Gender differences in the relationships between lean body mass, fat mass and peak bone mass in young adults

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Running title: body composition and peak bone mass

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Mini abstract

The relationships between fat mass and bone mass in young adults are unclear. In 1183 young Australians, lean body mass had a strong positive relationship with total body bone mass in both genders. Fat mass was a positive predictor of total body bone mass in females, with weaker association in males.

Abstract

Purpose: Body weight and lean body mass are established as major determinants of bone mass, but the relationships between fat mass (including visceral fat) and peak bone mass in young adults are unclear. The aim of this study was to evaluate the associations between bone mass in young adults and three body composition measurements: lean body mass, fat mass and trunk-to-limb fat mass ratio (a surrogate measure of visceral fat).

Methods: Study participants were 574 women and 609 men aged 19-22 years from the Raine study. Body composition, total body bone mineral content (TBBMC), bone area and areal bone mineral density (TBBMD) were measured using DXA.

Results: In multivariate linear regression models with height, lean body mass, fat mass and trunk-to-limb fat mass ratio as predictor variables, lean mass was uniquely associated with the largest proportion of variance of TBBMC and TBBMD in males (semi-partial R^2 0.275 and 0.345, respectively) and TBBMC in females (semi-partial R^2 0.183). Fat mass was a more important predictor of TBBMC and TBBMD in females (semi-partial R^2 0.126 and 0.039, respectively) than males (semi-partial R^2 0.006 and 0.018, respectively). Trunk-to-limb fat mass ratio had a weak, negative association with TBBMC and bone area in both genders (semi-partial R^2 0.004 to 0.034).

Conclusions: Lean body mass has strong positive relationship with total body bone mass in both genders. Fat mass may play a positive role in peak bone mass attainment in women but the association was weaker in men; different fat compartments may have different effects.

Introduction

Body weight is a major determinant of bone mass, reflecting in part the adaption of the skeleton to mechanical loading. As body mass is composed of lean, fat and bone mass, evaluating the role of lean and fat mass on bone has been the focus of many studies. Lean body mass has consistently been found to be positively associated with measurements of bone mass or density in studies of different age groups [1-5], which may reflect direct mechanical effects of muscle on bone, genetic factors that regulate both components [2] and lifestyle factors such as physical activity [6] that influence both. The findings of studies reporting relationships between fat mass and measurements of bone are less consistent, with the relationship being reported as positive [1-4], negative, or absent [5, 7-9]. This heterogeneity in findings could be due to the rather complex mechanisms underlying the relationship between fat and bone. As well as effects of mechanical loading, adipose tissue may indirectly influence bone metabolism by the action of hormones and cytokines. It has been suggested that fat may stimulate bone formation by producing estrogens through the aromatization of androgens, and increased insulin and peripheral leptin levels [10, 11], but fat may also have deleterious effects on bone due to increased inflammatory cytokines [12].

As attainment of an optimal peak bone mass is considered the best protection against subsequent age-related bone loss and susceptibility to bone fracture [13], it is important to understand the association between each of lean and fat mass and peak bone mass attained at skeletal maturity, particularly in the current context of the increased number of obese and overweight people worldwide and the resulting negative health consequences [14]. However, only a few studies have evaluated the association of lean and fat mass with peak bone mass in young adults, and the results were conflicting [2, 3, 5, 8, 15]. In some studies, data from young adults have not been analysed separately, but have been combined with other age groups such as adolescents [5] or middle-aged men [8]; interpretation of such data is difficult because of the effects of age on sex hormone levels and body composition, as well as interactions between these two potential confounders. During puberty and adolescence, gender differences in body composition become more pronounced, with a dramatic increase in lean body mass in boys and slight increase in fat mass in girls [16]. Gender differences in the association between body composition and bone density have been shown in middle age and older adults [17, 18], but have not been well studied in young adults. Furthermore, most studies examining the relationship between fat mass and bone have examined only total fat mass [2, 3, 5, 8, 15]. There are marked differences in metabolic activity between subcutaneous and visceral fat, and recent studies in adolescent girls and young women suggest that these fat compartments may have opposite relations with bone mass [19-21].

