Relations between frame size and body composition and bone mineral status[1–3]

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ABSTRACT

Background: Frame size is a description of the supportive structure of the skeleton that is used to adjust for skeletal mass and size in measures of body composition and weight.

Objective: Data from the Fels Longitudinal Study were used to investigate the relation between bicristal, elbow, knee, biacromial, and wrist breadths and measures of total body fat (TBF), fat-free mass (FFM), bone mineral content (BMC), and bone mineral density (BMD) from dual-energy X-ray absorptiometry.

Design: The sample consisted of cross-sectional data from 224 white men and 277 white women aged 23–65 y. Multiple regressions were conducted with stature-adjusted measures of body composition and bone mineral status as dependent variables and age and frame size as independent variables.

Results: Frame-size measures were significantly and positively associated with all body-composition and bone mineral measures in bivariate analyses. In both men and women, the significant models explained more of the variance in measures of TBF (R^2 = 0.51 and 0.66, respectively) and FFM (R^2 = 0.35 and 0.39, respectively) than in measures of BMC (R^2 = 0.18 and 0.23, respectively) and BMD (R^2 = 0.08 and 0.18, respectively). Bicristal, knee, and wrist breadths were associated with TBF, and biacromial, knee, and wrist breadths were positively associated with FFM. Biacromial breadth was positively associated with BMC and BMD.

Conclusions: Frame size was more closely associated with TBF and FFM than with BMC and BMD. The association between frame size and body composition seems to be more structural than substantive. The relations between frame size and BMC and BMD are weak and apparently not related to body composition. *Am J Clin Nutr* 2002;75:1012–6.

KEY WORDS Frame size, bone mineral content, bone mineral density, body composition, total body fat, fat-free mass, Fels Longitudinal Study

INTRODUCTION

Frame size is a descriptive term for skeletal size and robustness that together comprise the body's supportive structure (1, 2). Frame size is commonly estimated by measuring externally the breadth of a bone or of sets of bones at the shoulders, hips, wrists, elbows, knees, and ankles (1). Distributions or summations of the values of these bony breadths are used to categorize individuals as having small, medium, or large frames or to calculate indexes of frame size (3). Despite the large number of possible bone measurements, categorization of frame size is most frequently made by using measures of elbow breadth alone in relation to national reference data. These data consist of selected percentiles for elbow breadth within stature ranges for children and adults (1, 4). These and other bone-breadth data for whites, blacks, and Hispanic Americans were collected as part of the National Health and Nutrition Examination Surveys conducted by the National Center for Health Statistics (5–8).

Classifying a person as having a small, medium, or large frame is intended to adjust for supposed skeletal mass and size in describing body composition or adjusting for ideal body weight (1). Measures of frame size are significantly and positively correlated with fat-free mass (FFM), body fatness, and bone mass (1, 4, 9–12) and with body weight at all ages (13). These bone–body mass relations are also affected by the stress of muscle activity and the mechanical loading effects of gravity (13), which should be greatest at weight-bearing locations on the skeleton. In light of these relations between frame size and body mass or body composition, it is reasonable to hypothesize that measures of large frame size, which reflect a large skeleton, are more strongly associated with a high bone mineral content (BMC) and a high bone mineral density (BMD) than are measures of small frame size. A high BMC and BMD should be necessary to support a large skeletal frame. Similarly, it is expected that a large skeletal frame would be associated with a greater amount of muscle and adipose tissue than would a small skeletal frame.

Associations of frame-size measures with values of total-body BMC and total-body BMD have not been reported. This lack of knowledge regarding the supposedly inherent association between

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TABLE 1
Age, weight, stature, and frame-size and body-composition measures in men and women[1]

