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# Kyphosis and Decline in Physical Function Over 15 Years in Older Community-Dwelling Women: The Study of Osteoporotic Fractures

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**Background.** Maintaining physical function is an important prerequisite for preserving independence in later life. Greater degrees of kyphosis in the thoracic spine are prevalent in older persons and accompanied by reduced physical function in multiple cross-sectional studies. It is unknown whether kyphosis predicts worse physical function over time.

**Methods.** We retrospectively assessed whether greater magnitude of kyphosis is associated with decline in self-reported and objectively measured physical function over 15 years. Digitized Cobb angle kyphosis (T4–T12) was derived from supine lateral thoracic spine radiographs in a cohort of 1,196 women aged 65 and older (mean = 69.3 years [ $SD = 4.0$ ]). Using regression models, we evaluated associations of baseline kyphosis with both self-reported functional status and objectively measured gait speed, grip strength, and timed chair stands cross-sectionally and as change assessed over 15 years.

**Results.** In cross-sectional multivariate analyses, with each 10-degree increment of kyphosis, grip strength was 0.24 kg lower ( $p = .02$ ), but there were no significant associations between kyphosis and functional status, gait speed, or timed chair stand, likely reflecting the high functioning study participants. In multivariate longitudinal analysis, with each 10-degree increment in baseline kyphosis, there was 0.07 point additional decline in functional status ( $p = .09$ ), 0.01 m/s more decline in gait speed ( $p = .07$ ), and 0.32 s greater decline in time to complete five chair stands ( $p = .004$ ), but no association with decline in grip strength.

**Conclusions.** Greater magnitude of kyphosis may predict worsening lower extremity function over time in older women. Early recognition and preventative measures against kyphosis progression may help preserve physical function over the long term.

**Key Words:** Normative aging—Physical function—Imaging.

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PRESERVING functional independence in later life requires that an elderly individual has the physical ability to carry out the usual activities of daily life. With aging, kyphosis, an anterior curvature in the thoracic spine, tends to progress (1), and those who are affected by greater magnitude of kyphosis are more likely to suffer from functional limitations that affect the usual activities of daily living (2–5). For example, it has been reported in multiple cross-sectional studies that women with greater magnitude of kyphosis have difficulty reaching overhead and performing heavy housework and also scored lower on a basic activities of daily living scale than did their erect peers (4–7). Furthermore, women with greater magnitude of kyphosis

have demonstrated difficulty performing physical function tasks including rising from a chair without the use of their arms, balancing on a narrow base of support, walking on level ground, and stair climbing (3,6,8,9). These physical function limitations increase the risk of falls, fractures, disability, and mortality (8–12), thus highlighting the importance of determining whether kyphosis, a potentially modifiable risk factor (13–17), predicts worsening physical function over time.

We recently found that greater magnitude of kyphosis predicted longer performance times on the Timed Up and Go test over a mean 4.4 years in a cohort of older women with low hip bone mineral density (BMD) (18). These

findings were independent of other significant predictors of worsening physical function including age, health status, grip strength, body mass index, change in hip BMD, and new vertebral fractures (18). Given that this was the first longitudinal assessment of the effects of kyphosis on physical function over time and the cohort was restricted to older women with low hip BMD, it is of interest to determine whether greater magnitude of kyphosis predicts greater decline in physical function over time in older women irrespective of their BMD.

To answer this question, we retrospectively assessed whether a greater magnitude of kyphosis at baseline is associated with worse decline in self-reported and objectively measured physical function over an average follow-up of 15 years in healthy, community-dwelling older women in the Study of Osteoporotic Fractures irrespective of their BMD.

**METHODS**

*Participants*

For this retrospective study, participants were selected from the Study of Osteoporotic Fractures, a multicenter longitudinal study of risk factors for osteoporosis and fractures in older women. Between 1986 and 1988, women aged 65 years or older at baseline visit were recruited from population-based listings in four areas of the United States, and data collection took place at the Study of Osteoporotic Fractures clinical sites in Portland, OR, Minneapolis, MN, Baltimore, MD, and the Monongahela Valley, PA. Women unable to walk without assistance and with bilateral hip replacements were excluded from the study. From an original study population of 9,704 women, 9,575 had baseline lateral radiographs of the thoracic spine that were technically acceptable for interpretation by radiographic morphometry. Of these, a random sample of 1,000 Study of Osteoporotic

Fractures respondents who had a 15-year clinical site visit and offered a lateral thoracic spine radiograph were selected for the purposes of this study. An additional random sample of 196 who did not have a 15-year clinical site visit were included to account for survivor bias, resulting in a sample of 1,196 women. Of these, 119 were excluded due to poor scan quality, 2 because of a diagnosis of Parkinson’s disease, and 3 due to incomplete data, leaving 1,072 participants in the baseline analysis, including 124 of the 196 who were selected to account for survivor bias. Each center’s institutional review board approved the study protocol, and participants provided written informed consent.

