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ORIGINAL ARTICLE

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Relationship between body composition and bone mineral density in women with and without osteoporosis: relative contribution of lean and fat mass

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Abstract To assess the relationship of total fat mass (TFM) and total lean mass (TLM) with bone mineral density (BMD) and bone mineral content (BMC), we studied 770 postmenopausal white women after total body measurements by dual-energy X-ray absorptiometry. Height-independent bone mineral density (HIBMD) was also tested. The effects of TFM and TLM on the dependent variables HIBMD, BMD, and BMC were assessed by the univariate general linear model (UGLM). Age, age at menopause, height, and bone area were entered in the models as controlling variables when appropriate. In the total population, TLM and TFM were associated with BMD, BMC, and HIBMD ($P < 0.001$). Taking the T-score cut-off as –2.5, women without (463) and with (307) osteoporosis were then tested separately. In nonosteoporotic women, TLM was significantly associated with BMD, BMC, and HIBMD ($P < 0.001$), while TFM was not. In osteoporotic women, both TLM and TFM were associated with BMD to the same extent ($P < 0.05$), but not with HIBMD. Women without osteoporosis were then tested according to whether their TFM/TLM fraction was less than or greater than 1. In those with TFM/TLM less than 1, both TLM ($P < 0.001$) and TFM ($P < 0.01$), tested separately, were associated with BMD and BMC, but not with HIBMD. When TLM and TFM were tested at the same time and assessed by the same UGLM, only TLM ($P < 0.001$) still affected these three bone parameters. In women with TFM/TLM greater than 1, testing the body components both separately and at the same time and using the UGLM showed that TFM affected both BMC and BMD ($P < 0.05$), while TLM did not. In conclusion, our data indicate that both TFM and TLM affect bone density, with different physiological/pathological conditions modulating this relationship.

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Introduction

There is general agreement on the fact that low bone mineral density (BMD) is strongly associated with fracture risk in postmenopausal osteoporosis [1]. It follows that knowledge of the factors modulating the behavior of bone mass is crucial for preventing and treating osteoporotic disease. Among these factors, body weight has been shown to be of primary importance in postmenopausal women [2,3]. However, the relative effects of body composition indices, i.e., total fat mass (TFM) and total lean mass (TLM), on BMD are still being debated. On this issue, there are discrepant reports. TLM has been reported by some researchers to have the closest positive association with BMD [4,5], while others have reported that TFM has the closest relationship with BMD [6–11], and yet others have shown that TFM and TLM are equally associated with BMD [12,13]. Some possible biological mechanisms explaining the association of both indices of body composition with BMD have been reported [14–19], so that none of them, at present, can be shown to be wrong. According to other authors, these discrepancies depend on differences among the populations studied in relation to measurement methods and the skeletal site where the body composition was measured [13,20], as well as the race [21] and body weight [22] of the people studied. In this work, we analyzed the relationship of fat and lean mass with BMD in postmenopausal women, and also took into account the possible effect of differences in T-score in the general population and the individual body fat/lean mass fraction on this relationship. We therefore measured, by means of dual X-ray densitometry, the body weight, TLM, and TFM of postmenopausal Italian women, and analyzed their relationship with BMD.

Subjects and methods

The subjects were 770 Gucasian, postmenopausal women who had their first dual X-ray (DXA) examination at our center for a check on their bone density. All of them were noninstitutionalized women in good general health, and none was taking any medication that was likely to affect their bone, soft tissue, or lean tissue metabolism. Women who had used glucocorticoid drugs for more than 3 months at any time, had undergone hormone replacement therapy for more than 1 year, or who had a body mass index (BMI) lower than 19 or higher than 35 were excluded. Subjects taking drugs for hypertension or coronary diseases were not excluded, except for those taking oral anticoagulant therapy.

BMI was calculated as the weight (kg) divided by the square of the height (meters). BMI values of 25 and 30 were the cut-off levels for overweight and obese subjects, respectively.

The women's heights were measured by a stadiometer (Mod.220, SECA, Hamburg, Germany) with a precision error of 0.5 cm.

