**ABSTRACT • Aim of the study**: The aim of this study was to compare geometric indices of hip bone strength in male professional soccer players and controls. **Methods**: Twenty-three male professional soccer players and 21 male sedentary subjects whose ages range between 18 and 30 years participated in this study. Weight and height were measured, and body mass index (BMI) was calculated. Daily calcium intake and physical activity were evaluated using validated questionnaires. Hip bone mineral density was measured by dual-energy X-ray absorptiometry (DXA). To evaluate hip bone geometry, DXA scans were analyzed at the narrow-neck (NN), 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, section modulus (Z), an index of bending strength, cortical thickness (CT) and buckling ratio (BR) were measured from bone mass profiles. **Results**: CSA, CSMI, Z and CT of the three regions (NN, IT and FS) were higher in soccer players compared to controls. After adjustment for either age, body weight, height or physical activity duration (h/week), CSA, CSMI, Z and CT of the three regions remained higher in soccer players compared to controls. **Conclusion**: This study suggests that, in young adult males, soccer practice is associated with greater axial strength, bending strength and structural rigidity indices at the hip.

Keywords: peak bone mass; physical activity; proximal femur

**INTRODUCTION**

Osteoporosis is characterized by low bone mineral density (BMD) with microarchitectural deteriorations, which leads to an increased risk of fractures [1]. Although osteoporosis is known to mainly affect postmenopausal women, there is enough evidence to support substantial bone loss with aging in men as well [1]. It has been shown that peak bone mass attained at the third decade may be the single most important factor for the prevention of osteoporosis later in life [2]. Peak bone mass is influenced by several factors such as genetic factors, endocrine factors, nutritional factors and mechanical factors [1]. Physical activities that include sprints and jumps seem to have a positive effect on BMD [1-5]. For instance, soccer practice has been shown to increase bone mass and BMD in adolescents and adults [3-14]. Although BMD is a predictor of fracture, bone strength and bone geometry are not captured by the measurement. Interestingly, Beck et al. [15] developed a computer program to derive hip geometry from bone mineral data for an estimate of hip strength. Later, many researchers used this program to explore the influence of physical activity and obesity on bone strength and geometry [16-23]. However, little is known concerning the influence of soccer practice on hip geometry in adults. The aim of this study was to compare geometric indices of hip bone strength in male professional soccer players and controls. We hypothesized that professional soccer players should have higher axial and compression strength at the...
Cross-sectional moment of inertia (CSMI; (cm²)²), section modulus (Z; cm³), cortical thickness and buckling ratio (BR) were determined directly from the bone profile at the narrow-neck, the intertrochanteric and the femoral shaft regions using algorithms described previously [15]. 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 [24]. In mechanical terms, CSA is an indicator of resistance to loads directed along the bone axis [24]. Section modulus is an indicator of mechanical behavior [3, 8, 17-18].

### Methods

#### Subjects

Twenty-three professional soccer players and twenty-one sedentary men (not involved in impact sports) aged between 18 and 30 years participated in this study. The soccer 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. The participants were nonsmokers 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. This study did not include obese (body mass index/BMI > 30 kg/m²) subjects or extremely lean (BMI < 16 kg/m²) 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 sensitivity of 100 g. The subjects were weighed wearing only underclothes. BMI was calculated as body weight divided by height squared (kg/m²).

#### Bone Mineral Density Measurements

Bone mineral content (BMC, in g) and bone mineral density (BMD, in g/cm²) were determined for each individual by dual-energy X-ray absorptiometry (DXA, Hologic QDR-4500W; Waltham, MA) at the total hip (TH) and the femoral neck (FN). Daily quality control scans were performed with the manufacturer’s phantom. The same certified technician performed all analyses using the same technique for all measurements. In our center, the coefficients of variation for hip BMD were < 1% [19-21].

