Published in final edited form as:

Appl Physiol Nutr Metab. 2012 October ; 37(5): 947–954. doi:10.1139/h2012-075.

Total and Femoral Neck Bone Mineral Density and Physical Activity in a Sample of Men and Women

Sarah M. Camhi^{1,2} and Peter T. Katzmarzyk¹

¹Pennington Biomedical Research Center, Baton Rouge LA

²Department of Exercise and Health Sciences, University of Massachusetts, Boston, MA

Abstract

Purpose—Physical activity (PA), total body fat (TBF), and lean body mass (LBM) are associated with bone mineral density (BMD). However, the independent influence of PA on BMD, while controlling for body composition is less well understood, and is the purpose of the current study.

Methods—Whole-body BMD (g/cm²), femoral neck BMD (g/cm²), TBF (kg) and LBM (kg) were measured with dual-energy x-ray absorptiometry. PA levels (total, work, sport, non-sport) were estimated using the Baecke questionnaire. General linear models determined the independent effects of PA on BMD (whole-body and femoral neck), with adjustment for age, sex, ethnicity, smoking, menopausal status (as appropriate), LBM and TBF. These associations were also examined by sex and age group (20–34, 35–49 and 50–64 years).

Results—The sample included 802 adults (65% women; 13% African American) from the Pennington Center Longitudinal Study, 20 to 64 years of age (mean $\pm$ SD: 46.9 $\pm$ 11.0 years). Higher sports scores were associated with higher femoral neck BMD in the total group, men and women, and in 20–34 year-olds and 35–49 year-olds, but not significant in those 50–64 years of age. Similar significant associations were found for sports score with total body BMD, however, this relationship was not significant for women or for those 50–64 years of age. Total PA had inconsistent relationships with both femoral neck BMD and total body BMD.

Conclusions—Higher levels of sport-related PA are associated with higher femoral neck BMD, however these relationships vary by PA domain and site of BMD measurement.

Keywords

sex/gender; age; DXA; lean body mass; total body fat; body composition

Introduction

Evidence that bone mineral density (BMD) is related to physical activity (PA) remain equivocal (Kohrt et al. 2004). Several cross-sectional studies have shown that levels of PA are positively associated with BMD (Bendavid et al. 1996; Salamone et al. 1996; Lunt et al.

2001; Cheung et al. 2005), while several others have shown no overall association between BMD and PA or fitness measures (Orwoll et al. 2000; Lee et al. 2001; Cauley et al. 2005).

Some of the possible reasons that evidence for a link between PA and BMD is unclear, may be due to factors that are related to both PA and BMD, such as body composition. Body weight alone accounts for a large portion of the variability in BMD (Bleicher et al. 2010). BMD is 3–7% higher for every 10 kg higher body weight (Papaioannou et al. 2009). Anthropometric measures have positive associations with BMD, independent of age and race, in large epidemiological studies in both men (Cauley et al. 2005) and women (Orwoll et al. 1996). Andreoli et al., suggests that both lean mass (LBM) and total body fat (TBF) have influences on BMD, but that the absolute amounts of each may vary the effects on BMD (Andreoli 2011). However, these studies do not provide evidence to determine whether the associations of PA and BMD were influenced by TBF, LBM, or both. In fact, obesity status may be protective for low BMD (Nishizawa et al. 1991), but it is not known whether it is due to the excess weight overall, or excess TBF or LBM.

While body composition influences BMD, there is also a possible influence of PA on multiple components of body composition. People who are physically active tend to have higher BMD (Andreoli 2011), lower amounts of TBF (Kyle et al. 2001), and possibly higher LBM (Peterson et al. 2011), which may influence and alter the relationship between PA and BMD. Thus, it is necessary to consider multiple components of body composition when determining the independent influence of PA on BMD. Therefore, the purpose of this research is to evaluate the relationship between BMD and PA in sex and age groups, while controlling for TBF and LBM.

Methods

The sample included adults from the Pennington Center Longitudinal Study (PCLS), 20 to 64 years of age. The PCLS is made up of volunteers who have participated in nutrition, weight loss and other metabolic observational and intervention studies at the Pennington Biomedical Research Center in Baton Rouge, Louisiana since 1992 (Katzmarzyk et al. 2010).

The current cross-sectional study is limited to participants who were screened at PBRC (between 1996 and 2008) and who had PA questionnaires as well as dual-energy x-ray absorptiometry (DXA) whole body scans administered within 60 days of the anthropometric measurements. Each volunteer provided their written informed consent and all PCLS procedures, including this analysis, were approved by the PBRC Institutional Review Board.

Habitual PA levels were estimated using the Baecke questionnaire (Baecke et al. 1982). Several questions assess occupational PA (work score), leisure time sports participation (sport score), and non-sport leisure time PA (non-sport score). The work score is assessed from questions relating to the amount of time doing the following activities during work: sitting, standing, walking, lifting heavy loads, fatigue and sweating. The sport score is calculated by asking which two specific sports the person participates in most frequently, how many hours per week and months per year of participation, degree of sweating and a

comparison of PA levels with others the same age. Finally, the non-sport leisure score specifically asks about time spent watching television, walking, cycling and active transportation (via walking/cycling). A total score was computed by adding together the individual scores for work, sport and non-sport leisure. This questionnaire has been validated with energy expenditure in 20–70 year olds (Pols et al. 1995).

