Accepted version - Published 25th April 2019, Journal of Public Health

Objectively-measured sedentary time, habitual physical activity and bone strength in adults aged 62 years: the Newcastle Thousand Families Study

Hind K *Assistant Professor* [1, 3], Hayes L *Research Associate* [2], Basterfield L *Research Fellow* [2], Pearce MS *Professor* [2], Birrell F *Clinical Senior Lecturer* [3].

[1] Department of Sport and Exercise Science, Durham University, Durham, DH1 3HP, United Kingdom.

[2] Institute of Health and Society, Newcastle University, Sir James Spence Institute of Child Health, Royal Victoria Infirmary, Newcastle upon Tyne, NE1 4LP, United Kingdom.

[3] Institute of Cellular Medicine, Musculoskeletal Research Group, Newcastle University, Framlington Place, NE2 4HH, United Kingdom.

Corresponding author: Dr K. Hind, Assistant Professor, Department of Sport and Exercise Science, Durham University, Durham, DH1 3HP, United Kingdom. Email: karen.hind@durham.ac.uk

Abstract

Background

The influence of sedentary time (ST) and habitual physical activity (PA) on the bone health of middle aged adults is not well known.

Methods

Bone mineral density (BMD) and hip bone geometry were evaluated in 214 men (n=92) and women (n=112) aged 62.1± 0.5years from the Newcastle Thousand Families Study birth cohort. Accelerometry was used to measure PA and ST over four days. Regression models were adjusted for clinical risk factor covariates.

Results

Men were more sedentary than women ($p<0.05$). ST was negatively associated with spine BMD in men, with 84 minutes more ST corresponding to 0.268g.cm^{-2} lower BMD ($\beta= -0.268$; $p=0.017$). In men, light PA and steps/day were positively associated with bone geometry and BMD. Steps/day was positively associated with bone geometry and femur BMD in women, with a positive difference of 1415 steps/day corresponding to 0.232g.cm^{-2} greater BMD ($\beta=0.232$, $p=0.015$).

Conclusions

ST was unfavourably associated with bone strength in men born in North East England at age 62 years. Higher volumes of light PA and meeting public health daily step recommendations (reaching 10,000 steps/day) was positively associated with bone health in both sexes.

Introduction

Osteoporosis is defined by the World Health Organisation (WHO) as a 'progressive systemic skeletal disease characterized by low bone mass and microarchitectural deterioration of bone tissue, with a consequent increase in bone fragility and susceptibility to fracture', and is more common with age [1]. In the United Kingdom alone, there are over half a million new fragility fractures annually, and this number is expected to rise by 27% between 2010 and 2025 [2].

There are a number of factors that influence the risk for osteoporosis including glucocorticoids and parental history of osteoporosis. Modifiable factors include physical activity (PA) [3-8]. It is established that bone adapts to its loading environment [3] and that weight-bearing and muscle loading exercises are osteogenic in younger [4] and older populations [5-10]. In the absence of loading, bone strength is reduced [11-13]. As such, habitual sedentary behaviour might have a similar detrimental effect on bone as bed-rest or microgravity environments [11], through reduced muscle forces and skeletal unloading [12, 13].

Older adults are more sedentary than younger individuals [14] and less likely to meet the public health PA recommendations of 10 000 steps per day, or 150 minutes of moderate or 75 minutes of vigorous PA per week [15-17]. However, there is scant evidence on the contribution of objectively-measured habitual PA and sedentary time to bone strength in this population. One study reported significant adverse associations between sedentary time and hip bone mineral density (BMD) in older women, but not men [18], and another reported no associations in women [19]. The aim of this current study was to determine if objectively-measured sedentary time and PA are associated with BMD and bone geometry in men and women at age 62 years. Additionally, sex differences in PA levels and sedentary time, were explored.

Methods

Study population

Two hundred and fourteen adults (men, n = 92; women, n = 122) aged 62.1 ± 0.5 years, from the Newcastle Thousand Families Study birth cohort were included in this analysis. The NTFS was initiated in 1947, when 1142 children born in May and June that year to mothers resident in the city of Newcastle upon Tyne were recruited to a study of the health of children living in the city, in response to the high infant mortality rate and poverty levels in the city at that time [20]. The birth cohort has been described in detail at age 50 years [21]. The current study evaluated participants during the most recent follow up wave in 2011, where 352 participants returned for a clinical examination, having completed health and lifestyle questionnaires. The remainder of the

sample could not be contacted, had moved away from the area, did not wish to take part or had died. Of those who returned for clinical assessments, 214 provided sufficient accelerometry data to be included in the analyses. A favourable ethical opinion was obtained from the Sunderland Research Ethics Committee [Reference 09/H0904/40]. All included study members gave their written informed consent.

