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Original Article

Bone Mineral Density and Body Composition in Underweight and Normal Elderly Subjects

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Abstract. The importance of malnutrition as a risk factor in osteoporosis is emphasized by the evidence that patients with fractures of the proximal femur are often undernourished. In this study, nutritional status, bone mineral mass and its association with body composition were investigated in underweight and normal weight elderly subjects. Moreover the hypothesis that malnutrition in elderly is associated with a higher risk of osteoporosis was tested. The participants were 111 elderly subjects divided into two groups according to body mass index (BMI): 51 patients were underweight (BMI < 22 kg/m^2) while in 60 subjects BMI ranged from 22 to 30 kg/m^2. In all patients anthropometric parameters and blood indices of malnutrition and of bone turnover were measured. Fat-free soft mass (FFSM), fat mass (FM), bone mineral content (BMC) and bone mineral density (BMD) 'total body' and at the hip were obtained by dual-energy X-ray densitometry. Dietary intake was evaluated with the diet history method, while resting energy expenditure (REE) was measured by indirect calorimetry. Underweight subjects had other signs of malnutrition, such as low visceral proteins, sarcopenia, and an inadequate energy intake. Moreover they showed a significant reduction of BMC and BMD compared with normal subjects. In men with BMI <22 kg/m^2, T-score was below −2.5 (−3 at femoral neck and −2.7 at total hip) while men in the control group had normal bone mineral parameters. *T*-score at different sites was lower in underweight women than in underweight men, always showing values under −3.5, with clear osteoporosis and a high fracture risk. In healthy women the *T*-score values indicated the presence of mild osteoporosis. In underweight subjects, low levels of albumin (< 35 g/l) were associated with higher femoral bone loss. Using a partial correlation model, BMC, adjusted for age, bone area, knee height and albumin showed a significant association with FM in women ($r = 0.48$; $p < 0.01$) and with FFSM in men ($r = 0.48$; $p < 0.05$). Albumin, when adjusted for other variables, was significantly correlated ($r = 0.52$; $p < 0.05$) with femoral neck BMC only in women. In conclusion, the underweight state in the elderly is associated with malnutrition and osteoporosis; other factors occurring in malnutrition, besides body composition changes, such as protein deficiency, could be involved in the association between underweight and osteoporosis. Moreover bone mineral status seems to be related to fat-free soft mass tissue in men while in women it is much more closely associated with total body fat.

Keywords: Body composition; Elderly; Malnutrition; Osteoporosis

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Introduction

Malnutrition is a common problem in old people and it is associated with a high risk of morbidity and mortality [1,2]. The importance of nutritional status in involution osteoporosis was emphasized by the evidence that most patients with fractures of the proximal femur were

undernourished and had decreased femoral neck mineral densities [3].

In the elderly is difficult to define precise criteria of protein–calorie malnutrition, and the weight/height ratio is the most used parameter in clinical practice. However, a low weight does not always imply a state of malnutrition. For this reason it is necessary to consider other parameters of nutritional status to confirm the presence of malnutrition in underweight subjects.

Undernutrition produces a weight loss and a decrease in muscle mass which could influence physiological age-related changes in body composition and bone mineral content.

Indeed, body size is strongly associated with bone mass and subjects with high body weight have higher bone density than subjects with lower weight [4,5]. Body mass is made up of fat mass (FM) and fat-free mass (FFM), but it is not clear which of the two components is more strictly related to bone mass. In men, lean mass seems to be strongly related to bone mineral [5,6]. In women, cross-sectional studies in post- and premenopausal subjects [6,7] suggest that bone mineral is related to fat mass while in other surveys [5,8–10] both lean and fat mass were shown to be related to bone mass. The relationship between body compartments and bone mass is important because if bone density is related to FFM (constituted principally of muscle mass), an increase in physical activity associated with dietary support may protect bone against osteoporosis.

Other changes often occurring in malnutrition such as hypoalbuminemia, osteomalacia and physical impairment, could influence bone loss.

In this study, nutritional status, bone mineral mass and its association with body composition were investigated in underweight and normal weight elderly subjects. Moreover the hypothesis that malnutrition in elderly is associated with a higher risk of osteoporosis was tested.