Total body BMC and BMD, TFM, and TLM were measured using a Norland densitometer XR 36 (Norland, Fort Atchinson, WI, USA). Body weight was calculated from the BMC, TFM, and TLM measurements. The machine was recalibrated daily, and a daily quality assurance test was performed according to manufacturer's instructions. Whole body measurements were made using a standard procedure according to the manufacturer's instructions for scanning and analysis. The precision (% CV) of the device for BMD measurements performed on the manufacturer's phantom spine was less than 1%. We did not make any further assessments of the precision error of the Norland XR 36 densitometer for ethical reasons. This is a standardized commercial machine, whose in vivo precision (% CV) for whole body measurements has been reported in the literature to range from 1.0% to 2.2% for BMC, from 1.1% to 2.7% for TLM, and from 2.6% to 3.9% for TFM [23–28]. The women's T-score was calculated by subtracting the mean BMD value of the Norland young European women reference population from that of the women measured, and dividing the result by the standard deviation of the same reference population.

This study was approved by the local ethical committee.

Statistics

SPSS version 14.0.1 was used for the statistical analyses. As the outcome variables of this analysis we used BMC, BMD, and height-independent bone mineral density (HIBMD), based on the relationship between BMD and height. According to Harris and Dawson-Hughes [14], HIBMD is calculated by dividing BMD by the square-root of the height. HIBMD was calculated to assess the body composition measurement independently of cortical thickness, assuming that this measurement is related to height [8,14]. The results were expressed as mean±standard deviation (SD). Differences in continuous variables between groups were assessed by Student's unpaired *t*-test. The χ^2 test was used to test the differences among grouping variables. Correlations between continuous variables were tested by Pearson's correlation analysis. The univariate general linear model (UGLM) was used to assess the dependence of BMD, BMC, and HIBMD on TLM and TFM. Age and age at menopause were used to explore the dependent variable HIBMD as a controlling variable. Age, age at menopause, and height were used to explore the dependent variable BMD as a controlling variable. Age, age at menopause, height, and bone area (BA) were used to explore the dependent variables BMC, TLM, and TFM as controlling variables. TLM and TFM were first considered separately and then contemporarily in the tests. The η^2 statistic, which describes the proportion of the total variability attributable to one factor, was reported in the text for TLM and TFM only. The R^2 of the model was also reported.

Weight was not included as a controlling variable since TLM and TFM are closely related to weight, and its inclusion might lead to a misinterpretation of the results. For the same reason, when BMD was the dependent variable, the bone area was not included as a controlling variable, and bone area and height were not included when the dependent variable was HIBMD.

Results

The clinical, anthropometric, and densitometric data of the 770 women studied are given in Table 1. The population age ranged from 42 to 90 years, age at menopause from 40 to 60 years, and BMI from 19.01 to 34.27 $kg\,m^{-2}$. According to their BMI, 57.0% of the women were of normal weight, 36.0% were overweight, and 7% were obese.

Pearson's correlation analysis showed a significant ($P < 0.01$) correlation between the following variables, with TFM and TLM (correlation coefficients (r) reported in parenthe-

Table 1. Densitometric, anthropometric, and clinical data of the 770 women studied

Characteristics	Mean ± SD	Range	
		Min	Max
Age (years)	62 ± 10	42	90
Age at menopause (years)	49.0 ± 4.7	40	60
Height (cm)	160.0 ± 6.0	145	180
DXA weight (kg)	63.6 ± 8.9	41.2	84.8
BMI ($kg\,m^{-2}$)	24.8 ± 3.2	19.0	34.3
Lean mass (kg)	33.6 ± 4.7	19.8	48.6
Fat mass (kg)	27.8 ± 6.4	10.5	47.8
Fat mass/lean mass	0.84 ± 0.20	0.28	1.62
BMD ($g\,cm^{-2}$)	0.878 ± 0.094	0.597	1197
HIBMD ($g\,cm^{-2}/cm^{0.5}$)	0.069 ± 0.007	0.048	0.096
BMC (g)	2218 ± 275	1499	3569
Bone area (cm^2)	2524 ± 133	1977	3565
T-score	–2.26 ± 0.79	–4.61	0.39

Table 2. Univariate general linear model showing the association between bone densities and total lean mass (TLM) and/or total fat mass (TFM) in the whole population