*Kyphosis Measurement*

The degree of kyphosis was calculated as the digitized Cobb angle from supine lateral thoracic spine radiographs that were taken at baseline with a tube-to-film distance of 40 inches, centered at T8, using a modified Cobb protocol (19) and a fixed cutoff of T4 and T12 (Figure 1). Although the original Cobb method uses angles of inflection to determine the superior and inferior margins for line placement (19), the modified Cobb method uses a fixed cutoff of T4 and T12 largely because T1–T3 are usually not well visualized on lateral spine films (20,21). Using a translucent digitizer (GTCO, Rockville, MD) and cursor, four points were marked corresponding to the four corners of the vertebral body at T4 and T12. From the superior surface of T4 and inferior surface of T12, the computerized digitization program erected perpendicular lines whose intersection was the kyphotic angle. If for any reason T4 and/or T12 was not visible, the next adjacent visible vertebra (usually T5 if T4 was not visible and T11 if T12 was not visible) was used as an alternative. Intraclass correlation coefficients (ICC = 0.98) have previously been reported for modified Cobb angle measurement of kyphosis from lateral spine radiographs (22).

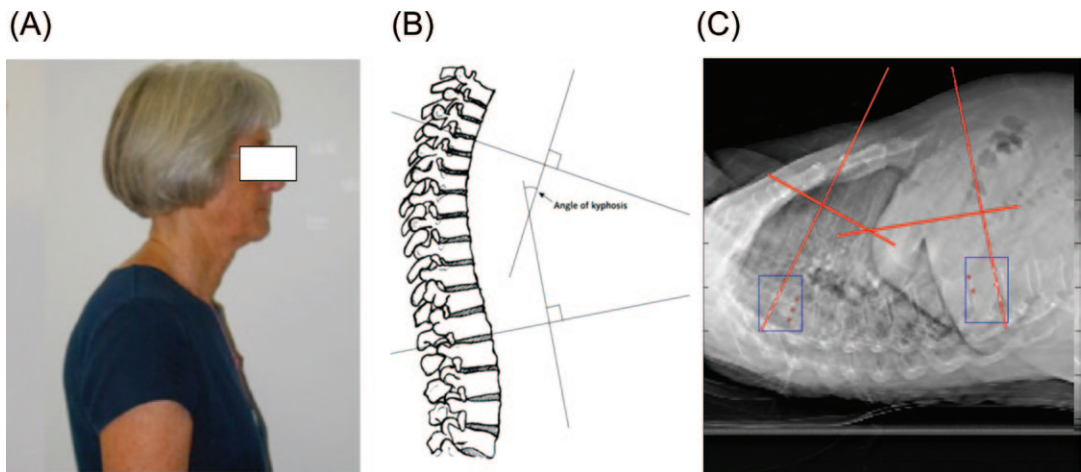


Figure 1. (A) Person standing with a 54-degree Cobb angle of kyphosis; (B) modified Cobb angle of kyphosis measured as the angle of intersecting lines drawn from the superior end plate of T4 and the inferior end plate of T12; (C) modified Cobb angle calculated from a supine lateral spine radiographic image.

*Physical Function*

3.5 *Self-reported functional status.*—Self-reported functional status was defined based on questions from the 1984 National Health Interview Survey Supplement on Aging (23) administered at baseline. Decline in functional status was calculated as the change in functional status from baseline to a 15-year follow-up clinical site visit. Participants were asked about their ability to perform six activities: walking two or more blocks outside on level ground, walking down 10 steps, climbing up 10 steps without stopping, preparing meals, shopping for groceries or clothes, and doing heavy housework (such as scrubbing floors or washing windows). Participants who reported any difficulty for any item were then asked to quantify their level of difficulty as no difficulty, some difficulty, much difficulty, or unable to perform the activity. Scores ranged from 0 (no difficulty) to 3 (unable on each item), with a maximum difficulty functional status score of 18.