Accelerometer-measured sedentary time and physical activity

Sedentary time and PA were assessed using validated Actigraph accelerometery [GT1M, Actigraph Corp, US], which participants were asked to wear for seven consecutive days [22, 23, 24]. Participants were requested to wear the monitor for as much of the day as possible, removing it for washing and bathing, swimming and for bed at night. The Actigraph detects vertical accelerations over a user-specified time interval epoch, and used is used to calculate time spent in activities of different intensity [25]. In this study, an epoch length of 60 seconds was specified. The accelerometer data files were processed using the Actilife Software package. Sedentary time was defined as less than 100 counts per minute [cpm], light PA as 100 - 1951 cpm, moderate intensity PA as 1952 - 5725 cpm and vigorous PA as more than 5725 cpm [25]. As the time spent in vigorous activity was very low, minutes of moderate and vigorous PA [MVPA] were combined. Runs of zero counts lasting more than 60 minutes were excluded, as it was considered the monitor must have been removed for this time. A valid day of recording was defined as one in which more than 500 minutes of monitored on-time were recorded in a 24 hour period [26]; only participants recording at least four valid days of accelerometry were included and only valid days were analysed. The total daily time [in minutes] spent in MVPA were obtained by totalling the duration of all the bouts at each level for each day. The values were then averaged over the number of valid days to derive the percentage of time spent in MVPA per day. Time spent sedentary and time spent in light PA were recorded. The number of daily steps were also obtained, which enabled comparisons with public health recommendations.

Bone strength

Participants wore light-weight clothing with shoes and all jewellery removed. Body weight was measured to the nearest 0.1 kg using calibrated electronic scales and standing height was measured to the nearest 0.1 cm using a stadiometer. BMI was subsequently calculated (weight [kg]/height[m]^2). Dual energy X-ray absorptiometry (Lunar iDXA, GE Healthcare, Madison, WI) was used to evaluate BMD (g.cm^{-2}) of the lumbar spine (L1 - L4), total hip and sub-regions of the hip. Structural geometry of the right proximal femur was estimated from the acquired scans by utilising the GE Lunar Advanced Hip Structural Analysis programme. Cross-sectional area

(CSA in cm^2), cross-sectional moment of inertia (CSMI, in cm^4) and femoral strength index (FSI) values were derived. Precision (CV) for the iDXA measurements are 0.4% for lumbar spine BMD and 0.9% for femoral neck BMD [27]. DXA precision error for CSMI and CSA are 3.7% and 3.1% respectively [28]. Scan analysis was performed by the same trained operator using the Lunar enCORE software (version 12.0, GE Healthcare, Madison, WI).

Clinical risk factors and falls

Clinical risk factors for bone fragility were evaluated and treat as covariates in the analysis. In addition to sex and BMI, the covariates included previous fracture, parent hip fracture, current smoking, rheumatoid arthritis, corticosteroid use and alcohol consumption, all ascertained from general health questionnaires. Participants also recorded the number of falls within the last 12 months.

Statistical analysis

All analyses were done using SPSS version 22.0 (IBM Corporation, US). Comparisons of BMI and femoral neck BMD between participants with (n = 214) and without (n = 138) accelerometer data were made by independent T-tests. Normality was tested using the Kolmogorov-Smirnov test. In men, total hip BMD, Wards BMD and FSI were not normally distributed, and in women, total hip BMD was not normally distributed. Therefore, the natural log-transformed values for these variables were created to be used in bivariate analysis and modelling. All descriptive data are expressed as means and their standard deviations (SDs). Associations with bone strength were initially explored using Pearson's correlation coefficients. Covariates (including CRFs) with a p-value < 0.05 (two tailed test) were included in the linear regression models, which were used to examine sex-specific relationships between bone strength, PA levels and sedentary time, with bone strength parameters as the dependent variables. Standardised coefficients enabled the interpretation of differentiation in bone strength parameters according to sedentary time (minutes) or steps per day.

Results

There were fewer men (44% *v* 51%) and more women (49% *v* 56%) in the current sample than in the 1947 cohort ($p = 0.008$). There were no differences in BMI or femoral neck BMD between those who did and did not have accelerometry data ($p > 0.05$). Over half of women had used hormone replacement therapy (58%). Clinical

risk factors for osteoporosis are given in Table I and Table II presents the anthropometric, PA and bone strength results for the cohort by sex.