Subjects and Methods

Subjects

This survey was performed in the Geriatric Hospital in Padua. The study design was approved by the ethics committee of the University of Padua and an individual written informed consent was obtained. The participants were 111 old subjects divided into two groups according to their nutritional status. Fifty-one underweight hospitalized patients: 30 women aged 81.3 ± 7 years, and 21 men aged 80.8 ± 8 years with body mass index (BMI) <22 kg/m^2 were selected. Mean BMI was 18.7 ± 2 kg/m^2 in men and 18 ± 2.3 kg/m^2 in women. Patients were not affected by acute illness, severe liver, heart or kidney dysfunction, and had a body weight which had been stable for 6 months. Subjects with endocrinopathy, neoplasia and other pathologies interfering with osteoblastic metabolism, as well as patients treated with steroids, diphenylhydantoin and heparin, were excluded. The subjects with total walking incapacity were also excluded. Mental status was not considered among the selection criteria so some individuals with mild cognitive impairment but able to collaborate in the execution of all instrumental examinations were included.

As control group, 60 healthy old subjects (30 women, 30 men) with BMI ranging from 22 to 30 kg/m^2 were recruited from our ambulatory patients. Mean BMI was 25.8 ± 2.6 kg/m^2 in men and 26.2 ± 2.8 kg/m^2 in women In order to exclude diseases or therapy affecting nutritional status, a brief history was charted and a physical examination was performed.

Methods

Anthropometry. Body weight was measured to the nearest 0.1 kg by using a precision scale with the subjects wearing light clothing and without shoes. Height was measured without shoes and recorded to the nearest millimetre. Mid-arm circumference (MAC) was determined with a plastic tape measure accurate to 1 mm. Triceps skinfold thickness (TSF) were taken with the Harpenden skinfold calipers. Each value represented the mean of three consecutive measurements performed by the same operator to minimize interobserver variation.

Hematological Investigations. A complete blood examination was done according to the usual methods. In particular we investigated the principal blood markers of malnutrition (albumin, prealbumin, retinol binding protein, transferrin) and bone turnover (serum calcium and phosphate, bone alkaline phosphatases, osteocalcin, urinary Cross-laps).

Body Composition and Bone Mineral Density Measurements. For dual-energy X-ray densitometry, a Hologic QDR 4500 W was used (Hologic, Waltham, MA). The principles underlying the analysis of body composition with fan beam DXA have been described previously [11]. Evaluation of fat mass (FM), fat-free mass (FFM), fat-free soft mass (FFSM), bone mineral content (BMC, g), bone area (g/cm^2) and bone mineral density (BMD) 'total body' were obtained by whole body scan. Fat mass index (FMI) and fat-free mass index (FFMI) have been calculated as the ratio between fat mass or fat free mass and subjects' height in meters squared, in analogy to the Quetelet BMI (kg/m^2). Appendicular skeletal muscle mass (ASMM) was derived as the sum of fat-free soft tissue mass of arms and legs, as described by Heymsfield et al. [12]. BMC, bone area and BMD at the hip and the spine were measured using standard protocols. Vertebrae with doubtful or definite fractures were excluded from the calculation of BMD and a spine scan was not performed on patients with severe osteoarthrosis. The coefficients of variation for the method were evaluated by repeated measurements of

both phantoms and normal subjects. Repeatability was 1.8% for FM, 1.7% for BMC, and 1.8% and 1.4% for BMD of spine and total hip respectively.

Dietary Intake. Dietary intake was evaluated by the same dietician with the diet history method. The calculations of nutrients were carried out with a computer program based on tables of recommended nutrient intake for the Italian population [13].

Resting Energy Expenditure (REE). REE was measured by open circuit indirect calorimetry with a moveable device (Sensor Medics 2900 Metabolic System, Anaheim, CA) and a ventilated hood system. Urinary nitrogen excretion was determined during the entire REE measurement to evaluate protein oxidation. The energy expenditure was calculated from VO_2 and VCO_2. The energy equivalent of VO_2 corrected for the non-protein respiratory quotient (RQ) and REE measurements were later extrapolated to 24 h.