To address these uncertainties, we examined the relationships between lean and fat mass and bone mass in a well-characterised cohort of young adults aged 19-22 years. In this relatively homogeneous population, we evaluated the relationships between each of lean mass, fat mass and trunk-to-limb fat mass ratio (as a surrogate marker of visceral fat) with three bone parameters: total body bone mineral content (BMC, reflecting the amount of bone mineral), bone area (reflecting the size of bone) and areal bone mineral density (BMD). A recent longitudinal study of Canadian children followed up to 30 years of age showed that bone mass reaches a plateau at approximately 18 years of age in girls and 20 years in boys [22]; thus our cohort is of an ideal age to examine relationships between body composition and peak bone mass.

Methods

Participants

The study participants were from the West Australian Pregnancy Cohort (Raine) Study. This study recruited 2,900 pregnant women from the public antenatal clinic at King Edward Memorial Hospital and surrounding private clinics in Perth, Western Australia between May 1989 and November 1991, and has subsequently followed the offspring as a birth cohort study. Inclusion criteria were a gestational age between 16 and 20 weeks, English language skills sufficient to understand the study demands, an expectation to deliver at King Edward Memorial Hospital, and an intention to remain in Western Australia to enable future follow-up of their child [23]. Compared with the general Western Australian population, the Raine cohort at birth was characterized by higher proportions of high-risk births and fathers employed in managerial and professional positions, however comparison of participants remaining in the study at the 14-year follow-up suggested attrition resulted in a cohort comparable with the general population [24]. Of the 2,868 children born to mothers recruited to the Raine Study, a total of 1,306 participants participated in the physical examination component of the 20 year cohort follow-up. Twenty-eight of these participants did not undergo a dual energy X-ray absorptiometry (DXA) scan for the following reasons: participant was pregnant or breastfeeding, had difficulty adopting the supine position for the required scan time, refused or the DXA machine was not available. Six hundred and seventy males and 608 females underwent DXA scanning. Data from 95 participants were excluded due to the presence of artefacts in the region of interest or because participants were too tall or large for their body to fit in the scanning area. Data from 574 females and 609 males aged 19-22 years were included in this analysis. This study was approved by the Human Research Ethics Committee of University of Western Australia. Written informed consent was obtained from each participant.

Whole body DXA

Whole body scan was performed using DXA on a Norland XR-36 densitometer (Norland Medical Systems, Inc., Fort Atkinson, WI, USA), according to manufacturer-recommended procedures. Analysis of scans was performed using built-in machine software (version 4.3.0) and the regions of interest for head, trunk, arms and legs manually placed by trained study staff according to a standard analysis protocol. All analyses were checked by one researcher (JM) for consistency. The analysis provided estimates of whole body fat mass (g), lean mass (bone free) (g), BMC (g), bone area (cm^2) and areal BMD (mg/cm^2). Trunk-to-limb fat mass ratio was calculated as trunk fat mass divided by fat mass of arms and legs, and used as the surrogate of visceral fat. A previous study showed that trunk-to-limb fat mass ratio has a good correlation with visceral fat tissue area measured by MRI at the level of L4 vertebra [25]. Percentage body fat mass was calculated as (fat mass divided by total mass) × 100 and percentage trunk fat mass was calculated as (trunk fat mass divided by total mass) × 100. Fat mass index was calculated as fat mass (kg)/height $(m)^2$ and lean mass index was calculated as lean mass (kg)/height $(m)^2$. Daily calibration was performed on the DXA machine prior to each scanning session. The densitometer had a variation in precision of <2.0% for the measured site at standard speed.

Other assessments

Weight and height were measured with subjects dressed in light clothes. Body weight was measured to the nearest 0.1 kg. Body height was measured with a hypsometer to the nearest 0.1 cm. Body mass index (BMI) was calculated as weight (kg)/height $(m)^2$.

