Journals of Gerontology: MEDICAL SCIENCES, 2015, 635–640
doi:10.1093/gerona/glu213
Research Article
Advance Access publication November 27, 2014

Research Article

Physical Function in Older Men With Hyperkyphosis

Wendy B. Katzman,[1] Stephanie L. Harrison,[2] Howard A. Fink,[3] Lynn M. Marshall,[4] Eric Orwoll,[4] Elizabeth Barrett-Connor,[5] Peggy M. Cawthon,[2] and Deborah M. Kado[5] for the Osteoporotic Fractures in Men (MrOS) Study Research Group

[1]Department of Physical Therapy and Rehabilitation Science, University of California, San Francisco. [2]California Pacific Medical Center Research Institute, San Francisco. [3]Geriatric Research Education & Clinical Center, VA Medical Center, Minneapolis, Minnesota. [4]Orthopaedics & Rehabilitation Department, Oregon Health and Science University, School of Medicine, Portland. [5]Departments of Family and Preventive Medicine and Internal Medicine, University of California, San Diego

Address correspondence to Wendy Katzman, PT, DPTSc, OCS, Department of Physical Therapy and Rehabilitation Science, School of Medicine, University of California San Francisco, 1500 Owens Suite 400, San Francisco, CA 94158. Email: wendy.katzman@ucsf.edu

Abstract

Background. Age-related hyperkyphosis has been associated with poor physical function and is a well-established predictor of adverse health outcomes in older women, but its impact on health in older men is less well understood.

Methods. We conducted a cross-sectional study to evaluate the association of hyperkyphosis and physical function in 2,363 men, aged 71–98 ($M = 79$) from the Osteoporotic Fractures in Men Study. Kyphosis was measured using the Rancho Bernardo Study block method. Measurements of grip strength and lower extremity function, including gait speed over 6 m, narrow walk (measure of dynamic balance), repeated chair stands ability and time, and lower extremity power (Nottingham Power Rig) were included separately as primary outcomes. We investigated associations of kyphosis and each outcome in age-adjusted and multivariable linear or logistic regression models, controlling for age, clinic, education, race, bone mineral density, height, weight, diabetes, and physical activity.

Results. In multivariate linear regression, we observed a dose-related response of worse scores on each lower extremity physical function test as number of blocks increased, p for trend ≤.001. Using a cutoff of ≥4 blocks, 20% ($N = 469$) of men were characterized with hyperkyphosis. In multivariate logistic regression, men with hyperkyphosis had increased odds (range 1.5–1.8) of being in the worst quartile of performing lower extremity physical function tasks ($p < .001$ for each outcome). Kyphosis was not associated with grip strength in any multivariate analysis.

Conclusions. Hyperkyphosis is associated with impaired lower extremity physical function in older men. Further studies are needed to determine the direction of causality.

Key words: Kyphosis—Hyperkyphosis—Normative aging—Physical function—Physical performance.

Decision Editor: Dr. Stephen Kritchevsky, PhD

Age-related hyperkyphosis, an excessive forward curvature of the thoracic spine, has been associated with difficulty performing physical function tasks and is a well-established predictor of adverse health outcomes in older women (1–6). While hyperkyphosis is often considered to be a common problem in older women, men had a greater prevalence of hyperkyphosis than women in a study that used the Rancho Bernardo block method of kyphosis measurement (4).

While there is evidence that hyperkyphosis affects both sexes, the impact of hyperkyphosis on the ability to perform physical function tasks in men is not well established. Maintaining physical independence with aging is of concern in any aging population. Men generally perform better on physical performance tests of lower extremity mobility than women (7) but how this apparent advantage translates to older men with hyperkyphosis is understudied. We have previously reported that there was a dose-related response of increased odds of difficulty completing a chair stand task with increasing kyphosis in older men (4), but a recent cross-sectional study reported that greater kyphosis was associated with poorer physical function in older women, but not men (8). Therefore, to gain further understanding of the effect of hyperkyphosis on physical function in men, we used data from a large cohort study of community-dwelling older men in which there were several objective measures of physical function as well as an assessment of kyphosis.

