ORIGINAL ARTICLE

Physical activity as measured by accelerometer in NHANES 2005–2006 is associated with better bone density and trabecular bone score in older adults

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Abstract

Summary In an analysis of NHANES 2005–2006, older, but not younger, women and men with higher levels of physical activity had higher TBS, total hip *T*-score, and femoral neck *T*-score. Even modest levels of physical activity may be a crucial component of bone health maintenance.

Purpose Physical activity is associated with improved bone parameters in adolescence, but it is not clear if this persists into adulthood. Further, it is unclear how low levels of physical activity as measured by accelerometer may impact bone parameters.

Methods We analyzed data from subjects from NHANES 2005–2006 over the age of 20 who had accelerometry and bone mineral density (BMD) testing. We analyzed women and men separately and grouped by over or under 50 years of age: 484 younger women, 486 older women, 604 younger men, and 609 older men. Moderate-to-vigorous physical activity (MVPA) was categorized as low (less than 5 min daily), intermediate (5–20 min daily), or high (at least 20 min daily).

Results Among younger women and men, there was no significant relationship between MVPA and BMD or trabecular bone score (TBS). Conversely, older women with intermediate and high MVPA had higher TBS (1.360 ± 0.008 and 1.377 ± 0.009 vs 1.298 ± 0.010, $p < 0.001$), total hip *T*-score ($- 1.02 \pm 0.13$ and $- 0.90 \pm 0.09$ vs. $- 1.51 \pm 0.08$, $p < 0.01$), and femoral neck *T*-score than women with low MVPA, respectively. Similarly, older men with high MVPA had higher TBS, total hip *T*-score, and femoral neck *T*-score than men with intermediate and low MVPA.

Conclusions Older, but not younger, women and men with higher levels of activity had higher BMD and TBS. Benefits were noted with as little as 5–20 min of daily physical activity. Our results suggest that physical activity is a crucial component of bone health maintenance.

Keywords Physical activity · Bone density · Trabecular bone score

Background

Osteoporosis is a devastating disease and leads to nine million fragility fractures worldwide per year [1]. Self-reported physical

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activity is known to reduce the risk of fracture with studies demonstrating a reduction in fractures by 30–70% in women and men [2–4]. Studies in children and young adulthood demonstrate that physical activity is associated with both higher bone mineral density (BMD) and better microarchitecture parameters as measured by high-resolution quantitative peripheral computerized tomography (HR-PQCT) [5, 6]. However, studies investigating the bone effects of physical activity in adults are fewer and have demonstrated small effects on BMD [7–10] with few studies on bone microarchitecture [11].

Further, many current studies have enrolled athletes and healthy subjects or have investigated the effect of an intervention at one particular loading site [12–14]. While these are important findings, the information may not be applicable to patients seen in clinical practice. In particular, patients in clinical practice are unlikely to meet the national recommendations

for physical activity and may have lower levels of physical activity. In addition, current studies often assess physical activity through questionnaires, which may be less reliable than objective accelerometry.

Recently, trabecular bone score (TBS) has been developed as an adjunct to BMD to aid in refining fracture risk [15]. TBS assesses the texture of the lumbar spine DXA image and correlates with measures of bone microarchitecture [16]. It has been shown to predict fracture risk in studies across North America, Europe, Australia, and Asia [17]. While clinical determinants of TBS have been studied (such as diabetes, glucocorticoid use, major fracture, and COPD [18, 19]), the effect of physical activity has not been evaluated to our knowledge. Thus, the purpose of this study was to examine associations between TBS, BMD, and accelerometry measures from NHANES 2005–2006, a US representative sample.

Methods

This is a study of NHANES 2005–2006 for which TBS and accelerometry data are publicly available. Methods used in NHANES have been reported previously [20]. Briefly, NHANES is a nationally representative US sample that uses a complex survey design. A subset of subjects underwent spine and femur DXA with Hologic QDR 4500A fan-beam densitometer (Hologic, Inc., Bedford, MA). In 2013, TBS software (Medimaps v2.1.0.2, Pessac, France) was used to estimate TBS for individual vertebrae, as well as for the total lumbar spine in adults aged 20 and older.