3.10  
3.15  
3.20  
3.25  
3.30  
*Objectively measured physical function.*—Gait speed was tested over a 6-m course according to a standard protocol (24). Participants were asked to walk at their usual pace, and it was recorded in meters/second. Isometric grip strength (kilograms) was measured in both hands at each clinical site visit using a hand-held isometric dynamometer (Sparks Instruments and Academics, Coralville, Iowa) and a standard protocol (25). The dominant grip strength was used in the analysis. Timed chair stand was measured as the time (seconds) to rise from a chair five times without the use of arms according to a standard protocol (26). Participants were instructed to rise from a 16-inch height chair and sit down as quickly as possible five times, keeping their arms folded across the chest.

3.35 *Other Measurements*

3.40 All study participants provided information on basic characteristics including age, race, educational level, self-reported overall health status (poor, fair, good, and excellent), and history of medical conditions including Parkinson’s disease, stroke, hypertension, diabetes, and osteoarthritis at baseline. Participants answered questions regarding health behaviors including smoking (current vs. past or never), alcohol use (average number of drinks per week), and physical activity over the past year (using a modified Paffenbarger survey to determine weekly caloric expenditure) (27,28). Participants were asked to report the frequency and duration of their participation in leisure time, sport activity, and household chores. While wearing light clothing without shoes, height and weight were measured, and body mass index was calculated in kilograms/meter (29). Calcaneal BMD (grams/centimeter) (29) was measured using single photon absorptiometry (OsteoAnalyzers-Siemens-Osteon, Wahiawa, HI).

3.55 Vertebral fractures from T4 to L4 were determined from

baseline radiographs using a semiquantitative grading scheme (30). Vertebral height ratios representing anterior, posterior, and crush deformations were calculated from T4 to L4, and if any of the three height ratios was more than 3 standard deviations below the study population-specific mean, the vertebra was classified as having a prevalent vertebral fracture (31).

*Statistical Analysis*

3.65 We used linear regression models to evaluate the association between baseline kyphosis and both self-reported functional status and objectively measured outcomes of physical function including gait speed, grip strength, and timed chair stand. Cross-sectional analyses of baseline values were performed to determine the association between kyphosis and the same measures of functional status and physical function. Longitudinal analyses were performed to determine the association between baseline kyphosis and change in physical function outcomes, which was calculated as change over 15 years. All models were adjusted for a priori potential confounders including age, clinical site, weight, hypertension, arthritis, physical activity, alcohol, health status and baseline prevalent vertebral fracture. We further adjusted for other potential confounders such as height, body mass index, diabetes, and BMD, and results remained unchanged. Thus, we did not include these covariates in the final model. We checked for an interaction between the individual clinical site and kyphosis for each outcome measure. To account for possible survivor bias, the 124 participants in our sample who were lost to follow up at the 15-year visit were differentially weighted to match the complete cohort’s probability of survival using a normalized mortality variable that was created from proportions at the 15-year visit. Survivors had a weight of 0.66, and nonsurvivors had a weight of 3.41. SAS software was used for all analyses (SAS Institute, Cary, NC).

**RESULTS**

3.95 At baseline, the women had a mean age of 69.3 (*SD* = 4.0) years and a mean kyphosis of 44.9 (*SD* = 11.8) degrees (Table 1). Approximately 90% of the participants reported good health and 42% had a high school or longer education. Prevalence of arthritis was high (60%), and approximately 15% had a prevalent vertebral fracture. Participants had a baseline mean self-reported functional status score of 0.4 (*SD* = 1.0), gait speed of 1.1 m/s (*SD* = 0.2), grip strength of 23.1 kg (*SD* = 4.0), and timed chair stand of 11.1 seconds (*SD* = 3.3). At the 15-year clinical site visit, 948 participants were included in the longitudinal analyses. Among these participants, their baseline kyphosis was approximately normally distributed (Figure 2); 24% of the sample had kyphosis ≥50 degrees. Kyphosis increased with age (Table 2) from a mean 44.1

3.60  
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Table 1. Baseline Characteristics of the Study Sample