	BMD[e] ($g\,cm^{-2}$)[a,b,c]			BMC[e] (g)[a,b,c,d]			HIBMD[e] ($g\,cm^{-2}/cm^{0.5}$)[a,c]		
	R^2	η^2	P	R^2	η^2	P	R^2	η^2	P
Model 1	0.364			0.525			0.298		
TLM[f]		0.123	<0.001		0.127	<0.001		0.103	<0.001
Model 2	0.304			0.479			0.249		
TFM[f]		0.041	<0.001		0.043	<0.001		0.040	<0.001
Model 3	0.379			0.538			0.310		
TLM[f]		0.107	<0.001		0.112	<0.001		0.082	<0.001
TFM[f]		0.024	<0.001		0.026	<0.001		0.017	<0.001

For each model, the first row shows the R^2 of the equation, and the following row or rows show the partial η^2 and its statistical significance
[a] Controlled for age
[b] Controlled for height
[c] Controlled for age at menopause
[d] Controlled for bone area
[e] Dependent variables
[f] Independent variables
BMC, total body bone mineral content; BMD, total body bone mineral density; HIBMD, height-independent bone mineral density; TLM, total lean mass; TFM, total fat mass

Table 3. Comparison of the densitometric, anthropometric, and clinical data of women without and with osteoporosis

	Women without osteoporosis (n = 463)	Women with osteoporosis (n = 307)	Student's t-test
	Mean ± SD		P
Age (years)	58.7 ± 9.4	67.0 ± 8.9	0.001
Age at menopause (years)	49.1 ± 4.7	49.0 ± 4.8	ns
Height (cm)	161.2 ± 5.2	158.5 ± 6.1	0.001
DXA weight (kg)	66.0 ± 8.7	60.1 ± 7.9	0.001
BMI ($kg\,m^{-2}$)	25.4 ± 3.3	23.9 ± 2.8	0.001
Lean mass (kg)	34.9 ± 4.5	31.6 ± 4.2	0.001
Fat mass (kg)	28.7 ± 6.6	26.5 ± 5.9	0.001
TFM/TLM	0.83 ± 0.20	0.85 ± 0.20	ns
BMD ($g\,cm^{-2}$)	0.938 ± 0.064	0.788 ± 0.050	0.001
HIBMD ($g\,cm^{-2}/cm^{0.5}$)	0.083 ± 0.005	0.063 ± 0.04	0.001
BMC (g)	2376 ± 216	1980 ± 157	0.001
Bone area (cm^{-2})	2532 ± 143	2512 ± 116	0.031
Age-corrected BMD ($g\,cm^{-2}$)	0.923 ± 0.066	0.810 ± 0.052	0.001
Age-corrected HIBMD ($gcm^{-2}/cm^{0.5}$)	0.072 ± 0.005	0.063 ± 0.0041	0.001
Age-corrected BMC (g)	2334 ± 216	2044 ± 156	0.001
T-score	–1.76 ± 0.53	–3.01 ± 0.42	0.001

DXA, dual X-ray

ses): height (TLM, $r = 0.448$; TFM, $r = 0.207$); body weight (TLM, $r = 0.678$; TFM, $r = 0.858$); BMC (TLM, $r = 0.474$; TFM, $r = 0.229$); BMD (TLM, $r = 0.437$; TFM, $r = 0.166$); HIBMD (TLM, $r = 0.372$; TFM, $r = 0.137$). TLM was also inversely related to age ($r = -0.202$, $P < 0.001$), while TFM was not age-related ($r = 0.086$, $P = 0.087$). TLM and TFM were also found to correlate significantly with each other ($r = 0.228$, $P < 0.001$). After checking for the covariate, the UGLM showed that TLM and TFM had a significant positive association with all the measured variables of bone density tested, both when they were included in the same equation and when they were considered separately (Table 2).

Based on the T-score in the selected population, there were 463 women without osteoporosis (T-score >–2.5) and 307 women with osteoporosis (T-score ≤–2.5). The osteoporotic women were older, shorter, thinner, and had lower BMD, BMC, HIBMD, and lower total body mass and body mass components than the nonosteoporotic women (Table 3). After correcting for age, the differences between groups for BMD, BMC, and HIBMD were still statistically significant by the t-test ($P < 0.001$).