Methods

Participants

The Osteoporotic Fractures in Men (MrOS) study population consists of 5,994 community dwelling, ambulatory men aged 65 or older who were recruited in 2000–2002 from six academic medical centers in Birmingham, AL; Minneapolis, MN; Palo Alto, CA; Pittsburgh, PA; Portland, OR; and San Diego, CA (9,10). The primary purpose of MrOS is to determine risk factors for falls, osteoporotic fractures, and other conditions of aging men. Of the 5,994 men enrolled in MrOS, 4,681 men returned for Visit 3 in 2006–2009, a mean 6.8 (*SD* = 0.4) years after enrollment. The block method measurement of kyphosis was implemented late due to limitations in funding; only 2,931 men who attended Visit 3 in the later part of 2007–2009 had this measurement. An additional 568 men were excluded because they lacked all physical function outcome measurements collected at Visit 3, leaving 2,363 men in the analytic sample. The 2,318 men who were not included in the analytic sample were slightly older, less physically active, and reported more dependence in activities of daily living, and more diabetes.

Conduct of the MrOS study was approved by the Institutional Review Board of each of the participating medical centers; written informed consent was obtained from all participants.

Measurements

Kyphosis

Kyphosis was measured at the third clinic visit using the Rancho Bernardo block method (11). Participants were asked to lie supine on a radiology table. As needed, 1.7-cm blocks were placed under each man's head until a neutral position (participant's head neither hyperextended nor hyperflexed) was achieved and with his eyes directed toward the ceiling (Figure 1). The number of 1.7-cm blocks needed to restore a neutral head and neck position while lying supine on the radiology table were recorded. For the purpose of this study, we prespecified hyperkyphosis as needing four or more blocks (4). The interrater reliability of the block method was calculated using Spearman correlation coefficients and ranged from 0.85 to 1.00, depending on the clinical site. In previous unpublished studies, the correlation between the block method of kyphosis and supine Cobb angle of kyphosis in men was $r = .28$, ($p = .02$).

Physical function tests

Participants completed performance-based measurements of lower extremity physical function tasks and grip strength. Participants' ability to complete five chair stands with their arms crossed at their chest was established and the time to complete five chair stands was recorded in seconds. Walking speed (m/s) was measured at usual pace over a 6-m course. The time (second) to complete a 20-cm wide narrow walking course over 6 m was recorded and used to determine dynamic balance. Leg extension power (watts) was measured on the Nottingham Power Rig (University of Nottingham, Nottingham, England) with up to five trials per leg (12). The maximum power of both legs was used in the analysis. Grip strength was measured using a Jamar handheld dynamometer in each hand twice, and the maximum strength of the four trials was used in the analysis (13).

Physical and anthropometric measures

All physical and anthropometric measures were obtained at Visit 3. Measurements of height and weight were obtained by Harpenden stadiometers and balance beam or digital scales. Participants reported their height at age 25, and height loss (cm) since that age was calculated. Bone mineral density (BMD) was measured at the proximal femur using dual energy X-ray absorptiometry (QDR 4500; Hologic, Inc., Waltham, MA). The ankle–brachial index was also measured (14), and an ankle–brachial index <0.9 was considered as indication of peripheral arterial disease.

Questionnaires

Information about age, medical history, current smoking, and alcohol intake (usual drinks per day) were obtained by self-administered questionnaires at Visit 3. Depression was quantified on the Geriatric Depression scale, and defined as a score ≥6 (15). Physical activity was quantified using the Physical Activity Scale for the Elderly (PASE) (16); and difficulty performing at least one instrumental activities of daily living was determined using the EQ-5D, an internationally recognized measure for quality of life estimation, at Visit 3 (17). Race and education were self-reported at the initial visit.

Statistical Analysis

The association between an a priori group of potential confounders and kyphosis based on biological plausibility and evidence from previous studies was examined. A p value <.1 was used to select confounders associated with hyperkyphosis and physical function outcomes that included age, clinic, education, race, hip BMD, height, weight, diabetes, and physical activity using PASE. Descriptive statistics characterized physical function by block measure of kyphosis (blocks 4+ vs block groups 0, 1, 2, 3 combined, and number of blocks of kyphosis). Age- and clinic-adjusted analyses investigated how kyphosis was associated with each of the physical function outcomes. Multivariable models, adjusting for confounders, investigated how kyphosis was associated with each of the physical function outcomes. Depending on the outcome of interest, we used either multivariable linear or logistic regression analyses. For the logistic regression, we created a worst category of each physical function test, and collapsed the slowest/weakest and those unable to physically perform the physical function test into the worst quartile of physical function compared with the other three quartiles combined.