Baseline Characteristics (n = 1,072)	Mean ± SD or N (%)
Cobb angle (degs)	44.9 ± 11.8
Age (yrs)	69.3 ± 4.0
Body mass index (kg/m <sup>2</sup> )	26.3 ± 4.4
Calcaneal bone mineral density (gm/cm <sup>2</sup> )	0.4 ± 0.1
Exercise, calories burned/week (kcal)	1922.8 ± 1808.0
Education (>12 yrs), n (%)	455 (42.4)
Arthritis, n (%)	623 (59.5)
Current smoker, n (%)	90 (8.4)
Alcohol user (drinks in past 12 mos), n (%)	813 (75.8)
Prevalence of vertebral fracture, n (%)	163 (15.2)
Self-reported health, fair/poor (%)	106 (9.9)
Functional status (0–18 points)	0.4 (1.0)
Gait speed (m/s)	1.1 (0.2)
Grip strength (kg)	23.1 (4.0)
Timed chair stands (s)	11.1 (3.3)

Table 2. Mean Baseline Kyphosis, by Age, Among 948 Women Included in the Longitudinal Analysis

Age Strata (yr)	Number of Participants	Mean Kyphosis in Degrees (SD)
65–69	614	44.1 (11.6)
70–74	265	45.5 (11.6)
75+	69	47.5 (13.5)

cross-sectional analysis to account for survivor bias were older, less active, less educated, more likely to smoke, and less likely to drink alcohol, reported poorer health, and had slightly lower calcaneal BMD.

*Cross-Sectional Analyses*

For each 10-degree increment in kyphosis, in age and clinical site-adjusted linear analyses, grip strength was 0.26 kg lower. In the multivariate linear models adjusted for age, clinical site, weight, physical activity, health status, and arthritis, grip strength was 0.24 kg lower (Table 4). There was no association between greater kyphosis and poorer functional status, slower gait speed, and/or longer time to complete timed chair stand in either type of analysis. Further adjustment for the specific clinical site did not modify the association between kyphosis and functional status or any physical function measure.

(SD = 11.6) degrees among those 65–69 years old to a mean 47.5 (SD = 13.5) degrees among those 75 years and older, p = .04. Although women with more baseline kyphosis tended to decline more in functional status and timed chair stand, these differences were not statistically significant (Table 3). Compared with the 948 participants with baseline and follow-up data, the 124 women with baseline but no follow-up data who were included in the

