



Prediction of bone mineral density and content from measures of physical activity and sedentary behavior in younger and older females

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ABSTRACT

Background. Little is known regarding the extent to which physical activity (PA) and sedentary behavior (SB) influence bone mineral content (BMC) and bone mineral density (BMD) in females across the lifespan.

Methods. Data from 2232 females aged 12 years and older collected as part of the 2007–2008 National Health and Nutrition Examination Survey were analyzed. Categories of PA and SB were used to predict femoral and spinal BMD and BMC in four age groups (G1: 12–17; G2: 18–39; G3: 40–64; G4: ≥65 years). Self-reported PA categories included sufficient moderate-to-vigorous recreational PA (S-MVRPA) and insufficient MVRPA (I-MVRPA).

Results. G1 females who accumulated S-MVRPA displayed greater femoral and spinal BMC and BMD compared to G1 females who displayed I-MVRPA. For G4 females, higher levels of SB were associated with lower femoral BMC and BMD.

Conclusions. These findings highlight the importance of engaging in sufficient moderate-to-vigorous physical activity during adolescence and reducing sedentary behavior in older adults to improve bone health in females.

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Introduction

Osteoporosis, a bone disease characterized by low bone mass and structural deterioration of bone tissue, currently impacts more than 10 million people in the United States and is predicted to affect more than 14 million people by 2020 (Burge et al., 2007). A strong association has been observed between non-fatal fractures and reduced functional performance and loss of independence in the elderly (Stevens et al., 2006), and postmenopausal women with osteoporotic vertebral fractures report a diminished quality of life (Silverman et al., 2001).

Engaging in appropriate levels of physical activity can reduce the potential for developing osteoporosis later in life (Gunter et al., 2012; Karlsson et al., 2008; MacKellvie et al., 2002; Ondrak and Morgan,

2007; Rizzoli et al., 2010). Current bone health recommendations for children and adolescents include participation in resistance exercise and high-impact physical activities at least three days a week for a total of 10 to 20 min daily (Kohrt et al., 2004). To maintain bone health during adulthood, it is recommended that individuals engage in weight-bearing endurance activities three to five times a week and jumping and/or resistance exercise two to three times a week, resulting in 30 to 60 min of daily combined physical activity (Kohrt et al., 2004). While performing regular physical activity can reduce bone fractures and the risk of falling in the elderly (Gregg et al., 2000), relatively few older men and women in the United States achieve current minimal physical activity recommendations (Brawley et al., 2003) and 47% of adults 65 to 74 years of age and 61% of adults over 75 years of age are physically inactive (Agency for Healthcare Research and Quality, 2013).

Independent of physical activity, sedentary living has also been shown to influence a variety of health outcomes (Tremblay et al., 2010a). Recent findings have demonstrated a positive dose–response relationship between sedentary time and all-cause/cardiovascular disease mortality (Dunstan et al., 2010; Katzmarzyk et al., 2009; Warren et al., 2010) and metabolic dysfunction has been linked to physical inactivity (Tremblay et al., 2010b). With respect to bone health, evidence suggests that a reduction in sedentary time should accompany increases in moderate-to-vigorous-intensity weight-bearing activity to mitigate bone loss (Zerwekh et al., 1998).

Abbreviations: BMC, bone mineral content; BMD, bone mineral density; I-MVRPA, insufficient moderate-to-vigorous recreational physical activity; S-MVRPA, sufficient moderate-to-vigorous recreational physical activity; SB, sedentary behavior; VMHDS, vitamins minerals, herbals, or other dietary supplements.

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While separate causal associations have been reported among physical activity, sedentary behavior, and selected health indices (Boreham and Riccoch, 2001), surprisingly little is known concerning the relative contributions of both physical activity and sedentary behavior on health status across the lifespan, particularly with regard to skeletal health measures such as bone mineral content (BMC) and bone mineral density (BMD). Against this backdrop, the purpose of our study was to evaluate the ability of physical activity and sedentary behavior to predict bone mineral density and content in a large and ethnically-diverse sample of female adolescents and younger and older women.

