip bone strength.

Keywords: Mechanical Loading, Peak Bone Mass, Osteoporosis Prevention

Introduction

Peak bone mineral density (BMD) is influenced by several factors such as genetics, ethnicity, hormones, nutrition (protein, calcium and vitamin D intakes), lifestyle factors (sun exposure, sleep duration etc), anthropometrical factors (weight, height and body mass index) and physical activity[1-8]. Weight-bearing physical activity is well-known to stimulate bone formation and thus increase peak BMD[1-14]. For instance, we have recently demonstrated that football practice is associated with an increased BMD at the hip in adults[15]. However, BMD is not a direct measure of bone strength[16-25]. In fact, bone strength is influenced by several factors other than BMD such as macro-architecture[16-25]. In 1990, Beck et al.[17] developed a computer program called hip structure analysis (HSA) to derive hip geometry from bone mineral data for an estimate of hip strength. The HSA program was developed originally to improve the predictive value of hip bone mineral data for osteoporosis fracture risk assessment[17]. Using this program, we have previously shown that body weight is a strong determinant of geometric indices of hip bone strength in adolescent girls and young women[18,24]. The first aim of this study was to investigate the influence of football practice on geometric indices of hip bone strength in adult women. To do so, we have used the HSA program to compare geometric indices of hip bone strength in adult female football players and controls. The second aim of this study was to explore the relationships between sleep, dietary intakes and anthropometric characteristics on the one hand and geometric indices of hip bone strength on the other hand in the whole population.

The author has no conflict of interest.

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Methods

Subjects and study design

18 healthy female Lebanese football players and 18 healthy sedentary (practicing less than 2 h of physical activity per

week and not involved in impact sports) Lebanese females whose ages range from 18 to 30 years participated in this study. The football players were regular participants in national or regional competitions. They had been training in their clubs 4 to 6 times per week, for 6–9 h/week for the past 5 years. All participants were non-smokers and had no history of major orthopaedic problems or other disorders known to affect bone metabolism. Other inclusion criteria included no diagnosis of comorbidities and history of fracture. Moreover, women participating in this study were not pregnant and had not taken hormonal contraceptives for the past 6 months. This study did not include obese (BMI>30 kg/m^2) subjects or extremely lean (BMI<16 kg/m^2) subjects. An informed written consent was obtained from the participants. 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 subjects were weighed wearing only underclothes. Body mass index (BMI) was calculated as body weight divided by height squared (kg/m^2).

Bone mass measurements

Bone mineral density (BMD, in g/cm^2) was determined for each individual by DXA at the total hip (TH) and the femoral neck (FN) (Hologic QDR-4500W; Waltham, MA). In our laboratory, the coefficients of variation were <1% for BMC and BMD[18,22-24]. The same certified technician performed all analyses using the same technique for all measurements.

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.[17]. The HSA technique calculates dimensions of bone cross-sections at specific locations across the proximal femur using bone mass images generated by absorptiometry scanners[17-33]. 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[17-33]. The femoral neck, the intertrochanteric and the femoral shaft regions were analysed in this study. Bone cross-sectional area (CSA; cm^2), cross-sectional moment of inertia (CSMI; (cm^2)^2), section modulus (Z; cm^3), cortical thickness and buckling ratio were determined directly from the bone profile at the femoral neck, the intertrochanteric and the femoral shaft regions using algorithms described previously[17-33]. 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[17-33]. In mechanical terms, CSA is an indicator of resistance to loads directed along the bone axis[17-33]. 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[17-33]. Section modulus (Z) is an indicator of strength of the bone to resist bending and torsion[17-33]. Cortical thickness and buckling ratio were also calculated in this study. BR is an index of susceptibility to local cortical buckling under compressive loads[17-33]. 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 subjects were <3%.

Daily calcium intake

The estimation of the daily calcium intake was based on a frequency questionnaire[34]. Selection of items was based on the food composition diet, frequency of use, and relative importance of food items as a calcium source. The total number of foods was 30 items. The questionnaire included the following food items: 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 1000 mg of calcium[35].