Functional Status. Functional status was assessed by the Activities of Daily Living (ADL) using the Katz Index [14]. Each item of ADL was scored on a three-level scale (0 = independent, 1 = human help, 2 = totally dependent) with total score ranging from 0 (independent) to 12 (totally dependent).

Statistical Analysis

All analyses were done with SPSS for Windows, version 8.01 (SPSS, Chicago, IL). All results were expressed as mean ± standard deviation. Differences of continuous variables between underweight and normal subjects in each sex were assessed by ANOVA comparisons for normally distributed parameters. The level of statistical significance for each test was set as < 0.05.

To examine the association between bone mineral parameters and body composition, linear and partial correlations were performed considering all elderly individuals (underweight and normal-weight subjects) divided by gender. Results were reported as simple or partial correlation coefficients. Linear unadjusted correlations were assessed between bone parameters (BMD and BMC) for whole body, femoral neck and trochanter as dependent variables, and body compartments and albumin levels as independent variables. We used FFSM instead of FFM because this includes bone mineral and so the correlation with bone parameters could be overestimated [6].

Partial correlations were performed applying the analytic strategy proposed by Prentice et al. [15] and also used by Baumgartner et al. [6]. In this model BMC was considered the dependent variable and was adjusted for the effects of body size (bone area, knee height) and age on the other independent variables that are FM, FFSM, ASMM and albumin. When one body compartment was used as an independent variable the correlation was also corrected for the other to eliminate the effect of the other component of body composition on bone. The correlation with albumin was corrected for both FM and FFSM to eliminate the intercorrelation between these variables because albumin seems to be closely associated with FFSM [16]. We considered BMC corrected for bone area, instead of BMD, since BMC is not proportional to bone area at many skeletal sites [15], and the use of BMD, calculated as BMC/BA, could introduce a size-related artifact for these sites.

The adjustment for stature was done using knee height instead of height because of the age-related changes in the axial skeleton that may introduce a bias in comparing individuals or groups for skeletal length [8,17]. Age was also included in the partial correlation models to check for the effects of aging on bone mineral and body composition.

Results

We compared in both genders, anthropometric characteristics and body composition parameters in healthy and underweight elderly subjects (Table 1). All groups were comparable for age. In both groups women were not different for height and knee height. Underweight men were shorter but they were comparable for knee height. In both genders, underweight subjects showed a significantly lower MAC and TSF; obviously also FM and FFM, both when expressed in kilograms and adjusted for height, were lower than in normal subjects.

Albumin, prealbumin and retinol binding protein values were significantly lower in underweight subjects than in normal subjects, while transferrin values were similar in the two groups (Table 2). In the underweight group, albumin was below 35 g/l in 46% of women and 33% of men, while it was normal in the control group. 25-Hydroxyvitamin D_3 ($25(OH)D_3$) was lower than 25 ng/ml in 59.5% of the underweight group and in 53.1% of the control group.

Underweight patients had a lower daily energy and protein intake than normal subjects (Table 2). Calcium intake was very low in underweight women (440 ± 157 mg/day), but the level of calcium intake was below the minimal recommended calcium allowance in both groups and genders [13]. Energy balance, estimated as the difference between energy intake and REE, in underweight women was −120 ± 376 kcal while in men it was 300 ± 510 kcal.

The analysis of bone mineral parameters measured by DXA demonstrated, in underweight patients, a lower whole body BMC and BA in both sexes while BMD was lower only in men (Table 3). At femoral level we found a significant reduction of BMC and BMD in underweight patients compared with normal subjects, in both sexes. There were no substantial differences in BA at femoral regions between the two groups in both genders.