Whole-body areal BMD (g/cm^2), femoral neck areal BMD (g/cm^2), total body fat mass (TBF; kg) and bone free lean body mass (LBM; kg) were measured with DXA. Areal bone density is defined as the bone mineral content divided by the area of the image of a bone projected in 2 dimensions that is produced using DXA procedures. and is used to estimate bone mineral density (Cummings et al. 2002). Two Hologic models (Bedford, MA) were utilized for imaging: the QDR2000 ($n=387$) was phased out in 2006, and replaced with the QDR4500 ($n=415$) which has been in service since 2001. Femoral neck BMD (g/cm^2) was only measured by the QDR4500, thus, only a subsample provides data for this analysis ($n=360$). Concordance between the two DXA machines for total body BMD was determined with same-day scans on a subsample of participants ($n=32$), resulting in a high degree of agreement for percent fat measurements ($R^2=0.987$), FM ($R^2=0.993$), LBM ($R^2=0.957$), and total body BMD ($R^2=0.901$). Equations were used to convert the QDR2000 data to QDR4500 data for percent fat ($Y=0.8015x + 2.3903$), FM ($Y=0.8323x + 1527.7$), LBM ($Y=1.0231x + 4499.6$) and total body BMD ($Y=0.8712x + 0.1013$). This conversion process was not needed for femoral neck BMD, as these measures were only available for the QDR4500 DXA Model. In order to assess reliability, coefficients of variation (CV; mean $\pm$ SD) were also calculated for repeated DXA measures obtained 14 days apart on a subsample ($n=88$) for total body BMD ($0.8 \pm 0.5\%$), LBM ($1.2 \pm 0.8\%$) and TBF ($1.8 \pm 1.4\%$), data were not available for femoral neck BMD. Each DXA used a phantom prior to data collection for calibration and to document stability of measures over time. Manufacturer calibrations were performed twice a year as recommended. Each participant's scan was analyzed with the latest software QDR for Windows V11.2.

Participant age was computed from birth and observation dates. Sex, race/ethnicity and smoking status were self-reported by questionnaire during the recruitment process. Participants were classified as “non-smokers”, “current smokers” or “former smokers”. Menopausal status (pre-menopausal/post-menopausal) was determined in women from their age and responses to questions regarding their reproductive history: women aged 55+ years of age or those who indicated that they can no longer have children because of achieving menopause were considered to be post-menopausal.

Statistical Analysis

All analyses were performed with SAS 9.2, and significance was defined as $p < 0.05$. T-tests, chi-square tests and general linear models (GLM), as appropriate, were used to examine differences in group characteristics by sex and age. Correlations were used to analyze the associations between BMD (total body and femoral neck), TBF, LBM and PA domains (total, work, sport, non-sport, TV, walking, cycling, active transport). GLMs were used to determine the association between the domains of PA (total, work, sport, non-sport), and total body BMD, independent from LBM, TBF, age, sex, ethnicity, smoking and

menopausal status (as appropriate). This same GLM analysis was done in a subset for femoral neck BMD when data were available. Due to known influences of sex and age on BMD, we also ran GLM models separately in men and women, and within the 3 age groups (20–34, 35–49 and 50–64 years). All continuous variables (TBF, LBM, PA) were standardized to a mean of zero and unit variance for the GLM analysis in order to directly compare the strength of relationship between the various domains of PA and BMD.

The total available sample included 810 participants who had complete DXA and PA data. Outliers were removed if studentized residual in the GLM models was greater than 3 ($n=2$), and participants were removed from analysis if they were missing smoking status ($n=6$). Total sample size for correlations and GLM for the total body BMD analysis was $n=802$, and femoral neck BMD was $n=360$ (45% of total sample). Although the femoral neck subsample was significantly younger in age than those without femoral neck BMD measures (43.3 ± 10.5 vs. 49.9 ± 10.3 ; $p < 0.0001$), and had a significantly greater percentage of African Americans (17% versus 11%; $p = 0.02$), there were no other significant differences found for sex, total body BMD, LBM or TBF.

Results

Table 1 presents the baseline characteristics of the PCLS sample. In general, the sample was 35% men, 13% African American, approximately 47 years of age, and classified as overweight according to BMI status. Men had significantly higher BMI, lower TBF, greater LBM, greater BMD (total body and femoral neck), higher total PA score and sports score when compared with women. There were also expected significant differences between age groups for age, postmenopausal status, TBF (increasing with age), LBM (decreasing with age), and BMD (decreasing with age for both total body and femoral neck BMD).

Associations of BMD and PA

Total body BMD (g/cm^2) was significantly correlated with total PA score ($r=0.16$, $p < 0.0001$), sport score ($r=0.28$ $p < 0.0001$), but not with any other PA components. Correlations were consistent with femoral neck BMD (g/cm^2) and domains of PA in the subsample, whereby significant associations were only found with total score ($r=0.18$, $p = 0.005$), and sport score ($r=0.22$, $p < 0.0001$).

Adjusted GLM results for the associations between total body BMD and PA domains are presented in Tables 2 (gender comparisons) and 3 (age group comparisons). Results for the associations between femoral neck BMD and PA domains are presented in Tables 4 (gender comparisons) and 5 (age group comparisons).

GLMs revealed that independent from TBF and LBM, sport score was significantly and associated with femoral neck BMD for the overall group ($p=0.001$), for men ($p < 0.0001$), for women ($p=0.001$), for adults 20–34 years ($p=0.0008$) and for adults 35–49 years ($p=0.02$), but not significantly associated for adults 50–64 years of age. These results were consistent when evaluating the association of sport score and total body BMD, whereby significant associations were found in the overall group ($p=0.001$), in men ($p < 0.0001$) in 20–34 years

($p=0.005$) and in 35–49 years ($p=0.03$), but not significantly associated in either women or in adults 50–64 years of age.