#### Hip Structure Analysis

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. [15]. The HSA technique calculates dimensions of bone cross-sections at specific locations across the proximal femur using bone mass images generated by absorptiometry scanners [15]. 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 [15]. The narrow-neck, the intertrochanteric and the femoral shaft regions were analyzed in this study. Bone cross-sectional area (CSA; cm²), cross-sectional moment of inertia (CSMI; (cm²)²), section modulus (Z; cm³), cortical thickness and buckling ratio (BR) were determined directly from the bone profile at the narrow-neck, the intertrochanteric and the femoral shaft regions using algorithms described previously [15]. 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 [24]. In mechanical terms, CSA is an indicator of resistance to loads directed along the bone axis [24]. Section modulus is an indicator of mechanical behavior [3, 8, 17-18].
strength of the bone to resist bending and torsion [24].

CSMI (cm$^2$) 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 [24]. Cortical thickness and buckling ratio were
also calculated in this study. BR is an index of suscepti-

bility to local cortical buckling under compressive loads
[24-25]. 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 (NN, IT and FS) evaluated by duplicate mea-
surements in 10 subjects were < 3%.

Daily calcium intake
The estimation of the daily calcium intake (DCI) was
based on a frequency questionnaire [26]. Selection of
items was based on the food composition diet, frequen-
cy of use, and relative importance of food items as a cal-
cium source. The total number of foods was 30 items.
The questionnaire included the following [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
1,300 mg of calcium [27].

Statistical analysis
The means and standard deviations or standard errors
were calculated for all clinical data and for the bone mea-
surements. Comparisons between the two groups (soccer
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. Multiple linear regres-
sion analysis models were used to test the relationship
between bone variables with age, weight and physical
activity. Bone variables were compared between the two
groups after adjustment for total body weight, height,
physical activity and age using a one-way analysis of
covariance. 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, physi-
cal activity (h/week), and hip BMD are shown in table I.
Age, weight, height, physical activity, TH BMD and
FN BMD were higher in soccer players compared to
controls ($p < 0.05$). BMI and daily calcium intake were
not significantly different between the two groups
(Table I).

Hip structure analysis variables of the study population
CSA, CSMI, Z, CT and BR of the NN, the IT and the FS
regions are shown in table II. CSA, CSMI, Z and CT of
the three regions were higher in soccer players compared
to controls ($p < 0.05$). BR of the three regions was lower
in soccer players compared to controls ($p < 0.05$).

Correlations between clinical characteristics and hip
structure analysis variables of the study population
Age was positively correlated to Z of the three regions.
Weight and physical activity were positively correlated
to CSA, Z and CT of the three regions (Tables III-V).

Multiple linear regression analysis models
Body weight was a stronger determinant of CSA and Z
of the three regions (NN, IT and FS) than age and physi-

cal activity (Table VI). Physical activity remained posi-
tively correlated to CSA and Z of the narrow-neck after
controlling for age and body weight.

Adjusted hip structure analysis variables
After adjusting for either weight, height, physical activity
or age, CSA, CSMI, Z and CT of the three regions
(NN, IT and FS) remained higher in soccer players com-
pared to controls ($p < 0.05$) (Table VII).

---

### TABLE III

<table>
<thead>
<tr>
<th>CORRELATIONS between CLINICAL CHARACTERISTICS  and GEOMETRIC INDICES of NARROW-NECK BONE STRENGTH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CSA</strong> (cm$^2$)</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>Height (cm)</td>
</tr>
<tr>
<td>Body mass index (kg/m$^2$)</td>
</tr>
<tr>
<td>Daily calcium intake (mg/d)</td>
</tr>
<tr>
<td>Physical activity (h/week)</td>
</tr>
</tbody>
</table>

CSA: cross sectional area  
CSMI: cross sectional moment of inertia  
Z: section modulus  
CT: cortical thickness  
BR: buckling ratio
TABLE IV
CORRELATIONS between CLINICAL CHARACTERISTICS and GEOMETRIC INDICES of INTERTROCHANTERIC BONE STRENGTH