Protein intake

The estimation of the daily protein intake was based on a frequency questionnaire[36].

Sleep duration

The estimation of the sleep duration was evaluated using a self-reported questionnaire[37].

Statistical analysis

The means and standard deviations were calculated for all clinical data and for the bone measurements. Comparisons between the two groups (football players and controls) were made after checking for Gaussian distribution. If Gaussian distribution was found, parametric unpaired t-tests were used. In other cases, Mann-Whitney U tests were used. Associations between physical characteristics and bone data were given as Pearson correlation coefficients. HSA variables were compared between the two groups (football players and controls) after adjustment for weight or height using a one-way analysis of covariance (ANCOVA). Data were analyzed with Number Cruncher Statistical System (NCSS, 2001). A level of significance of P<0.05 was used.

Results

Clinical characteristics and bone data of the study population

Age, weight, height, BMI, daily calcium intake, daily protein intake, sleep duration and bone mineral density are shown in Table 1. Age, weight, height, BMI, height, daily protein intake, and sleep duration were not significantly different between the two groups (Table 1). TH BMD, FN BMD, FN CSA, FN Z, FN CT, IT CSA, IT Z, IT CT, FS CSA and FS Z were significantly higher in football players compared to controls (Tables 1 and 2).

	Football players (n=18)	Sedentary subjects (n=18)	P-value
Age (years)	22.2±3.1	20.7±3.7	0.18
Weight (kg)	60.2±7.8	57.2±9.2	0.29
Height (cm)	162.7±5.7	159.1±5.3	0.06
BMI (kg/m²)	22.7±2.4	22.6±3.3	0.88
DCI (mg/day)	934±329	807±275	0.30
Daily protein intake (g/day)	82.6±31.6	87.0±18.8	0.91
Sleep (h/day)	7.2±1.5	6.5±1.2	0.38
TH BMD (g/cm²)	0.972±0.081	0.846±0.084	0.00006
FN BMD (g/cm²)	0.868±0.095	0.796±0.089	0.02

BMI: Body Mass Index; DCI: Daily Calcium Intake; TH: Total Hip; FN: Femoral Neck; BMD: Bone Mineral Density.

Table 1. Clinical characteristics and hip bone mineral density of the study population.

	Football players (n=18)	Sedentary subjects (n=18)	Percentage group differences	P-value
FN CSA (cm²)	3.12±0.41 [CI: 2.43-3.77]	2.74±0.35 [CI: 2.33-3.48]	12%	0.007
FN CSMI (cm²)²	2.72±0.79 [CI: 1.57-4.33]	2.31±0.64 [CI: 1.49-3.59]	15%	0.07
FN Z (cm³)	1.60±0.31 [CI: 1.14-2.17]	1.36±0.27 [CI: 1.04-1.93]	15%	0.02
FN CT (cm)	0.202±0.020 [CI: 0.164-0.236]	0.177±0.020 [CI: 0.138-0.200]	12%	0.0008
FN BR	8.45±1.43 [CI: 6.40-11.08]	9.57±0.46 [CI: 6.94-14.34]	12%	0.05
IT CSA (cm²)	4.91±0.61 [CI: 3.82-5.67]	3.96±0.55 [CI: 3.22-3.48]	19%	0.00002
IT CSMI (cm²)²	10.27±1.96 [CI: 7.32-12.88]	8.17±1.84 [CI: 6.01-11.97]	19%	0.002
IT Z (cm³)	3.58±0.56 [CI: 2.63-4.24]	2.89±0.58 [CI: 2.15-4.18]	19%	0.001
IT CT (cm)	0.415±0.048 [CI: 0.340-0.478]	0.348±0.050 [CI: 0.280-0.446]	16%	0.0002
IT BR	6.97±1.01 [CI: 5.48-8.56]	8.27±1.48 [CI: 6.04-11.02]	16%	0.004
FS CSA (cm²)	4.03±0.34 [CI: 3.49-4.62]	3.53±0.36 [CI: 2.95-4.31]	12%	0.0001
FS CSMI (cm²)²	3.14±0.63 [CI: 1.99-4.31]	2.46±0.68 [CI: 1.71-4.08]	12%	0.004
FS Z (cm³)	2.09±0.29 [CI: 1.54-2.60]	1.74±0.30 [CI: 1.38-2.41]	17%	0.001
FS CT (cm)	0.558±0.061 [CI: 0.456-0.666]	0.522±0.081 [CI: 0.394-0.644]	6%	0.13
FS BR	2.72±0.45 [CI: 2.00-3.56]	2.77±0.68 [CI: 1.90-4.08]	2%	0.77