Figure 1 shows that men with BMI < 22 kg/m^2 had a *T*-score below −2.5 (−3 at femoral neck and −2.7 at total hip). On the other hand men in the control group had normal bone mineral parameters. In underweight

Table 1. Anthropometric and body composition characteristics of subjects (mean ± standard deviation)

	Men		Women	
	BMI<22 kg/m^2	BMI ⩾ 22 kg/m^2	BMI<22 kg/m^2	BMI ⩾ 22 kg/m^2
Age	80.8 ± 8.5	77.4 ± 7.2	81.3 ± 7	79.6 ± 9.1
Weight (kg)	51 ± 7	74.4 ± 9.9***	41.3 ± 5.9	61.4 ± 8 ***
Height (cm)	164.9 ± 6.6	169.4 ± 6.3*	151.6 ± 6.6	153 ± 7.3
Knee height (cm)	50 ± 3.2	51.5 ± 2.8	45 ± 2.8	45.5 ± 2.7
MAC (cm)	22.0 ± 2.0	29.1 ± 3.3***	20.6 ± 2.7	28.4 ± 3.1***
TSF (mm)	4.1 ± 1.6	7.2 ± 2.4***	8.2 ± 3.4	10.2 ± 5.2***
FM (kg)	8.2 ± 2.4	16.3 ± 4.8***	8.9 ± 3.3	21.3 ± 5***
FFM (kg)	41.3 ± 5.6	56.7 ± 7***	31.9 ± 3.9	39.2 ± 4.4***
FFSM (kg)	39.4 ± 5.4	53.9 ± 6.8***	30.7 ± 3.7	37.4 ± 4.2***
ASM (kg)	15.8 ± 2.8	22.8 ± 3.3***	11.8 ± 1.9	14.7 ± 1.77***
FFMI (kg/m^2)	15.2 ± 1.6	19.7 ± 1.7 ***	13.9 ± 1.3	16.7 ± 1.4***
FMI (kg/m^2)	3.0 ± 0.9	5.6 ± 1.6***	3.8 ± 1.4	9.0 ± 1.9***
Katz index (range 0–12)	1.6 ± 1.7	0.2 ± 0.3**	4.9 ± 4.9	0.26 ± 0.7***

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. MAC, midarm circumfrence; TSF, triceps skinfold; BMI, body mass index; FM, fat mass; FFM, fat-free mass; FFSM, fat-free soft mass; ASM, appendicular skeletal mass; FFMI, fat-free mass index; FMI, fat mass index.

Table 2. Nutritional status: biohumoral parameters and nutrient intakes (mean ± standard deviation)

	Men		Women	
	BMI<22 kg/m^2	BMI ⩾ 22 kg/m^2	BMI<22 kg/m^2	BMI ⩾ 22 kg/m^2
Proteins (g/l)	67.3 ± 7.5	70.7 ± 5.4	67.3 ± 8.6	73.2 ± 6.3*
Albumin (g/l)	36.3 ± 5.02	42.9 ± 3.9***	34 ± 4.9	42.5 ± 6***
Prealbumin (mg/l)	211.6 ± 105.4	357.3 ± 86**	176.2 ± 75.2	296.4 ± 32.4***
RBP (mg/l)	35.6 ± 21.1	60.7 ± 16.7*	31.6 ± 15.7	67.06 ± 39.7**
Transferrin (mg/dl)	248.2 ± 53.9	232.6 ± 51.1	209 ± 58.8	241 ± 36.6
25(OH)D_3 (ng/ml)	20.5 ± 3.5	21.1 ± 4.9	17.9 ± 16.2	24 ± 5.2
Intake (kcal/day)	1615 ± 519	2208 ± 562**	999.3 ± 325.6	1749 ± 527**
Protein intake (g/day)	54.5 ± 23.1	71 ± 20.3**	35.5 ± 14.7	60 ± 20.9**
Calcium intake (g/day)	670 ± 425	717 ± 317	440.1 ± 156.6	644 ± 281*
REE (kcal/day)	1370 ± 186	1709 ± 249***	1121 ± 261.5	1420 ± 183.2***

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. RBP, retinol binding protein; REE, resting energy expenditure.