In our analysis, only subjects over age 20 who had accelerometry and had both spine and femur DXA were analyzed. Subjects were only analyzed if they had valid spine BMD and TBS images with at least two evaluable vertebrae. The same vertebrae were graded as valid or invalid (e.g., degenerative disease) for both spine BMD and TBS. Spine BMD and TBS were then calculated over the same region of interest. *T*-scores were derived using reference data. For both the spine and hip, aged 20–29, female non-Hispanic white data from NHANES 2005–2008 was used as the reference. The primary analysis included only subjects with body mass index (BMI) of 15–37, as this is considered the working BMI range for TBS [17].

The accelerometer used in NHANES was the ActiGraph AM-7164. Subjects who used wheelchairs and subjects with other impairments that prevented them from walking or wearing the device were not included. The device is not waterproof so water-based activities were not recorded. Only subjects with at least 10 h of wear time for at least 4 days were included. In addition to the raw data (1-min intervals of data for each subject), the CDC offers tutorials and summarized datasets that includes the average daily accumulated sedentary, light, moderate, and vigorous activity per subject [21, 22]. Based on previous studies, moderate activity was defined at a threshold

of 2020 counts (equivalent to three metabolic equivalents of task, METs) and vigorous activity was defined at a threshold of 5999 counts (equivalent to six METs) [23]. Moderate and vigorous activity time were summed and categorized by whether the participant averaged less than 5 min of activity daily (low), between 5 and 20 min of activity daily (intermediate), or at least 20 min of activity daily (high). Light physical activity was not included. Women and men were evaluated separately and grouped into under 50 and over 50 years of age. In addition, we also analyzed subjects age 50–64 separately from those 65 and older.

We also examined whether the relationship between the activity and bone parameters was affected by clinical status of the participants by including the following additional covariates: glucocorticoid use, chronic obstructive pulmonary disease (COPD), diabetes, and non-traumatic fractures. Glucocorticoid use was taken from the medication questionnaire and pill bottle review. Participants were asked to report use of medications within the past 30 days, and participants who reported using prednisone, prednisolone, methylprednisolone, or dexamethasone were coded as glucocorticoid users. Those not reporting the use of these medicines were recorded as no glucocorticoid use. COPD was recorded as yes if participants self-reported either "chronic bronchitis" or "emphysema." Diabetes was either self-reported or determined through A1c value of 6.5% or greater [24]. Non-traumatic fractures (excluding fractures of the fingers, toes, and skull) were determined as reported previously [25].

Statistical analysis

All analyses were conducted with Stata 14 (StataCorp, College Station, TX) and were done using population-based sampling weights. Standard errors of the mean for all estimates were obtained using a linearization method (Taylor series). In subpopulation analyses, strata with a single sampling unit were centered at the overall mean to calculate standard errors. A 95% CI is presented for group comparisons at $p < 0.05$ significance level. Adjusted Wald tests were used to compare demographic variables, bone density, TBS, and physical activity. Linear regression was used to assess the association between TBS, BMD, and physical activity with and without known determinants of BMD and TBS, such as age and BMI, and the above mentioned clinical features (covariates).

Results

Subjects

Among 2387 men at least 20 years old in NHANES, 1213 men were included, while among 2592 women at least 20 years old in NHANES, 970 women were included. As

compared with subjects over the age of 20 who were not included, our sample has more male (52.0% vs. 44.2%, $p < 0.001$), was older (47.6 ± 0.72 vs. 45.5 ± 0.82, $p < 0.001$), and was lower in BMI (26.9 ± 0.16 vs. 30.2 ± 0.30, $p < 0.001$). Our sample also had a higher composition of Caucasian and lower composition of African American background (Caucasian 73.9% vs. 69.8%, $p = 0.006$; African American 9.2% vs. 13.7%, $p < 0.001$). The reasons for excluding were unavailable DXA and/or accelerometer data ($n = 1543$ in women, $n = 1141$ men), BMI over 37 ($n = 78$ in women, $n = 33$ in men), and BMI under 15 ($n = 1$ in women, $n = 0$ in men).