Variable	Men (n = 224)	Women (n = 277)
Age (y)	40.6 ± 11.5	41.5 ± 11.6
Weight (kg)	81.3 ± 12.4	66.7 ± 13.1[2]
Stature (cm)	179.3 ± 6.5	165.9 ± 6.1[2]
Breadth		
Biacromial (cm)	41.1 ± 2.1	36.8 ± 1.7[2]
Bicristal (cm)	29.5 ± 1.9	29.7 ± 2.3
Knee (cm)	10.1 ± 0.5	9.5 ± 0.7[2]
Elbow (cm)	7.4 ± 0.4	6.5 ± 0.4[2]
Wrist (cm)	5.8 ± 0.3	5.0 ± 0.3[2]
TBF (kg)	20.2 ± 8.1	24.9 ± 10.2[2]
FFM (kg)	60.8 ± 6.9	41.7 ± 5.3[2]
BMC (kg)	3.1 ± 0.4	2.4 ± 0.4[2]
BMD (g/cm^2)	1.24 ± 0.09	1.16 ± 0.09[2]

[1] $\bar{x}$ ± SD. TBF, total body fat; FFM, fat-free mass; BMC, bone mineral content; BMD, bone mineral density.

[2] Significantly different from men, $P < 0.05$.

frame size and skeletal mass and density is because of earlier difficulties in measuring skeletal mass in living persons. In the present study, the relations between measures of frame size and estimates of body composition [FFM and total body fat (TBF)] and bone mineral status (BMC and BMD) from dual-energy X-ray absorptiometry were analyzed to address several questions. Are measures of frame size statistically and biologically related to FFM, TBF, BMC, and BMD? Are the relations of frame-size measures with bone mineral measures greater than the corresponding relations with body muscle and fatness? Are these relations a function of stature and age? Answers to these questions will help clarify the degree to which measures of frame size interlink the mass and density of the skeleton with other quantitative aspects of body composition. Knowledge of the extent of the relations between frame size and BMC, BMD, and body composition will help us to interpret the role that frame size plays in classifying individuals at risk of certain nutritional outcomes and diseases.

SUBJECTS AND METHODS

This cross-sectional study sample included 224 white men and 277 white women aged 23–65 y. Data were collected between 1990 and 1999 from participants in the Fels Longitudinal Study. The study protocol was approved by the institutional review board of Wright State University. A more complete description of the sample and the Fels Longitudinal Study was reported previously (14). The anthropometric data analyzed were stature, measured to the nearest 0.1 cm with the use of a stadiometer (Holtain Ltd, Croswell, Crymych, United Kingdom), and weight, measured to the nearest 0.1 kg with the use of a digital scale (Seca, Hamburg, Germany). Five frame-size measures were collected as breadths at the shoulders (biacromial breadth), hips (bicristal breadth), knee, elbow, and wrist; frame size was measured to the nearest 0.1 cm with the use of a sliding caliper (Holtain Ltd). These data were collected by using procedures similar to those in the third National Health and Nutrition Examination Survey (8) and the *Anthropometric Standardization Reference Manual* (15).

Body composition (FFM and TBF, both in kg) and bone mineral status [BMC (in g) and BMD (in g/cm^2)] were measured with the use of a DPX instrument (Lunar Corp, Madison, WI) at medium speed with 3.6z software (Lunar Corp). The total tissue mass of the whole body was calculated as the sum of the values for lean and fat soft tissue and BMC. The FFM of the whole body was calculated as the sum of the values for lean tissue and BMC.

Age-adjusted Pearson correlation coefficients between the 5 frame-size measures and weight, TBF, FFM, BMC, BMD, and stature were calculated by sex. To clarify the associations of frame-size measures with body composition and bone mineral status, a multivariate model was used. The body composition and bone mineral variables were first adjusted for stature to remove the effects of differences in linear body size among individuals on the relations. Multiple regression analyses by sex were then performed with the stature-adjusted body composition and bone mineral measures as the dependent variables and the 5 frame-size measures and age as independent variables. Age was included as an independent variable because changes in adult body composition occur with increasing age as well as with changes in stature. Only those independent variables that were significantly associated with the dependent variables were included in the multiple regression models. The significance level for all tests was $P < 0.05$, and SAS (16) was used for all statistical procedures.

RESULTS

Means and SDs for all variables are presented in **Table 1**. The mean age of the men and women was not significantly different (≈41 y). The men were significantly heavier and taller than the women and had significantly higher FFM, BMC, and BMD as well as broader shoulders, elbows, knees, and wrists than did the women. The women had significantly higher TBF than did the men. There was no significant difference between the sexes in bicristal breadth.