Table 3. Bone area, bone mineral content (BMC) and bone mineral density (BMD) of the total body and femoral sites (mean ± standard deviation)

	Men		Women	
	BMI<22 kg/m^2	BMI ⩾ 22 kg/m^2	BMI<22 kg/m^2	BMI ⩾ 22 kg/m^2
Total body				
BMC (g)	1981 ± 366	2766 ± 366***	1273 ± 325	1794 ± 34 ***
Bone area (cm^2)	1755 ± 217	2233 ± 186***	1298 ± 259	1799 ± 217***
BMD (g/cm^2)	1.12 ± 0.14	1.23 ± 0.12**	0.97 ± 0.13	0.99 ± 0.13
Femoral neck				
BMC (g)	3.7 ± 0.8	4.9 ± 0.8***	2.4 ± 0.5	3.0 ± 0.5**
Bone area (cm^2)	5.6 ± 0.5	5.8 ± 0.4	4.7 ± 0.7	4.7 ± 0.7
BMD (g/cm^2)	0.65 ± 0.1	0.85 ± 0.1***	0.51 ± 0.1	0.63 ± 0.1***
Femoral: trochanter				
BMC (g)	7.6 ± 2.2	10.6 ± 2.6**	4.4 ± 1.7	6.3 ± 1.3**
Bone Area (cm^2)	13.2 ± 1.5	14.7 ± 2.4	10.2 ± 3.1	11.3 ± 1.3
BMD (g/cm^2)	0.55 ± 0.1	0.7 ± 0.1**	0.41 ± 0.1	0.55 ± 0.1***
Femoral: total				
BMC (g)	32.8 ± 9.3	43.9 ± 7.4**	18.8 ± 5.6	26.1 ± 4.5***
Bone Area (cm^2)	45.5 ± 5.9	47.4 ± 4.9	35.0 ± 5.5	35.9 ± 2.1
BMD (g/cm^2)	0.72 ± 0.13	0.95 ± 0.1***	0.53 ± 0.12	0.72 ± 0.11***

**$p < 0.01$; ***$p < 0.001$.

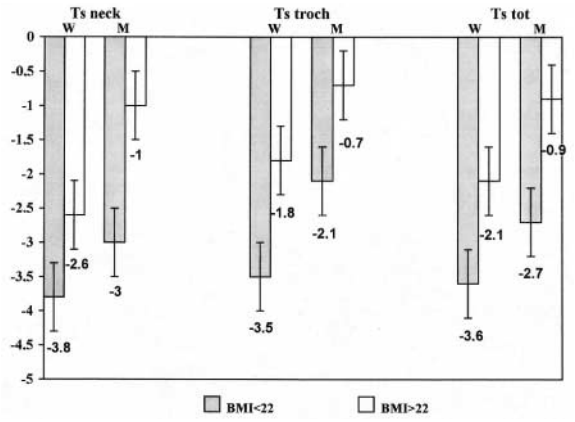

Fig. 1. *T*-score (*Ts*) at different femoral sites (neck, trochanter (*troch*), and total) in underweight and normal women (*W*) and in underweight and normal men (*M*).

women, *T*-score values at different sites analyzed were lower than in underweight men, with values always below −3.5, revealing clear osteoporosis. However, in women, the control group also showed values of BMD consistent with the presence of mild osteoporosis.

Table 4 shows, in both genders, BMD and *T*-score values of underweight subjects categorized according to albumin values, with 35 g/l as the cutoff value. Hypoalbuminemic subjects had a similar BMI but a significantly reduced bone femoral mass compared with normoalbuminemic underweight subjects.

Markers of bone turnover were in the normal ranges in both underweight and normal subjects (data not shown).

Table 5 shows linear and partial correlations of bone parameters with body composition and albumin levels in all subjects divided for gender.

Whole body BMD correlated with FFSM in both

Table 4. Bone parameters values in underweight patients with serum albumin levels (ALB) ⩾ 35 g/l and < 35 g/l, in both genders (mean ± standard deviation)