Men spent more time sedentary and less time in light PA than women (Table 2). Sedentary time ranged from 305 to 676 minutes per day in men and 283 to 691 minutes per day in women. Time spent in MVPA in women ranged from 1 to 115 minutes per day and in men, 0 to 111 minutes. The average daily steps ranged from 1371 to 19 294 in women and 889 to 19 922 in men, and mean values fell short of the recommended 10 000 steps/day [15 - 17]. Twelve women (10%) and 7 men (8%) met or exceeded 10 000 steps per day. There were no differences in sedentary time or PA levels between participants who had or had not fallen in the last 12 months (Table III).

Lumbar spine BMD, total hip BMD, CSMI and CSA were higher in men than women, but there were no differences in femoral neck BMD and FSI (Table 2). In this cohort, 63% (n = 71) of women and 48% (n = 44) of men were either osteopenic or osteoporotic.

Women

Sex-specific unadjusted correlation coefficients between dependent and independent variables are given in Table IV. BMI was positively associated with all BMD outcomes. There were no associations between self-reported hormone therapy and BMD. Smoking was associated with lower CSA, and use of corticosteroids was associated with lower total hip, femoral neck and Wards area BMD, and lower CSMI. Higher number of steps per day were associated with higher femoral neck and Wards area BMD, and with a greater CSA.

After adjustment for BMI and use of corticosteroids, steps per day remained associated with femoral neck BMD ($\beta = 0.232$ g.cm^{-2}; CI 0.228 - 0.236; $p = 0.015$). The standardised coefficient corresponds to a 0.232 g.cm^{-2} higher femoral neck BMD for 1415 more steps per day. After adjusting for BMI ($\beta = 0.174$ mm^2) and smoking ($\beta = -0.256$ mm^2), the regression coefficient for CSA and steps per day was $\beta = 0.253$ mm^2 (CI 0.249 - 0.257; $p = 0.006$).

Men

BMI was associated with lumbar spine BMD but no other measures of bone strength, and smoking was associated with lower CSA (Table IV). Sedentary time was associated with lower lumbar spine, total hip and Wards area BMD, and time spent in light PA was positively associated with lumbar spine, femoral neck, Wards area and total

hip BMD (Table IV). Steps per day were positively associated with total hip BMD and all hip bone geometry outcomes, FSI, CSMI and CSA (Table IV).

Lumbar spine BMD remained associated with sedentary time after adjustment for BMI (β = - 0.268 $g.cm^{-2}$; CI -0.347 - -0.189; p = 0.017). The standardised coefficient corresponds to 0.268 $g.cm^{-2}$ lower lumbar spine BMD for 84 more minutes per day spent sedentary. As TH and Wards area BMD were transformed a similar interpretation was not feasible. After adjustment for BMI, lumbar spine BMD remained positively associated with light PA (β = 0.322 $g.cm^{-2}$; CI 0.237 - 0.395; p = 0.004), corresponding to a 0.322 $g.cm^{-2}$ higher lumbar spine BMD for 82 minutes more per day spent in light PA. The linear regression coefficient between steps per day and CSA, after adjustment for smoking was β = 0.210 mm^2 (CI 0.109 - 0.319; p = 0.05).

Discussion

Main findings of this study

In this study of men and women aged 62 years and born in the North East of England, there were negative associations between sedentary time and BMD in men. Notably men were also found to be more sedentary than women. Although there were no associations with MVPA, the amount of time men spent in light PA was favourably associated with spine and hip BMD. In both sexes, a higher number of steps/ day was associated with higher BMD and positive bone geometrical properties, suggesting that a more active lifestyle was associated with better bone health.

What is already known on this topic

Previous studies have reported negative associations between objectively-measured sedentary time and bone strength only in women [18, 29]. A negative association between self-reported sedentary time and bone strength in men has been reported previously [30]. Self-reported non-study use of the internet in male adolescents was associated with lower total body and femoral neck bone mineral content [30]. In older men, greater self-reported sitting time has been shown to be associated with reduced lean mass and an increased risk of sarcopenia [31], suggesting a similar disuse trajectory.