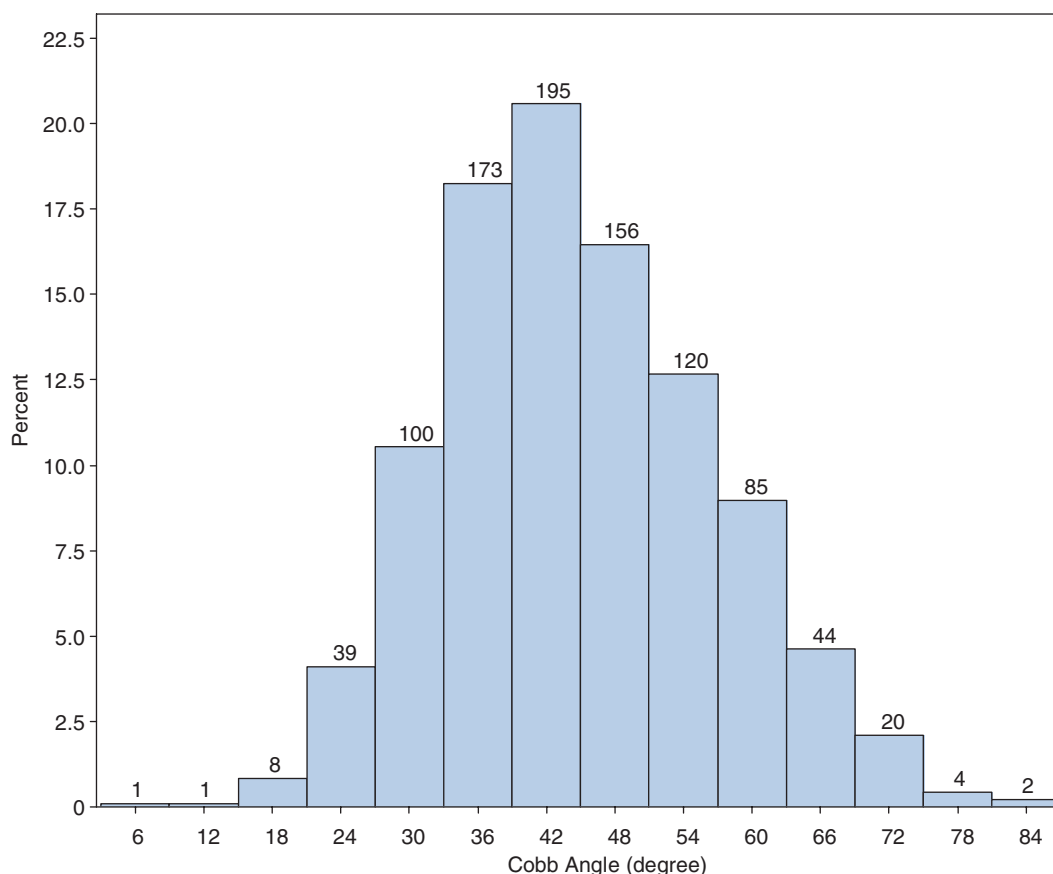


Figure 2. Distribution of Cobb angle of kyphosis among 948 women aged 65–83.

Table 3. Magnitude of Baseline Cobb Angle of Kyphosis by Tertile of Change in Physical Function (Lower Tertile Means Less Decline Over Time)

	Kyphosis Degrees ( <i>SD</i> )		
	Change in Physical Function Tertile 1	Change in Physical Function Tertile 2	Change in Physical Function Tertile 3
Functional status (0–18 points)	42.6 (12.8)	44.4 (11.09)	45.55 (12.3)
Gait speed (m/s)	44.4 (10.75)	43.7 (11.9)	45.2 (12.2)
Grip strength (kg)	44.7 (11.9)	44.7 (11.6)	44.2 (11.8)
Timed chair stand (s)	42.9 (11.4)	43.6 (11.6)	44.4 (10.75)

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*Longitudinal analyses.*—For each 10-degree increment in baseline kyphosis, in the age- and clinical site–adjusted longitudinal analyses, gait speed declined an additional 0.01 m/s over 15 years ( $p = .07$ ). In these basic models, kyphosis was not significantly associated with change in functional status, grip strength, or timed chair stand.

In the multivariate linear models, after adjustment for age, clinical site, weight, health status, physical activity, hypertension, arthritis, and baseline vertebral fracture, for each 10-degree increment in kyphosis, there was an additional 0.07 point decline in functional status, 0.01 m/s more

decline in gait speed, and 0.32 s more time to complete five timed chair stands (Table 5). Kyphosis was not associated with decline in grip strength. After controlling for negative confounders including weight and hypertension that allowed for a more precise estimate of the effects of kyphosis on functional status, the estimated effect of kyphosis on decline in functional status strengthened but still was not statistically significant ( $p = .09$ ). Similar findings were true of kyphosis and decline in gait speed ( $p = .07$ ). However, in the case of timed chair stand, adjustment for covariates did not change the estimated effect of kyphosis, but did explain much of the variability of the outcome, and increased the precision of the kyphosis estimate ( $p = .004$ ). Moreover, after adjustment for kyphosis, prevalent radiographic vertebral fractures and arthritis were not significantly associated with decline in any outcome.

Table 4. Association Between Cobb Angle of Kyphosis and Physical Function at Baseline

	Cobb Angle of Kyphosis (per 10-degree increment)	
	$\beta$ Coefficient ( <i>SE</i> )	<i>p</i> Value
Age and clinical site–adjusted model		
Functional status (0–18 points)	0.03 (0.03)	.36
Gait speed (m/s)	0.01 (0.01)	.24
Grip strength (kg)	−0.26 (0.11)	.01
Timed chair stand (s)	−0.01 (0.09)	.91
Multivariate model*		
Functional status (0–18 points)	0.02 (0.03)	.56
Gait speed (m/s)	0.00 (0.01)	.17
Grip strength (kg)	−0.24 (0.11)	.02
Timed chair stand (s)	−0.04 (0.09)	.68

\*Adjusted for age, clinical site, weight, hypertension, physical activity, arthritis, health status, and baseline vertebral fracture.