FN: Femoral Neck; IT: Intertrochanteric; FS: Femoral shaft; CSA: Cross-Sectional Area; CSMI: Cross-Sectional Moment of Inertia; Z: Section Modulus; CT: Cortical Thickness; BR: Buckling Ratio; CI: 95% Confidence Intervals.

Table 2. Hip structure analysis variables of the study population.

	CSA (cm²)	CSMI (cm²)²	Z (cm³)	CT (cm)	BR
Age (years)	0.06	0.12	0.09	0.06	-0.00
Weight (kg)	0.59***	0.58***	0.60***	0.33*	-0.06
Height (cm)	0.44**	0.43**	0.43**	0.26	0.05
BMI (kg/m²)	0.42**	0.42*	0.44**	0.23	-0.11
DCI (mg/day)	0.15	0.02	0.10	0.21	-0.24
DPI (g/day)	-0.39	-0.28	-0.33	-0.44	0.27
Sleep (h/day)	-0.09	-0.02	-0.09	-0.12	0.08

*BMI: Body Mass Index; DCI: Daily Calcium Intake; DPI: Daily Protein Intake; CSA: Cross-Sectional Area; CSMI: Cross-Sectional Moment of Inertia; Z: Section Modulus; CT: Cortical Thickness; BR: Buckling Ratio; ***P<0.001; **P<0.01; *P<0.05.*

Table 3. Correlations between clinical characteristics and geometric indices of narrow-neck bone strength.

	CSA (cm²)	CSMI (cm²)²	Z (cm³)	CT (cm)	BR
Age (years)	0.07	0.00	-0.04	-0.05	0.07
Weight (kg)	0.48**	0.66***	0.61***	0.18	-0.05
Height (cm)	0.37*	0.53***	0.43**	0.26	0.05
BMI (kg/m²)	0.34*	0.45**	0.47**	0.18	-0.15
DCI (mg/day)	0.14	0.08	0.08	0.16	-0.20
DPI (g/day)	-0.48*	-0.43	-0.49*	-0.37	0.30
Sleep (h/day)	-0.02	-0.12	-0.09	-0.01	-0.04

*BMI: Body Mass Index; DCI: Daily Calcium Intake; DPI: Daily Protein Intake; CSA: Cross-Sectional Area; CSMI: Cross-Sectional Moment of Inertia; Z: Section Modulus; CT: Cortical Thickness; BR: Buckling Ratio; ***P<0.001; **P<0.01; *P<0.05.*

Table 4. Correlations between clinical characteristics and geometric indices of intertrochanteric bone strength.

	CSA (cm²)	CSMI (cm²)²	Z (cm³)	CT (cm)	BR
Age (years)	0.01	0.16	0.10	-0.18	0.26
Weight (kg)	0.38*	0.53***	0.53***	-0.11	0.26
Height (cm)	0.38*	0.61***	0.58***	-0.22	0.40*
BMI (kg/m²)	0.21	0.25	0.26	-0.00	0.07
DCI (mg/day)	0.05	-0.05	-0.04	0.18	-0.19
DPI (g/day)	-0.38	-0.39	-0.43	-0.02	-0.14
Sleep (h/day)	0.04	0.02	0.02	0.02	-0.00

*BMI: Body Mass Index; DCI: Daily Calcium Intake; DPI: Daily Protein Intake; CSA: Cross-Sectional Area; CSMI: Cross-Sectional Moment of Inertia; Z: Section Modulus; CT: Cortical Thickness; BR: Buckling Ratio; ***P<0.001; **P<0.01; *P<0.05.*

Table 5. Correlations between clinical characteristics and geometric indices of femoral shaft bone strength.

