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Relationship between body composition and bone mineral content in young and elderly women

G. BEDOGNI†, C. MUSSI‡, M. MALAVOLTI†, A. BORGHI†, M. POLI†, N. BATTISTINI† and G. SALVIOLI‡

† Human Nutrition Chair, University of Modena and Reggio Emilia, Modena, Italy
‡ Geriatrics Chair, University of Modena and Reggio Emilia, Modena, Italy

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Summary. *Primary objective*: To study the relationship between bone mineral content (BMC), lean tissue mass (LTM) and fat mass (FM) in a large sample of young and elderly women.
Research design: Cross-sectional.
Methods and procedures: BMC, LTM and FM were measured by dual-energy X-ray absorptiometry in 2009 free-dwelling Caucasian women aged 63 ± 7 years (mean $\pm$ SD; range: 37–88 years). The majority of women were postmenopausal (96%).
Results: LTM explained 13% more variance of BMC than FM ($R^2_{adj} = 0.39$ vs 0.26, $p < 0.0001$) but weight (Wt) explained 5% more variance of BMC than LTM ($R^2_{adj} = 0.44$, $p < 0.0001$). The prediction of BMC obtained from LTM and FM ($R^2_{adj} = 0.46$, $p < 0.0001$) was only slightly better than that obtained from Wt. After the effects of age, Wt and height (Ht) on BMC were taken into account by multiple regression, the contribution of LTM and FM to BMC was just one-fifth of that of Wt (R^2_{adj} for full models $\leqslant 0.56$, $p < 0.0001$). After a further correction for bone area (BA), the contribution of LTM and FM to BMC was just one-tenth of that of BA and not different from that of Wt and Ht on practical grounds (R^2_{adj} for full models = 0.84, $p < 0.0001$). Thus, after inter-individual differences in age, Wt, Ht (and bone size) are taken into account, the relationship between body composition and BMC is substantially weakened.
Conclusions: In Caucasian women, (1) LTM is a stronger predictor of BMC than FM, but (2) Wt is a better predictor of BMC than body composition for practical purposes, and (3) Wt and body composition are not able to explain more than 46% of BMC variance.

1. Introduction

Ageing is accompanied by a progressive decline in bone mineral content (BMC) and density (BMD). The identification of the factors responsible for this decline may help prevent its pathological manifestations, i.e. osteopenia and osteoporosis (Christiansen 1995).

A direct relationship exists between body weight (Wt), BMC and BMD, with overweight subjects experiencing the lowest prevalence of osteoporosis and incidence of fractures (Wardlaw 1996). However, the contribution of fat and lean tissues to this protective effect of Wt is controversial (Taaffe, Villa, Holloway *et al.* 2000). While some studies have shown that lean tissues are stronger predictors of BMC and BMD than fat tissues (Aloia, Vaswani, Ma *et al.* 1995, Chen, Lohman, Stini *et al.* 1997), the opposite was shown by others (Compston, Bhambhani, Laskey *et al.* 1992, Reid, Ames, Evans *et al.* 1992, Reid, Plank and Evans 1992, Taaffe *et al.* 2000).

Decrease of BMC is however just one of the changes in body composition that occur with ageing (Van Loan 1996). A decrease in fat-free components other than BMC and an increase in fat mass (FM) were observed in elderly as compared with young women (Mazariegos, Wang, Gallagher *et al.* 1994). Apart from these modifications, the relationship between body compartments may change with ageing and

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this may have important implications for the prevention of osteoporosis. In order to answer this question, a study sample consisting of both young and elderly women should be employed.

The present study aimed therefore at assessing the contribution of lean and fat tissues to BMC in a large sample of young and elderly women.

2. Materials and methods

2.1. Subjects

The study hypothesis was tested on a large series of free-dwelling women evaluated at our Centre during a study on nutritional status and osteoporosis (Bedogni, Simonini, Viaggi *et al.* 1999). All the women recruited as of September 2001 who had never made use of oestrogens, diphosphonates or vitamin D were selected for this study ($n = 2009$). The study protocol was approved by the local Ethical Committee and all subjects gave their informed consent.

2.2. Anthropometry

Wt and height (Ht) were measured to the nearest 0.1 kg and 0.5 cm, respectively (Lohman, Roche and Martorell 1988). Body mass index (BMI) was calculated as Wt (kg)/Ht $(m)^2$ (World Health Organization 1998).