<table>
<thead>
<tr>
<th></th>
<th>CSA (cm²)</th>
<th>CSMI (cm²)²</th>
<th>Z (cm³)</th>
<th>CT (cm)</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>0.29 *</td>
<td>0.35 *</td>
<td>0.31 *</td>
<td>0.22</td>
<td>−0.18</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>0.39 *</td>
<td>0.40 **</td>
<td>0.37 *</td>
<td>0.31</td>
<td>−0.16</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.27</td>
<td>0.36 *</td>
<td>0.30 *</td>
<td>0.22</td>
<td>−0.07</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>0.28</td>
<td>0.22</td>
<td>0.23</td>
<td>0.22</td>
<td>−0.14</td>
</tr>
<tr>
<td>Daily calcium intake (mg/d)</td>
<td>−0.04</td>
<td>−0.04</td>
<td>−0.06</td>
<td>−0.10</td>
<td>0.03</td>
</tr>
<tr>
<td>Physical activity (h/week)</td>
<td>0.39 *</td>
<td>0.41 *</td>
<td>0.41 *</td>
<td>0.33 *</td>
<td>−0.07</td>
</tr>
</tbody>
</table>

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 V
CORRELATIONS between CLINICAL CHARACTERISTICS and GEOMETRIC INDICES of FEMORAL SHAFT BONE STRENGTH

<table>
<thead>
<tr>
<th></th>
<th>CSA (cm²)</th>
<th>CSMI (cm²)²</th>
<th>Z (cm³)</th>
<th>CT (cm)</th>
<th>BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>0.46 *</td>
<td>0.34 *</td>
<td>0.41 **</td>
<td>0.42 **</td>
<td>−0.37 *</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>0.57 ***</td>
<td>0.68 ***</td>
<td>0.67 ***</td>
<td>0.26</td>
<td>−0.08</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>0.57 ***</td>
<td>0.57 ***</td>
<td>0.52 ***</td>
<td>0.07</td>
<td>0.03</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>0.44 *</td>
<td>0.47 **</td>
<td>0.48 ***</td>
<td>0.25</td>
<td>−0.10</td>
</tr>
<tr>
<td>Daily calcium intake (mg/d)</td>
<td>−0.18</td>
<td>−0.22</td>
<td>−0.22</td>
<td>−0.21</td>
<td>0.06</td>
</tr>
<tr>
<td>Physical activity (h/week)</td>
<td>0.43 *</td>
<td>0.29</td>
<td>0.37 *</td>
<td>0.40 *</td>
<td>−0.41 *</td>
</tr>
</tbody>
</table>

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 VII
GEOMETRIC INDICES of HIP BONE STRENGTH ADJUSTED for BODY WEIGHT, PHYSICAL ACTIVITY and AGE in the TWO GROUPS

<table>
<thead>
<tr>
<th></th>
<th>ADJUSTED FOR BODY WEIGHT</th>
<th>ADJUSTED FOR PHYSICAL ACTIVITY</th>
<th>ADJUSTED FOR AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soccer players (n = 23)</td>
<td>Sedentary subjects (n = 21)</td>
<td>Soccer players (n = 23)</td>
</tr>
<tr>
<td>NN CSA (cm²)</td>
<td>4.35 ± 0.12 ***</td>
<td>3.66 ± 0.12</td>
<td>4.55 ± 0.15 ***</td>
</tr>
<tr>
<td>NN CSMI (cm²)²</td>
<td>4.79 ± 0.17 ***</td>
<td>3.71 ± 0.18</td>
<td>5.02 ± 0.21 **</td>
</tr>
<tr>
<td>NN Z (cm³)</td>
<td>2.56 ± 0.07 ***</td>
<td>2.04 ± 0.08</td>
<td>2.69 ± 0.09 **</td>
</tr>
<tr>
<td>NN CT (cm)</td>
<td>0.247 ± 0.007 *</td>
<td>0.216 ± 0.008</td>
<td>0.262 ± 0.009 **</td>
</tr>
<tr>
<td>NN BR</td>
<td>7.64 ± 0.32 *</td>
<td>8.71 ± 0.33</td>
<td>7.27 ± 0.41</td>
</tr>
<tr>
<td>IT CSA (cm²)</td>
<td>6.52 ± 0.21 **</td>
<td>5.64 ± 0.21</td>
<td>7.00 ± 0.28 *</td>
</tr>
<tr>
<td>IT CSMI (cm²)²</td>
<td>15.85 ± 0.59 *</td>
<td>13.56 ± 0.60</td>
<td>17.30 ± 0.80 *</td>
</tr>
<tr>
<td>IT Z (cm³)</td>
<td>5.23 ± 0.17 **</td>
<td>4.43 ± 0.18</td>
<td>5.61 ± 0.24 *</td>
</tr>
<tr>
<td>IT CT (cm)</td>
<td>0.523 ± 0.018 **</td>
<td>0.448 ± 0.018</td>
<td>0.547 ± 0.02 *</td>
</tr>
<tr>
<td>IT BR</td>
<td>5.94 ± 0.29 *</td>
<td>7.09 ± 0.29</td>
<td>5.97 ± 0.36</td>
</tr>
<tr>
<td>FS CSA (cm²)</td>
<td>5.57 ± 0.14 ***</td>
<td>4.68 ± 0.15</td>
<td>5.86 ± 0.19 **</td>
</tr>
<tr>
<td>FS CSMI (cm²)²</td>
<td>4.81 ± 0.08 *</td>
<td>4.24 ± 0.18</td>
<td>5.42 ± 0.27 *</td>
</tr>
<tr>
<td>FS Z (cm³)</td>
<td>2.99 ± 0.08 **</td>
<td>2.60 ± 0.08</td>
<td>3.26 ± 0.12 *</td>
</tr>
<tr>
<td>FS CT (cm)</td>
<td>0.799 ± 0.003 ***</td>
<td>0.607 ± 0.003</td>
<td>0.823 ± 0.003 **</td>
</tr>
<tr>
<td>FS BR</td>
<td>2.11 ± 0.12 **</td>
<td>2.75 ± 0.13</td>
<td>2.21 ± 0.15</td>
</tr>
</tbody>
</table>