Materials and methods

Subjects

Data from 2232 females aged 12 years and older, collected as part of the 2007–2008 National Health and Nutrition Examination Survey (NHANES), were included in this analysis. Study participants were grouped into four age categories; a) adolescents (12 to 17 years, $n =$

337, G1); b) young adults (18 to 39 years, $n = 721$, G2); c) middle-aged adults (40 to 64 years, $n = 847$, G3); and d) older adults (65 years and older, $n = 327$, G4). Descriptive characteristics of the sample are shown in Table 1.

Physical activity

Measures of physical activity were obtained from self-reported time spent in moderate-to-vigorous-intensity recreational physical activity (MVRPA) (excluding work and transportation). Calculation of MVRPA was based on written responses to a physical activity survey. Vigorous-intensity recreational physical activity (VRPA) was evaluated by asking the following question (Question 1); “Do you do any vigorous-intensity sports, fitness, or recreational activities that cause large increases in breathing or heart rate like running or basketball for at least 10 min continuously?” Participants who answered ‘yes’ to Question 1 were requested to answer two additional questions: (a) “In a typical week, on how many days do you do vigorous-intensity sports, fitness or recreational activities?” (Question 2); and

Table 1
Descriptive statistics for study participants by age group in younger and older females.

	All ^a ($N = 2232$)	Adolescents ($n = 337$)	Young adults ($n = 721$)	Middle-aged Adults ($n = 847$)	Older adults ($n = 327$)
Age group (%)		11.26 (0.95)	35.29 (1.57)	42.86 (1.25)	10.59 (0.72)
Race/ethnicity (%)					
Non-Hispanic White	69.67 (3.28)	60.76 (4.28)	64.37 (4.01)	72.83 (3.34)	83.99 (3.55)
Non-Hispanic Black	11.85 (1.90)	16.59 (2.28)	13.29 (2.27)	10.46 (1.83)	7.63 (2.28)
Mexican	8.12 (1.55)	12.24 (2.83)	10.88 (2.28)	5.94 (1.07)	3.38 (1.04)
Hispanic & others	10.36 (1.54)	10.41 (2.95)	11.46 (1.60)	10.77 (1.70)	5.01 (1.62)
BMI (%)					
Normal	42.59 (1.63)	69.31 (2.59)	43.57 (3.07)	35.83 (1.79)	38.23 (3.34)
Overweight	29.04 (1.50)	19.20 (2.77)	26.64 (1.80)	31.68 (2.54)	36.77 (2.93)
Obese	28.38 (1.35)	11.49 (2.73)	29.79 (2.62)	32.48 (2.17)	25.00 (2.86)
MVRPA (%)					
I-MVRPA	62.38 (2.35)	42.50 (3.34)	57.56 (2.60)	67.95 (3.79)	77.00 (3.14)
S-MVRPA	37.62 (2.35)	57.50 (3.34)	42.44 (2.60)	32.05 (3.79)	23.00 (3.14)
Sedentary time (min·day ⁻¹)	338.04 (7.17)	463.97 (9.05)	325.51 (11.36)	320.66 (9.51)	316.33 (13.56)
BMC (g)					
Femur	29.56 (0.21)	28.54 (0.57)	30.54 (0.30)	29.61 (0.33)	27.20 (0.32)
Spine	57.87 (0.37)	52.57 (1.00)	61.01 (0.48)	58.12 (0.70)	52.06 (0.65)
BMD (g·cm ⁻²)					
Femur	0.93 (0.01)	0.94 (0.01)	0.98 (0.01)	0.92 (0.01)	0.81 (0.01)
Spine	1.02 (0.01)	0.97 (0.01)	1.07 (0.01)	1.01 (0.01)	0.93 (0.01)
Supplement intake					
Vitamin D (μg)	3.70 (0.11)	3.42 (0.32)	3.42 (0.20)	3.96 (0.16)	3.85 (0.19)
Calcium (mg)	844.39 (23.97)	821.37 (53.41)	853.64 (25.88)	856.54 (31.40)	788.82 (25.38)
Magnesium (mg)	257.64 (7.30)	207.16 (11.98)	255.26 (9.38)	276.33 (8.50)	243.63 (7.08)
Sugar (g)	108.34 (2.38)	117.21 (5.61)	112.93 (3.71)	106.67 (3.53)	90.43 (2.48)
Protein (g)	67.60 (1.24)	61.28 (2.33)	68.90 (1.42)	70.17 (2.06)	59.58 (0.95)
Milk consumption					
No Milk	16.02 (0.70)	12.69 (2.28)	12.32 (1.31)	18.74 (1.25)	20.89 (3.25)
>1 glass/day	83.98 (0.70)	87.31 (2.28)	87.68 (1.31)	81.26 (1.25)	79.11 (3.25)
Smoking ^b					
Yes	17.86 (1.62)	–	22.72 (2.17)	20.55 (2.95)	9.78 (1.72)
No	82.14 (1.62)	100	77.28 (2.17)	79.45 (2.95)	90.22 (1.72)
Osteoporosis history ^c					
Yes	4.68 (0.66)	–	0.64 (0.55)	5.37 (1.25)	20.37 (2.36)
No	95.32 (0.66)	100	99.36 (0.55)	94.63 (1.25)	79.63 (2.36)
Prednisone or cortisone ^d					
Yes	4.90 (0.70)	–	97.11 (0.72)	93.30 (1.02)	90.48 (1.50)
No	95.10 (0.70)	100	2.89 (0.72)	6.70 (1.02)	9.52 (1.50)
Menopausal status ^e					
Menopause/hysterectomy	33.43 (1.32)	–	2.67 (0.85)	52.13 (2.26)	95.78 (1.23)
Others/No	66.57 (1.32)	100	93.33 (0.85)	47.87 (2.26)	4.22 (1.23)

