Osteoporosis is a systemic skeletal condition characterized by low bone mineral density (BMD) and micro-architectural deterioration of bone tissue, leading to decreased bone strength and increased risk of fragility fractures [1]. Although osteoporosis is generally considered to affect mainly post-menopausal women, there is enough evidence to support substantial bone loss with ageing in men [1-10].

Factors contributing to BMD variance include genetics, race, gender, BMI, diet (e.g., calcium and vitamin D intake), physical activity (e.g. impact sports) and lifestyle variables. Lean mass, body weight, fat mass and height related to a lower fracture risk, whereas body mass index (BMI) > 25 kg/m² was associated with an increased risk of fracture [19].

CONCLUSION: This study suggests that overweight elderly men have greater indices of bone axial and bending strength in comparison to controls at the intertrochanteric and the femoral shaft.

Keywords: ageing, body mass index, body weight, hip structure.

INTRODUCTION

Osteoporosis is a systemic skeletal condition characterized by low bone mineral density (BMD) and micro-architectural deterioration of bone tissue, leading to decreased bone strength and increased risk of fragility fractures [1]. Although osteoporosis is generally considered to affect mainly post-menopausal women, there is enough evidence to support substantial bone loss with ageing in men [1-10].

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Sixteen overweight (body mass index > 25 kg/m²) and 38 control (body mass index < 25 kg/m²) elderly men (aged 65-84 years) participated in the study. The men were randomly selected from the Greater Beirut area with an estimated resident population around one million (a mixture of the various Lebanese communities) [7].

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 scales with a precision of 100 g. The men were weighed wearing only underclothes. Body mass index (BMI) was calculated as body weight divided by height squared (kg/m²). Body composition (lean mass, fat mass, body fat percentage) was assessed by DXA (Hologic QDR-4500W; Waltham, MA).

Bone mass measurements
Bone mineral content (BMC, in g) and density (BMD, in g/cm²) were determined for each individual. DXA measurements were completed for the whole body (WB), the total hip and the femoral neck. The coefficients of variation were < 1.5% for BMC and BMD [26-28, 34]. 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 femoral neck, the intertrochanteric and the femoral shaft regions were analyzed in this study. Bone cross-sectional area (CSA; cm²) and section modulus (Z; cm³) were determined directly from the bone profile at the intertrochanteric and the femoral shaft regions using algorithms described previously [18-25]. In mechanical terms, CSA is an indicator of resistance to loads directed along the bone axis [18-25]. Section modulus (Z) is an indicator of strength of the bone to resist bending and torsion [18-25]. CSMI (cm³)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 [18-25]. Cortical thickness and buckling ratio were also calculated in this study.

All HSA analyses were completed by a single technician at Balamand University.

Statistical analysis
The means and SDs were calculated for all clinical data and bone measurements. Associations between clinical and bone data were given as Pearson correlation coefficients. Comparisons between overweight and control groups 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. HSA variables of the groups (overweight and normal weight) were compared after adjustment for total body weight, lean mass, height, BMI and age 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 BMD of the study population
Age, anthropometric characteristics (weight, height, BMI, lean mass, fat mass and fat mass percentage) and BMD of the total hip and the femoral neck are displayed in Table I. Weight, height, BMI, lean mass, fat mass, TH BMD and FN BMD were higher in overweight men compared to controls (p < 0.05).

Crude HSA variables of the study population
CSA, CSMI, Z, CT and BR of the FN, the IT and the FS are displayed in Table II. CSA and Z of the three sites were higher in overweight men compared to controls (p < 0.05).

Correlations between clinical characteristics and HSA variables of the study population
Weight, height, BMI and lean mass were positively correlated to CSA, CSMI, Z and CT of the three sites (Table III). Figure 1 shows the relation between body weight and FS Z. Figure 2 shows the relation between BMI and femoral shaft section modulus.

Adjusted HSA variables of the study population
Overweight men displayed higher IT and FS CSA, CSMI and Z values in comparison to controls after adjusting for age (p < 0.05). After adjusting for either body weight, BMI or lean mass, there were no differences between the two groups regarding HSA variables. After adjusting for height, overweight men displayed higher NN CT, IT CSA and IT CT values compared to controls while NN and IT BR values were lower in overweight men compared to controls.

DISCUSSION

This study conducted on 16 overweight elderly men and 38 controls shows that being overweight is associated with greater hip bone strength indices in overweight elderly men. Moreover, these differences between the two groups disappeared after controlling for body weight, BMI or lean mass. Thus, this study suggests that hip bone strength is adapted to the increased body weight in overweight elderly men.

In our study, body weight, lean mass and fat mass were higher in overweight men compared to controls. Lean mass and body weight were strong determinants of bone strength indices in our study. Moreover, increased fat mass may influence bone tissue by several mechanisms. First, increased fat mass augments

### TABLE I

| Clinical characteristics and Proximal Femur BMD of the Study Population |
|------------------------|------------------------|
| **Overweight** (n = 16) | **Controls** (n = 38) |
| Age (years) | 72.6 ± 6.9 | 75.5 ± 4.8 |
| Weight (kg) | 87.1 ± 9.5*** | 68.8 ± 10.4 |
| Height (m) | 1.67 ± 0.06* | 1.64 ± 0.05 |
| BMI (kg/m²) | 27.7 ± 2.7*** | 21.0 ± 2.8 |
| Lean mass (kg) | 58.53 ± 4.07*** | 47.94 ± 6.04 |
| Fat mass (kg) | 25.38 ± 4.20*** | 17.62 ± 5.51 |
| Fat mass (%) | 29.3 ± 4.0 | 25.8 ± 5.8 |
| TH BMD (g/cm²) | 0.920 ± 0.130** | 0.800 ± 0.134 |
| FN BMD (g/cm²) | 0.756 ± 0.129** | 0.655 ± 0.112 |