Total PA score had an inconsistent relationship with gender depending on the BMD site. The relationship between total PA score and total body BMD was significant in men ($p=0.04$), but not significant in women. In contrast, total PA score and femoral neck BMD was significant in women ($p = 0.004$), but not significant in men. However, higher total PA score was significantly associated with higher total body and femoral neck BMD in 20–34 year olds, with no association in the adults 35–49 or 50–64 years.

Non-sport score was not significantly associated with total body BMD in any subgroup, however, femoral neck BMD did show significant associations in women ($p=0.02$), and in adults 20–34 years. Work score was consistently not significantly associated with for both total body BMD and femoral neck BMD in both genders and all three age groups.

While all analyses did adjust for both TBF and LBM, the influence of these variables was dependent on the BMD site. For total body BMD, both TBF and LBM were significantly associated in the group overall, in both genders, and in all age groups. Interestingly, TBF had a negative association, whereas LBM had a positive association with total body BMD. For the analyses with femoral neck BMD, only LBM was significantly and positively associated in all subgroups.

Discussion

The relationship between body composition, BMD and PA is quite complex, however, significant and positive associations emerged between sports PA and femoral neck BMD, though this relationship was not significant in the oldest age group. These results were supported with our analysis of total body BMD and sport score, however, results varied for the other domains of PA including total PA, non-sport, and work.

Varying results for the association of BMD and total PA may be due to the assessment and estimation of PA. Other studies which generalized PA into a total amount, as done in this study, also showed non-significant relationships with BMD (Orwoll et al. 2000; Stewart et al. 2002; Cauley et al. 2005; Lau et al. 2006). Total PA likely includes activities which are non-weight bearing and of lighter intensities, and may not be a sensitive enough measure to capture activities which are known to promote bone loading. Thus, overall and total PA may not be appropriate for assessing the associations between PA and BMD. Furthermore, non-sport leisure PA includes both weight bearing (ie., walking), non-weight bearing (ie., cycling) activities, and sedentary behaviors (i.e., watching television), making this category difficult to interpret in the context of its possible relationship with BMD.

According to the American College of Sports Medicine, weight-bearing PA is beneficial to bone health and BMD across the lifespan (Kohrt et al. 2004). Regular engagement in high impact physical activities (ie., activities that involve weight bearing activities which involve bone loading, such as jumping, running and/or moderate resistance training) are thought to promote BMD. These types of activities are common in sports play. Our results demonstrate that the association between BMD and sports PA have significant and more consistent

positive associations than total PA. Bleicher et al., (2010) was also able to discriminate intensity and/or type of PA and found the association with BMD to be significant only among those individuals engaging in bone-loading activities (ie., dancing, jogging and tennis). Greendale et al., (2003) found that higher levels of sport activity were associated with greater BMD, but not related to work activity, even after adjustment for BMI. Several other studies also found positive associations for BMD and PA, when PA was defined as intense (Greendale et al. 1995), vigorous (Andreoli et al. 2001), or weight bearing (Cheung et al. 2005). Other research shows that the more intense the exercise reported, the greater the BMD found in the hip (Greendale et al. 1995). Our results extend these findings by also exploring these associations across several age groups and in both men and women, while also controlling for both LBM and TBF.

The importance of assessing specific type and intensity of PA and its relationship to BMD was also supported by our sub-analysis utilizing femoral neck BMD. Since the femoral neck is a component of a weight-bearing joint, it may be indicative of a specific site where bone-loading occurs. Total body BMD may be too general to capture the effects of bone-loading activities on weight-bearing joints as it is a reflection of the average BMD of the entire skeleton. Several studies have shown that PA may be related to certain sites which are weight bearing (ie., calcaneus BMD), but not others which are non-weight bearing (ie., radius BMD) (Korpelainen et al. 2003). Greendale et al., found that PA levels were only associated with BMD at the hip, and not at the wrist, spine or radius in older adults, even after controlling for BMI (1995). These findings are especially important in light of the public health burden of hip fractures in the elderly and the related disability (Bertram 2011).

Relationships between PA and BMD were inconsistent within the age groups whereby sports PA and femoral neck BMD were significantly associated in 20–34, and 35–49 year olds, but not in 50–64 year olds. Typically with aging, both body composition components and PA behavior changes: BMD decreases (2004), TBF is increased (Hughes et al. 2004; Kuk et al. 2009), LBM is increased until approximately middle age, and then decreases into old age (Andreoli 2011), and PA levels decrease (Troiano et al. 2008). These complex changes in body composition may influence their relationship with PA and each other, though few other studies have examined the relationship between PA and BMD within or between different age groups. It is important to note that our study was cross-sectional in nature, thus, we cannot extrapolate our findings to the continuum of aging. Future studies are needed to confirm the effects of aging on the relationship between BMD and PA, as the effects of PA on BMD health across the lifespan are not currently understood.