Abbreviations: BMI = body mass index; MVRPA = self-reported moderate- to vigorous-intensity recreational physical activity (activities of at least 10 min continuously that cause small to a large increases in breathing or heart rates); I-MVRPA = insufficient MVRPA (0 to <150 min·week⁻¹ for adults and <60 min·day⁻¹ for adolescents); S-MVRPA = sufficient MVRPA (≥150 min·week⁻¹ for adults and >60 min·day⁻¹ for adolescents); BMC = bone mineral content; BMD = bone mineral density.

All values are presented as a percentage (%) and standard error (SE) for categorical variables, and mean and SE for continuous variables.

^a Adolescents = ages 12 to 17, young adults = 18 to 39, middle-aged adults = 40 to 64, old adults = ages 65 and older.

^b Smoking = smoking status at the time of survey.

^c Osteoporosis history = ever treated for osteoporosis (yes vs. no/don't know/no response).

^d Prednisone or cortisone = ever taken prednisone or cortisone daily (yes vs. no/no response).

^e Menopausal status = not having regular periods due to menopause or hysterectomy (yes vs. no); not including adolescents.

(b) “How much time do you spend doing vigorous-intensity sports, fitness or recreational activities on a typical day?” (Question 3). To determine the total amount of time per week spent in VRPA among individuals who answered ‘yes’ to Question 1, the number of days engaged in VRPA during the week was multiplied by the time spent participating in VRPA on a typical day. Moderate-intensity recreational physical activity (MRPA) was quantified by asking the following question (Question 4); “Do you do any moderate-intensity sports, fitness, or recreational activities that cause a small increase in breathing or heart rate, such as brisk walking, bicycling, swimming, or golf, for at least 10 min continuously?” Participants who answered ‘yes’ to Question 4 were asked to respond to two other questions (a) “In a typical week, on how many days do you do moderate-intensity sports, fitness or recreational activities?” (Question 5); and (b) “How much time do you spend doing moderate-intensity sports, fitness or recreational activities on a typical day?” (Question 6). To determine the total amount of time per week spent in MRPA among persons who answered ‘yes’ to Question 4, the number of days engaged in MRPA during the week was multiplied by the time spent participating in MRPA on a typical day. Weekly time spent in MRPA and VRPA was summed to categorize individuals in G2, G3, and G4 into one of the two physical activity groups: (a) sufficient moderate- and vigorous-intensity recreational physical activity (S-MVRPA); or (b) insufficient MVRPA (I-MVRPA). S-MVRPA was defined as 150 min or more per week of MVRPA (i.e., meeting or exceeding the 2008 *Physical Activity Guidelines for Adults*) (U. S. Department of Health & Human Sciences, 2008), while I-MVRPA was defined as 0 to less than 150 min a week. As no specific cutpoint has been established for an appropriate mix of moderate and vigorous physical activity, participating in 150 min per week of any combination of MRPA and VRPA was considered as meeting the S-MVRPA standard. Respondents who