Table 1 shows demographic characteristics of the study population. In general, older women and men had higher percentages of Caucasians, lower T-scores and TBS, and lower activity levels than their younger counterparts. BMI was similar between those of the same gender. Among older women, there were significantly lower proportions of women in the high MVPA group and significantly more in the low MVPA group compared with younger women. Among older men, there was a significantly higher proportion in the low MVPA group and lower portions in the intermediate and high MVPA groups.

Younger women and men

Among 484 younger women and 604 younger men, there was no significant difference in TBS, femoral neck T-score, total hip T-score, or lumbar spine T-score among the MVPA groups. Adjustment for age, race, and BMI did not change the results.

Older women

Among 486 older women, those in both the intermediate and high MVPA groups had higher TBS than those in the low MVPA group (1.360 ± 0.008 and 1.377 ± 0.009 vs. 1.298 ± 0.010, $p < 0.001$ for both; Fig. 1). Similarly, those in the intermediate and high MVPA groups had higher total hip T-score (-1.02 ± 0.13 and -0.90 ± 0.09 vs. -1.51 ± 0.08, $p < 0.01$ for both; Fig. 2) and femoral neck T-score (-1.41 ± 0.13 and -1.35 ± 0.09 vs. -1.71 ± 0.07, $p = 0.047$ and $p < 0.001$, respectively) than the low MVPA group. Conversely, there were no significant differences for lumbar spine T-score among those in different MVPA groups.

In regression models (Table 2), these differences remained statistically significant when controlling for age, BMI, race, and lumbar spine T-score (for TBS only). In a subset of subjects with all data ($n = 447$), controlling for COPD, diabetes, glucocorticoid use, and non-traumatic fractures did not significantly affect results (Supplemental Table 1). Results for femoral neck T-score were also similar to unadjusted results (data not shown). Further stratification of older women by age

Table 1 Demographic information

		Younger women (age < 50) (n = 484)	Older women (age ≥ 50) (n = 486)	Younger men (age < 50) (n = 604)	Older men (age ≥ 50) (n = 609)
Age		36.1 ± 0.3 (35.4–36.8)	63.1 ± 0.7 (61.5–64.6)	35.7 ± 0.4 (34.9–36.5)	62.4 ± 0.6 (61.2–63.6)
Caucasian		66.8 ± 3.7% (58.6–74.1%)	81.0 ± 2.8% (74.4–86.2%)	68.8 ± 3.1% (61.9–74.9%)	82.5 ± 2.7% (76.0–87.5%)
BMI		26.3 ± 0.3 (25.8–26.9)	26.5 ± 0.3 (26.0–27.0)	27.1 ± 0.2 (26.7–27.5)	27.7 ± 0.2 (27.3–28.1)
Spine T-score		−0.08 ± 0.05 (−0.18 to 0.01)	−1.08 ± 0.06 (−1.21 to −0.95)	−0.12 ± 0.03 (−0.19 to −0.05)	0.01 ± 0.08 (−0.16 to 0.19)
Femoral neck T-score		−0.34 ± 0.03 (−0.41 to −0.27)	−1.50 (−1.66 to −1.34)	0.18 ± 0.06 (0.05–0.32)	−0.71 (−0.79 to −0.62)
Total hip T-score		−0.14 (−0.23 to −0.06)	−1.15 (−1.34 to −0.97)	0.70 ± 0.06 (0.57–0.82)	0.10 ± 0.04 (0.02–0.19)
Lowest T-score		−0.66 ± 0.04 (−0.74 to −0.58)	−1.81 ± 0.06 (−1.94 to −1.69)	−0.42 ± 0.04 (−0.50 to −0.34)	−0.91 ± 0.05 (−1.01 to −0.81)
TBS		1.474 ± 0.005 (1.463–1.485)	1.343 ± 0.005 (1.332–1.355)	1.434 ± 0.004 (1.426–1.444)	1.344 ± 0.007 (1.328–1.359)
Daily moderate-to-vigorous activity (min)		24.4 ± 1.0 (22.2–26.6)	14.2 ± 1.1 (12.0–16.5)	37.9 ± 1.3 (35.2–40.6)	22.0 ± 1.1 (19.6–24.3)
Daily moderate or vigorous activity	< 5 min	8.8% (6.1–12.7%)	34.1% (28.2–40.5%)	2.6% (1.4–4.9%)	23.4% (20.7–26.4%)
	Between 5 and 20 min	39.8% (34.2–45.8%)	40.2% (35.6–45.0%)	21.8% (18.0–26.2%)	35.3% (28.6–36.8%)
	≥20 min per day	51.3% (44.3–58.3%)	25.7% (19.3–33.3%)	75.6% (71.3–79.4%)	44.0% (40.0–48.1%)