We were able to control for both TBF and LBM in our analysis, whereby other studies may have only been able to adjust for weight (Orwoll et al. 2000; Lunt et al. 2001; Cauley et al. 2005; Lau et al. 2006; Bleicher et al. 2010) or BMI (Greendale et al. 1995; Bendavid et al. 1996; Salamon et al. 1996; Greendale et al. 2003; Cheung et al. 2005). Other studies have found that the relationship between PA and BMD varies by BMI status (Korpelainen et al. 2003; Elgan and Fridlund 2006). However, once the relationship between PA and BMD was adjusted for body weight, this association was no longer significant (Lau et al. 2006). Only a few BMD studies which examine PA have adjusted for more accurate measures of body composition such as LBM and TBF. One such study found that lumbar spine BMD was

correlated with PA (defined as: at least 2 hrs/week of various activities- mostly walking/running), independent of age, TBF and LBM (as measured by DXA) in postmenopausal women (Douchi et al. 2000). After adjusting for various measures of TBF and LBM, Stewart et al., did not find a relationship between overall PA and total body BMD in men and women (n=84), although type and intensity of PA was not able to be discerned (Stewart et al. 2002). These relationships also may be influenced by physical activity levels, whereby TBF and BMD were associated in women who had low levels of activity, but not significant in women with higher levels of activity (Reid et al. 1995). We are able to expand these findings to examine sports activity, larger sample sizes in both sexes, and also in age groups which spanned 20–64 years. As can be observed in our results, the influence of TBF and LBM as covariates in the association between BMD and sports PA was dependent on the BMD site. At equal levels of TBF, higher levels of LBM was associated with higher total body and femoral neck BMD, adjusted for any PA domain. At constant LBM, lower TBF was associated with higher total body BMD adjusting for any PA domain. Thus, both components have influences on BMD in unique ways, and according to the beta magnitudes, LBM (β range: 0.09–0.10) may have a larger influence on BMD when compared to TBF (β : –0.02). However, when examining femoral neck BMD, TBF was not significantly related to femoral neck BMD, which may indicate that LBM would be a more important component of body composition on femoral neck BMD. Another study also suggests LBM is a more important determinant of BMD in physically active women than TBF (Douchi et al. 2003). Thus, the relationships between BMD, PA and body composition are complex, and both LBM and TBF should be considered when examining the relationship between PA and BMD at any site.

The current study contains a large sample of both Caucasian and African Americans with a range of body compositions. Race has been shown to be one of the largest influences on BMD (Cauley et al. 2005), despite controlling for it in our analyses, we did not have the statistical power to examine race differences. Some of the race differences may be due to differences in LBM and TBF (Wagner and Heyward 2000), and our study was also able to control for these components of body composition using sophisticated and accurate measures (DXA). Additional strengths of the current analysis include separate analyses for sex and age groups to investigate associations for PA (total and subcomponents) and BMD (total body and femoral neck) independently within these groups.

Despite the current study's strengths, it has a cross-sectional design and we cannot imply causation between PA and BMD, or assume any longitudinal effects of aging. In addition, our sample was comprised of volunteers from Baton Rouge, Louisiana, which may not be generalizable to other populations. A limitation of the current study is the lack of data in this particular sample concerning dietary intake (ie., calcium intake), family history of osteoporosis, or medication use, which could all influence body composition, and specifically BMD, however, we were able to control for other behavioral and physiological modifiers of body composition such as age, sex, race, smoking status, and menopause. While the Baecke questionnaire has been validated as a measure of PA, this method is meant to capture current PA levels, and BMD is likely influenced by long-term PA patterns. Thus, future studies are needed which capture habitual and long-term PA patterns, as well more specific PA information that captures intensity of effort and weight bearing status. Within

the context of this limitation, our results should be interpreted as the relationship between current PA levels and BMD. We also cannot eliminate the possibility of the “self-selection bias”, whereby those who have genetically higher BMD are more likely to excel and participate in sports. Finally, while body composition (LBM and TBF) and PA can have both positive and negative influences on BMD, this cross-sectional study is not able to truly separate out the independent effects, and can only make assumptions based on statistical modeling regarding the combined influence. In conclusion, the relationship between BMD and PA is complex and influenced by body composition, age, sex and BMD site. When taking all of these factors into account, PA which included sports activities were shown to be positively associated with BMD. This evidence supports the national recommendations for Americans to engage in weight-bearing sport specific activities to preserve bone health (USDHHS 2008). Maintaining BMD is important in order to curb progression of aged related bone loss, or osteoporosis, which may result in fracture and possible disability (Marshall et al. 1996). Future interventional and longitudinal studies are needed to better understand the effects of aging and engaging in these types of activities for maintaining and preserving BMD throughout the lifespan.

Acknowledgments

This research was supported by the Pennington Biomedical Research Center. This work was partially supported by a NORC Center Grant #2P30-DK072476-06 entitled “Nutritional Programming: Environmental and Molecular Interactions” sponsored by NIDDK. SMC performed the analysis and wrote the manuscript; PTK provided the PCLS cohort, edited the manuscript and provided statistical support.