answered ‘no’ to Questions 1 and 4 were also assigned to the I-MVRPA group. Because current federal activity guidelines recommend that youth participate in 60 min or more of MVRPA daily (U. S. Department of Health & Human Sciences, 2008), total weekly MVRPA time for individuals in G1 was divided by seven to calculate mean daily time spent in MVRPA. Adolescent females in G1 who reported at least 60 min per day of MVRPA were assigned to the S-MVRPA group, whereas females in G1 who engaged in less than 60 min per day of MVRPA were assigned to the I-MVRPA group. In addition, female youth who answered ‘no’ to questions concerning participation in MVRPA were included in the I-MVRPA group.

Sedentary behavior

Self-reported daily sedentary behavior (e.g., sitting, watching TV, driving) (Tremblay et al., 2010a) data were obtained in minutes per day by having participants answer this question: “The following question is about sitting or reclining at work, at home, or at school. Include time spent sitting at a desk, sitting with friends, traveling in a car, bus, or train, reading, playing cards, watching television, or using a computer. Do not include time spent sleeping. How much time do you usually spend sitting or reclining on a typical day?”

Bone mineral content and density

Bone mineral content (BMC; g) and bone mineral density (BMD; $\text{g}\cdot\text{cm}^{-2}$) of the femoral neck and total lumbar spine (L1–L4) were measured using a Hologic QDR 4500A fan-beam densitometer (Hologic, Inc., Bedford, MA) and scanned data were analyzed using Hologic Discovery software, Version 12.4. Values for BMC and BMD were obtained for the femoral neck, trochanter, intertrochanter, Ward’s triangle, and total femur from the proximal hip scan, and these data were available for each of the lumbar vertebrae (i.e., L1, L2, L3, and L4) and total lumbar spine. Due to their clinical relevancy in predicting risk for developing osteoporosis (Cummings et al., 2002; Lewiecki et al., 2008), femoral neck

and total lumbar spine BMC and BMD values were chosen as dependent variables in this analysis.

Body mass index

Body mass index (BMI; $\text{kg}\cdot\text{m}^{-2}$) was determined from height and weight measurements obtained using standardized examination methods and a fixed stadiometer and calibrated floor scale, respectively.

Recent milk consumption and related dietary intake

Consumption of milk products was determined from responses to the following question: “In the past 30 days, how often did you have milk to drink or on your cereal? Please include chocolate and other flavored milks as well as hot cocoa made with milk”. Do not count small amounts of milk added to coffee or tea. Answer choices ranged from 0 “never,” 1 “rarely,” 2 “sometimes — once a week or more,” to often “once a day or more.” Dietary intake of calcium, Vitamin D, protein, and magnesium was assessed by the question, “Have you used or taken any vitamins, minerals, herbals or other dietary supplements (VMHDS) in the past 30 days?” Participants who answered ‘yes’ to this question were asked to identify which VMHDS were taken and the amount ingested during the previous month.