Data analysis

Variables are presented as means ± standard deviations (SD) by gender. Comparisons between males and females were made by Student's t-test and analysis of covariance (ANCOVA). Correlation coefficients between body composition (lean body mass, fat mass and trunk-to-limb fat mass ratio) and bone measures (total body BMC, bone area and BMD) were calculated using

Pearson's correlation analysis separately for each gender. Linear regression analysis was used to evaluate the relationships between body composition and bone measures, with total body BMC, bone area and BMD as dependent variables; lean mass, fat mass and trunk-to-limb fat mass ratio as the predictor variables; and age and height as covariates. The interaction terms for gender and each body composition measure were tested in each model. To account for the inter-correlation between body size and body composition measures, the semi-partial R^2 for each predictor variable was calculated to estimate the proportion of the variance associated uniquely with each predictor. Collinearity was tested in each regression model, and a variance inflation factor (VIF) value larger than 10 was considered as showing the existence of collinearity or near collinearity [26]. The adequacy of the assumption of linearity of associations for each predictor adjusted for other predictors and covariates was assessed by examination of the partial regression plots for each model. The normality and independence of the residuals and the homogeneity of variance of each model were checked using residual plots (normal probability plot and plot of residuals vs predicted values). Statistical significance level was set at $P < 0.05$ (two-tailed). All analyses were performed using IBM SPSS (version 20, IBM, Chicago, IL, USA).

Results

Descriptive statistics

The mean age of male participants was 20.1 ± 0.5 years and female 20.0 ± 0.4 years. Males were taller and heavier compared with females but there was no significant difference in BMI (**Table 1**). The percentage of participants with normal BMI (20-25 kg/m^2) was similar in males and females (54.5% vs 52.6%), but a higher proportion of females were underweight (12.2% in males vs. 18.3% in females), whereas a higher proportion of males were overweight (BMI 25-30 kg/m^2 24.3% in males vs 19.2% in females). The prevalence of obesity (BMI >30 kg/m^2) was similar in males and females (9.1% vs 9.9%). Young men had significantly higher lean body mass and lean mass index, whereas women had significantly higher fat mass, fat mass index, percentage body and trunk fat and a higher trunk-to-limb fat mass ratio (Table 1). Total body BMC, bone area and BMD were significantly higher in males compared with females (Table 1). Adjusting for body weight, height and total body bone area, males still had significantly higher size-adjusted total body BMC than females (estimated mean ± SE: 2,993 ± 11 vs 2,881 ± 11 g, $P < 0.001$).

Correlation analyses

The correlation coefficients between anthropometry and body composition variables with total body bone parameters are shown in **Table 2**. Body weight had moderate correlation with all bone parameters in both genders (r = 0.54-0.69). In both males and females, height was strongly correlated with bone area (r = 0.73-0.82), moderately correlated with total body BMC (0.58-0.62), but only weakly correlated with total body BMD (r = 0.26-0.29). Lean body mass had moderate to strong correlation with all bone measures in males (r = 0.66-0.80), and the correlation was slightly weaker in females (r = 0.50-0.66). Fat mass was weakly correlated with bone measures in males (r = 0.19 – 0.26), and moderately correlated in females (r = 0.40-0.50). Trunk-to-limb fat mass ratio had a very weak inverse correlation with total body bone area (r = -0.13) in males, and a weak positive correlation with BMD (r = 0.15) in males and with total body BMC and BMD in females (r = 0.18-0.25).

Regression analyses

In the regression analysis for all three bone parameters, age was not a significant predictor in any of the models, indicating that there was no significant additional contribution of age for total body BMC, bone area and BMD in the narrow age range of study participants. Accordingly, age was not retained in the final models. For total body BMC, there was significant gender and fat mass interaction ($P < 0.001$), indicating gender-specific associations between fat mass and total body BMC. For total body bone area, there were significant interactions between gender and all three body composition measures (lean body mass $P = 0.002$; fat mass $P <0.001$; trunk-limb-fat mass ratio, $P = 0.050$), indicating gender-specific associations between measures of body composition and bone area. There were no significant interactions between gender and body composition measures for total body BMD. All subsequent analysis was performed separately for each gender. **Table 3** shows the regression coefficients of predictor variables and corresponding semi-partial R^2 values, which can be interpreted as the proportion of variability in each outcome specifically explained by each predictor.