We observed positive associations between light PA and bone strength in men and steps per day and bone strength in both sexes. This is in agreement with previous cross-sectional and prospective studies measuring PA by self-report [32-35] suggesting the importance of habitual PA for bone health. Most previous studies have

reported positive associations between PA and femur BMD only, and not the lumbar spine [18, 32-35]. Although we found no associations at the lumbar spine in women, BMD at this site was greater in men who engaged in higher levels of light PA and who recorded more steps per day. This might reflect the site-specific mechanics of exercise [36] and it should be considered that bone can become accustomed to repetitive patterns of loading [e.g. walking and running] [37]. It is also possible that earlier life PA might have impacted on later life bone strength [38].

What this study adds

To our knowledge this is the first study to demonstrate an unfavourable relationship between objectively-measured sedentary time and bone strength in men. Our study found that additional 84 minutes per day spent sedentary was associated with a 0.268 $g.cm^{-2}$ lower lumbar spine BMD. This is clinically relevant given that in real terms, it could mean the difference between having normal T-score or an osteopenic T-score. It should also be considered that the strength of the association between sedentary time and total hip BMD (R = -0.195) was not dissimilar to that of smoking (R = −0.209), which is a known risk factor for osteoporosis. The findings of the present study together with evidence elsewhere, suggest that sedentary behaviour is a modifiable factor influencing bone health in men, as well as in women [18, 29]. Our findings also support recent calls for interventions aimed at reducing sedentary behaviour including sitting time, in older adults [39], following accumulation of evidence linking sedentary behaviours with cardiometabolic health [40]. We suggest that there may be benefits in promoting a reduction in sedentary time for improving bone health in men in addition to the well documented cardiometabolic benefits.

Interestingly, MVPA was not associated with any bone health outcomes, unlike in several previous accelerometry-based studies, which have reported positive associations between comparable levels of MVPA and femoral neck, total hip and tibial BMD [18, 41]. Steps/day and light PA were more predictive of bone strength outcomes than MVPA. In women, the regression coefficient describing the relationship between steps per day and femoral neck BMD after correction for significant CRFs, indicates that a change of 1415 steps per day corresponds to a 0.232 $g.cm^{-2}$ higher femoral neck BMD. This would constitute as a clinically meaningful difference in terms of equivalent diagnostic T-score. The number of steps is equivalent to around 15 minutes extra of moderate intensity walking per day [42] This figure is also similar to that derived by Chastin et al. of 0.300 $g.cm^{-2}$ higher total femur BMD for every 10 minutes of MVPA in men [18]. Walking is an accessible and inexpensive form of PA with multifarious health benefits, and the aforementioned PA levels are comparable to those shown to deliver

improved cardiovascular health, lower cancer and mortality rates, through active commuting in adults [43] and of relevance to policy makers, support the current public health recommendation of 10 000 steps/day [15 - 17].

It is notable that in both sexes, the strength of the associations observed between steps/day and light PA with BMD were greater or comparable to those for smoking, corticosteroid use and BMI. Furthermore, adjustment for CRFs did not change the positive associations between PA and bone strength. These findings suggest that PA interventions for bone health in older adults could include light PA, associated with achievable benefits regardless of BMI, smoking and corticosteroid use. However, there are currently no specific guidelines for light PA or for reducing sedentary time at population level. Such an approach might be particularly useful for older adults who may find MVPA difficult to achieve independently, and who may, following retirement, be more likely to engage in sedentary behaviours such as increased television viewing time [44].

Limitations of this study

The firstly limitation is that although we found no associations between MVPA and bone strength, accelerometry is not able to classify all types of PA including some high impact loading exercises [e.g resistance training], which are known to be especially oestogenic [12, 45]. Secondly, it has been hypothesised that attaining a 10% higher peak bone mass in young adulthood could delay the development of osteoporosis by around 13 years [46]. Therefore it is possible that individuals who have greater BMD at age 62 years, had previously achieved a higher peak bone mass at a time when the skeleton was especially responsive to exercise [4]. It is not possible to confirm this from the current cross-sectional analysis and there is risk for reverse causation arising from morbidity, none-the-less, elsewhere, bone loss has been clearly evidenced in adults who are sedentary or in bed rest [18]. Finally, caution should be taken when making inferences given that the study was performed among members of a birth cohort born in Newcastle upon Tyne, UK who were aged 61 to 63 years. This age group does however, have particular public health importance because the risk of osteoporosis and fracture is increased compared to younger ages, and effective risk factor modification is still viable.

Conclusions

In conclusion, the results from this present study demonstrate an unfavourable relationship between sedentary time and bone strength in men. Light PA and steps taken per day were associated with better bone strength in older men and women independent of clinical risk factors, and more so than MVPA. These findings provide

impetus for interventions in older adults that seek to reduce sedentary time and increase habitual PA levels regardless of intensity.