Smoking status

Smoking status was evaluated by following question: ‘Do you now smoke cigarettes,’ with ‘every day,’ ‘some days,’ ‘not at all,’ and ‘refused’ as possible answers. Participants who selected one of the first two responses were assigned to the ‘yes’ category, while participants who selected ‘not at all’ or ‘refused’ responses were assigned to the ‘no’ category.

Treatment history of osteoporosis and related medication use

Prior treatment for osteoporosis was designated as either ‘yes’ or ‘no’, with an answer of ‘don’t know’ being placed in the ‘no’ category. Additionally, a question stating ‘Have you ever taken any prednisone or cortisone pills nearly every day for a month or longer’ was included in the analysis and classified as either being in the ‘yes’ category or in the ‘no’ category for those who answered ‘no’ or ‘don’t know.’

Menopausal status

With the exception of the adolescent age group, menstrual status was extracted from the NHANES data set based on the following question, ‘What is the reason that you have not had a period in the past 12 months?’ Answer choices, which included ‘pregnancy,’ ‘breast feeding,’ ‘menopause/hysterectomy,’ ‘medical conditions/treatments,’ ‘other,’ or ‘don’t know,’ were categorized as ‘menopause/hysterectomy’ or ‘others.’ Respondents who answered ‘don’t know’ were also included in the ‘others’ category.

Statistical analysis

A binary indicator for level of physical activity (i.e., I-MVRPA and S-MVRPA) and daily average time spent in sedentary behaviors were used as primary independent variables to predict BMC and BMD of the femoral and spinal regions for each participant group after controlling for race/ethnicity, BMI, recent milk consumption and related dietary intake, smoking status, treatment history of osteoporosis and related medication use, and menopausal status. The SAS v9.3 SURVEYREG procedure with ESTIMATE statement was used to obtain the least squares adjusted means of the outcome variables across levels of categorical indicators. Unstandardized regression coefficients and 95% confidence intervals were derived for continuous variables. Unstandardized beta values for sedentary minutes are presented as changes in BMC and

BMD per 30 min of sedentary time. The multistage and complex nature of the NHANES sampling scheme was accounted for in the calculation of unbiased estimates of population parameters. Statistical significance was established at $P < .05$.

Results

As depicted in Table 2, adolescent girls who engaged in at least 60 min a day of MVRPA displayed significantly greater femoral BMC, femoral BMD, spinal BMC, and spinal BMD values compared to girls in the I-MVRPA category. However, self-reported sedentary time was not a significant predictor of femoral BMC, femoral BMD, spinal BMC, and spinal BMD in this group.

Table 2

Regression analysis predicting bone mineral content and bone mineral density at the femoral neck and lumbar spine in younger and older females.