The significant age-adjusted Pearson correlation coefficients between measures of frame size and weight, measures of body composition and bone mineral status, and stature are presented in **Table 2** by sex. From a simple descriptive standpoint, there is a pattern among these correlation coefficients. Bicristal, knee, and elbow breadths were more highly correlated with weight, TBF, and FFM than were biacromial and wrist breadths in both the men and the women, but these differences were greater in the women. In the men, the correlation coefficients between the frame-size measures and FFM and stature were similar. The corresponding correlations in the women were slightly more variable than in the men. In the women, knee breadth was less correlated with stature than was wrist breadth, whereas in the men the opposite was true. The 5 frame-size measures were more highly correlated with BMC than with BMD in both the men and the women. With a few exceptions, the frame-size measures were the least correlated with BMD. The correlations for BMC were similar to those for TBF, FFM, and stature in both the men and the women. In the women, biacromial breadth was more highly correlated with both BMC and BMD than were the other breadths, whereas in the men, the elbow and wrist breadths were most highly correlated with BMC and BMD.

On the basis of these age-adjusted correlations, bicristal and knee breadths appear to be associated more highly with the mass

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TABLE 2
Significant age-adjusted Pearson correlation coefficients between frame-size measures and weight, stature, and body-composition measures[1]

	Weight	TBF	FFM	BMC	BMD	Stature
Men						
Breadth						
Biacromial	0.51	0.22	0.59	0.45	0.26	0.44
Bicristal	0.76	0.58	0.60	0.43	0.22	0.42
Knee	0.71	0.48	0.65	0.46	0.20	0.43
Elbow	0.59	0.35	0.59	0.52	0.28	0.42
Wrist	0.45	0.17	0.59	0.48	0.28	0.36
Women						
Breadth						
Biacromial	0.55	0.44	0.57	0.59	0.43	0.49
Bicristal	0.79	0.71	0.65	0.48	0.31	0.43
Knee	0.82	0.78	0.58	0.47	0.36	0.25
Elbow	0.72	0.62	0.66	0.48	0.33	0.39
Wrist	0.37	0.21	0.56	0.43	0.23	0.39

[1] TBF, total body fat; FFM, fat-free mass; BMC, bone mineral content; BMD, bone mineral density. All coefficients were significantly different from zero, $P < 0.05$.

and adiposity compartments of the body in men and women, whereas all the breadths are equally descriptive of FFM. These findings imply that persons with large frames at the hips and knees tend to have greater body weight and more muscle and fat than do persons with small frames at these body locations. Neither the significance of the hierarchy among these correlation coefficients nor the significance of the differences between the sexes in these coefficients was determined.

The results of the multiple regression analyses on the stature-adjusted variables—with the R^2 values for TBF, FFM, BMC, and BMD and the significant regression coefficients for age and the 5 frame-size measures—for the men and the women are shown in **Table 3**. The R^2 values were highest for TBF in both the men and the women; 51–66% of the variance in body fatness after adjustment for stature was explained by the frame-size measures. In the men and the women, the R^2 for FFM was smaller than that for TBF, but the frame-size measures still accounted for 35–39% of the variance in FFM after adjustment for stature. Thus, measures of frame size were significantly associated with amounts of fat and muscle in both the men and the women and accounted for a large amount of the interindividual variance in these body-composition variables after adjustment for stature. In the men and the women, the R^2 values for BMC and BMD were smaller than those for TBF and FFM and were higher in the women than in the men. The lowest R^2 values in both sexes were for BMD. These results indicate that, overall, the frame-size measures were more strongly associated with measures of fat and muscle than with measures of bone mineral status in both the men and the women. Overall, these frame-size measures were more strongly associated with BMC than with BMD after adjustment for stature, and both of these associations were stronger in the women than in the men.

In the men, broad hips and knees and narrow wrists were significantly associated with high TBF, whereas broad shoulders, knees, and wrists were significantly associated with high FFM. There was a small significant increase in TBF with age. Elbow breadth was not a significant independent predictor of TBF or FFM after adjustment for stature. In the women, broad hips, knees, and elbows and narrow wrists were significantly associated with high TBF. As in the men, broad shoulders, knees, and wrists were also significantly associated with high FFM.