**DISCUSSION**

This study shows that in older women, irrespective of BMD, greater baseline kyphosis preceded long-term decline in physical function, particularly in measures of lower extremity function. In the longitudinal analyses, timed chair stand, an objective measure of lower extremity function, was the most significantly affected by greater magnitudes of baseline kyphosis. Accentuated kyphosis alters the center of mass of the body (5,6) that may impair the ability to move from sit to stand. The significant association with kyphosis and chair rise performance is interesting and

5.30

5.85

5.35

5.90

5.40

5.95

Table 5. Cobb Angle of Kyphosis and Additional 15-Year Decline in Physical Function: Multivariate Linear Regression

Covariates	Functional Status*		Gait Speed		Grip Strength		Timed Chair Stand	
	$\beta$ Coefficient ( <i>SE</i> )	<i>p</i> Value	$\beta$ Coefficient ( <i>SE</i> )	<i>p</i> Value	$\beta$ Coefficient ( <i>SE</i> )	<i>p</i> Value	$\beta$ Coefficient ( <i>SE</i> )	<i>p</i> Value
Cobb angle (per 10-degree increment)	0.07 (0.04)	.09	−0.01 (0.07)	.07	0.01 (0.12)	.92	0.32 (0.16)	.004
Age	0.08 (0.015)	<.0001	−0.01 (0.002)	.01	−0.05 (0.04)	.22	0.08 (0.06)	.18
Weight	0.01 (0.005)	.01	0.00 (0.001)	.04	−0.04 (0.01)	.00	0.03 (0.02)	.04
Hypertension	0.36 (0.11)	<.0001	−0.01 (0.02)	.68	−0.46 (0.29)	.12	0.24 (0.40)	.56
Physical activity	0.00 (0.0003)	.91	0.00 (0.00)	.37	0.00 (0.001)	.04	0.00 (0.00)	.14
Arthritis	0.11 (0.10)	.27	−0.01 (0.02)	.49	−0.17 (0.27)	.52	−0.14 (0.36)	.71
Self-reported status (fair/poor)	−0.08 (0.18)	.65	0.03 (0.03)	.27	−0.40 (0.50)	.42	−1.47 (0.67)	.03
Prevalent vertebral fracture	−0.01 (0.14)	.72	−0.01 (0.02)	.73	−0.44 (0.37)	.24	0.02 (0.52)	.97

\*Positive score means decline. All covariates from baseline visit.

5.55

5.110

makes sense when one considers the posture and positioning of the body for the chair rise movement. A person with more kyphosis would likely be more wary of a forward fall during the chair rises.

6.5 Moreover, self-reported functional status and gait speed over 15 years declined although these associations did not reach statistical significance. These findings were independent of the effects of other significant predictors commonly associated with physical decline including age, weight, hypertension, physical activity, and self-reported health status. Unexpectedly, with or without kyphosis included in the model, prevalent radiographic vertebral fractures and arthritis were not independently associated with decline in physical function as others have previously reported. Even though 15% of the women in our cohort had vertebral fractures and almost 60% reported osteoarthritis at baseline, these factors did not contribute to the decline in physical function over time.

6.10 Individuals often overestimate their self-reported function or do not recognize decline in function until a more obvious clinical event occurs (32). Used alone, this self-reported measure may not accurately reflect true decline in physical function. Also, in the clinical setting, there is often not the time to do an in-depth assessment of physical function. Thus, although the small additional decline in self-reported functional status for each 10-degree increment of kyphosis is not likely large enough to be clinically meaningful, the findings in our study are suggestive that more pronounced kyphosis does in fact precede long-term decline in objective measures of physical function. Therefore, a visual assessment of an older patient's kyphosis might serve as a helpful indicator to identify those who are at greater risk for functional decline.

6.15 Greater magnitude of kyphosis accelerated the decline in gait speed among our sample of healthy older women. For every 10-degree increment in kyphosis, there was an additional decline in gait speed, above the decline observed in our cohort over 15 years. Although our cohort's mean gait speed at baseline was comparable to the gait speed of community-dwelling older women of similar age (33,34), the decline in gait speed overall in our healthy cohort is less than previously reported among older women in general over time (35). A small meaningful change in gait speed ranges from 0.04 to 0.06 m/s (36). Although the 0.01 m/s additional decline in gait speed over 15 years with each 10-degree increment of kyphosis was small and perhaps insignificant, it is comparable to the effects on gait speed that we observed of a 2-year increase in age or a 5-kg increase in weight. Furthermore, gait speed is known to be a predictor of decline in physical function in older adults (37-39), and among a less robust sample of women with lower physical capacity and functional reserve, we expect small increments of kyphosis could have greater affect on physical function.