References

- Bone Health and Osteoporosis: A Report of the Surgeon General. from <http://www.surgeongeneral.gov/library/bonehealth/content.html>
- Andreoli A, Monteleone M, Van Loan M, Promenzio L, Tarantino U, De Lorenzo A. Effects of different sports on bone density and muscle mass in highly trained athletes. *Med Sci Sports Exerc.* 2001; 33(4):507–511. [PubMed: 11283423]
- Andreoli AB, Celi AM, Lauro D, Sorge R, Tarantino U, Guglielmi G. Relationship between body composition, body mass index and bone mineral density in a large population of normal, osteopenic and osteoporotic women. *Radiology Medicine.* 2011; 116(7):1115–1123.
- Andreoli ACM, Volpe SL, Sorge R, Tarantino U. Long-term effect of exercise on bone mineral density and body composition in post-menopausal ex-elite athletes: a retrospective study. *European Journal of Clinical Nutrition.* 2011; 66(1):69–74. [PubMed: 21673718]
- Baecke JA, Burema J, Frijters JE. A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *Am J Clin Nutr.* 1982; 36(5):936–942. 1982/11/01. [PubMed: 7137077]
- Bendavid EJ, Shan J, Barrett-Connor E. Factors associated with bone mineral density in middle-aged men. *J Bone Miner Res.* 1996; 11(8):1185–1190. [PubMed: 8854255]
- Bertram MNR, Kemp L, Vos T. Review of the long-term disability associated with hip fractures. *Injury Prevention.* 2011; 17(6):365–370. [PubMed: 21486987]
- Bleicher K, Cumming RG, Naganathan V, Seibel MJ, Sambrook PN, Blyth FM, et al. Lifestyle factors, medications, and disease influence bone mineral density in older men: findings from the CHAMP study. *Osteoporos Int.* 2010; 22(9):2421–2437. [PubMed: 21110006]
- Cauley JA, Fullman RL, Stone KL, Zmuda JM, Bauer DC, Barrett-Connor E, et al. Factors associated with the lumbar spine and proximal femur bone mineral density in older men. *Osteoporos Int.* 2005; 16(12):1525–1537. [PubMed: 15889316]

- Cheung EY, Ho AY, Lam KF, Tam S, Kung AW. Determinants of bone mineral density in Chinese men. *Osteoporos Int.* 2005; 16(12):1481–1486. [PubMed: 16133639]
- Cummings SR, Bates D, Black DM. Clinical use of bone densitometry: scientific review. *JAMA.* 2002; 288(15):1889–1897. 2002/10/17. [PubMed: 12377088]
- Douchi T, Matsuo T, Uto H, Kuwahata T, Oki T, Nagata Y. Lean body mass and bone mineral density in physically exercising postmenopausal women. *Maturitas.* 2003; 45(3):185–190. [PubMed: 12818463]
- Douchi T, Yamamoto S, Oki T, Maruta K, Kuwahata R, Yamasaki H, et al. The effects of physical exercise on body fat distribution and bone mineral density in postmenopausal women. *Maturitas.* 2000; 35(1):25–30. [PubMed: 10802396]
- Elgan C, Fridlund B. Bone mineral density in relation to body mass index among young women: a prospective cohort study. *Int J Nurs Stud.* 2006; 43(6):663–672. [PubMed: 16343501]
- Greendale GA, Barrett-Connor E, Edelstein S, Ingles S, Haile R. Lifetime leisure exercise and osteoporosis. The Rancho Bernardo study. *Am J Epidemiol.* 1995; 141(10):951–959. [PubMed: 7741125]
- Greendale GA, Huang MH, Wang Y, Finkelstein JS, Danielson ME, Sternfeld B. Sport and home physical activity are independently associated with bone density. *Med Sci Sports Exerc.* 2003; 35(3):506–512. [PubMed: 12618583]
- Hughes VA, Roubenoff R, Wood M, Frontera WR, Evans WJ, Fiatarone Singh MA. Anthropometric assessment of 10-y changes in body composition in the elderly. *Am J Clin Nutr.* 2004; 80(2):475–482. [PubMed: 15277173]
- Katzmarzyk PT, Bray GA, Greenway FL, Johnson WD, Newton RL Jr, Ravussin E, et al. Racial differences in abdominal depot-specific adiposity in white and African American adults. *Am J Clin Nutr.* 2010; 91(1):7–15. [PubMed: 19828714]
- Kohrt WM, Bloomfield SA, Little KD, Nelson ME, Yingling VR. American College of Sports Medicine Position Stand: physical activity and bone health. *Med Sci Sports Exerc.* 2004; 36(11):1985–1996. [PubMed: 15514517]
- Korpelainen R, Korpelainen J, Heikkinen J, Vaananen K, Keinanen-Kiukaanniemi S. Lifestyle factors are associated with osteoporosis in lean women but not in normal and overweight women: a population-based cohort study of 1222 women. *Osteoporos Int.* 2003; 14(1):34–43. [PubMed: 12577183]
- Kuk JL, Saunders TJ, Davidson LE, Ross R. Age-related changes in total and regional fat distribution. *Ageing Res Rev.* 2009; 8(4):339–348. [PubMed: 19576300]
- Kyle UG, Gremion G, Genton L, Slosman DO, Golay A, Pichard C. Physical activity and fat-free and fat mass by bioelectrical impedance in 3853 adults. *Med Sci Sports Exerc.* 2001; 33(4):576–584. [PubMed: 11283433]
- Lau EM, Leung PC, Kwok T, Woo J, Lynn H, Orwoll E, et al. The determinants of bone mineral density in Chinese men—results from Mr. Os (Hong Kong), the first cohort study on osteoporosis in Asian men. *Osteoporos Int.* 2006; 17(2):297–303. [PubMed: 16175311]
- Lee JS, Kawakubo K, Sato H, Kobayashi Y, Haruna Y. Relationship between total and regional bone mineral density and menopausal state, body composition and life style factors in overweight Japanese women. *Int J Obes Relat Metab Disord.* 2001; 25(6):880–886. [PubMed: 11439303]
- Lunt M, Masaryk P, Scheidt-Nave C, Nijs J, Poor G, Pols H, et al. The effects of lifestyle, dietary dairy intake and diabetes on bone density and vertebral deformity prevalence: the EVOS study. *Osteoporos Int.* 2001; 12(8):688–698. [PubMed: 11580083]
- Marshall D, Johnell O, Wedel H. Meta-analysis of how well measures of bone mineral density predict occurrence of osteoporotic fractures. *BMJ.* 1996; 312(7041):1254–1259. [PubMed: 8634613]
- Nishizawa Y, Koyama H, Shoji T, Aratani H, Hagiwara S, Miki T, et al. Obesity as a determinant of regional bone mineral density. *J Nutr Sci Vitaminol (Tokyo).* 1991; 37(Suppl):S65–70. [PubMed: 1820447]
- Orwoll ES, Bauer DC, Vogt TM, Fox KM. Axial bone mass in older women. Study of Osteoporotic Fractures Research Group. *Ann Intern Med.* 1996; 124(2):187–196. [PubMed: 8533993]
- Orwoll ES, Bevan L, Phipps KR. Determinants of bone mineral density in older men. *Osteoporos Int.* 2000; 11(10):815–821. [PubMed: 11199184]