	Adolescents (n = 337)	Young adults (n = 721)	Middle-aged Adults (n = 847)	Older adults (n = 327)
Femoral BMC (g)				
MVRPA ^a				
I-MVRPA	28.37 (0.77)	30.43 (0.32)	28.94 (0.35)	26.32 (0.39)
S-MVRPA	30.97 (0.78)	30.66 (0.39)	29.55 (0.44)	26.71 (0.66)
P	.013	.612	.269	.590
Sedentary minutes^b				
b (SE)	−0.02 (0.08)	−0.002 (0.03)	−0.019 (0.02)	−0.104 (0.04)
P	.777	.959	.451	.021
Femoral BMD (g·cm^{−2})				
MVRPA ^a				
I-MVRPA	0.95 (0.02)	0.98 (0.01)	0.91 (0.01)	0.80 (0.01)
S-MVRPA	1.01 (0.01)	0.99 (0.01)	0.92 (0.01)	0.81 (0.01)
P	.010	.475	.293	.592
Sedentary minutes^b				
b (SE)	−0.0004 (.0002)	−0.0002 (.0005)	0.0005 (.0007)	−0.0028 (0.0001)
P	.815	.761	.408	.027
Spinal BMC (g)				
MVRPA ^a				
I-MVRPA	52.16 (1.23)	60.45 (0.52)	56.78 (0.74)	49.99 (0.80)
S-MVRPA	56.45 (1.30)	60.63 (0.61)	56.50 (1.01)	50.46 (2.37)
P	.003	.781	.737	0.847
Sedentary minutes^b				
b (SE)	0.19 (0.13)	0.07 (0.07)	−0.02 (0.08)	−0.02 (0.09)
P	.166	.348	.781	.816
Spinal BMD (g·cm^{−2})				
MVRPA ^a				
I-MVRPA	0.98 (0.01)	1.07 (0.01)	0.99 (0.01)	0.91 (0.01)
S-MVRPA	1.03 (0.02)	1.08 (0.01)	0.99 (0.01)	0.91 (0.03)
P	.012	.438	.660	.851
Sedentary minutes^b				
b (SE)	0.0013 (0.0017)	0.0010 (0.0008)	0.0005 (0.0011)	−0.0004 (0.0012)
P	.465	.198	.613	.720

Abbreviations: BMC = bone mineral content; BMD = bone mineral density; MVRPA = self-reported moderate- to vigorous-intensity recreational physical activity (activities of at least 10 min continuously that cause a small to a large increases in breathing or heart rates); I-MVRPA = insufficient MVRPA (0 to <150 min·week^{−1} for adults and <60 min·day^{−1} for adolescents); S-MVRPA = sufficient MVRPA (≥150 min·week^{−1} for adults and >60 min·day^{−1} for adolescents); SE = standard error.

Unstandardized estimates (b) are adjusted for race/ethnicity, milk consumption/supplement use, and body mass index (BMI) for adolescents; additional covariates including smoking, osteoporosis history, prednisone or cortisone use, and menopausal status were adjusted for other age groups.

^a Least square adjusted mean values of BMC and BMD.

^b Unstandardized beta values for sedentary minutes reflect changes in BMC and BMD per 30 min of sedentary time.

Among young adult women, neither physical activity level nor sedentary time were significant predictors of femoral BMC, femoral BMD, spinal BMC, and spinal BMD. For middle-aged females, sedentary time was not a significant predictor of femoral BMC, femoral BMD, spinal BMC, and spinal BMD and no significant difference in any bone descriptor was observed between middle-aged females engaged in I-MVRPA and S-MVRPA.

In considering older adult females, physical activity level was not a significant predictor of femoral BMC, femoral BMD, spinal BMC, and spinal BMD, meaning that no difference in any bone measure was present between participants in the I-MVRPA and S-MVRPA categories. Additionally, sedentary time was not a significant predictor of spinal BMC and BMD in this group. However, sedentary time was a significant predictor of femoral BMC and femoral BMD in this group, indicating that lower levels of femoral BMC and BMD were associated with increased sedentary time.

Discussion

Physical activity, sedentary behavior, and bone health during adolescence

Female adolescents who engaged in sufficient amounts of MVRPA displayed greater femoral BMC, femoral BMD, spinal BMC, and spinal BMD compared to participants who reported insufficient levels of MVRPA. This finding highlights the importance of engaging in a minimum of 60 min of daily weight-bearing activity to increase bone mass during adolescence (Bass, 2000; French et al., 2000; MacKelvie et al., 2002) and reinforces the current belief that pre- and early-pubertal periods are windows of opportunity for girls to optimize peak bone mass and possibly reduce the risk of osteoporosis-related fractures later in life (Biddle et al., 2004; Gunter et al., 2012). Results from the Iowa Bone Development Study (Janz et al., 2007), which demonstrated that MVPA was a significant contributor to bone strength at the femoral neck in children, also emphasize the potency of health-producing levels of physical activity as a means of improving skeletal health in adolescent girls. From a long-term health perspective, accumulating evidence suggests that bone mass gained during early childhood can be maintained in the transition to adolescence and young adulthood (Baxter-Jones et al., 2008; Janz et al., 2010; Scerpella et al., 2011). To test this hypothesis, prospective longitudinal studies are needed to document the sustainability of gains in bone strength achieved by younger and older girls performing various types and combinations of MVRPA (Biddle et al., 2004). In this regard, school-based interventions have been shown to be effective in positively influencing children's activity behaviors and bone health (Biddle et al., 2004; Gunter et al., 2012) and a recent meta-analysis has underscored the benefits of having female youth perform weight-bearing activity at least three days a week to enhance bone mineral accrual in the lumbar spine (Ishikawa et al., 2013).