Total body BMC: In males, lean body mass was the most significant predictor of total body BMC, uniquely associated with 27.5% of the variance, whereas fat mass only explained a small proportion of the variance (1.8%). In females, both lean and fat mass were important predictors of total body BMC, uniquely associated with 9.9% and 12.6% of the variance, respectively. The estimated increase in total body BMC associated with each additional kilogram of lean mass was 35.7g in men and 25.2g in women, whereas for fat mass, each additional kilogram was associated with BMC increases of 9.4 g in men and 15.0 g in women (**Figure 1**). In both genders, height had a positive association with total body BMC, whereas trunk-to-limb fat mass ratio had a negative association with total body BMC. Each additional 0.1 unit increase in the trunk-to-limb fat mass ratio was associated with a decrease in total body BMC of 16.4 g in males and 23.0 g in females.

Total body bone area: In both men and women, height was the most significant predictor of total body bone area, accounting for 21.1% and 26.6% of the variance, respectively. In males, both lean and fat mass had a positive association with bone area. In females, fat mass was an important predictor of bone area and was uniquely associated with 14.8% of the variance, whereas lean mass was only of borderline significance. In both genders, trunk-to-limb fat mass ratio had a negative association with total body bone area, and could account for 2.3% of the variance in male and 3.4% in female. Each additional 0.1 unit in trunk-to-limb fat mass ratio was associated with a decrease in total body bone area of 17.6 cm^2 in males and 23.1 cm^2 in females.

Total body BMD: Lean body mass was the most significant predictor of total body BMD, with a stronger predictive value in males than females. It was uniquely associated with 34.5% of the variance in males and 18.3% in females. Fat mass was associated with 3.9% of the variance in female, but was only of borderline significance in males. The estimated increase in total body BMD associated with each additional kilogram of lean mass was 10.1 mg/cm^2 in males and 8.7 mg/cm^2 in females, whereas for fat mass each additional kilogram was associated with total body BMD increases of 1.3 and 2.1 mg/cm^2 in males and females, respectively (Figure 1). Height had a negative relationship with total body BMD in males after accounting for lean and fat body mass, and was not a significant predictor in females. Trunk-to-limb fat mass ratio was not a significant predictor of total BMD in either gender.

Discussion

In this study of young Australian adults, we found that lean body mass was strongly associated with total body BMC and BMD in both genders, uniquely accounting for 9.9-34.5% of the variation in these parameters, and associated with a greater proportion of the variance in males. Our study demonstrated gender differences in the association between fat mass and peak bone mass. Whereas fat mass was strongly associated with peak bone mass in females, accounting for 12.6% and 3.9% of the variation in total body BMC and BMD, respectively, it accounted for less than 2% of variation in these parameters in males. Trunk-to-limb fat mass ratio, which we used as a surrogate measure of visceral fat [25], had a weak negative association with total body bone area and consequently total body BMC in both genders.

There is growing concern regarding the global epidemic of obesity. In 2008, 1.5 billion people aged 20 years or above were overweight, and among them over 200 million men and nearly 300 million women were obese [14]. Despite the adverse health consequences of overweight and obesity, body weight and BMI are major determinants of bone density, and a meta-analysis of population-based cohort studies showed that low BMI is a risk factor for total, osteoporotic and hip fracture in both men and women [27]. As attainment of an optimal peak bone mass is considered the best protection against subsequent age-related bone loss and fracture [13], it is important to understand determinants of peak bone mass including the role of lean mass, fat mass and different fat compartments.