2.3. Dual-energy X-ray absorptiometry (DXA)

FM, lean tissue mass (LTM) and BMC were measured using a Lunar DPX-L densitometer (Lunar Corporation, Cary, NC, USA, software version 3.6). Percent fat mass (FM:Wt), percent lean tissue mass (LTM:Wt) and percent bone mineral content (BMC:Wt) were obtained by dividing FM, LTM and BMC, respectively, by Wt. The difference between body mass measured by DXA and Wt measured by scale was -0.5 ± 1.1 kg (mean $\pm$ SD; $n = 2009$). Although this difference is statistically significant ($p < 0.0001$, paired t-test), it amounts to only $-1 \pm 2\%$ (mean $\pm$ SD) of Wt and is therefore negligible on practical grounds.

2.4. Statistical analysis

Statistical analysis was performed on a MacOS computer using the Statview 5.0.1 (SAS, Chicago, IL, USA) and SPSS 10.0 (SPSS, USA) software packages. BMC was log-transformed to better approach the normal distribution. Between-group comparisons were performed by unpaired t-tests. The adjusted determination coefficient (R^2_{adj}) and the root mean square error (RMSE) obtained from simple and multiple regressions of BMC versus anthropometric dimensions, body compartments and age were used to quantify the contribution of these variables to BMC (Guo, Chumlea and Cockram 1996). To control the effects of age, Wt and Ht on the relationship between BMC and body composition, a multiple regression model was employed using age, Wt, Ht and LTM:Wt or FM:Wt as predictors. Another model added bone area (BA) to the above predictors to control the confounding effect of bone size on BMC (Prentice, Parsons and Cole 1994). All regressions were performed on log-transformed values to ensure homoscedasticity of residuals. Statistical significance was set to a value of $p < 0.05$ for all tests.

3. Results

The measurements of the study subjects are given in table 1. The 2009 studied women were aged 63 ± 7 years (mean $\pm$ SD; range: 37–88 years). A total of 786

Table 1. Measurements of the study subjects. Values are mean ± SD unless stated otherwise.

n	All 2009	Young 1223	Elderly 786
Age (years)	63 ± 7	58 ± 5	70 ± 4**
Wt (kg)	64.6 ± 9.3	64.9 ± 9.4	64.1 ± 9.1
Ht (m)	1.57 ± 0.06	1.58 ± 0.06	1.56 ± 0.06**
BMI ($kg \cdot m^{-2}$)	26.2 ± 3.6	26.1 ± 3.6	26.3 ± 3.5
FM (kg)	23.6 ± 6.5	23.8 ± 6.5	23.4 ± 6.6
FM:Wt (%)	36.0 ± 5.8	36.1 ± 57	35.9 ± 6.0
LTM (kg)	38.3 ± 4.0	38.5 ± 4.1	38.0 ± 3.9*
LTM:Wt (%)	59.8 ± 5.5	59.8 ± 5.4	59.8 ± 5.6
BMC (kg)†	2.1	2.2	2.0**
BMC:Wt (%)†	3.3	3.4	3.2**

† Geometric mean.
* $p = 0.01$ and ** $p < 0.0001$ versus young (unpaired *t*-test).
Abbreviations: Wt = weight; Ht = height; BMI = body mass index; FM = fat mass; LTM = lean tissue mass; BMC = bone mineral content.

women were aged 65 years or higher and were classified as 'elderly' while the remaining 1223 women were classified as 'young'. This classification was made for descriptive purposes only because age is a continuous variable whose association with body composition is better controlled for by regression analysis. As in our previous report (Bedogni *et al.* 1999), the majority of women were post-menopausal (96%).

As expected, age was higher ($p < 0.0001$) and Ht lower ($p < 0.0001$) in elderly than young women. However, Wt, BMI, FM and FM:Wt were not different between groups (p = NS). LTM was lower in elderly than young women ($p = 0.01$) but no difference was seen for LTM:Wt (p = NS). As expected, BMC and BMC:Wt were significantly lower in elderly than young women ($p < 0.0001$). The percentage of osteoporotic and osteopenic women was virtually the same observed in our previous report (Bedogni *et al.* 1999): 8% and 37% respectively.