Acknowledgements

We thank the previous research teams involved in the Newcastle Thousand Families Study and the study members for taking part in the investigation. Thanks also to Katherine Kirton and Emma Thompson for their excellent clerical assistance to the study.

Funding

This work was supported by the JGW Patterson Foundation and the National Institute for Health Research.

Conflict of interest

None declared.

References

1. Genant HK, Cooper C, Poor G, et al. Interim report and recommendations of the World Health Organization task-force for osteoporosis. *Osteoporos Int* 1999;**20:10**:259-64.

2. Svedbom A, Hernlund E, Ivergård M, et al. Osteoporosis in the European Union: a compendium of country-specific reports. *Arch Osteoporos* 2013;**1:8**:137

3. Frost HM. Bone "mass" and the "mechanostat": a proposal. The anatomical record. 1987;1:**219[1]:**1-9.

4. Hind K, Burrows M. Weight-bearing exercise and bone mineral accrual in children and adolescents: a review of controlled trials. *Bone* 2007; **31:40[1]**:14-27.

5. Howe TE, Shea B, Dawson LJ, et al. Exercise for preventing and treating osteoporosis in postmenopausal women. *The Cochrane Library* 2011; Jul 6.

6. Bolam KA, Van Uffelen JG, Taaffe DR. The effect of physical exercise on bone density in middle-aged and older men: a systematic review. *Osteoporos Int* 2013;**1:24[11]:**2749-62.

7. Kelley GA, Kelley KS, Kohrt WM. Exercise and bone mineral density in men: a meta-analysis of randomized controlled trials. *Bone* 2013; **31:53[1]:**103-11.

8. Xu J, Lombardi G, Jiao W, Banfi G. Effects of exercise on bone status in female subjects, from young girls to postmenopausal women: an overview of systematic reviews and meta-analyses. *Sports Med* 2016;**1:46[8]:**1165-82.

9. Turner CH, Akhter MP, Raab DM, Kimmel DB, Recker RR. A non invasive, in vivo model for studying strain adaptive bone modeling. *Bone* 1991; **1:12[2]:**73-9.

10. Beck BR, Daly RM, Singh MA, Taaffe DR. Exercise and Sports Science Australia [ESSA] position statement on exercise prescription for the prevention and management of osteoporosis. *J Sci Med Sport* 2016; Oct 31.

11. Rittweger J, Frost HM, Schiessl H, et al. Muscle atrophy and bone loss after 90 days' bed rest and the effects of flywheel resistive exercise and pamidronate: results from the LTBR study. Bone 2005; **30:36[6]:**1019-29.

12. Dehority W, Halloran BP, Bikle DD, et al. Bone and hormonal changes induced by skeletal unloading in the mature male rat. *Am J Physiol Endocrin Metab* 1999; **1:276[1]:**E62-9.

13. Mulder ER, Stegeman DF, Gerrits KH, et al. Strength, size and activation of knee extensors followed during 8 weeks of horizontal bed rest and the influence of a countermeasure. *Eur J Appl Physiol* 2006;**1:97[6]:**706-15.

14. Harvey JA, Chastin SF, Skelton DA. How sedentary are older people? A systematic review of the amount of sedentary behavior. *J Ageing Physical Activity* 2015; **23[3]:**471-87.

15. Besser LM, Dannenberg AL. Walking to public transit: steps to help meet physical activity recommendations. *Am J Prev Med* 2005; **30:29[4]:**273-80.

16. Public Health England. Physical activity data tool: September 2017 update. https://www.gov.uk/government/statistics/physical-activity-data-tool-september-2017-update accessed Oct 2017

17. Haskell WL, Lee IM, Pate RR, et al. Physical activity and public health. Updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Circulation* 2007; Aug 1.

18. Chastin SF, Mandrichenko O, Helbostadt JL, Skelton DA. Associations between objectively-measured sedentary behaviour and physical activity with bone mineral density in adults and older adults, the NHANES study. *Bone* 2014;**31:64:**254-62.

19. Gába A, Kapuš O, Pelclová J, Riegerová J. The relationship between accelerometer-determined physical activity and body composition and bone mineral density in postmenopausal women. *Arch Geront Geriat* 2012; **30:54[3]:**e315-21.

20. Miller FJ. The epidemiological approach to the family as a unit in health statistics and the measurement of community health. *Soc Sci Med* 1974;**30:8:9**:479-82.