- Papaoiannou A, Kennedy CC, Cranney A, Hawker G, Brown JP, Kaiser SM, et al. Risk factors for low BMD in healthy men age 50 years or older: a systematic review. *Osteoporos Int.* 2009; 20(4):507–518. [PubMed: 18758880]
- Peterson MD, Sen A, Gordon PM. Influence of resistance exercise on lean body mass in aging adults: a meta-analysis. *Med Sci Sports Exerc.* 2011; 43(2):249–258. [PubMed: 20543750]
- Pols MA, Peeters PH, Bueno-De-Mesquita HB, Ocke MC, Wentink CA, Kemper HC, et al. Validity and repeatability of a modified Baecke questionnaire on physical activity. *Int J Epidemiol.* 1995; 24(2):381–388. [PubMed: 7635600]
- Reid IR, Legge M, Stapleton JP, Evans MC, Grey AB. Regular exercise dissociates fat mass and bone density in premenopausal women. *J Clin Endocrinol Metab.* 1995; 80(6):1764–1768. [PubMed: 7775619]
- Salamone LM, Glynn NW, Black DM, Ferrell RE, Palermo L, Epstein RS, et al. Determinants of premenopausal bone mineral density: the interplay of genetic and lifestyle factors. *J Bone Miner Res.* 1996; 11(10):1557–1565. [PubMed: 8889857]
- Stewart KJ, Deregis JR, Turner KL, Bacher AC, Sung J, Hees PS, et al. Fitness, fatness and activity as predictors of bone mineral density in older persons. *J Intern Med.* 2002; 252(5):381–388. [PubMed: 12528755]
- Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc.* 2008; 40(1):181–188. 2007/12/20. [PubMed: 18091006]
- USDHHS. Physical Activity Guidelines for Americans. 2008. Retrieved May 15, 2010, from <http://www.health.gov/paguidelines>
- Wagner DR V, Heyward H. Measures of body composition in blacks and whites: a comparative review. *Am J Clin Nutr.* 2000; 71(6):1392–1402. [PubMed: 10837277]

Table 1

Demographic and PA baseline characteristics of PCLS sample (n=802).

	Total	Sex		Age Group (years)				
		Men	Women	p-value	20–34	35–49	50–64	p-value
n (%)	802	281 (35)	521 (65)		118 (15)	281 (35)	403 (50)	
Age (years)	46.9 ± 11.0	46.4 ± 11.2	47.3 ± 10.8	0.27	27.1 ± 4.2	42.8 ± 4.5	55.6 ± 4.0	<0.0001
African American n (%)	108 (13)	30 (15)	78 (11)	0.09	31 (26)	40 (14)	37 (9)	<0.0001
BMI (kg/m ²)	27.7 ± 5.1	28.4 ± 4.0	27.3 ± 5.6	<0.0001	26.4 ± 6.0	28.1 ± 5.5	27.7 ± 4.5	0.02
FM (kg)	25.7 ± 9.9	22.6 ± 8.1	27.4 ± 10.4	<0.0001	21.9 ± 11.8	25.8 ± 10.2	26.7 ± 8.7	<0.0001
LBM (kg)	50.8 ± 12.2	64.4 ± 8.0	43.4 ± 6.3	<0.0001	51.1 ± 12.9	52.6 ± 12.5	49.4 ± 11.6	0.005
Total Body BMD (g/cm ²)	1.11 ± 0.11	1.18 ± 0.11	1.07 ± 0.09	<0.0001	1.13 ± 0.12	1.12 ± 0.11	1.09 ± 0.11	<0.0001
Femoral neck BMD (g/cm ²) *	0.82 ± 0.14	0.86 ± 0.14	0.80 ± 0.13	<0.0001	0.88 ± 0.16	0.82 ± 0.12	0.77 ± 0.12	<0.0001
Smoking:								
Never n (%)	505 (63)	169 (60)	336 (65)		89 (75)	169 (60)	247 (61)	
Former n (%)	202 (25)	83 (29)	119 (23)	0.09	19 (16)	60 (21)	123 (31)	<0.0001
Current n (%)	95 (12)	29 (10)	66 (12)		10 (8)	52 (19)	33 (8)	
Postmenopausal n (%)	n/a	n/a	212 (41)	n/a	0 (0)	9 (5)	203 (74)	<0.0001
PA Score:								
Total	7.4 ± 1.3	7.6 ± 1.3	7.2 ± 1.3	<0.0001	7.5 ± 1.5	7.4 ± 1.2	7.3 ± 1.3	0.29
Work	2.5 ± 0.7	2.5 ± 0.8	2.5 ± 0.7	0.3	2.6 ± 0.8	2.6 ± 0.7	2.4 ± 0.6	0.009
Sport	2.4 ± 0.7	2.6 ± 0.8	2.2 ± 0.7	<0.0001	2.4 ± 0.8	2.4 ± 0.7	2.4 ± 0.7	0.65
Non-sport	2.5 ± 0.6	2.5 ± 0.5	2.5 ± 0.6	0.08	2.5 ± 0.6	2.5 ± 0.6	2.5 ± 0.6	0.58

Data presented as mean ± SD.