In the men, biacromial and wrist breadths were significantly and positively associated with BMC and BMD. In the women, biacromial and knee breadths were significantly and positively associated with BMC and BMD, but wrist breadth was not. In the women, the amount and density of bone decreased significantly with age after adjustment for stature (Table 3). Bicristal and

TABLE 3
Significant regression coefficients between frame-size measures and stature-adjusted body composition and bone mineral measures in men and women[1]

	Men				Women			
Independent variable	TBF ($R^2 = 0.51$)	FFM ($R^2 = 0.35$)	BMC ($R^2 = 0.18$)	BMD ($R^2 = 0.08$)	TBF ($R^2 = 0.66$)	FFM ($R^2 = 0.39$)	BMC ($R^2 = 0.23$)	BMD ($R^2 = 0.18$)
Intercept	−77.03[2]	−86.79[2]	−3.45[2]	−0.61[2]	−91.38[2]	−52.54[2]	−2.23[2]	−0.56[2]
Age	0.14[2]	—	—	—	—	−0.09[2]	−0.006[2]	−0.002[2]
Breadth								
Biacromial	—	0.86[2]	0.03[3]	0.008[3]	—	0.42[3]	0.04[2]	0.01[2]
Bicristal	2.18[2]	—	—	—	1.55[2]	—	—	—
Knee	4.73[2]	2.33[3]	—	—	7.48[2]	2.53[2]	0.10[2]	0.03[2]
Elbow	—	—	—	—	2.88[3]	—	—	—
Wrist	−7.05[2]	4.86[3]	0.39[2]	0.05[3]	−8.77[2]	3.46[2]	—	—

[1] TBF, total body fat; FFM, fat-free mass; BMC, bone mineral content; BMD, bone mineral density. $P < 0.001$ for all values unless noted otherwise.
[2] $P < 0.001$.
[3] $P < 0.05$.

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elbow breadths were not significant determinants of BMC or BMD in either the men or the women. Although these associations between frame size and bone mineral status were independent of stature, the strength of the associations was small in comparison with that of the corresponding associations between frame size and TBF and FFM.

DISCUSSION

The distributions of stature, weight, and body breadths for these adults were within the 5th and 95th percentiles of corresponding values for adults at the same ages from national reference data (6). The differences between the sexes in this sample in the mean values presented in Table 1 were as expected for normal adults. These differences reflect the basic sexually dimorphic patterns in body size and composition among men and women.

The age-adjusted Pearson correlation coefficients presented in Table 2 are similar in value to coefficients between frame-size measures and FFM and TBF reported previously by Himes and Bouchard (9). The values of the coefficients between bicristal and knee breadths and TBF in the present sample are larger than those reported previously (9). A possible explanation for these differences, besides sampling, is that body composition in the present study was estimated with the use of dual-energy X-ray absorptiometry rather than hydrodensitometry (9). In the previous study, the correlations with TBF were adjusted (partial correlations) for either stature or FFM. The adjustment for stature produced little effect on the coefficients. The partial correlation coefficients with TBF are not directly comparable with those of the present study but do indicate the differential relations between measures of frame size and body fatness (9).

On the basis of the age-adjusted Pearson correlation coefficients, there were positive associations between each frame size measure and body composition, but some frame sites on the body were more strongly associated than others with particular compartments of the body's composition (Table 2). From these initial results, bicristal and knee breadths appeared to be the breadths most associated with fat and lean tissues. There was not a lot of difference between the breadths in their associations with BMC or BMD, and these associations were less than those with TBF and FFM (Table 2). However, these findings are to some degree confounded by the effects of stature because tall persons generally have a larger overall body size than do short persons.

To discern more clearly the independent associations of these frame-size measures with body composition and bone mineral status, a sex-specific multiple regression was conducted in which the differences in stature between the participants were controlled for. Among the 5 frame-size measures used for this analysis (Table 3), the breadths of the shoulders, hips, knees, and wrists accounted for most of the associations with measures of soft and bony tissues. The men and women in the present sample with broad hips and knees had more TBF than did those with small frame measures at these body locations, irrespective of age or stature. At the same time, the men and women with broad shoulders and knees had more FFM than did those with small frame measures at these body locations, irrespective of age or stature. The role of the knees in these associations is clearly structural because the legs have to support the trunk regardless of the amount of muscle or fat on it. There may also be an association between ankle breadth and measures of soft and bony tissues, but ankle breadth was not measured in the present study.