Among women without osteoporosis, the UGLM showed that TLM, either separately or considered in the same equation with TFM, was positively associated with BMC, BMD, and HIBMD. TFM did not affect any of the bone density parameters considered either separately or when tested with TLM (Table 4). Among osteoporotic women, TLM and TFM, both separately and when analyzed in the same equation, were positively associated with BMD

Table 4. Univariate general linear model showing the association between bone densities and lean and/or fat body mass in women without osteoporosis

	BMD[e] ($g\,cm^{-2}$)[a,b,c]			BMC[e] (g)[a,b,c,d]			HIBMD[e] ($g\,cm^{-2}/cm^{0.5}$)[a,c]		
	R^2	η^2	P	R^2	η^2	P	R^2	η^2	P
Model 1	0.180			0.543			0.110		
TLM[f]		0.074	<0.001		0.079	<0.001		0.045	<0.001
Model 2	0.119			0.507			0.071		
TFM[f]		0.005	ns		0.006	ns		0.003	ns
Model 3	0.181			0.544			0.110		
TLM[f]		0.070	<0.001		0.075	<0.001		0.042	<0.001
TFM[f]		0.001	ns		0.001	ns		0.001	ns

For each model, the first row shows the R^2 of the equation, and the following row or rows show the partial η^2 and its statistical significance
[a] Controlled for age
[b] Controlled for height
[c] Controlled for age at menopause
[d] Controlled for bone area
[e] Dependent variables
[f] Independent variables
BMC, total body bone mineral content; BMD, total body bone mineral density; HIBMD, height-independent bone mineral density; TLM, total lean mass; TFM, total fat mass

Table 5. Univariate general linear model showing the association between bone densities and lean and/or fat body mass in women with osteoporosis

	BMD[e] ($g\,cm^{-2}$)[a,b,c]			BMC[e] (g)[a,b,c,d]			HIBMD[e] ($g\,cm^{-2}/cm^{0.5}$)[a,c]		
	R^2	η^2	P	R^2	η^2	P	R^2	η^2	P
Model 1	0.170			0.463			0.092		
TLM[f]		0.017	<0.05		0.020	<0.02		0.002	ns
Model 2	0.168			0.463			0.094		
TFM[f]		0.014	<0.05		0.020	<0.02		0.004	ns
Model 3	0.180			0.473			0.095		
TLM[f]		0.016	<0.05		0.019	<0.02		0.001	ns
TFM[f]		0.013	<0.05		0.018	<0.02		0.003	ns

For each model, the first row shows the R^2 of the equation, and the following row or rows shows the partial η^2 and its statistical significance
[a] Controlled for age
[b] Controlled for height
[c] Controlled for age at menopause
[d] Controlled for bone area
[e] Dependent variables
[f] Independent variables
BMC, total body bone mineral content; BMD, total body bone mineral density; HIBMD, height-independent bone mineral density; TLM, total lean mass; TFM, total fat mass

and BMC. Neither of them was associated with HIBMD (Table 5).

To test whether the predominance of any one of the body components over another was affecting bone density, women without osteoporosis were divided into two subgroups according to their TFM/TLM ratio: 369 women had a TFM/TLM <1 (women with a predominantly lean mass) and 94 women had a TFM/TLM >1 (women with a predominantly fat mass). Among women with a predominantly lean mass, 56% had a normal BMI, 38% were overweight, and 6% were obese. Among women with a predominantly fat mass, the figures were 25%, 46%, and 29%, respectively. The percentages of those who were of normal weight, overweight, or obese were significantly different between the two groups considered (χ^2 test, $P < 0.001$). Women with a predominantly fat mass were older and of significantly higher weight, TFM, and BMI, and lower BMD, BMC, and HIBMD, than those with a predominantly lean mass (Table 6). After correcting for age, the differences in BMD, BMC, and HIBMD between subgroups were no longer statistically significant.