Correlations between clinical characteristics and bone data

Age, daily calcium intake and sleep duration were not correlated to bone data (Tables 3-5). Weight and height were positively correlated to CSA and Z of the three regions (FN, IT and FS). BMI was positively correlated to CSA and Z of the FN and the IT (Tables 3-5).

Adjusted HSA variables

After adjusting for weight, TH BMD, FN BMD, FN CSA, FN Z, FN CT, IT CSA, IT Z, IT CT, FS CSA and FS Z remained significantly higher in football players compared to controls (P<0.05). After adjusting for height, TH BMD, FN BMD, FN CSA, FN Z, FN CT, IT CSA, IT Z, IT CT, FS CSA and FS Z remained significantly higher in football players compared to controls (P<0.05).

Discussion

The main finding of this study was that football players had greater indices of hip bone strength compared to controls.

Total hip BMD and femoral neck BMD were higher in football players compared to controls.

Cross-sectional area at all regions (FN, IT and the FS) was higher in football players compared to controls. Section modulus at all regions (FN, IT and the FS) was also higher in football players compared to controls. Cortical thickness at the femoral neck and the intertrochanteric regions was higher in football players compared to controls. Our results confirm the results of previous studies which showed that football players have higher BMD and geometric indices of hip bone strength compared to controls[3-15]. In fact, the hip is a weight-bearing site which is strongly influenced by mechanical loading[1,2,21]. Football is a high impact sport since it involves jumping, running, and kicking[3-15]. In fact, football is considered to be an odd-impact loading modality (high intensity, including accelerating and decelerating movements, often loading the lower body and hip regions in directions not apparent in usual daily activities)[3-15]. Our results suggest a positive effect of football practice during adolescence and adulthood on peak BMD and geometric indices of hip bone strength.

Intertrochanteric buckling ratio was lower in soccer players compared to controls. BR is a geometric configuration that describes threshold behavior beyond which strength may be compromised under compressive loads[28,29]. BR values are elevated in osteoporotic subjects and are positively associated with the incidence of hip fractures[28,29]. Thus, our results suggest that football practice during adolescence and adulthood may protect against hip fractures later in life.

Body weight was the strongest predictor of geometric indices of femoral neck bone strength. This result is in line with those of our previous studies conducted on adolescents and young adults[18,24]. In fact, low body weight and BMI are associated with an increased risk of hip fracture while obesity is associated with a decreased risk of hip fracture[30,31].

Protein intake and daily calcium intake were not positively correlated to HSA variables despite the fact that these nutriments enhance bone acquisition during adolescence and are necessary for bone health[38,39]. The lack of positive correlation in our study may be explained by the low number of subjects and the cross-sectional nature of the study.

Sleep duration was not correlated to HSA variables. Our results are in contrast with those of several studies[40-43]. In fact, it has been shown that sleep deprivation has a detrimental effect on bone mass and bone strength[40-43]. The mechanisms by which sleep deprivation may affect bone mass have been previously reported[44]. Further studies are necessary to understand the interactions between sleep, physical activity status and bone strength variables in young adults.

Our study had some limitations. The cross-sectional nature of this study is a limitation since it cannot evaluate the confounding variables. The second limitation is the two-dimensional nature of DXA[33]. The third limitation is the relatively small number of subjects in each group. However, up to our knowledge, it is one of few studies that aimed at exploring the effects of football practice on hip geometry in adult females.

In conclusion, this study suggests that in adult women, football practice is associated with greater geometric indices of hip bone strength. Since hip bone strength is directly related to these geometric parameters, it is suggested that football practice in adolescence and adulthood may reduce osteoporotic fractures at the hip later in life.

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