	Men		Women	
	ALB < 35 (n = 7)	ALB ⩾ 35 (n = 14)	ALB < 35 (n = 14)	ALB ⩾ 35 (n = 16)
BMI (kg/m^2)	18.3 ± 2.4	19.0 ± 1.7	17.7 ± 2.6	18.6 ± 1.7
Total body				
BMD (g/cm^2)	1.16 ± 0.2	1.14 ± 0.1	0.95 ± 0.1	0.96 ± 0.1
Femoral neck				
BMD (g/cm^2)	0.56 ± 0.05	0.69. ± 0.1*	0.45 ± 0.08	0.57 ± 0.1**
T-score	−3.7 ± 0.9	−2.7 ± 1**	−4.3 ± 0.9	−3.2 ± 0.7 **
Femoral: trochanter				
BMD (g/cm^2)	0.45 ± 0.1	0.6 ± 0.1*	0.35 ± 0.06	0.45 ± 0.1*
T-score	−3.2 ± 1.1	−1.7 ± 0.9*	−4.2 ± 1.1	−2.9 ± 1.1*
Femoral: total				
BMD (g/cm^2)	0.61 ± 0.1	0.75 ± 0.1*	0.47 ± 0.1	0.60 ± 0.1*
T-score	−3.5 ± 0.9	−2.4 ± 0.9*	−4.2 ± 0.9	−3.1 ± 1*

*p < 0.05; **p < 0.01.
BMD, bone mineral density; BMC, bone mineral content.

Table 5. Linear and partial correlations (r) of bone parameters (BMC=bone mineral content and BMD=bone mineral density) with fat mass (FM), fat-free soft mass (FFSM) and appendicular skeletal mass (ASM)

	FM		FFSM		ASM		Albumin	
	Men	Women	Men	Women	Men	Women	Men	Women
Linear correlations								
BMD (g/cm^2)								
Total body	0.20 NS	0.14 NS	0.34 *	0.31 *	0.35 *	0.17 NS	−0.002 *	−0.05 *
Femoral neck	0.53 **	0.70 ***	0.68 ***	0.46 **	0.59 ***	0.43 **	0.51 *	0.67 ***
Femoral trochanter	0.44 *	0.59 ***	0.52 ***	0.46 **	0.46 **	0.55 **	0.51 *	0.64 ***
Partial correlations								
BMC (g)[a]								
Total body	−0.15 NS	−0.25 NS	0.05 NS	0.23 NS	0.18 NS	−0.13 NS	−0.002 NS	−0.05 NS
Femoral neck	0.06 NS	0.48 **	0.48 *	0.047 NS	0.32 NS	−0.03 NS	0.31 NS	0.52 *
Femoral trochanter	0.15 NS	0.35 NS	0.16 NS	0.18 NS	0.006 NS	0.02 NS	0.31 NS	0.28 NS

[a]BMC values are adjusted for area. In partial correlations FM was adjusted for FFM, age and knee height; FFSM was adjusted for FM, age and knee height; ASM was adjusted for FM, age and knee height; albumin was adjusted for FM, FFSM, age and knee height.
*p < 0.05; **p < 0.01; ***p < 0.001.

genders and with ASMM only in men. The BMD of the femoral neck and trochanter correlated significantly with FM, FFSM and ASMM in both sexes, but these correlations were stronger with FM in women (r = 0.70 neck; r = 0.59 trochanter) and with FFSM in men (r = 0.68 neck; r = 0.52 trochanter). All bone parameters correlated more strongly with FFSM than with ASMM. In both sexes, but especially in women, albumin values were positively and significantly correlated with BMD at all sites.

Partial correlations of FM, FFSM, ASMM and albumin with BMC adjusted for age, bone area, knee height and other variables are shown in Table 5. In this model only BMC at the femoral neck was significantly associated with FM in women (r = 0.48; $p < 0.01$) and with FFSM in men (r = 0.48; $p < 0.05$). No relationship was found between ASMM and BMC. Serum albumin levels correlated only with femoral neck BMC (r = 0.52; $p < 0.05$) in women.

Discussion

The aim of this work was to investigate the association between the underweight state, malnutrition and bone loss in elderly patients and the relationship between bone mineral status and body composition. Two groups of elderly subjects selected for different nutritional status were studied, the first including subjects in an apparent normal nutritional and health status and the second including hospitalized underweight subjects, hypothesized to be malnourished, selected for BMI < 22 kg/m^2. BMI is a routine nutritional parameter and cutoff of 22 is the one mostly used in literature [18] representing the 10th percentile of the distribution of BMI in a sample of Italian elderly subjects [19]. However, a low BMI does not always imply malnutrition. For this reason we considered other parameters of nutritional status such as visceral proteins, fat-free mass and energy balance. Underweight subjects showed a reduction in anthropometric parameters and the depletion of albumin and other visceral proteins except transferrin. An albumin decline should better represent an index of chronic undernutrition because of its longer half-life compared with other visceral proteins. In any case albumin also varies in conditions other than malnutrition, such as chronic liver diseases, septic states, nephrotic syndromes or body fluid alterations; however, subjects affected with these pathologies were excluded from the study.