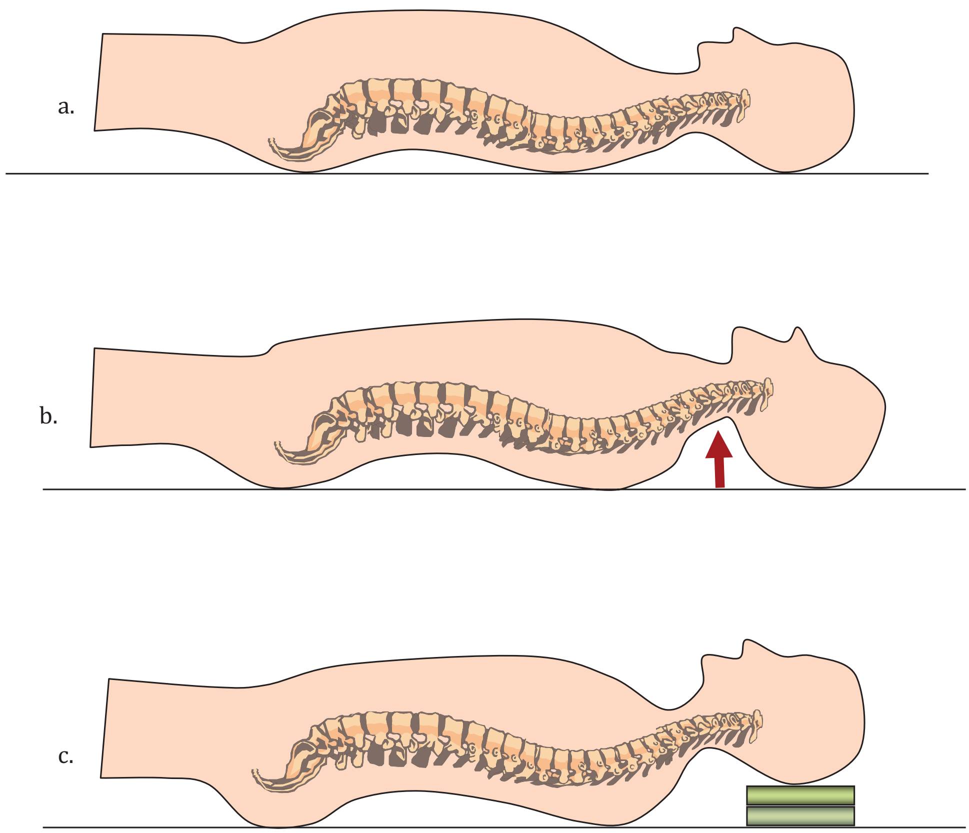

Figure 1. Illustration of the block method of estimating kyphotic posture. (**a**) Normal spine with neutral head and neck position. (**b**) Kyphotic spine with hyperextended neck. (**c**) Kyphotic spine with head on blocks, which restores neutral head and neck position. *Each block measures 1.7-cm thick.

Results

The study sample included 2,363 men with a mean age of 79 (*SD* = 5) years. Using a cutoff of 4 or more blocks to define hyperkyphosis, 20% of the study sample was characterized as having hyperkyphosis. The range of blocks required to position the head in neutral was 0–10; 3% of the men required no blocks, 18% required one block, 32% required two blocks, 28% required three blocks, 12% required four blocks, 5% required five blocks, and 2% required six or more blocks. Men with hyperkyphosis were older, had lower hip BMD, were more likely to self-report difficulty with at least one instrumental activities of daily living, and were less physically active (Table 1). In addition, men with hyperkyphosis, compared with those without, had decreased grip strength and poorer scores on all lower extremity physical function tests. While there was no difference in height in both groups, men with hyperkyphosis had lost more height since the age of 25 (Table 1).

In age- and clinic-adjusted linear models, when the number of blocks used was included as an ordinal variable, we generally observed lower scores on each of the physical function tests as the number of blocks increased (Table 2). In the multivariate models, after controlling for age, clinic, race, education, height, weight, hip BMD, diabetes, and physical activity, grip strength was no longer associated with hyperkyphosis (p = .12), but associations with all other physical function tests remained significant.