Bold typeface indicates significant differences between groups.

Key: PA: physical activity; PCLS: Pennington Center Longitudinal Study; BMI: body mass index; BMD: bone mineral density; TBF: total body fat; LBM: lean body mass.

* N=360 total; Men n=122; Women n=238; 20–34 years n=74; 35–49 years n=168; 50–64 years n=118.

Table 2

Association between total body BMD and PA domains in total sample (n=802), men (n=281), and women (n=521), independent from TBF and LBM.*

Model	Total Body BMD	Total			Men			Women		
		Beta [†]	95% CI	P-value	Beta	95% CI	P-value	Beta	95% CI	P-value
1	TBF	-0.02	(-0.03, -0.01)	<0.0001	-0.02	(-0.03, -0.005)	0.04	-0.02	(-0.03, -0.02)	<0.0001
	LBM	0.10	(0.08, 0.11)	<0.0001	0.09	(0.08, -0.11)	<0.0001	0.1	(0.08, 0.12)	<0.0001
	Total PA	0.003	(-0.003, 0.008)	0.4	0.011	(0.0007, 0.02)	0.04	-0.002	(-0.01, 0.005)	0.5
2	TBF	-0.02	(-0.03, -0.02)	<0.0001	-0.02	(-0.04, -0.006)	0.005	-0.02	(-0.03, -0.02)	<0.0001
	LBM	0.1	(0.08, 0.11)	<0.0001	0.10	(0.08, 0.12)	<0.0001	0.1	(0.08, 0.12)	<0.0001
	Work	-0.003	(-0.008, 0.003)	0.3	0.0002	(-0.01, 0.009)	0.97	-0.005	(-0.01, 0.002)	0.16
3	TBF	-0.02	(-0.03, -0.01)	<0.0001	-0.008	(-0.02, 0.008)	0.32	-0.02	(-0.03, -0.01)	<0.0001
	LBM	0.09	(0.08, 0.10)	<0.0001	0.09	(0.07, 0.10)	<0.0001	0.1	(0.08, 0.11)	<0.0001
	Sport	0.01	(0.004, 0.02)	0.001	0.02	(0.01-0.03)	<0.0001	0.003	(-0.005, 0.01)	0.48
4	TBF	-0.02	(-0.03, -0.02)	<0.0001	-0.02	(-0.04, -0.006)	0.005	-0.02	(-0.03, -0.02)	<0.0001
	LBM	0.1	(0.08, 0.11)	<0.0001	0.10	(0.08, 0.12)	<0.0001	0.10	(0.08, 0.11)	<0.0001
	Non-Sport	-0.002	(-0.008, 0.004)	0.49	-0.002	(-0.01, 0.009)	0.69	-0.002	(-0.009, 0.005)	0.55

Bold typeface indicates significant association.

Key: BMD: bone mineral density; PA: physical activity; TBF: total body fat; LBM: lean body mass.

* Total model adjusted for age, sex, race/ethnicity, total body fat, lean mass, smoking status and postmenopausal status (where appropriate).

[†] Beta reported in standard deviation units for TBF (SD = 9.9 kg), LBM (SD = 12.4 kg) and PA (SD = Total 1.3; Work 0.7; Sport 0.7; Non-Sport 0.6).

Table 3

Association between total body BMD and PA domains by age (n=802), controlling for LBM and TBF.*

	Age: 20–34 years (n=121)			Age: 35–49 years (n=282)			Age: 50–64 years (n=405)		
	Beta [†]	F-value	P-value	Beta	F-value	P-value	Beta	F-value	P-value
TBF	–0.03	12.6	0.0006	–0.01	4.6	0.03	–0.02	14.9	0.0001
LBM	0.1	43.3	<0.0001	0.08	56.4	<0.0001	0.1	119.7	<0.0001
Total PA	0.02	8.9	0.004	0.003	0.3	0.59	–0.004	0.7	0.4
TBF	–0.04	20.1	<0.0001	–0.02	5.7	0.02	–0.02	15.8	<0.0001
LBM	0.11	47.9	<0.0001	0.08	61.9	<0.0001	0.1	122.5	<0.0001
Work	0.009	1.5	0.2	–0.004	0.9	0.34	–0.007	2.4	0.12
TBF	–0.03	11.6	0.0009	–0.01	2.0	0.16	–0.02	10	0.002
LBM	0.1	38.8	<0.0001	0.08	47.4	<0.0001	0.1	108.7	<0.0001
Sport	0.02	8.1	0.005	0.01	4.9	0.03	0.005	1.4	0.23
TBF	–0.04	20.3	<0.0001	–0.02	5.5	0.02	–0.02	16.6	<0.0001
LBM	0.11	51.8	<0.0001	0.08	60.2	<0.0001	0.1	123.3	<0.0001
Non-Sport	0.01	2.0	0.17	–0.00002	0.0	0.99	–0.006	2.2	0.14

Bold typeface indicates significant association.