6.20 In contrast to previous cross-sectional studies showing that greater increments of kyphosis are associated with worse self-reported functional status, slow gait speed,

low grip strength, and slow timed chair stand (3,4,6,7,40), grip strength was the only baseline measure that we found to be associated with greater increments of kyphosis. Grip strength is an important predictor of disability and mortality among old people (29,41,42), and we expect that declines in grip strength would only magnify these associations. However, kyphosis was not a significant predictor of decline in grip strength over 15 years, likely attributable to the robust health status of our cohort. Although we performed weighted models in an attempt to account for problems of survivor bias, more than 90% of our cohort reported good to excellent health status at baseline. And, among our study survivors, grip strength declined a mean 5.2 (3.9) kg over 15 years, decreasing to 17.9 kg, but it still remained above the cutoff criterion of 17.3 kg for physical frailty for women of average body mass index (41). Thus, although our study results demonstrate a strong cross-sectional association between low grip strength and greater degree of kyphosis, it may be that in high-functioning cohorts, it is not a sensitive predictor of long-term outcomes.

6.25 In our study, although the additional decline in the timed chair stand (0.32 s) with each 10-degree increment of kyphosis was small, it was comparable to the effect we observed of more than a 4-year increment in age. The timed chair stand, a measure of lower extremity function, is a strong predictor of falls and functional decline (43), and worse values predict more disability over time (44). In our study sample, the mean timed chair stand at baseline was comparable to age-matched norms among healthy, community-dwelling older adults (45). There are currently no accepted definitions for clinically significant change in timed chair stands though we postulate that among a less robust cohort of individuals, an additional decline in the timed chair stand values could have serious clinical implications.

#### *Strengths and Limitations*

6.30 The strengths of our study include its large sample size and the ability to control for many potential confounders of physical function decline such as age, weight, health status, physical activity, arthritis, hypertension, and underlying vertebral fractures. Our study has a number of limitations. This is an observational retrospective cohort study that cannot establish causality. Furthermore, the extended 15-year follow-up could have introduced bias from unmeasured confounders. However, this is a longitudinal study with extended follow-up, and our rationale was to determine whether, even among the healthiest study participants who survived at least 15 years, early kyphotic changes might be predictive of more long-term outcomes. Although we included 196 women, approximately 20% of the analytic cohort, to account for survivor bias, it is possible we over-selected for survivors and did not adequately control for this effect. We did not observe a change in self-reported

physical function using the 1984 Health Interview Survey Supplement on Aging instrument. The women we studied were robust at baseline and did not deteriorate substantially, limiting the power to detect change in this self-report measure because of ceiling effects. To address potential important confounders, we included several a priori covariates known to affect physical function and kyphosis, including age, weight, health status, physical activity, arthritis, hypertension, and vertebral fractures. We found that adjustment for these factors actually served to strengthen the association between kyphosis and decline in physical function. We used calcaneal measurement of BMD by single photon absorptiometry instead of hip measurements of BMD by dual-energy x-ray absorptiometry because this was the measurement done when kyphosis was assessed. Although the calcaneus is quite distal to the site of kyphosis and hip BMD measurement, there is a strong correlation between these measurements of BMD (46), and it has previously been shown in our cohort that the peripheral calcaneal measure of BMD continues to be as strong a predictor of future fractures as more proximal measures of hip bone density (47). We used a supine measurement of Cobb angle of kyphosis that is known to underestimate the degree of kyphosis, particularly among those with greater magnitude of kyphosis. However, this would serve to underestimate any effects we found. Finally, the effects of greater increments of kyphosis on physical function decline were small in magnitude and of unknown clinical relevance. However, our findings that greater increments of baseline kyphosis precede long-term decline in physical function corroborates the previous study among a cohort of women with low BMD reporting the negative impact of greater magnitudes of kyphosis on physical function over time (18).

**CONCLUSIONS**

These results suggest that greater magnitude of kyphosis predicts worse physical function over time in older women irrespective of BMD. We found that greater kyphosis predicted additional long-term decline in objective measures of lower extremity function in the timed chair stand; self-reported functional status and gait speed slightly but not significantly declined. We suggest that early recognition and preventative measures against progression of kyphosis may help preserve lower extremity physical function over the long term.

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