In age-, clinic-adjusted, and multivariate-adjusted logistic models, hyperkyphosis was associated with worse lower extremity physical function (data not shown). Men with hyperkyphosis had 1.7-fold odds of being in the worst chair stand quartile (95% confidence interval: 1.3, 2.1); 1.8-fold odds of being in the worst walking speed quartile (95% confidence interval: 1.4, 2.4); 1.5-fold odds of being in the worst dynamic balance quartile (95% confidence interval: 1.3, 2.0); and 1.8-fold odds of being in the worst leg extension power quartile (95% confidence interval: 1.4, 2.4). The association with grip strength was not significant in any model.

Discussion

We observed an association between hyperkyphosis and impaired lower extremity physical function assessed by multiple validated methods, and this association remained significant after adjustment for confounding factors. Our results are consistent with previous well-controlled cross-sectional studies reporting associations of greater degrees of kyphosis and impaired objective lower extremity physical function in older women (6,18), and also replicate the Rancho Bernardo findings of hyperkyphosis and poor chair stand test performance in a cohort of both older men and women (4). However, our results contrast those from a recent study that reported greater kyphosis was associated with lower scores on the Short Physical Performance Battery in older women but not men (8). These differences could be explained by the small sample size of men in that study and the use of the standing flexible ruler method that may capture a different domain of hyperkyphosis compared with the block method used in this study.

Hyperkyphosis was not associated with poor grip strength in multivariate analysis, indicating that hyperkyphosis has a more specific association with lower extremity function. Importantly, objective measures of lower extremity function are highly predictive of

Table 1. Characteristics (mean ± *SD*, or *N* (%)) of MrOS Participants by Block Group 0–3 vs 4+

	Number of Blocks Used		*p* Value
	0–3 (*N* = 1,894)	4+ (*N* = 469)	
Age (y)	78.7 ± 4.9	80.5 ± 5.6	<.001
Age groups			
71–75	579 (30.8)	104 (22.2)	<.001
76–80	673 (35.5)	140 (29.9)	
81–85	438 (23.1)	124 (26.4)	
86+	204 (10.8)	101 (21.5)	
Height (cm)	173.1 ± 6.7	173.53 ± 7.5	.23
Weight (kg)	80.8 ± 13.2	81.6 ± 13.8	.24
Non-Hispanic white	1,704 (89.0)	432 (92.1)	.16
Education			
HS or less	423 (22.3)	81 (17.3)	.06
College grad or some college	764 (40.3)	203 (43.3)	
Grad school	707 (37.3)	185 (39.5)	
Drinks per week			
None	626 (33.3)	160 (34.2)	.08
1–13	1,139 (60.6)	292 (62.4)	
14+	114 (6.1)	16 (3.4)	
Current smoker	34 (1.8)	11 (2.4)	.44
1+ Instrumental activities of daily living	349 (18.5)	131 (28.0)	<.001
Diabetes	269 (14.2)	70 (14.9)	.69
Peripheral arterial disease	141 (8.2)	34 (8.5)	.86
Depression	98 (5.2)	22 (4.7)	.68
Height change since age 25 (cm)	3.1 (2.8)	3.9 (3.1)	<.001
Total hip BMD (g/cm^2)	0.95 ± 0.14	0.92 ± 0.16	.001
PASE score	138.5 ± 67.8	120.8 ± 63.2	<.001
Chair stand (s)	11.5 ± 3.4	12.4 ± 4	<.001
Chair stand (worst quartile)	506 (26.7)	183 (39.0)	<.001
Unable to do five chair stands	100 (0.05)	44 (0.09)	<.001
Walking speed (m/s)	1.16 ± 0.22	1.09 ± 0.23	<.001
Walking speed (worst quartile)	332 (17.5)	140 (29.9)	<.001
Narrow walk (m/s)	1.13 ± 0.24	1.07 ± 0.28	<.001
Narrow walk (worst quartile)	625 (33)	243 (51.8)	<.001
Leg power (watts)	184.3 ± 57.2	168.8 ± 58.0	<.001
Leg power (worst quartile)	474 (25.0)	174 (37.1)	<.001
Max grip strength (kg)	39.2 ± 8.2	38.0 ± 9.1	0.01
Max grip strength (worst quartile)	334 (17.6)	108 (23.0)	0.01

Notes: BMD = bone mineral density; PASE = Physical Activity Scale for the Elderly.

subsequent disability, suggesting that future analyses should investigate the association between hyperkyphosis and the risk of disability over time in older men (19).