Changes in body cell mass occur in malnutrition and the measurement of body compartments is important to determine nutritional status. In particular FFM constitutes the metabolically more active body component and its progressive decrease is the most relevant consequence of malnutrition. The current practice of reporting FFM as a percentage of body weight or as absolute weight is unsatisfactory; for example, tall malnourished subjects can exhibit values for FFM similar to those of shorter well-nourished individuals. Thus, as proposed by other authors [20], we used height-normalized indices for FFM (FFMI) and FM (FMI). In the underweight group, all men and 90% of women had FFMI values below the 10th percentile of a normal aged population of the same geographical area (unpublished data). Almost all underweight subjects were sarcopenic.

Moreover all the women had a negative energy balance while in the men the declared energy intake exceeded the resting energy expenditure by 300 kcal; this might not be sufficient to cover the energy for dietary-induced thermogenesis and for minimal physical activity. This observation could contrast with the anamnestic assertion of a steady weight for 6 months. Since the resting energy expenditure measurement with indirect calorimetry is accurate, this contrast could be due to an inaccurate weight report, to variability of daily intake, or to a difficulty in recording energy intake with the diet history, especially in the elderly.

Considering the findings regarding visceral protein, body composition and energy balance, we supposed that underweight individuals were at risk of malnutrition or malnourished compared with the control group.

Elderly underweight subjects showed a greater bone loss than control subjects, with T-score values below −2.5. These values are consistent with the diagnosis of severe osteoporosis, especially in women, according to WHO criteria [21]. These findings agree with population studies in which a direct relationship between BMD and BMI has been observed [4,5]. In fact obese subjects have higher BMD values than the normal population and are exposed to a lower fracture risk. Our study also confirms these observations in underweight elderly subjects, emphasizing their high fracture risk. Since the fracture risk increases 2.5 times for every unit of T-score reduction [21], underweight men and women were theoretically exposed to a fracture risk respectively 7 to 9 times higher than the young population.

The hypoalbuminemic underweight subjects had a significant reduction of BMD. Moreover albumin after correction for other influencing factors significantly correlated with bone femoral neck in all women (Table 5). This suggests that protein depletion can increase bone loss in elderly individuals and that malnutrition, besides weight loss, has a negative association with BMD.

The results regarding bone parameters reveal a difference in total body bone area between the two groups, the underweight subjects having lower areas than normal subjects. This could be due to an error of detection or the limited accuracy of a total body scan, but in this case this should be present in both groups. Moreover this different area in total body analysis could simply be attributed to a different skeletal size of the two groups of subjects. However, in this case the femoral area should also be smaller. In our subjects femoral area at all sites was only slightly lower in underweight subjects but this difference was not statistically significant. Probably, this small difference in body size can explain part of the difference in bone area. Another important reason for this difference could be the presence of spine abnormalities in underweight subjects. In fact, looking at skeletal height there is a significant

difference between malnourished and normal men, even if their knee height is similar. In women there is a small, but not significant, difference in skeletal height between the two groups. We thus hypothesized that spine abnormalities (kyphosis and vertebral fractures) may explain the low bone area in underweight persons to some extent. In conclusion, this different total bone area may have multifactorial origins.

Regarding body mass it is important to establish in particular which component, i.e. fat mass or lean mass, better predicts bone mass loss.