The variance of BMC explained by age, BA, Wt, Ht, LTM and FM and selected combinations of them is given table 2. As expected (Prentice *et al.* 1994), BA was the strongest predictor of BMC ($R^2_{adj} = 0.80$). Even if LTM explained 13% more variance of BMC than FM ($R^2_{adj} = 0.39$ vs 0.26), Wt explained 5% more variance of BMC than LTM ($R^2_{adj} = 0.44$). Moreover, the prediction of BMC obtained from LTM and FM ($R^2_{adj} = 0.46$) was only slightly better than that obtained from Wt. Age explained only 8% of BMC variance. However, its use as a predictor with Wt increased the explained variance of BMC by 7% as compared to Wt alone ($R^2_{adj} = 0.51$). A lower increase in the explained variance of BMC (4%) was seen when age was used as a predictor with LTM and FM ($R^2_{adj} = 0.50$).

Taken together, these data suggest that even if LTM is a better determinant of BMC than FM, it is not superior to Wt. To test this hypothesis more thoroughly, we evaluated the contribution of LTM:Wt and FM:Wt to BMC after correction for age, Wt, Ht and BA (tables 3 and 4). (Using LTM instead of LTM:Wt or FM instead of FM:Wt in the same models was prone to multicollinearity—with variance inflation factors as high as 9 for the FM models—and was thus avoided.)

The contribution of LTM:Wt to BMC after correction for age, Wt and Ht was 18% of that of Wt (model A1 of table 3; standardized regression coefficient or $\beta = 0.12$ vs 0.67) and removing LTM:Wt from the model did not change the accuracy of the estimate. When BA was added to the predictors, the contribution of

Table 2. Variance of Bone Mineral Content explained by age, anthropometric variables and body compartments employed as single and multiple predictors. All calculations were performed on log-transformed values.

Predictor/s	R^2_{adj}*
BA	0.80
Wt, age†	0.51
FM, LTM, age†	0.50
FM, LTM	0.46
Wt	0.44
LTM	0.39
FM	0.26
Ht	0.23
Age†	0.08

* $p < 0.0001$ for all values
† Negative association.
Abbreviations: R^2_{adj} = adjusted coefficient of determination; BA = bone area; Wt = weight; FM = fat mass; LTM = lean tissue mass; Ht = height.

Table 3. Prediction of Bone Mineral Content from percent lean tissue mass after correction for age, weight and height (model A1) and for age, weight, height and bone area (model A2). All calculations were performed on log-transformed values.

	Coeff.	Std. coeff.	*p*-coeff.	R^2_{adj}	*p*	RMSE
Model A1						
Intercept	−1.01	−1.01	< 0.0001			
Age	−0.33	−0.24	< 0.0001			
Wt	0.78	0.67	< 0.0001	0.55	< 0.0001	0.05
Ht	0.75	0.18	< 0.0001			
LTM:Wt	0.22	0.12	< 0.0001			
Model A2						
Intercept	0.53	0.53	< 0.0001			
Age	−0.24	−0.17	< 0.0001			
Wt	0.07	0.06	0.0016	0.84	< 0.0001	0.03
Ht	−0.39	−0.09	< 0.0001			
BA	1.49	0.87	< 0.0001			
LTM:Wt	−0.16	−0.09	< 0.0001			

Abbreviations: coeff. = regression coefficient; std. coeff. = standardized regression coefficient; *p*-coeff. = *p*-value for the regression coefficient; R^2_{adj} = adjusted coefficient of determination; RMSE = root mean square error; Wt = weight; Ht = height; LTM = lean tissue mass, BA = bone area.

LTM:Wt to BMC was 10% of that of BA (model A2 of table 3; $\beta = 0.09$ vs 0.87) and not different from that of Wt ($\beta = 0.06$) and Ht ($\beta = 0.09$) on practical grounds. Similarly, the contribution of FM:Wt to BMC after correction for age, Wt and Ht was 23% of that of Wt (model B1 of table 4; $\beta = 0.16$ vs 0.70) and removing FM:Wt from the model did not change the power of the estimate. When BA was added to the predictors, the contribution of FM:Wt was 8% of that of BA ($\beta = 0.07$ vs 0.86) and not different from that of Wt ($\beta = 0.08$) and Ht ($\beta = 0.10$) on practical grounds. Thus, after inter-individual differences in age, Wt, Ht (and bone size) are taken into account, the relationship between body composition and BMC is substantially weakened.

Table 4. Prediction of Bone Mineral Content from percent fat mass after correction for age, weight and height (model B1) and for age, weight, height and bone area (model B2). All calculations were performed on log-transformed values.