While the magnitude of the associations between hyperkyphosis and physical function tended to be modest, the differences in physical function in men with hyperkyphosis may be physiologically significant. For instance, we found the mean time to complete the chair stand test in men with hyperkyphosis was 12.3 seconds, which exceeds a cutoff of 12.2 seconds considered normal for men 71–79 years old (20). Additionally, the difference in mean walking speed between the men with 0 blocks (1.17 m/s) and men with 4+ blocks (1.10 m/s) is 0.07 m/s which exceeds the minimally important clinical change in this measure according to Perera and colleagues (21).

We hypothesize several possible explanations for the associations between hyperkyphosis and impaired lower extremity physical function. First, hyperkyphosis has been described as a new geriatric syndrome (22–24) and may be a marker for physiologic aging. In fact, age, vertebral fractures, low BMD and BMD loss, low body weight and weight loss are important determinants of greater kyphosis progression in older women (23). However, it is not clear whether hyperkyphosis is a cause of decreased physical function, and thus a target for intervention such as spinal extension muscle strengthening (25), or an associated phenomenon and the result of accelerated aging or physical dysfunction. Second, it is plausible that the observed lower limb performance differences reflected impaired lower limb arterial perfusion (26). However, there was no difference between the block groups in the prevalence of peripheral arterial disease defined as an ankle–brachial index score <0.9 (14). Furthermore, when we ran a multivariate model that included peripheral arterial disease, there was no change in the association between the number of blocks and physical function outcomes. Third, hyperkyphosis restricts forced vital capacity and forced expiratory volume pulmonary function (27–29) which may have a negative impact on the ability to perform repeated chair stands, walking speed, narrow walk, and leg extension power. Fourth, hyperkyphosis increases anterior thoracic curvature in the spine which alters sagittal plane alignment. Kyphotic posture places the body's center of gravity closer to the limit of stability (30) which may have a negative

Table 2. Kyphosis and Physical Function: Adjusted Means (95% CI) for Physical Function Tests

Number of Blocks	Chair Stands (s)	Walking Speed (m/s)	Narrow walk (m/s)	Leg Extension Power (watts)	Grip Strength (kg)
Age- and clinic-adjusted models					
0	11.4 (10.5, 12.2)	1.18 (1.13, 1.23)	1.18 (1.12, 1.24)	180.9 (168.6,193.2)	40.2 (38.3, 42.1)
1	10.7 (10.4, 11.1)	1.18 (1.16, 1.20)	1.15 (1.12, 1.17)	186.2 (181.3, 191.1)	38.8 (38.0, 39.6)
2	11.3 (11.1, 11.6)	1.16 (1.14, 1.17)	1.13 (1.11, 1.15)	184.0 (180.4, 187.5)	39.6 (39.1, 40.2)
3	12.1 (12.2, 12.4)	1.13 (1.12, 1.49)	1.11 (1.09, 1.13)	182.0 (178.2, 185.9)	38.4 (37.8, 39.0)
4+	12.5 (12.2, 12.9)	1.09 (1.08, 1.11)	1.08 (1.05, 1.10)	171.0 (166.4, 175.7)	38.5 (37.8, 39.2)
p for trend	<.001	<.001	<.001	<.001	.04
Multivariate-adjusted models*					
0	11.6 (10.7, 12.4)	1.17 (1.13, 1.22)	1.17 (1.11, 1.23)	184.6 (172.8, 196.3)	40.2 (38.3, 42.1)
1	10.9 (10.6, 11.3)	1.17 (1.15, 1.19)	1.14 (1.11, 1.16)	187.9 (183.2, 192.5)	38.7 (38.0, 39.5)
2	11.4 (11.2, 11.6)	1.16 (1.15, 1.17)	1.13 (1.11, 1.15)	183.6 (180.3, 187.0)	39.5 (39.0, 40.0)
3	12.1 (11.8, 12.3)	1.14 (1.12, 1.15)	1.11 (1.09, 1.13)	181.6 (177.9, 185.2)	38.6 (38.0, 39.2)
4	12.3 (12.0, 12.6)	1.10 (1.09, 1.12)	1.09 (1.06, 1.11)	170.9 (166.5, 175.3)	38.6 (37.9, 39.3)
p for trend	<.001	<.001	.001	<.001	.12