Our study showed a positive relationship between fat mass and bone in female participants, which is consistent with the findings of previous studies in young women [2, 3], but not with a study that included adolescent girls in the study population [5]. In young men, we found fat mass had a weak but positive association with total body bone measures, whereas the relationships observed in previous studies with young men were conflicting, with some studies showing a positive association

[2], and others an inverse or no association [5, 8]. The differences in findings could in part be due to the bone sites assessed and the techniques used. In a study with opposite sex twins, fat mass was positively correlated with total body and hip BMD in women aged under 50 years, but not in men of similar age [17]. Overall these results together with the findings of our study suggest that fat mass plays a less important role in determining bone mass in young males, compared to young females.

Our study demonstrated that lean mass had a greater association with total body BMC and BMD than fat mass (kilogram for kilogram) in both genders, with the differences more pronounced in males (Figure 1). A previous study in 921 young women aged 20-25 years also showed that per kg change of lean mass associated with greater increased in BMD of femoral neck, spine and total body compared with that of fat mass [3].

There are marked differences in metabolic activity between subcutaneous and visceral fat, and recent studies in adolescent girls and young women suggest that subcutaneous fat may be positively associated with bone mass whereas visceral fat may have negative association with bone mass [19-21]. Consistent with that, our study demonstrated a negative association between trunk-to-limb fat mass ratio (a surrogate of visceral fat) and peak bone mass in young women. Furthermore, our study is the first to demonstrate a significant negative association between visceral fat and each of bone size and bone mass in young men, suggesting a negative relationship of visceral fat and peak bone mass attained in males. One study with Korean adults aged 21-83 years showed that visceral fat area had an inverse association with BMD of hip and spine in both men and women [28], indicating the adverse impact of visceral fat in all age groups. The adverse influence of visceral fat on bone in our study appears to be mainly on bone size. Consistently, a study with 100 healthy women aged 15-25 years also showed that visceral fat had a negative association with femoral cross-sectional bone area as assessed by QCT [21]. As bone strength is related to both the size and shape of bone and the amount of mineralization [29], the smaller bone area associated with high visceral fat may imply an increased fracture risk in later life. The negative association between visceral fat and bone could be related to increased inflammatory cytokines, such as TNF-α or IL-6, which are more related to visceral adiposity [30, 31] and have deleterious effects on bone mediated by increased bone resorption or inhibited osteoblast function [12]. In addition, hyperlipidaemia associated with central adiposity may also play a role; a negative relationship between hyperlipidaemia and bone mass has been reported in adult men and women [32].

Strengths of our study include the large sample size and the relatively homogeneous nature of the cohort, particularly with regard to age. The latter is important for evaluating the relationship between body composition and bone, as the association varies with age [11, 33]. The inclusion of males and females, analysed separately, enabled us to evaluate gender differences in the relationships between body composition and peak bone mass. In addition, our analysis controlled for height rather than body weight, avoiding the problem of collinearity associated with adjusting for body weight in the analysis [11], as body weight and body fat are highly correlated ($r = 0.807$ for males and $r = 0.925$ for females in our study population). Furthermore, the calculation of semi-partial R^2 for each predictor variable accounted for the inter-correlation between body size and body composition measure, and thus allowed the evaluation of the proportion of variance uniquely associated with each predictor. Limitations of the study include the observational, cross-sectional nature of the study, and we cannot assume that the relationships demonstrated are causal in nature. Another limitation is that we did not have bone structure assessment and bone strength estimate using pQCT or QCT. Nevertheless, DXA is considered as the “gold standard” for areal BMD measurements and its role in fracture risk prediction is well accepted [34]. Our study population was at an age expected to have reached peak bone mass [22], however the negative relationship between height and total body BMD in males may indicate that full bone mineralization had not been achieved in the taller participants. Our study population was recruited from the offspring of a pregnancy cohort but the general characteristics of the cohort are comparable with the general population [24].