NN: narrow-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  *** p < 0.001  ** p < 0.01  * p < 0.05.
The main finding of this study was that axial strength, bending strength and structural rigidity indices at the hip are higher in professional soccer players compared to controls. These differences remained significant after adjustment for body weight.

Total hip BMD and femoral neck BMD were higher in soccer players compared to controls. These results are in line with those of several previous studies [19, 22-23]. 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 [29]. Furthermore, it has been shown that lean mass is a stronger predictor of geometric indices of hip bone strength than fat mass [23, 30-31].

Physical activity (h/week) was positively correlated to CSA, Z and CT of the three regions. In fact, the hip is a weight-bearing site which is strongly influenced by physical activity [2, 8]. The positive influence of physical activity on hip geometry has been well documented [8, 16-18]. There is some evidence to suggest that the positive effects of exercise on bone strength are not detected by bone mass measurements [9, 16]. For instance, Haapasalo et al. [9] have shown significant increases in the bending strength of the arm of tennis players without any increase in its volumetric BMD.

Daily calcium intake was not correlated to HSA variables in our study. The lack of correlation between DCI and bone variables may be due to the cross-sectional nature of the study.

Our study had some limitations. The cross-sectional nature of this study is a limitation because it cannot evaluate the confounding variables. The second limitation is the relatively small number of subjects in each group. The third limitation is the two-dimensional nature of DXA [32]. However, up to our knowledge, it’s one of few studies that aimed at exploring the influence of soccer practice on geometric indices of hip bone strength in young men.

In conclusion, this study suggests that soccer practice is associated with increased axial strength, bending strength and structural rigidity at the hip in young men. Thus, it is suggested that soccer practice during adulthood may prevent osteoporosis at the hip later in life.

DISCUSSION

The main finding of this study was that axial strength, bending strength and structural rigidity indices at the hip are higher in professional soccer players compared to controls. These differences remained significant after adjustment for body weight.

Total hip BMD and femoral neck BMD were higher in soccer players compared to controls. These results are in line with those of several studies and can confirm the positive effect of soccer practice on hip BMD [8, 10, 13].

CSA, CSMI, Z and CT values were higher in soccer players compared to controls. These results are in line with those of several studies and can confirm the positive effect of soccer practice on geometric indices of hip bone strength [8, 10, 13].

In conclusion, this study suggests that soccer practice is associated with increased axial strength, bending strength and structural rigidity at the hip in young men. Thus, it is suggested that soccer practice during adulthood may prevent osteoporosis at the hip later in life.

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CONFLICTS OF INTEREST: None to declare.
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