Note: CI = confidence interval.

impact on balance and physical function performance. Moreover, older adults with hyperkyphosis have weak trunk muscle extensor strength and poor trunk muscle composition, characteristics that have been independently associated with reduced physical function in longitudinal analyses (31–34), thus confounding definitive conclusions about cause and effect. Fifth, kyphosis may also be the effect of poor posture that could be associated with severe depression. However, only 8.5% of the men in our cohort had depression, defined by the Geriatric Depression scale ≥6 (15), and we did not find any differences in the depression scores by block group. Finally, hyperkyphosis may be a result of decreased physical activity, and in fact men with hyperkyphosis had significantly lower physical activity PASE scores. However, because analyses were cross-sectional it was not possible to determine the directionality of the association between kyphosis and physical function.

While we found cross-sectional associations between hyperkyphosis and impaired lower extremity function in older men, we did not investigate whether hyperkyphosis predicts worse physical function over time. In previous studies in older women, we found that greater baseline kyphosis predicted worse lower extremity physical function over time, and in fact increasing kyphosis over a mean 4.4 years was a stronger predictor of concurrent worsening physical function than was baseline degree of kyphosis (1,6). However, a recent study in the MrOS cohort reported that poor physical function is associated with an increased risk of incident radiographic vertebral fracture in older men (35). Incident vertebral fractures could lead to worse kyphosis; hence, whether it is kyphotic posture or worse physical function that initiates the cascade of poor health outcomes is not clear.

This study has a number of strengths including the large MrOS cohort comprised of community-dwelling older men residing in multiple geographic areas of the United States who were not preselected for hyperkyphosis or comorbidity. The primary limitation of our study is the cross-sectional nature of this analysis, which does not allow us to confirm causality. Second, there is no standard definition of hyperkyphosis using the block method. While the block method may be an accurate measure of the forward head component of hyperkyphosis, it is different from the Cobb method measurement of the anterior curvature in the thoracic spine and may capture a different domain of hyperkyphosis. However, while previous studies have reported 20%–40% prevalence of hyperkyphosis when using a cutoff of 40° using the Cobb method in older women (23), we found a similar prevalence of 20% when we used a cutoff of 4 blocks using the block method. Moreover, the Rancho Bernardo Study described a distribution of the block measure of kyphosis that reported 18% of the men using three or more blocks, and 9% of the men using four or more blocks. Given that our cohort was approximately 5 years older than the Rancho Bernardo cohort, we considered four blocks an acceptable cutoff to define hyperkyphosis in our cohort. Third, we recognize that the block method is a crude measurement of kyphosis that is subject to measurement variability. While there was some variability in the measurement by clinic, the Spearman correlation coefficients across all six clinics were very good to outstanding. Furthermore, the block method of kyphosis has now been used in multiple large studies, demonstrating construct validity as there have been consistent dose–response relationships between increasing blocks and adverse health outcomes including falls, fractures, and mortality (2,4,5,11). Fourth, we are unable to account for possible residual confounding that may have affected our results. Finally, our study was limited to older, relatively healthy, mostly white men who returned to the clinic for assessment; thus, extrapolation of these results to other populations may not be warranted.

Conclusion

Hyperkyphosis affects aging men, and is associated with poor lower extremity physical function. Future studies should establish the temporal associations between kyphosis and poor physical function in older men. Although causality cannot be inferred from cross-sectional studies, it may be reasonable to consider trials assessing the benefit of early assessment and interventions to reduce kyphosis in the prevention of future lower extremity functional limitations in aging men.