	Coeff.	Std. coeff.	*p*-coeff.	R^2_{adj}	*p*	RMSE
Model B1						
Intercept	−0.44	−0.44	< 0.0001			
Age	−0.34	−0.24	< 0.0001			
Wt	0.82	0.70	< 0.0001	0.56	< 0.0001	0.05
Ht	0.70	0.16	< 0.0001			
FM:Wt	−0.16	−0.16	< 0.0001			
Model B2						
Intercept	0.11	0.11	0.0005			
Age	−0.24	−0.17	< 0.0001			
Wt	0.09	0.08	< 0.0001	0.84	< 0.0001	0.03
Ht	−0.43	−0.10	< 0.0001			
BA	1.48	0.86	< 0.0001			
FM:Wt	0.07	0.07	< 0.0001			

Abbreviations: coeff. = regression coefficient; std. coeff. = standardized regression coefficient; *p*-coeff. = *p*-value for the regression coefficient; R^2_{adj} = adjusted coefficient of determination; RMSE = root mean square error; Wt = weight; Ht = height; FM = fat mass, BA = bone area.

4. Discussion

The contribution of LTM and FM to the protective effect of Wt on BMC is controversial (Taaffe *et al.* 2000). The present study suggests that in postmenopausal women LTM is a better predictor of BMC than FM. Our results are thus in agreement with those of Chen *et al.* (1997) ($n = 50$) and Aloia *et al.* (1995) ($n = 164$), showing that LTM measured by DXA or fat-free mass measured by a variety of methods is the major determinant of BMC or total body calcium in postmenopausal women. An advantage of this study as compared to the others available in the literature is its very high number of subjects ($n = 2009$), which allows a greater degree of confidence in the results. However, a transversal study cannot by its very nature test any cause–effect relationship and only longitudinal studies should establish whether LTM is a more useful predictor of BMC than FM. Since there is preliminary evidence that LTM is inversely associated with the occurrence of bone fractures (Takada, Washino and Iwata 1997), the finding of LTM as the body compartment most strongly associated with BMC, suggests the opportunity of trials aimed at testing whether interventions targeted at increasing LTM can reduce the risk of osteoporosis. These longitudinal trials would also offer the possibility of separating more thoroughly the effect of LTM on BMC from that of FM.

Even if LTM emerges from this study as a better predictor of BMC than FM, it was not superior to Wt. In fact, after inter-individual differences in age, Wt and Ht were taken into account, the relationship between LTM and BMC was substantially weakened (this may be partly due to the higher precision with which Wt is measured as compared to LTM). This implies that Wt is to be preferred to LTM on practical grounds for selecting patients with low BMC. Wt is, in fact, simpler to measure and offers a better discrimination of normal, osteopenic and osteoporotic women than many other anthropometric indicators (Bedogni *et al.* 1999). This does not modify, however, the pathophysiological relevance of being able to separate the effects of LTM on BMC from those of FM by means of longitudinal studies.

Use of LTM and FM as predictors did increase the accuracy of the estimate of BMC as compared with LTM alone but this estimate was only slightly better than

that based on Wt. It is nonetheless of interest that the inclusion of age among the predictors did increase the power of the estimate.

However, the most relevant finding of this study is that age and body compartments leave a large portion of BMC variability unexplained. A value of 50% for the unexplained variance of BMC does indeed suggest that factors other than age and body composition influence BMC. Among these factors, genetics may play a role, as shown by twin studies, but environmental factors, especially nutrition and physical activity, may be involved too (Seeman, Hopper, Young *et al.* 1996, Nguyen, Howard, Kelly *et al.* 1998).

We conclude that in Caucasian women: (1) LTM is a stronger predictor of BMC than FM, but (2) Wt is a better predictor of BMC than body composition for practical purposes, and (3) Wt and body composition are not able to explain more than 46% of BMC variance.