Mean ± SE. 95% CI presented in parenthesis. Confidence intervals between groups that do not cross are statistically significant, $p < 0.05$

Fig. 1 TBS by activity level in older women and men. Error bars represent standard error
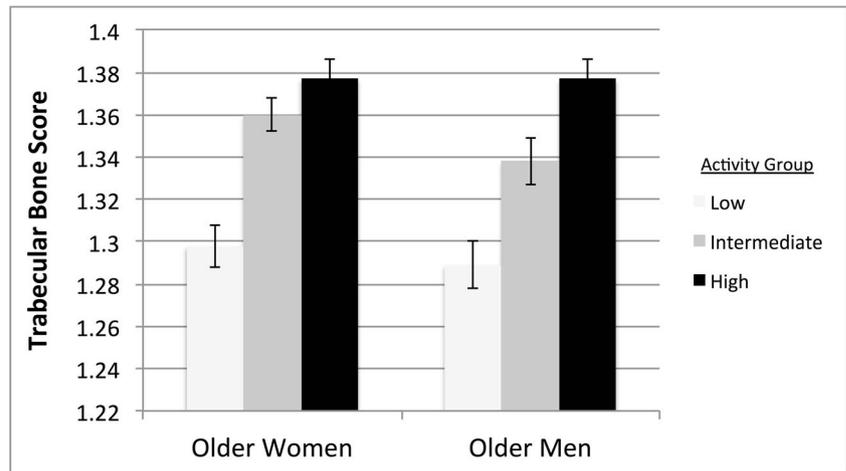
demonstrated the differences between MVPA groups to be most prominent in women between the ages of 50 and 64 ($n = 260$) with no statistically significant differences of TBS or total hip T-score in women over the age of 65 ($n = 226$, Table 3).

Older men

Among 609 older men, there were stepwise increases in TBS with activity level (1.289 ± 0.011 in the low MVPA group, 1.338 ± 0.011 in the intermediate MVPA group, and 1.377 ± 0.009 in the high MVPA group, $p < 0.05$ for all comparisons; Fig. 1). Those in the high MVPA group had higher total hip T-score (0.38 ± 0.07 vs. 0.02 ± 0.11 and -0.31 ± 0.08, $p < 0.02$ for both; Fig. 2) and femoral neck T-score (-0.45 ± 0.07 vs. -0.81 ± 0.11 and -1.06 ± 0.12, $p < 0.03$ for both) than intermediate and low MVPA groups, respectively. Similar to older women, there were no significant differences for lumbar spine T-score among those in different MVPA groups.

In regression models (Table 2), these differences remained statistically significant when controlling for age, BMI, race,

and lumbar spine T-score (for TBS only). In a subset of subjects with all data ($n = 547$), controlling for COPD, diabetes, steroid use, and non-traumatic fractures did not significantly affect results (Supplemental Table 1). Results for femoral neck T-score were also similar to the unadjusted results (data not shown). Further stratification of older men by age demonstrated the differences between MVPA groups to be more prominent in men between the ages of 50 and 64 ($n = 286$) than in men over the age of 65 ($n = 323$, see Table 3). The differences of TBS by MVPA group were not significantly different in men over the age of 65, while the differences of total hip T-score by MVPA group were smaller in men over 65 than in men aged 50–64.