Funding

The Osteoporotic Fractures in Men (MrOS) Study is supported by National Institutes of Health funding. The following institutes provide support: the National Institute on Aging (NIA), the National Institute of Arthritis and Musculoskeletal and Skin Diseases (NIAMS), the National Center for Advancing Translational Sciences (NCATS), the NIH Roadmap for Medical Research, and the Office of Research in Women's Health under the following grant numbers: U01 AG027810, U01 AG042124, U01 AG042139, U01 AG042140, U01 AG042143, U01 AG042145, U01 AG042168, U01 AR066160, UL1 TR000128, AR06828, RO1 AG041921, and P50 AR063043.

References

1. Katzman WB, Huang MH, Lane NE, Ensrud KE, Kado DM. Kyphosis and decline in physical function over 15 years in older community-dwelling women: the Study of Osteoporotic Fractures. *J Gerontol A Biol Sci Med Sci*. 2013;68:976–983. doi:10.1093/gerona/glt009
2. Huang MH, Barrett-Connor E, Greendale GA, Kado DM. Hyperkyphotic posture and risk of future osteoporotic fractures: the Rancho Bernardo study. *J Bone Miner Res*. 2006;21:419–423.
3 .Huang MH KW, Cummings SR, Kado DM. Hyperkyphosis and decline in functional status in older community dwelling women: The Study of Osteoporotic Fractures Paper presented at: ASBMR, 2010.
4. Kado DM, Huang MH, Barrett-Connor E, Greendale GA. Hyperkyphotic posture and poor physical functional ability in older community-dwelling men and women: the Rancho Bernardo study. *J Gerontol A Biol Sci Med Sci*. 2005;60:633–637.
5. Kado DM, Huang MH, Nguyen CB, Barrett-Connor E, Greendale GA. Hyperkyphotic posture and risk of injurious falls in older persons: the Rancho Bernardo Study. *J Gerontol A Biol Sci Med Sci*. 2007;62:652–657.
6. Katzman WB, Vittinghoff E, Ensrud K, Black DM, Kado DM. Increasing kyphosis predicts worsening mobility in older community-dwelling women: a prospective cohort study. *J Am Geriatr Soc*. 2011;59:96–100. doi:10.1111/j.1532-5415.2010.03214.x
7. Vincent HK, Vincent KR, Lamb KM. Obesity and mobility disability in the older adult. *Obes Rev*. 2010;11:568–579. doi:10.1111/j.1467-789X.2009.00703.x
8. Eum R, Leveille SG, Kiely DK, Kiel DP, Samelson EJ, Bean JF. Is kyphosis related to mobility, balance, and disability? *Am J Phys Med Rehabil*. 2013;92:980–989. doi:10.1097/PHM.0b013e31829233ee
9. Orwoll E, Blank JB, Barrett-Connor E, et al. Design and baseline characteristics of the osteoporotic fractures in men (MrOS) study–a large observational study of the determinants of fracture in older men. *Contemp Clin Trials*. 2005;26:569–585.
10. Blank JB, Cawthon PM, Carrion-Petersen ML, et al. Overview of recruitment for the osteoporotic fractures in men study (MrOS). *Contemp Clin Trials*. 2005;26:557–568.
11. Kado DM, Huang MH, Karlamangla AS, Barrett-Connor E, Greendale GA. Hyperkyphotic posture predicts mortality in older community-dwelling men and women: a prospective study. *J Am Geriatr Soc*. 2004;52:1662–1667.
12. Bassey EJ, Fiatarone MA, O'Neill EF, Kelly M, Evans WJ, Lipsitz LA. Leg extensor power and functional performance in very old men and women. *Clin Sci (Lond)*. 1992;82:321–327.
13. Härkönen R, Harju R, Alaranta H. Accuracy of the Jamar dynamometer. *J Hand Ther*. 1993;6:259–262.
14. Newman AB, Siscovick DS, Manolio TA, et al. Ankle-arm index as a marker of atherosclerosis in the Cardiovascular Health Study. Cardiovascular Heart Study (CHS) Collaborative Research Group. *Circulation*. 1993;88:837–845.
15. Yesavage JA. Geriatric Depression Scale. *Psychopharmacol Bull*. 1988;24:709–711.
16. Washburn RA, Smith KW, Jette AM, Janney CA. The Physical Activity Scale for the Elderly (PASE): development and evaluation. *J Clin Epidemiol*. 1993;46:153–162.