Key: BMD: bone mineral density; PA: physical activity; TBF: total body fat; LBM: lean body mass.

* Total model adjusted for age, sex, race/ethnicity, total body fat, lean mass, smoking status and postmenopausal status (where appropriate).

[†] Beta reported in standard deviation units for TBF (SD = 9.9 kg), LBM (SD = 12.4 kg) and PA (SD = Total 1.3; Work 0.7; Sport 0.7; Non-Sport 0.6).

Table 4

Association between femoral neck BMD and PA domains in subsample (n=360), men (122), and women (238), adjusted for TBF and TBF.*

Model	Femoral neck BMD	Total			Men			Women		
		Beta [†]	95% CI	P-value	Beta	95% CI	P-value	Beta	95% CI	P-value
1	TBF	0.007	(-0.007, 0.02)	0.31	0.0001	(-0.03, 0.03)	0.83	0.004	(-0.01, 0.02)	0.68
	LBM	0.07	(0.04, 0.09)	<0.0001	0.06	(0.02, 0.09)	0.001	0.09	(0.05, 0.13)	<0.0001
	Total PA	0.02	(0.008, 0.03)	0.002	0.012	(-0.01, 0.04)	0.30	0.02	(0.007, 0.04)	0.004
2	TBF	-0.0003	(-0.01, 0.01)	0.97	-0.003	(-0.03, 0.03)	0.84	-0.007	(-0.03, 0.01)	0.41
	LBM	0.08	(0.05, 0.10)	<0.0001	0.06	(0.02, 0.09)	0.002	0.11	(0.07, 0.15)	<0.0001
	Work	-0.003	(-0.01, 0.007)	0.56	-0.009	(-0.006, -0.002)	0.36	-0.002	(-0.02, 0.01)	0.70
3	TBF	0.01	(-0.002, 0.03)	0.09	0.01	(-0.02, 0.04)	0.44	0.004	(-0.01, 0.02)	0.64
	LBM	0.06	(0.04, 0.09)	<0.0001	0.05	(0.01, 0.08)	0.01	0.09	(0.06, 0.13)	<0.0001
	Sport	0.03	(0.02, 0.05)	<0.0001	0.04	(0.01, 0.06)	0.001	0.03	(0.02, 0.05)	<0.0001
4	TBF	0.0003	(-0.01, 0.02)	0.69	-0.004	(-0.03, 0.03)	0.78	-0.002	(-0.02, 0.02)	0.86
	LBM	0.07	(0.05, 0.10)	<0.0001	0.06	(0.02, 0.10)	0.001	0.10	(0.06, 0.14)	<0.0001
	Non-Sport	0.01	(-0.0009, 0.02)	0.07	-0.004	(-0.03, 0.02)	0.74	0.02	(0.002, 0.03)	0.02

Bold typeface indicates significant association.

Key: BMD: bone mineral density; PA: physical activity; TBF: total body fat; LBM: lean body mass.

* Total model adjusted for age, sex, race/ethnicity, total body fat, lean mass, smoking status and postmenopausal status (where appropriate).

[†] Beta reported in standard deviation units for TBF (SD = 9.9 kg), LBM (SD = 12.4 kg) and PA (SD = Total 1.3; Work 0.7; Sport 0.7; Non-Sport 0.6).

Table 5

Association between femoral neck BMD and PA domains by age (n=360), controlling for TBF and LBM*.

	Age: 20–34 years (n=74)			Age: 35–49 years (n=168)			Age: 50–64 years (n=118)		
	Beta [†]	F-value	P-value	Beta	F-value	P-value	Beta	F-value	P-value
TBF	0.005	0.1	0.75	0.02	2.3	0.14	–0.0006	0.2	0.63
LBM	0.09	6.0	0.02	0.05	7.1	0.009	0.11	35.8	<0.0001
Total PA	0.04	12.0	0.001	0.02	3.8	0.05	–0.005	0	0.95
TBF	–0.01	0.6	0.46	0.01	1.1	0.30	–0.006	0.3	0.59
LBM	0.12	10.0	0.002	0.05	8.7	0.004	0.11	26.3	<0.0001
Work	0.009	0.3	0.56	0.0008	0.01	0.91	–0.006	0.5	0.46
TBF	0.005	0.5	0.77	0.02	2.9	0.09	0.001	0.01	0.92
LBM	0.09	6.3	0.01	0.04	6.3	0.01	0.10	21.1	<0.0001
Sport	0.05	12.4	0.0008	0.02	5.0	0.02	0.02	2.1	0.15
TBF	–0.0007	0.19	0.66	0.01	1.6	0.21	–0.009	0.5	0.48
LBM	0.10	8.7	0.004	0.05	7.9	0.006	0.12	27.2	<0.0001
Non-Sport Leisure	0.05	6.7	0.01	0.01	2.0	0.16	–0.007	0.6	0.45

Bold typeface indicates significant association

Key: BMD: bone mineral density; PA: physical activity; TBF: total body fat; LBM: lean body mass.

* Total model adjusted for age, sex, race/ethnicity, total body fat, lean mass, smoking status and postmenopausal status (where appropriate).

[†] Beta reported in standard deviation units for TBF (SD = 9.9 kg), LBM (SD = 12.4 kg) and PA (SD = Total 1.3; Work 0.7; Sport 0.7; Non-Sport 0.6).