When testing the two body mass components separately by UGLM among the nonosteoporotic women with a predominantly fat mass, we found that TLM was not significantly associated with any of the bone density measurements, and that TFM was associated with the dependent variables BMD and BMC, but not with HIBMD, while among those with a predominantly lean mass, both TFM and TLM were significantly associated with each one of the three bone density measurements considered (Table 7). When both

Table 6. Comparison of the densitometric, anthropometric, and clinical data of women without osteoporosis grouped according their predominant lean or fat body mass

	Women with a predominantly lean body mass (n = 369)	Women with a predominantly fat body mass (n = 94)	t-test
	Mean ± SD		p
Age (years)	57.7 ± 9.2	62.8 ± 8.8	0.001
Age at menopause (years)	49.0 ± 4.7	49.4 ± 4.6	ns
Height (cm)	161.5 ± 5.7	160.1 ± 6.3	ns
DXA weight (kg)	64.7 ± 8.3	71.1 ± 8.2	0.001
BMI ($kg\,m^{-2}$)	24.8 ± 3.1	27.7 ± 3.2	0.001
Lean mass (kg)	35.6 ± 4.3	32.2 ± 3.9	0.001
Fat mass (kg)	26.7 ± 5.4	36.5 ± 4.8	0.001
TFM/TLM	0.75 ± 0.13	1.13 ± 0.11	0.001
BMD ($g\,cm^{-}$)	0.943 ± 0.067	0.917 ± 0.046	0.001
HIBMD ($g\,cm^{-2}/cm^{0.5}$)	0.074 ± 0.005	0.072 ± 0.004	0.001
BMC (g)	2385 ± 219	2343 ± 204	0.078
Bone area (cm^2)	2527 ± 134	2552 ± 173	ns
Age-corrected BMD ($g\,cm^{-2}$)	0.878 ± 0.085	0.877 ± 0.072	ns
Age-corrected HIBMD ($g\,cm^{-2}/cm^{0.5}$)	0.068 ± 0.007	0.068 ± 0.006	ns
Age-corrected BMC (g)	2214 ± 246	2236 ± 226	ns
T-score	−1.7 ± 0.6	−1.9 ± 0.4	0.001

Table 7. Univariate general linear model showing the association between bone densities and lean and/or fat body mass in women without osteoporosis who had a TFM/TLM fraction ≥1 or <1

	BMD[e] ($g\,cm^{-2}$)[a,b,c]			BMC[e] (g)[a,b,c,d]			HIBMD[e] ($g\,cm^{-2}/cm^{0.5}$)[a,c]		
	R^2	η^2	P	R^2	η^2	P	R^2	η^2	P
TFM/TLM > 1									
Model 1	0.148			0.720			0.086		
TLM[f]		0.008	ns		0.009	ns		0.001	ns
Model 2	0.185			0.733			0.109		
TFM[f]		0.052	<0.05		0.054	<0.05		0.025	ns
Model 3	0.193			0.735			0.134		
TLM[f]		0.003	ns		0.009	ns		0.019	ns
TFM[f]		0.052	<0.05		0.054	<0.05		0.043	<0.05
TFM/TLM < 1									
Model 1	0.170			0.507			0.103		
TLM[f]		0.080	<0.001		0.085	<0.001		0.050	<0.001
Model 2	0.120			0.475			0.073		
TFM[f]		0.025	<0.01		0.025	<0.01		0.019	<0.01
Model 3	0.172			0.508			0.108		
TLM[f]		0.059	<0.001		0.064	<0.001		0.034	<0.001
TFM[f]		0.003	ns		0.003	ns		0.002	ns

For each model, the first row shows the R^2 of the equation, and the next row or rows show the partial η^2 and its statistical significance
[a] Controlled for age
[b] Controlled for height
[c] Controlled for age at menopause
[d] Controlled for bone area
[e] Dependent variables
[f] Independent variables
BMC, total body bone mineral content; BMD, total body bone mineral density; HIBMD, height-independent bone mineral density; TLM, total lean mass; TFM, total fat mass

body mass components were included in the same equation there was significant association of TLM with BMD and BMC in subjects with predominant lean mass, and of TFM with BMD and BMC in those with prevalent fat mass (Table 7).

Discussion

In this study, we evaluated the relationship of body composition with the whole body BMD, BMC, and HIBMD in

postmenopausal women. The rationale for further investigating the association of fat and lean mass with bone density is that their relative influence on bone density is still a subject of debate. The action of muscles, which exert mechanical stress on bone and therefore act positively on bone mass [14,15], is the theoretical background supporting the role of TLM on bone density, together with genetic factors that may also regulate their relationship [29]. More uncertain is the means by which fat tissue acts on bone mass. In fact, weight per se is not effective as a mechanical stimulus as there is no evidence of bone response to static loads [16,17,30]. Some authors have therefore suggested that increasing loads of fat mass act on bone mass by increasing the muscle-mediated skeletal dynamic load [16,17]. Other authors have reported an independent action of fat mass on BMD mediated by estrogen, leptin [18,31], insulin, or amylin [32,33].