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Address for correspondence: G. Bedogni, Human Nutrition Chair, Department of Biomedical Sciences, Faculty of Medicine and Surgery, University of Modena and Reggio Emilia, Via Campi 287, 41100 Modena, Italy. Email: giorgiobedogni@libero.it

Zusammenfassung. *Zielstellung:* Es soll das Verhältnis von Knochenmineralgehalt (BMC), Magermasse (LTM) und Fettmasse (FM) in einer grossen Gruppe von jungen und älteren Frauen untersucht werden.
Untersuchungsmethode: Querschnitt
Methodik: BMC, LTM und FM wurden mittels Dual-Energy-X-Ray Absorptiometry (DEXA) bei 2009 Kaukasischen Frauen mit freiem Wohnsitz im Alter von 63 ± 7 Jahren (Mittelwert $\pm$ SD, Min. 37 – Max. 88 Jahre) gemessen. Die Mehrzahl der Frauen war in der Postmenopause. (96%).
Ergebnisse: LTM erklärte 13% mehr Varianz des BMC als FM ($R^2_{adj} = 0.39$ vs 0.26, $p < 0.0001$), während das Gewicht (Wt) 5% mehr Varianz des BMC erklärt als die LTM ($R^2_{adj} = 0.44$, $p < 0.0001$). Die Vorhersage des BMC aus LTM und FM ($R^2_{adj} = 0.46$, $p < 0.0001$) war nur geringfügig besser als aus dem Gewicht. Berücksichtigt man den Einfluss von Alter, Gewicht und Grösse den BMC bei der Multiplen Regression, so beträgt der Beitrag der LTM und der FM am BMC gerade einmal 1/5 im Vergleich zum Gewicht (R^2_{adj} für das Gesamtmodell $= 0.56$, $p < 0.0001$). Nach einer weiteren Korrektur des Modells für die Knochenregion (BA), betrug der Beitrag der LTM und der FM am BMC nur noch 1/10 von dem der BA und unterschied sich praktisch nicht mehr von dem von Grösse und Gewicht (R^2_{adj} für des Gesamtmodell $= 0.84$, $p < 0.0001$). Folglich werden, bei Berücksichtigung der interindividuellen Unterschiede bei Alter, Gewicht, Körperhöhe (und Knochengrösse), die Zusammenhänge zwischen Körperzusammensetzung und Knochenmineralgehalt beträchtlich abgeschwächt.
Schlussfolgerungen: Bei Kaukasischen Frauen ist die LTM ein stärkerer Prädiktor für den BMC als für die FM, aber aus praktischen Gründen ist das Gewicht ein besserer Prädiktor für den BMC als die Körperzusammensetzung. Gewicht und Körperzusammensetzung erklären nicht mehr als 46% der Varianz des Knochenmineralgehaltes.

Résumé. *Objectif:* Etudier les rapports entre le contenu minéral osseux (CMO), la masse tissulaire maigre (MTM) et la masse grasse (MG) dans un vaste échantillon de femmes jeunes et âgées.
Type de recherche: transversale
Méthodes et procédures: On a mesuré les CMO,MTM et MG par absorptiométrie de rayons X d'énergie duale chez 2009 femmes caucasiennes non hospitalisées âgées de 63 ± 7 ans (moyenne $\pm$ ET; gamme de variation : 37–88 ans), la majorité des femmes étant ménopausées (96%).
Résultats: La MTM explique 13% de variance de CMO en plus que la MG ($R^2_{adj} = 0{,}39$ contre 0,26 $p < 0{,}0001$) mais le poids explique 5% de variance de CMO en plus que la MTM ($R^2_{adj} = 0{,}44$ $p < 0{,}0001$). La prédiction du CMO obtenue à partir de la MTM et de la MG ($R^2_{adj} = 0{,}46$ $p < 0{,}0001$) est seulement légèrement meilleure que celle obtenue par le poids. Après que les effets de l'âge, du poids et de la stature sur le CMO aient été pris en compte par régression multiple, la contribution de la MTM et de la MG au CMO est juste un cinquième de celle du poids (R^2_{adj} pour modèles totaux $= 0{,}56$ $p < 0{,}0001$). Après correction supplémentaire pour la surface osseuse (SO), la contribution de la MTM et de la MG au CMO est juste un dixième de celle de la SO et au point de vue de la pratique, semblable à celle du poids et de la stature (R^2_{adj} pour modèles totaux $= 0{,}84$ $p < 0{,}0001$). Après que les différences individuelles en âge, en poids, stature (et dimension de l'os) aient été prises en compte, la relation entre la composition corporelle et le CMO est substantiellement diminuée.
Conclusions: Chez les femmes caucasiennes, (1) La MTM est un meilleur prédicateur du CMO que la MG, mais (2) le poids est un meilleur prédicateur du CMO que la composition corporelle pour des fins pratiques et (3) le poids et la composition corporelle ne sont pas en mesure d'expliquer plus de 46% de la variance du CMO.