17. Johnson JA, Coons SJ, Ergo A, Szava-Kovats G. Valuation of EuroQOL (EQ-5D) health states in an adult US sample. *Pharmacoeconomics*. 1998;13:421–433.
18. Katzman WB, Vittinghoff E, Kado DM. Age-related hyperkyphosis, independent of spinal osteoporosis, is associated with impaired mobility in older community-dwelling women. *Osteoporos Int*. 2011;22:85–90. doi:10.1007/s00198-010-1265-7
19. Guralnik JM, Ferrucci L, Simonsick EM, Salive ME, Wallace RB. Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *N Engl J Med*. 1995;332:556–561.
20. Guralnik JM, Seeman TE, Tinetti ME, Nevitt MC, Berkman LF. Validation and use of performance measures of functioning in a non-disabled older population: MacArthur studies of successful aging. *Aging (Milano)*. 1994;6:410–419.
21. Perera S, Mody SH, Woodman RC, Studenski SA. Meaningful change and responsiveness in common physical performance measures in older adults. *J Am Geriatr Soc*. 2006;54:743–749.
22. Kado DM, Prenovost K, Crandall C. Narrative review: hyperkyphosis in older persons. *Ann Intern Med*. 2007;147:330–338.
23. Kado DM, Huang MH, Karlamangla AS, et al. Factors associated with kyphosis progression in older women: 15 years' experience in the study of osteoporotic fractures. *J Bone Miner Res*. 2013;28:179–187. doi:10.1002/jbmr.1728
24. Tinetti ME, Williams CS, Gill TM. Dizziness among older adults: a possible geriatric syndrome. *Ann Intern Med*. 2000;132:337–344.
25. Bansal S, Katzman WB, Giangregorio LM. Exercise for improving age-related hyperkyphotic posture: a systematic review. *Arch Phys Med Rehabil*. 2014;95:129–140. doi:10.1016/j.apmr.2013.06.022
26. Wong SY, Kwok T, Woo J, et al. Bone mineral density and the risk of peripheral arterial disease in men and women: results from Mr. and Ms Os, Hong Kong. *Osteoporos Int*. 2005;16:1933–1938.
27. Leech JA, Dulberg C, Kellie S, Pattee L, Gay J. Relationship of lung function to severity of osteoporosis in women. *Am Rev Respir Dis*. 1990;141:68–71.
28. Schlaich C, Minne HW, Bruckner T, et al. Reduced pulmonary function in patients with spinal osteoporotic fractures. *Osteoporos Int*. 1998;8:261–267.
29. Di Bari M, Chiarlone M, Matteuzzi D, et al. Thoracic kyphosis and ventilatory dysfunction in unselected older persons: an epidemiological study in Dicomano, Italy. *J Am Geriatr Soc*. 2004;52:909–915.
30. Sinaki M, Brey RH, Hughes CA, Larson DR, Kaufman KR. Significant reduction in risk of falls and back pain in osteoporotic-kyphotic women through a Spinal Proprioceptive Extension Exercise Dynamic (SPEED) program. *Mayo Clin Proc*. 2005;80:849–855.
31. Granacher U, Lacroix A, Roettger K, Gollhofer A, Muehlbauer T. Relationships between trunk muscle strength, spinal mobility and balance performance in older adults. *J Aging Phys Act*. 2014;22:490–498. doi:10.1123/japa.2013-0108
32. Hicks GE, Simonsick EM, Harris TB, et al. Cross-sectional associations between trunk muscle composition, back pain, and physical function in the health, aging and body composition study. *J Gerontol A Biol Sci Med Sci*. 2005;60:882–887.
33. Hicks GE, Simonsick EM, Harris TB, et al. Trunk muscle composition as a predictor of reduced functional capacity in the health, aging and body composition study: the moderating role of back pain. *J Gerontol A Biol Sci Med Sci*. 2005;60:1420–1424.
34. Suri P, Kiely DK, Leveille SG, Frontera WR, Bean JF. Trunk muscle attributes are associated with balance and mobility in older adults: a pilot study. *PM R*. 2009;1:916–924. doi:10.1016/j.pmrj.2009.09.009
35. Cawthon PM, Blackwell TL, Marshall LM, et al. Physical performance and radiographic and clinical vertebral fractures in older men. *J Bone Miner Res*. 2014;29:2101–2108. doi:10.1002/jbmr.2239