We found that in all our subjects where the women were considered independently from their T-score and fat/lean fraction, both TLM and TFM were significantly associated with bone density, as already reported elsewhere [12,13]. We also found that between the two body mass components, TLM showed a better coefficient of correlation with bone density than TFM, which is in agreement with other authors [5,22], and that the association of the two body mass components with bone density became weaker when the HIBMD was considered rather than BMD or BMC, as shown by other authors [8,14]. Nevertheless, contrary to the reports of these authors [8,14], we still observed a statistical correlation between TLM and HIBMD which was not lower than that between TFM and HIBMD. This disagreement might be due to differences in the algorithms for separating lean from fat mass between the Norland and other dual X-ray systems, or even because of differences in the T-scores of the selected populations.

With regards to this, in our population we found that the relationships between the bone density measurements considered and the body mass components were different when women with and without osteoporosis were considered separately. In women without osteoporosis, only TLM was found to affect all three bone density measurements, while TFM did not. This gives more robust evidence than in the whole population of the strong association between TLM and the bone mineral density measurements considered, and supports the data of others workers [4,5]. Conversely, in osteoporotic women, both TFM and TLM were significantly and independently associated with BMD and BMC. However, the association of TLM with bone density in osteoporotic women was lower than that observed in women without osteoporosis, probably because of their lower TLM (and therefore muscle mass), which could be linked to a less effective muscle stimulation on bone. This lower muscle action on bone could also explain, at least partially, why bone density is also significantly affected by fat mass in osteoporotic people, despite their lower fat mass weight compared with nonosteoporotic women. In fact, the fat mass contribution to bone mineral density could become effective when the muscle-mediated mechanical loads are not strong enough to sustain bone density adequately by themselves. Our finding of the association of body fat mass and bone mass in osteoporotic women is not new, since Coin et al. [9] had already reported it in underweight malnourished osteoporotic older women. They had explained this fact by the possible role of adipose tissue as a source of estrogens [34] and leptin [35].

Finally, we observed that the lack of association between the two body mass components and HIBMD in osteoporotic women maybe due to the fact that height, which was used to derive the HIBMD from the BMD, was significantly associated with TFM and TLM, and therefore could have biased the effects of the body components on the HIBMD.

As variations in the TLM could affect the relationship of both body mass components with bone density, as observed in osteoporotic compared with nonosteoporotic women, we further investigated this topic by considering, among women without osteoporosis, two subgroups of women with predominantly fat or lean mass fractions. The same analysis was not performed for osteoporotic women because the number of those with a predominantly fat mass was not high enough to be acceptable for valid statistical analysis.

In the subjects with a predominantly lean mass, TLM had a better association with bone density than TFM, which lacked a lean mass-independent association with bone density. This further supported the theory that TLM, as an expression of muscle mass, exerts a positive influence on bone density [36,37], while in this case, fat mass had a complementary effect. Conversely, in nonosteoporotic subjects with a predominantly fat mass, only TFM effectively influenced bone density. This suggests that there is a critical ratio of fat mass above which its effect of favoring an increase in bone mass [38–40] is largely dominant over that of lean body mass. We also observed that the predominance of body fat mass did not equate with obesity based on the BMI definition [41], and therefore that the influence of fat mass on bone density in those with a predominance of body fat mass is not limited to obese people.

An overall examination of our data therefore suggests that both fat and lean body mass can influence bone mass, and that their relative effect on bone could be modulated by their absolute amount and by their ratio to total body mass weight. This study has some limitations: it is not population-based; it is limited to the evaluation of fat and lean mass by DXA; it considers BMD measured only at the total body site; it does not take into account other possible determinants of BMD, such as lifestyle habits, and the use of drugs; it is limited to the female sex and to single-equipment measurements; and it does not enquire into possible mechanisms of action of the body components on the bone density.

Nevertheless, the study highlights the possibility that different physiological or pathological conditions influencing the ratio of body mass components can modulate their effect on bone density, as shown by differences in the association of TLM and TFM with the bone density in postmenopausal women according to their T-score and TFM/TLM fraction.