21. Pearce MS, Unwin NC, Parker L, Craft AW. Cohort profile: the Newcastle Thousand Families 1947 birth cohort. *Int J Epidemiol.* 2009;**1:38:4:**932-7.

22. Welk GJ, Schaben JA, Morrow Jr JR. Reliability of accelerometry-based activity monitors: a generalizability study. *Med Sci Sport Exerc* 2004; **36[9]:**1637-45.

23. Plasqui G, Westerterp KR. Physical activity assessment with accelerometers: an evaluation against doubly labeled water. *Obesity* 2007;**1:15[10]:**2371-9.

24. Nichols JF, Morgan CG, Chabot LE, Sallis JF, Calfas KJ. Assessment of physical activity with the Computer Science and Applications, Inc., accelerometer: laboratory versus field validation. *Res Q Sport Exerc* 2000; **1:71[1]:**36-43.

25. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sport Exerc* 1998;**30[5]:**777-81.

26. Matthew CE. Calibration of accelerometer output for adults. *Med Sci Sport Exerc* 2005;**37[**11 Suppl]:S512-22.

27. Hind K, Oldroyd B, Truscott JG. In vivo precision of the GE Lunar iDXA densitometer for the measurement of total-body, lumbar spine, and femoral bone mineral density in adults. *J Clin Densitom* 2010; **31:13[4]:**413-7.

28. Hind K, Oldroyd B, Prajapati A, Rhodes L. In vivo precision of dual-energy X-ray absorptiometry-derived hip structural analysis in adults. *J Clin Densitom* 2012; **30:15[3]:**302-7.

29. Nguyen TV, Sambrook PN, Eisman JA. Bone loss, physical activity, and weight change in elderly women: the Dubbo Osteoporosis Epidemiology Study. *J Bone Miner Res* 1998; **1:13[9]:**1458-67.

30. Gracia-Marco L, Moreno LA, Ortega FB, et al, HELENA Study Group. Levels of physical activity that predict optimal bone mass in adolescents: the HELENA study. *Am J Prev Med* 2011; **30:40[6]:**599-607.

31. Gianoudis J, Bailey CA, Daly RM. Associations between sedentary behaviour and body composition, muscle function and sarcopenia in community-dwelling older adults. *Osteoporos Int* 2015; **1:26[2]:**571-9.

32. Langsetmo L, Hitchcock CL, Kingwell EJ, et al. Physical activity, body mass index and bone mineral density—associations in a prospective population-based cohort of women and men: The Canadian Multicentre Osteoporosis Study [CaMos]. *Bone* 2012; **31:50[1]:**401-8.

33. Nokes NR, Tucker LA. Changes in hip bone mineral density and objectively measured physical activity in middle-aged women: a 6-year prospective study. *Am J Health Prom* 2012;**26[6]:**341-7.

34. Mori T, Ishii S, Greendale GA, et al. Physical activity as determinant of femoral neck strength relative to load in adult women: findings from the hip strength across the menopause transition study. *Osteoporos Int* 2014; **1:25[1]:**265-72.

35. Menzel J, Di Giuseppe R, Wientzek A, et al. Physical activity, bone health, and obesity in peri-/pre-and postmenopausal women: Results from the EPIC-Potsdam study. *Calcif Tiss Int* 2015; **1:97[4]:**376-84.

36. Hind K, Gannon L, Whatley E, Cooke C, Truscott J. Bone cross-sectional geometry in male runners, gymnasts, swimmers and non-athletic controls: a hip-structural analysis study. *Eur J App Physiol* 2012; **1:112[2]:**535-41.

37. Lanyon LE. Using functional loading to influence bone mass and architecture: objectives, mechanisms, and relationship with estrogen of the mechanically adaptive process in bone. *Bone* 1996;**1:18[1]:**S37-43.

38. Warden SJ, Fuchs RK, Castillo AB, Nelson IR, Turner CH. Exercise when young provides lifelong benefits to bone structure and strength. *J Bone Miner Res* 2007;**1:22[2]:**251-9.

39. Keadle SK, Conroy DE, Buman MP, Dunstan DW, Matthews CE. Targeting Reductions in Sitting Time to Increase Physical Activity and Improve Health. *Med Sci Sport Exerc* 2017; Mar 8.

40. Healy GN, Matthews CE, Dunstan DW, Winkler EA, Owen N. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003–06. *Eur Heart J* 2011;**11:32[5]:**590-7.