Other reports investigating the association between bone mineral and soft tissue composition in men found, in agreement with our results, a stronger association of bone mineral with lean mass than with fat mass [5,6]. In women some studies reported an association between bone mineral and fat mass [7,8]. In other studies FFM is reported to be the main determinant of bone mineral [5,9,10]. Using several different methods to obtain independent estimates of FM and FFM it has been suggested that FFM remains the most important determinant of bone mineral mass regardless of menopausal status [10]. Nevertheless FFM also includes bone mineral and no adjustments were made for bone and body size. Therefore these contradictions could depend on the use of different indices of bone mineral mass as BMC and areal BMD, adjusted or not for body size. The use of volumetric BMD instead of linear BMD to analyze the relationship between body composition and lumbar spine bone mineral has been proposed [7]. Using volumetric BMD different authors concluded that vertebral BMD is related to FM and not to lean mass in women [7,23]. The volumetric estimation of bone mineral density should be more correct for long bones. In our study we did not consider the volumetric approach at femoral sites because in the literature there are no previous reports on the subject. Baumgartner et al. [6] applied a model of multiple regression in which BMC was corrected for bone area, knee height, weight, age, fat and lean mass, as previously presented by Prentice et al. [15]. In this study, linear correlations have already demonstrated a strong association of BMD with FFSM in men and with FM in women. Excluding confounding factors with multiple regression analysis, this different effect on bone mass of lean mass in men and of FFM in women, even in the underweight malnourished elderly, was confirmed. These results show different associations between soft tissue composition and relative bone mass in the two genders, suggesting different underlying mechanisms even if the presence of a statistical relationship does not always infer a causal link.

In men, bone mineral could be affected by mechanical stresses mediated through muscle and mass gravitational action. However, in our study the correlation between BMC and lean mass in men was not confirmed when considering only the appendicular skeletal muscular component. This is probably due to the reduction of muscle mass and physical activity in malnourished subjects. Furthermore the relationship between FFSM and bone mass might be explained by a prevalent gravitational effect because lean mass represents the major body weight component, especially in men.

In women, on the other hand, bone mineral status was more closely associated with body fat, supporting the hypothesis that in postmenopause the endocrine role of adipose tissue is more important than mechanical stresses. In fact adipose tissue is a possible source of estrogen which may help to prevent bone mineral loss. In addition it has been observed that leptin, produced in white adipose cells and several other organs, could influence bone mass [24].

We did not observe any significant correlation between trochanter mineral content and body mass in either sex. The reason for this is not clear and probably other factors, related to malnutrition, are responsible for osteoporosis at this site. Unfortunately, previous reports do not consider the trochanteric site, except for that of Compston et al. [9] which includes postmenopausal women younger than our subjects.

Osteomalacia, mainly due to low levels of $25(OH)D_3$ in the elderly [25], could increase bone mineral loss in our subjects and result in difficulty discriminating low BMD due to poor mineralization from true osteoporosis. However, low levels of $25(OH)D_3$ were found both in underweight and in normal weight subjects. We therefore hypothesized that differences in bone mass between underweight and normal subjects could be prevalently due to osteoporosis.

Finally, in this study we investigated the possible role of physical impairment on bone loss in underweight malnourished subjects, some of them being partially disabled. The effect of disuse on bone mass is well known. We excluded immobilized subjects but some of the underweight individuals had a mild degree of functional impairment in ADL which could implicate a reduction in physical activity with a consequent effect on bone mass. An inverse correlation between the Katz index and BMD was found in the underweight group. To investigate whether this effect could be due to reduced physical activity or otherwise to an intercorrelation with soft mass depletion, we elaborated a partial correlation model of BMC at different sites with the Katz index as an independent variable, adjusted for bone area, age, knee height, FM, FFSM and albumin. In this case there was no evidence of a relationship. Moreover, the partial correlations shown in Table 5 between BMC and body composition parameters were no different when we added the Katz index as a correcting factor. Then, even if functional impairment, underweight, sarcopenia and bone mass loss may be associated, our results suggest that bone loss is principally related to body mass depletion, independently of the way in which it occurs.

In conclusion, underweight in the elderly is associated with malnutrition and osteoporosis; other factors occurring in malnutrition, besides body composition changes, such as protein deficiency could be involved in the association between underweight and osteoporosis. Moreover bone mineral status seems to be related to fat-free soft mass tissue in men while in women it is much more closely associated with total body fat.

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