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References

1. Kanis JA (2002) Diagnosis of osteoporosis and assessment of fracture risk. Lancet 359:1929–1936
2. Harris S, Dallal GE, Dawson-Huges B (1992) Influence of body weight on rates of change in bone density of the spine, hip, and radius in postmenopausal women. Calcif Tissue Int 50:19–23
3. Felson DT, Zhang Y, Hannan MT, Anderson JJ (1993) Effects of weight and body mass index on bone mineral density in men and women: the Framingham study. J Bone Miner Res 8:567–573
4. Li S, Wagner R, Holm K, Lehotsky J, Zinaman MJ (2004) Relationship between soft tissue body composition and bone mass in perimenopausal women. Maturitas 20:47(2):99–105
5. Chen Z, Lohman TG, Stini WA, Ritenbaugh C, Aickin M (1997) Fat or lean tissue mass: which one is the major determinat of bone mineral mass in healthy postmenopausal women? J Bone Miner Res 12:144–151
6. Kirchengast S, Peterson B, Hauser G, Knogler W (2001) Body composition characteristics are associated with the bone density of the proximal femur end in middle- and old-aged women and men. Maturitas 39:133–145
7. Reid IR, Ames R, Evans MC, Sharpe S, Gamble G, France JT, Lim TM, Cundy TF (1992) Determinants of total body and regional bone mineral density in normal postmenopausal women: a key role for fat mass. J Clin Endocrinol Metab 75:45–51
8. Reid IR, Plank LD, Evans MC (1992) Fat mass is an important determinant of whole body bone density in premenopausal women but not in men. J Clin Endocrinol Metab 75:779–782
9. Coin A, Sergi G, Benincà P, Lupoli L, Cinti G, Ferrara L, Benedetti G, Tomasi G, Pisent C, Enzi G (2000) Bone mineral density and body composition in underweight and normal elderly subjects. Osteoporosis Int 11:1043–1050
10. Gillette-Guyonnet S, Nourhashemi F, Lauque S, Grandjean H, Vellas B (2000) Body composition and osteoporosis in elderly women. Gerontology 46(4):189–193
11. Compston JE, Bhambhani M, Laskey MA, Murphy S, Khaw KT (1992) Body composition and bone mass in postmenopausal women. Clin Endocrinol 37:426–431
12. Lim S, Joung H, Shin CS, Lee HK, Kim KS, Shin EK, Kim HY, Lim MK, Cho SI (2004) Body composition changes with age have gender-specific impacts on bone mineral density. Bone 35: 792–798
13. Khosla S, Atkinson EJ, Riggs BL, Melton LJ 3rd (1996) Relationship between body composition and bone mass in women. J Bone Miner Res 11:857–863
14. Harris SS, Dawson-Hughes B (1996) Weight, body composition, and bone density in postmenopausal women. Calcif Tissue Int 59:428–432
15. Schultheis L (1991) The mechanical control system of bone in weightless space-flight and in aging. Exp Gerontol 26:203–214
16. Lanyon LE, Rubin CT (1984) Static vs dynamic loads as an influence on bone remodelling. J Biomech 17:897–905
17. Forwood MR, Turner CH (1995) Skeletal adaptations to mechanical usage: results from tibial loading studies in rats. Bone 17(Suppl 4):197S–205S
18. Elefteriou F, Takeda S, Ebihara K, Magre J, Patano N, Kim CA, Ogawa Y, Liu X, Ware SM, Craigen WJ, Robert JJ, Vinson C, Nakao K, Capeau J, Karsenty G (2004) Serum leptin level is a regulator of bone mass. PNAS 101(9):3258–3263
19. Thomas T, Burguera B (2002) Is leptin the link between fat and bone mass? J Bone Miner Res 17:1563–1569
20. Bolanowski M, Nilsson BE (2001) Assessment of human body composition using dual-energy X-ray absorptiometry and bioelectrical impedance analysis. Med Sci Monit 7(5):1029–1033
21. Taaffe DR, Cauley JA, Danielson M, Nevitt MC, Lang TF, Bauer DC, Harris TB (2001) Race and sex effects on the association between muscle strength, soft tissue, and bone mineral density in healthy elders: the Health, Aging and Body Composition Study. J Bone Miner Res 7(16):1343–1356