Discussion

Our analysis of NHANES 2005–2006 demonstrates important association between objectively measured physical activity, and TBS and BMD in older women and men. In our analysis, older women and men with 5–20 min of moderate-to-vigorous

Fig. 2 Total hip T-score by activity level in older women and men. Error bars represent standard error
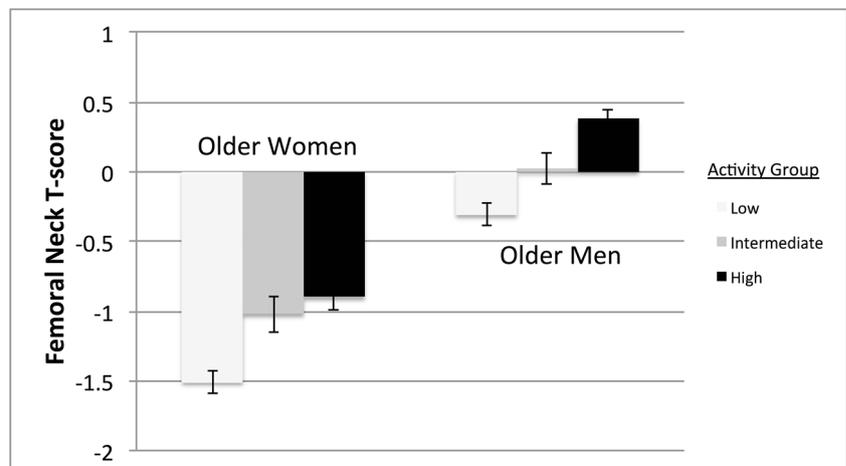
Table 2 TBS and total hip *T*-score stratified by physical activity with adjustment for demographics[1]

		Sample size	Less than 5 min	Between 5 and 20 min	Greater than 20 min	*p* value[2]
TBS	Women 50+	486	1.324 ± 0.010	1.352 ± 0.006	1.356 ± 0.008	0.008
	Men 50+	609	1.314 ± 0.009	1.340 ± 0.007	1.362 ± 0.006	< 0.001
TH *T*-score	Women 50+	486	-1.41 ± 0.09	-1.11 ± 0.11	-0.89 ± 0.09	0.003
	Men 50+	609	-0.30 ± 0.06	0.01 ± 0.10	0.38 ± 0.09	< 0.001

TBS, trabecular bone score; *TH*, total hip

[1] All values adjusted by age, BMI, and race. TBS also adjusted by lumbar spine *T*-score

[2] Overall *p* value for trend across activity levels

daily physical activity had greater TBS (approximately one-fourth standard deviation in women and one-half standard deviation in men) and greater total hip *T*-score (approximately 0.7–0.8 *T*-score). These differences, while relatively modest, could contribute to the reduced fracture risk observed in those who exercise [2–4].

Our results further show that differences exist even at low levels of physical activity as compared with little or none, a novel finding given that most previous studies have focused on higher activity individuals or athletes. The levels of physical activity in NHANES are quite low—i.e., averaging 14.2 min per day in older women. Even older women and men participating in 5–20 min of MVPA, which is below national guidelines of 150 min per week, demonstrated some improvement in bone parameters [26]. Given our results, more research may be required to understand the effects low levels of physical activity may have on bone health.

Somewhat surprising, these associations were not observed in younger women and men. A meta-analysis of studies in premenopausal women demonstrated small, though statistically significant, changes in BMD (~ 0.007–0.009 g/cm^2, approximately equal to 0.08 *T*-score) with high-intensity exercise and/or odd-impact loading [27]. However, as already noted, the subjects in NHANES had lower levels of activity and participated in more heterogeneous activities as compared with

previous studies. Because NHANES is cross-sectional, the activity of the older individuals may be indicative of habitual physical activity over a lifetime and may suggest that physical activity is crucial to the maintenance of bone health with aging.