While MVRPA was associated with greater femoral and spinal BMC and BMD values in adolescent girls, sedentary time was not linked to any bone health outcome. This finding suggests that in adolescent females, regular participation in sufficient amounts of weekly MVRPA may exert a stronger influence on bone mass accumulation than replacing sedentary behaviors with light-intensity physical activities.

Physical activity, sedentary behavior, and bone health during early-to-mid-adulthood

Physical activity and sedentary behavior were not predictors of femoral BMC, femoral BMD, spinal BMC, and spinal BMD in adult women aged 18 to 64 years. Although speculative, these results may partly reflect findings indicating that the vast majority of bone mass in females is realized by 20 years of age and remains fairly constant until about the age of 50 (Kanis et al., 2008; Lebrun, 2006; National Institute of Health, 2013). Other lifestyle factors, such as smoking, alcohol consumption, previous sporting activities (Beasley et al., 2010; Fehily

et al., 1992), and measures of reproductive function (Fehily et al., 1992) (e.g., age at menarche, menopausal status) may also influence bone health in younger and middle-aged women. In considering this possibility, Fehily et al. (1992) reported that current calcium and vitamin D use was associated with radial bone density in young adult females. Additionally, these researchers noted that radial bone density in adulthood was affected by past history of sport participation during childhood (Fehily et al., 1992) and increased sun exposure and a delayed age of menopause positively impacted bone health in premenopausal women (Cranney et al., 2007; Fehily et al., 1992; Welten et al., 1995). In the present study, the potential confounding effects of smoking status, recent milk consumption and dietary intake of calcium, protein, vitamin D and magnesium, history of being treated for osteoporosis and prednisone and cortisone use, and menopausal status were controlled to better isolate the unique roles of physical activity and sedentary behavior on lumbar spine and femoral neck BMC and BMD in younger and middle-aged adult women.

Physical activity, sedentary behavior, and bone health in older adults

While physical activity was not a predictor of femoral BMC and BMD and spinal BMC and BMD in women aged 65 years and older, greater amounts of sedentary time were related to lower femoral BMC and BMD levels. In reporting these results, it should be noted that the potential influence of physical activity level was controlled for statistically in evaluating the contribution of sedentary behavior to bone health. Although research is sparse concerning the effect of sedentary behaviors on bone indices among older females, our findings raise the intriguing possibility that bone loss in this group may be lessened, at least to some extent, by replacing sedentary behaviors with light-intensity, weight-bearing physical activities that can be easily incorporated into daily living routines. Based on findings presented in Table 2, we estimate that reducing sedentary time by 1 h each day would lead to an increase in femoral BMD and BMC of 0.8% and 0.7%, respectively. While the relative magnitude of these changes in bone mineral density and content is not large, only a small relative gain in radial BMC (~1.4%) was noted following a combined program of 10 months of general aerobic training and upper-body weight training in women aged 57 to 83 years (Rikli and McManis, 1990). In addition, findings from two meta-analyses (Kelley, 1998; Wolff et al., 1999) have shown that more intense levels of weight-bearing physical activity and strength training increased femoral bone mass by only about 2% and reversed bone loss by just under 1% each year at the lumbar spine and femoral neck in pre- and post-menopausal women, while graded high-intensity exercise training and walking interventions yielded no improvement in femoral neck BMD in older females (Martyn-St James and Carroll, 2006; Palombaro, 2005). Viewed collectively, these results lend support to the notion that replacing sedentary behavior with regular light-intensity physical activity may be useful in supplementing the positive role of moderate-to-vigorous exercise or helping to maintain or improve bone strength in older women who exhibit diminished physical function (Stevens et al., 2006), decreased cardiovascular endurance and muscle strength (Fleg et al., 2005; Goodpaster et al., 2006) or a heightened risk of bone fracture (Kanis et al., 2009; National Institute of Health Senior Health, 2013). To address these questions, additional studies are needed to develop, implement, and evaluate multifaceted behavioral change approaches (Marcus et al., 2000; Owen et al., 2010) featuring health-producing physical activity and reductions in sedentariness (Sevick et al., 2007) to enhance bone health among older female adults.