22. Aloia JF, Vaswani A, Ma R, Flaster E (1995) To what extent is bone mass determined by fat-free or fat mass? Am J Clin Nutr 61:1110–1114 (abstract)
23. Tothill P, Avenell A, Love J, Reid DM (1994) Comparisons between hologic, lunar and Norland dual-energy X-ray absorptiometers and other techniques used for whole-body soft tissues measurements. Eur J Clin Nutr 48:781–794
24. Tothill P, Avenell A, Reid DM (1994) Precision and accuracy of measurements of whole-body bone mineral: comparisons between hologic, lunar and Norland dual-energy X-ray absorptiometers. Br J Radiol 67:1210–1217
25. Gotfredsen A, Baeksgaard L, Hilsted J (1997) Body composition analysis by DEXA by using dynamically changing samarium filtration. J Appl Physiol 82:1200–1209
26. Haderslev KV, Staun M (2000) Comparison of dual-energy X-ray absorptiometry with four methods to determine body composition in underweight patients with chronic gastrointestinal disease. Metabolism 49:360–366
27. Hendel HW, Gotfredsen A, Andersen T, Hojgaard L, Hilsted J (1996) Body composition during weight loss in obese patients estimated by dual-energy X-ray absorptiometry and by total body potassium. Int J Obes Relat Metab Disord 20:1111–1119
28. Haderslev KV, Haderslev PH, Staum M (2005) Accuracy of body composition measurements by dual-energy X-ray absorptiometry in underweight patients with chronic intestinal disease and in lean subjects. Dyn Med 4:1
29. Seeman E, Hopper JL, Young NR, Formica C, Goss P, Tsalamandris C (1996) Do genetic factors explain associations between muscle strength, lean mass, and bone density? A twin study. Am J Physiol 270:E320–E327
30. Beck TJ, Oreskovic TL, Stone KL, Ruff CB, Ensrud K, Nevitt MC, Genant HK, Cummings SR (2001) Structural adaptation to changing skeletal load in the progression toward hip fragility: the study of osteoporotic fractures. J Bone Miner Res 16(6):1108–1119
31. Pasco JA, Henry MJ, Kotowicz MA, Collier GR, Ball MJ, Ugoni AM, Nicholson GC (2001) Serum leptin levels are associated with bone mass in non-obese women. J Clin Endocrinol Metab 86(5):1884–1887
32. Thrailkill KM, Lumpkin CK Jr, Bunn RC, Kemp SF, Fowlkes JL (2005) Is insulin an anabolic agent in bone? Dissecting the diabetic bone for clues. Am J Physiol Endocrinol Metab 289:(5)E735–745
33. Cornish J, Reid IR (2001) Effects of amylin and adrenomedullin on the skeleton. J Musculoskelet Neuronal Interact 2:15–24
34. Schindler AE, Ebert A, Friedrich E (1972) Conversion of androstenedione to estrone by human tissue. J Clin Endocrinol Metab 35:627–630
35. Thomas T, Gori F, Khosla S, Jensen MD, Burguera B, Riggs BL (1999) Leptin acts on human marrow stromal cells to enhance differentiation to osteoblasts and to inhibit differentiation to adipocytes. Endocrinology 140(4):1630–1638
36. Frost HM (1997) On our age-related bone loss: insights from a new paradigm. J Bone Miner Res 12:1539–1546
37. Burr DB (1997) Muscle strength, bone mass, and age-related bone loss. J Bone Miner Res 12(10):1547–1551
38. Reid IR (2002) Relationship among body mass, its components, and bone. Bone 31:547–555
39. Ostlund RE Jr, Yang JW, Klein S, Gingerich R (1996) Relation between plasma leptin concentration and body fat, gender, diet, age and metabolic covariates. J Clin Endocrinol Metab 81:3909–3913
40. Siiteri PK (1987) Adipose tissue as a source of hormones. Am J Clin Nutr 45:277–282
41. Movsesyan L, Tanko LB, Larsen PJ, Christiansen C, Svendsen OL (2003) Variations in percentage of body fat within different BMI groups in young, middle-aged and old women. Clin Physiol Funct Imaging 23:130–133