BMI: body mass index, TH: total hip, FN: femoral neck
***p < 0.001 **p < 0.01 *p < 0.05

### TABLE II

| Crude Hip Structure Analysis Variables of the Study Population |
|----------------------|----------------------|
| **Overweight** (n = 16) | **Controls** (n = 38) |
| FN CSA (cm²) | 2.89 ± 0.53* | 2.56 ± 0.50 |
| FN CSMI (cm²)² | 3.42 ± 1.03 | 3.03 ± 0.81 |
| FN Z (cm³) | 1.69 ± 0.44* | 1.48 ± 0.34 |
| FN CT (cm) | 0.159 ± 0.029* | 0.141 ± 0.026 |
| FN BR | 13.1 ± 3.3 | 14.8 ± 2.6 |
| IT CSA (cm²) | 5.06 ± 0.98** | 4.23 ± 0.84 |
| IT CSMI (cm²)² | 14.61 ± 4.10** | 11.85 ± 2.97 |
| IT Z (cm³) | 4.58 ± 1.04** | 3.73 ± 0.87 |
| IT CT (cm) | 0.369 ± 0.074* | 0.315 ± 0.069 |
| IT BR | 8.8 ± 1.7* | 10.5 ± 2.2 |
| FS CSA (cm²) | 5.07 ± 0.81** | 4.45 ± 0.71 |
| FS CSMI (cm²)² | 5.36 ± 1.26** | 4.48 ± 0.85 |
| FS Z (cm³) | 3.17 ± 0.57** | 2.72 ± 0.43 |
| FS CT (cm) | 0.611 ± 0.123 | 0.546 ± 0.123 |
| FS BR | 3.4 ± 2.1 | 3.1 ± 0.9 |

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
*p < 0.05 **p < 0.01
mechanical loading on the skeleton [33]. Second, increased fat mass is associated with higher insulin, leptin, amylin and preptin circulating levels and lower adiponectin circulating levels [32-33]. Insulin, leptin, amylin and preptin have peripheral osteogenic effects through direct osteoblast stimulation or osteoclast inhibition while adiponectin promotes the osteoblast production of RANKL and inhibits osteoprotegerin (OPG) production and is negatively correlated to BMD in adults [32-33].

Third, free testosterone levels are attenuated in overweight and obese men [32-33]. However, free testosterone levels are positively correlated to BMD in men [42-46]. Despite this, overweight men displayed greater crude hip bone strength indices compared to controls in our study. Besides, with ageing, there is a process of fat redistribution in which bone marrow is infiltrated by newly formed fat [47-49]. Bone marrow fat is negatively correlated to bone mass in elderly [47-49]. In fact, high levels of peroxisome proliferator-activated receptors γ (PPARγ) within the bone marrow decrease bone formation, increase bone resorption and induce a predominant differentiation of mesenchymal stem cells into adipocytes [47-49]. Another potential mechanism for fat is its effect as absorber of environmental toxins thus protecting other tissues from their harmful effect [50-52]. A larger fat mass leads to a lower circulation of environmental toxins thus reducing their negative impact on bone during bone formation years [50-52]. Overall, the relation between fat mass and bone mass seems to be influenced by age, gender and exercise status [31-33, 53-54]. For instance, fat mass excess is a risk factor for fracture in pre-pubertal children but is protective against fracture in elderly [48].

In our study, overweight men displayed higher intertrochanteric and femoral shaft CSA, CSMI and Z values in comparison to control men after adjusting for age. These differences disappeared after controlling for body weight, BMI and lean mass which were the strongest predictors of hip bone strength indices in our study. Thus, this study suggests that hip bone strength indices adapt properly to the increased body weight and lean mass in the overweight elderly men.

Our study had some limitations. First, the cross-sectional nature of the study would not allow for proper evaluation of a causal mechanical relationship between weight and hip strength variables. Second, our small sample size may have prevented us from reaching statistical significance for some variables. Third, we did not assess endocrine factors which are well-known to have an impact on BMD in normal weight and overweight elderly men such as growth hormone (GH), insulin-like growth factor 1 (IGF-1), testosterone, estrogen, sex hormone-binding globulin (SHBG) and dehydroepiandrosterone (DHEA). Fourth, we also did not assess other determinants of BMC and BMD such as physical activity, daily calcium intake, protein intake and vitamin D status. Finally, subcutaneous and visceral fat may have different effects on bone structure and strength while DXA cannot distinguish between subcutaneous and visceral fat, or between subcutaneous and intramuscular peripheral fat [55-56]. Nevertheless, up to our knowledge, it is one of few studies to explore the effect of being overweight on hip strength indices in elderly men.

CONCLUSION

Our study suggests that overweight elderly men have greater indices of bone axial and bending strength in comparison to normal weight elderly men at the inter-
trochanteric region and the femoral shaft. Since lean mass was a strong predictor of geometric indices of hip bone strength in the whole population, implementing strategies to increase lean mass may be necessary in elderly men to prevent hip fractures.

CONFLICTS OF INTEREST: The authors state that they have no conflicts of interest.

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