Study limitations

As with any study, we acknowledge the presence of some limitations in our project. Because the nature of the dose–response relationship between physical activity level and bone strength in adults remains

unclear (Rankinen and Bouchard, 2002), a dichotomous approach (either meeting or not meeting federal physical activity guidelines) rather than a continuous approach incorporating actual weekly minutes of MVRPA was used to classify physical activity status to align our findings with currently-accepted national physical activity guidelines (U.S. Department of Health and Human Services, 2008). However, a drawback of this grouping scheme is the loss of data regarding individual differences in weekly physical activity within the S-MVRPA and I-MVRPA categories. Secondly, the use of questionnaires to gather data on physical activity and sedentary behavior, while cost-effective and low in participant burden, can lead to an underestimation or overestimation of actual physical activity rates and levels of inactivity (Prince et al., 2008). Related to this point, it should be noted that the measurement of physical activity as defined in the 2008 *Physical Activity Guidelines for Americans* (U.S. Department of Health and Human Sciences, 2008) incorporates a broader definition of physical activity which includes sport, planned exercise, recreation, transport, and other forms of purposeful moderate aerobic physical activity compared to the NHANES survey, which highlights leisure-time physical activity and/or sport and recreational physical activity. As such, the use of NHANES physical activity measures may have resulted in some older women being classified as physically inactive who received an adequate load-bearing stimulus by engaging in active transport and weight-supported activities of daily living to maintain or enhance bone density. The inclusion of responses such as “don’t know” or “refuse to answer” to questions related to the treatment of osteoporosis, use of prednisone/cortisone, smoking and menopausal status, while increasing statistical power, may have also potentially resulted in some misclassification of answers to these queries. As a final point, recent studies have demonstrated that sedentary behavior is a distinct variable that is considered to be independent from moderate-to-vigorous intensity physical activity in affecting the health status of adolescents (De Moraes et al., 2013), adults (Maher et al., 2013), and middle-aged and older adults (Dogra and Stathokostas, 2012). Consequently, while the current investigation focused on documenting the unique contributions of accumulating sufficient amounts of MVRPA or limiting periods of physical inactivity on bone strength in younger and older females, an optimal health goal for persons of all ages should be to participate in both moderate-to-vigorous physical activity and reduce sedentary time by increasing light-intensity physical activity.

Conclusions

Results from our study indicate that performing at least 60 min of daily moderate-to-vigorous recreational physical activity is associated with greater levels of femoral BMC, femoral BMD, spinal BMC, and spinal BMD in adolescent girls, while increased amounts of sedentary time are predictive of lower femoral BMC and BMD in older women. Given the descriptive nature of this investigation, more research is needed to quantify the singular and interactive effects of increasing MVRPA and reducing sedentary time on bone health in females at various stages of life. Because self-report measures of physical activity and sedentary behavior were used in the present study, our findings should also be confirmed using objectively-determined measures of physical activity and sedentary behavior.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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