41. Johansson J, Nordström A, Nordström P. Objectively measured physical activity is associated with parameters of bone in 70-year-old men and women. *Bone* 2015; **31:81:**72-9.

42. Marshall SJ, Levy SS, Tudor-Locke CE, et al. Translating physical activity recommendations into a pedometer-based step goal: 3000 steps in 30 minutes. *Am J Prev Med* 2009;**31:36[5]:**410-5.

43. Celis-Morales CA, Lyall DM, Welsh P, et al. Association between active commuting and incident cardiovascular disease, cancer, and mortality: prospective cohort study. *BMJ* 2017;**19:357**:j1456. doi: 10.1136/bmj.j1456.

44. Barnett I, van Sluijs E, Ogilvie D, Wareham NJ. Changes in household, transport and recreational physical activity and television viewing time across the transition to retirement: longitudinal evidence from the EPIC-Norfolk cohort. *J Epidemiol Comm Health* 2014; **68:8.**

45. Watson SL, Weeks BK, Weis LJ, Horan SA, Beck BR. Heavy resistance training is safe and improves bone, function, and stature in postmenopausal women with low to very low bone mass: novel early findings from the LIFTMOR trial. *Osteoporos Int* 2015;**1:26[12]:**2889-94.

46. Hernandez CJ, Beaupre GS, Carter DR. A theoretical analysis of the relative influences of peak BMD, age-related bone loss and menopause on the development of osteoporosis. *Osteoporos Int* 2003; **1:14[10]:**843-7.

Table I. Clinical risk factors for osteoporosis and fracture, age 62 years

	Women	*Men*
Use of corticosteroids [>3 months]	7 (5.8%)	5 (5.7%)
Parental fracture	4 (3.3%)	6 (6.7%)
Previous fracture	21 (17.1%)	16 (18.2%)
Hip fracture	1 (0.8%)	2 (2.2%)
Rheumatoid arthritis	1 (0.8%)	1 (1.1%)
Current smoking	9 (7.4%)	12 (13.6%)
Alcohol consumption ≥3 units/daily	15 (12.4%)	23 (26.1%)
Fallen within last 12 months	20 (16.5%)	16 (17.4%)

Table II. Anthropometric, bone strength and physical activity parameters (mean, SD)

	Women	*Men*	*P*
Height, cm	161.2 ± 6.8	173.3 ± 7.2	*< 0.001*
Weight, cm	73.3 ± 14.5	82.7 ± 15.2	*< 0.001*
Body mass index, $kg.m^{-2}$	28.2 ± 5.4	27.6 ± 4.9	0.346
Sedentary time, minutes/day	493.6 ± 69.7	523.2 ± 83.7	0.008
Light activity time, minutes/day	275.9 ± 59.7	253.2 ± 82.2	0.028
MPVA time, minutes/day	22.1 ± 19.9	23.8 ± 17.9	0.525
Steps per day	8,035.9 ± 1,415.2	8,113.9 ± 1,572.1	0.970
Lumbar spine BMD, $g.cm^{-2}$	1.105 ± 0.175	1.207 ± 0.168	*< 0.001*
Lumbar spine T-score	- 0.7 ± 1.4	- 0.2 ± 1.4	*< 0.001*
Total hip BMD, $g.m^{-2}$	0.987 ± 0.138	1.077 ± 0.155	*< 0.001*
Femoral neck BMD, $g.cm^{-2}$	0.918 ± 0.169	0.961 ± 0.166	0.070
Femoral neck T-score	- 0.5 ± 1.2	- 0.8 ± 1.2	0.070
Wards area BMD, $g.cm^{-2}$	0.739 ± 0.161	0.771 ± 0.176	0.179
Trochanter BMD, $g.cm^{-2}$	0.821 ± 0.135	0.985 ± 0.178	*< 0.001*
Femoral Strength Index	1.5 ± 0.5	1.5 ± 0.4	0.640
CSMI [mm^4]	10,092.6 ± 2,603.5	17,231.5 ± 4,480.2	*< 0.001*
CSA [mm^2]	141.2 ± 29.9	173.9 ± 31.5	*< 0.001*

MVPA: moderate to vigorous physical activity; BMD: bone mineral density; CSMI: cross-sectional moment of inertia; CSA: cross-sectional area

Table III. Sedentary time, physical activity levels and reported falls in the last 12 months (mean, SD)