In conclusion, our study confirmed a positive association between fat mass and peak bone mass in young women. However, the relationships differed between fat compartments, with high visceral fat associated with smaller bone area and consequently lower BMC. In young males, fat mass was not an important determinant of peak bone mass overall, but a similar negative association between visceral fat and bone was demonstrated. Therefore, besides other health benefits such as reduced risk for cardiovascular disease and metabolic syndrome, preventing the accumulation of visceral fat from an early age may benefit bone health and contribute to skeletal integrity and fracture prevention. Our study demonstrates a strong positive relationship between lean body mass and total body bone mass in both genders, thus lifestyle factors such as physical activity that benefit both bone and lean body mass should be encouraged for the achievement of optimal peak bone mass.

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Table 1 Anthropometric, body composition and bone measures in participants

	Male (n = 609)	Female (n = 574)	P*
Age (year)	20.1 ± 0.5	20.0 ± 0.4	0.109
Height (cm)	178.3 ± 7.1	165.9 ± 6.4	<0.001
Weight (kg)	76.8 ± 14.0	65.3 ± 13.1	<0.001
BMI (kg/m^2)	24.1 ± 3.9	23.8 ± 4.7	0.180
Body composition measures			
Lean mass (kg)	56.7 ± 7.9	36.5 ± 5.0	<0.001
Lean mass index (kg/m^2)	17.8 ± 2.0	13.3 ± 1.5	<0.001
Fat mass (kg)	17.5 ± 10.0	26.9 ± 11.0	<0.001
Fat mass index (kg/m^2)	5.5 ± 3.1	9.8 ± 4.1	<0.001
Percentage body fat (%)	21.7 ± 8.7	39.4 ± 8.9	<0.001
Percentage trunk fat (%)	9.9 ± 5.4	18.4 ± 5.8	<0.001
Trunk-to-limb fat mass ratio	0.89 ± 0.27	0.95 ± 0.21	<0.001
Total body bone measures			
BMC (g)	3174 ± 428	2689 ± 327	<0.001
Bone area (cm^2)	2825 ± 194	2633 ± 180	<0.001
BMD (mg/cm^2)	1121 ± 108	1019 ± 83	<0.001

Values are mean ± SD. * Student's t-test.

Table 2 Correlation coefficients between body composition and total body bone measures

	Male			Female		
	BMC	Bone area	BMD	BMC	Bone area	BMD
Weight	0.669**	0.539**	0.563**	0.685**	0.541**	0.556**
Height	0.615**	0.824**	0.288**	0.581**	0.728**	0.261**
Lean mass	0.799**	0.663**	0.657**	0.656**	0.496**	0.566**
Fat mass	0.258**	0.185**	0.234**	0.497**	0.402**	0.402**
Trunk-to-limb fat mass ratio	0.040	-0.128*	0.146**	0.174**	0.015	0.251**

*P < 0.01; ** P < 0.001.

Table 3 Predictors of total body bone measures

	Male			Female		
	Regression coefficient (95% CI)	**P**	**R^2 ***	**Regression coefficient (95% CI)**	**P**	**R^2**
Total body BMC (g)						
Height (cm)	10.8 (7.2, 14.3)	<0.001	0.018	17.0 (14.1, 20.0)	<0.001	0.073
Lean body mass (kg)	35.7 (32.6, 38.7)	<0.001	0.275	25.2 (21.4, 29.0)	<0.001	0.099
Fat mass (kg)	9.4 (6.3, 12.5)	<0.001	0.018	15.0 (13.0, 17.0)	<0.001	0.126
Trunk-to-limb fat mass ratio (0.1 unit increase)	-16.4 (-27.7, -5.1)	0.005	0.004	-23.0 (-33.8, -12.2)	<0.001	0.010
Common variance shared by all predictors			0.373			0.361
Total variance explained			0.688			0.669
Total body bone area (cm^2)						
Height (cm)	16.4 (15.0, 17.8)	<0.001	0.211	17.8 (16.3, 19.4)	<0.001	0.266
Lean body mass (kg)	6.4 (5.2, 7.7)	<0.001	0.043	2.1 (0.1, 4.1)	0.035	0.002
Fat mass (kg)	5.1 (3.9, 6.4)	<0.001	0.027	9.0 (7.9, 10.0)	<0.001	0.148
Trunk-to-limb fat mass ratio (0.1 unit increase)	-17.6 (-22.2, -13.0)	<0.001	0.023	-23.1 (-28.7, -17.5)	<0.001	0.034
Common variance shared by all predictors			0.446			0.255
Total variance explained			0.750			0.705
Total body BMD (mg/cm^2)						
Height (cm)	-2.5 (-3.7, -1.4)	<0.001	0.016	-0.4 (-1.4, 0.7)	0.489	0.0005
Lean body mass (kg)	10.1 (9.1, 11.1)	<0.001	0.345	8.7 (7.4, 10.0)	<0.001	0.183
Fat mass (kg)	1.3 (0.3, 2.4)	0.009	0.006	2.1 (1.4, 2.8)	<0.001	0.039
Trunk-to-limb fat mass ratio (0.1 unit increase)	1.0 (-2.7, 4.7)	0.598	0.0003	0.8 (-2.8, 4.5)	0.656	0.0002
Common variance shared by all predictors			0.100			0.180