Our results differed in women and men over the age of 65 as compared with women and men ages 50–64. In particular, the adjusted differences in TBS between MVPA groups were not statistically significant for women or men over the age of 65, while adjusted differences in total hip *T*-score were smaller in magnitude in men over age 65 as compared with ages 50–64. This may suggest that physical activity has smaller effects as we age, though this is speculative given our cross-sectional design. Previous clinical studies have controlled for age by design or in analysis [7, 9, 28], and, to our knowledge, no previous study has examined the differences in the relationship between physical activity and bone density in middle aged as compared with older adults. Further research will be necessary to understand if the bone effects of physical activity vary as we age.

Our study has important limitations. First, it is a cross-sectional study and, thus, we can only report associations between greater physical activity and higher bone density and TBS. We cannot be sure that there is a causative relationship, as there are a multitude of factors that may affect both physical activity and bone health. Second, the accelerometer was worn for 1 week only—it is possible that the activity during that

Table 3 TBS and total hip *T*-score stratified by gender, physical activity, and age group with adjustment for demographics[1]

		Sample size	Less than 5 min	Between 5 and 20 min	Greater than 20 min	*p* value[2]
TBS	Women 50–64	260	1.331 ± 0.009	1.368 ± 0.008	1.376 ± 0.008	0.011
	Women 65+	226	1.302 ± 0.015	1.331 ± 0.005	1.318 ± 0.016	0.125
TH *T*-score	Women 50–64	260	-1.43 ± 0.14	-0.87 ± 0.14	-0.61 ± 0.08	< 0.001
	Women 65+	226	-1.60 ± 0.05	-1.51 ± 0.12	-1.47 ± 0.19	0.44
TBS	Men 50–64	286	1.304 ± 0.017	1.358 ± 0.008	1.377 ± 0.007	< 0.001
	Men 65+	323	1.304 ± 0.009	1.318 ± 0.010	1.317 ± 0.008	0.24
TH *T*-score	Men 50–64	286	-0.33 ± 0.18	0.06 ± 0.17	0.44 ± 0.09	0.002
	Men 65+	323	-0.35 ± 0.09	-0.03 ± 0.08	0.21 ± 0.12	0.001

TBS, trabecular bone score; *TH*, total hip

[1] All values adjusted by age, BMI, and race. TBS also adjusted by lumbar spine *T*-score

[2] Overall *p* value for trend across activity levels

week was not indicative of their usual activity or that participants changed their activity as a response to being monitored (Hawthorne effect). Third, we chose to analyze physical activity as all moderate or vigorous activity combined, which may encompass a wide range of exercise. Studies suggest that very high-intensity exercise, even for a short duration, may have important benefits for bone health [29, 30]. Fourth, because of our various inclusion and exclusion criteria, the study population differed from NHANES overall and, therefore, was not necessarily representative of the USA as a whole. Fifth, glucocorticoid use was assessed in NHANES only over the past 30 days, and previous glucocorticoid use, which could still affect TBS, was not captured. Finally, TBS is not a direct measure of microarchitecture and can be affected by BMI or race/ethnicity [31–33]. We attempted to minimize the impact of BMI and race/ethnicity on our results by limiting our analysis to only those with BMI 15–37 and by controlling for BMI and race/ethnicity in our regression models.

Our study also has several important strengths. First, as a result of using data from NHANES, we had a wide range of age, BMI, and race/ethnicity in our analysis. Second, we also had a wide range of physical activity that allowed for the study of low levels of physical activity as compared with moderate levels of physical activity. Third, we adjusted for several factors, including diabetes, prior fracture, COPD, and steroid use, which are known to affect TBS and/or BMD without a meaningful change to our results. Finally, and most important, we used objectively measured exercise level (accelerometry) in contrast to most other studies that rely on self-report by questionnaires.

Overall, our study demonstrated an association between physical activity as measured by accelerometry with bone density and TBS. Our results suggest that even modest levels of physical activity may improve bone density and microarchitecture, which may be a part of the causal pathways of physical activity and reduced fracture risk.

Compliance with ethical standards

Conflicts of interest   None.

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