	Women			*Men*		
	Fall (n=17)	*No fall (n=105)*	*P*	*Fall (n=15)*	*No fall (n=77)*	*P*
Sedentary time, min/day	483.0 ± 74.1	495.3 ± 69.1	0.516	517.1 ± 70.1	526.9 ± 87.9	0.697
Light physical activity, min/day	271.8 ± 62.7	276.6 ± 59.6	0.767	233.4 ± 90.3	260.5 ± 82.2	0.275
MVPA, min/day	20.6 ± 26.6	23.5 ± 20.6	0.614	23.9 ± 13.7	24.1 ± 18.8	0.984
Steps per day	6348.4 ± 3591.3	7017.7 ± 3001.1	0.572	7351.4 ± 3744.7	6545.1 ± 3235.3	0.400

Table IV. Unadjusted Pearson correlation coefficients [p values] of physical activity levels and bone strength parameters

	Sedentary time	*Light physical activity*	*MPVA*	*Steps per day*	*BMI*	*Smoking*	*Corticosteroids*
Women							
Lumbar spine BMD	0.017 [0.860]	0.038 [0.699]	-0.145 [0.129]	0.123 [0.183]	0.369 [<0.001]*	-0.051 [0.595]	-0.186 [0.051]
Total hip BMD¶	-0.018 [0.856]	0.079 [0.415]	-0.024 [0.806]	0.145 [0.116]	0.326 [<0.001]*	-0.116 [0.227]	-0.225 [0.018]*
Femoral neck BMD	-0.077 [0.431]	0.074 [0.447]	-0.100 [0.273]	0.203 [0.037]*	0.255 [0.008]*	-0.141 [0.145]	-0.208 [0.030]*
Wards area BMD	0.051 [0.626]	0.043 [0.658]	-0.030 [0.753]	0.183 [0.057]	0.248 [0.010]*	-0.176 [0.068]	0.211 [0.028]*
Trochanter BMD	-0.024 [0.805]	0.079 [0.417]	-0.072 [0.458]	0.156 [0.109]	0.330 [<0.001]*	-0.039 [0.683]	0.187 [0.051]
Femoral Strength Index	-0.094 [0.334]	0.159 [0.101]	0.126 [0.194]	0.172 [0.079]	n/a	-0.115 [0.233]	0.069 [0.477]
Femur CSMI	-0.014 [0.888]	-0.002 [0.986]	0.088 [0.338]	0.171 [0.080]	0.086 [0.378]	-0.004 [0.964]	0.185 [0.050]*
Femur CSA	-0.045 [0.645]	0.048 [0.627]	0.052 [0.574]	0.243 [0.011]*	0.137 [0.174]	-0.235 [0.014]*	0.162 [0.093]
Men							
Lumbar spine BMD	-0.221 [0.050]*	0.260 [0.021]*	0.036 [0.741]	0.057 [0.614]	0.229 [0.033]*	-0.037 [0.736]	-0.050 [0.653]
Total hip BMD ¶	-0.195 [0.048]*	0.257 [0.021]*	0.041 [0.705]	0.282 [0.038]*	0.160 [0.137]	-0.209 [0.050]*	-0.132 [0.232]
Femoral neck BMD	-0.131 [0.242]	0.230 [0.039]*	0.020 [0.981]	0.145 [0.190]	0.100 [0.353]	-0.021 [0.851]	-0.023 [0.837]
Wards area BMD ¶	-0.264 [0.017]*	0.254 [0.023]*	0.052 [0.626]	0.175 [0.110]	-0.012 [0.909]	-0.058 [0.595]	-0.081 [0.462]
Trochanter BMD	-0.083 [0.467]	0.168 [0.135]	0.075 [0.483]	0.117 [0.292]	0.101 [0.349]	-0.129 [0.239]	-0.209 [0.056]
Femoral Strength Index¶	-0.093 [0.407]	0.064 [0.571]	0.113 [0.210]	0.320 [0.002]*	n/a	-0.150 [0.169]	0.011 [0.921]
Femur CSMI	-0.174 [0.121]	0.117 [0.297]	0.198 [0.060]	0.261 [0.017]*	0.028 [0.795]	-0.165 [0.129]	-0.045 [0.682]
Femur CSA	-0.166 [0.138]	0.171 [0.126]	0.148 [0.166]	0.308 [0.005]*	0.135 [0.208]	-0.275 [0.010]*	-0.119 [0.280]

BMD: bone mineral density; CSMI: cross-sectional moment of inertia; CSA: cross-sectional area; BMI: body mass index; * significant association at $p < 0.05$; ¶ Log transformed