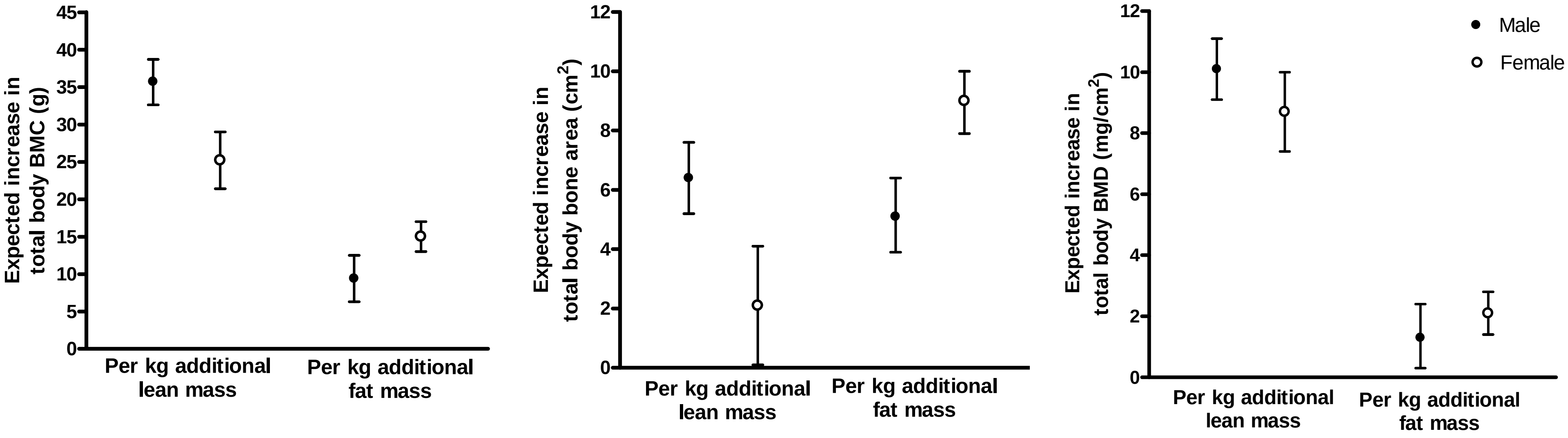
Total variance explained	0.467	0.402

*R^2 for individual predictor variable refers to semi-partial R^2, which is the proportion of the variance associated uniquely with the predictor.

Figure Legends

Figure 1 Mean differences in bone measure in relation to lean and fat body mass, values are mean (95% CI). BMC, bone mineral content; BMD, bone mineral density.

Figure 1


Expected increase in total body BMC (g)
45
40
35
30
25
20
15
10
5
0
Per kg additional lean mass
Per kg additional fat mass
Expected increase in total body bone area (cm2)
12
10
8
6
4
2
0
Per kg additional lean mass
Per kg additional fat mass
Expected increase in total body BMD (mg/cm2)
12
10
8
6
4
2
0
Male
Female
Per kg additional lean mass
Per kg additional fat mass