Broad shoulders represent a masculine physique, ie, greater muscularity, whereas broad hips represent a feminine physique, ie, greater adiposity. Thus, the associations between the breadths of the shoulders and hips and the amount of lean and fat tissue, respectively, reflect the basic sex differences in body size and composition. However, men with broad hips have a greater degree of adiposity than do men with narrow hips. What is not understood is whether the increased adiposity causes the broadening of the hips or whether broad hips allow for a greater ability to carry additional fat. The developmental aspects of these associations in childhood are an even greater mystery.

Wrist breadth is potentially the best discriminator of an association between frame size and amounts of fat and muscle, independent of stature. Broad wrists are negatively associated with TBF and positively associated with FFM and vice versa. It has been reported that wrist and ankle breadths are poorly associated with body fatness (1). In the present study, ankle breadth was not measured, but wrist breadth was less correlated with TBF than were the other frame-size measures studied (Table 2). In contrast, in the multiple regression analyses (Table 3), wrist breadth was significantly and negatively associated with TBF and significantly and positively associated with FFM in both the men and the women after adjustment for stature. This suggests that wrist breadth contributes information regarding the size of the upper appendages that is associated with amounts of fat and lean tissue. There may be some linkage between the breadths of the trunk and the wrists that is associated with amounts of lean and fat tissue in the body. However, elbow breadth, the customary measure of frame size, was not significantly associated with measures of body composition and bone mineral status, except for a limited association with TBF in the women. Elbow breadth is probably more related to stature than it is to amounts of lean or fat tissue or bone.

One reason for accounting for frame size in relation to body composition has been to help identify persons with a health risk. The present findings indicate that there is an intrinsic association between frame size and total body composition because adiposity and muscularity are positively associated with frame size, independent of stature. It is possible to have a high degree of muscularity and a large frame without a lot of adipose tissue but the converse is not true. This relation does not address the risk associated with the location of the adipose tissue in the body. These findings also tend to support the notion that stress from a high degree of muscularity positively affects the size of the skeleton. However, similar stress from an excess of body fat would appear to have an opposite effect on skeletal size.

In the present study, the men and women with large frames tended to have higher BMC than did those with small frames, irrespective of age and stature. The frame-size measures explained a greater proportion of the variance in BMC than in BMD. These findings indicate that large frames are associated slightly with greater absolute amounts of bone than are small frames but are not associated with the amount of bone per unit area. However, the men with broad shoulders and wrists and the women with broad shoulders and knees tended to have somewhat denser bones than did the men and women with narrow shoulders, wrists, and knees.

In the present study, frame size was found to be more closely associated with TBF and FFM than with BMC and BMD. The association between frame size and body composition is apparently

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more structural than substantive. Large frames at the shoulders, arms, and knees are related to carrying large amounts of muscle. Conversely, wide hips and knees are associated with increased amounts of adipose tissue throughout the whole body. This dimensional aspect of the skeletal frame in relation to muscle and adipose tissue is not significantly related to differences between persons in skeletal mass and density. The size of a person's frame at these measurement locations is not closely related to the density of their bones and is probably also not closely related to the strength of their bones. The relations between frame size and BMC and BMD are small and are apparently not related to a person's body composition, because stature was included in the regression models. There may be architectural aspects of the internal structure of bone that are related to frame-size measures, but these were not detected.

There were no severely obese persons in the present study; thus, the associations that we uncovered were only for persons of normal weight. These associations were for the body as a whole and not for specific skeletal regions such as the spine or the hip; measurements of body composition and bone mineral status at specific skeletal regions can be made with the use of dual-energy X-ray absorptiometry, but such measurements were not made in the present study. Some frame-size measures are more difficult to collect in obese persons, as are measures of body composition. Thus, any extension or inference of these findings to an obese sample should be done with caution. Additional research is also indicated to explore the relations between frame size and bone density and strength and the possible health implications of these relations.

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