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ORIGINAL ARTICLE

Kyphosis and incident falls among community-dwelling older adults

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Abstract
Summary Hyperkyphosis commonly affects older persons and is associated with morbidity and mortality. Many have hypothesized that hyperkyphosis increases fall risk. Within this prospective study of older adults, kyphosis was significantly associated with incident falls over 1 year. Measures of hyperkyphosis could enhance falls risk assessments during primary care office visits.
Introduction To determine the association between four measures of kyphosis and incident and injurious falls in older persons.
Methods Community-dwelling adults aged 65 and older ($n = 72$) residing in southern California were invited to participate in a prospective cohort study. Participants had kyphosis assessed four ways. Two standing measures included a flexicurve ruler placed against the back to derive a kyphotic index and the Debrunner kyphometer, a protractor used to measure the kyphotic angle in degrees. Two lying measures included the blocks method (number of 1.7 cm blocks needed to achieve a neutral head position while lying supine) and traditional Cobb angle calculation derived from DXA based lateral vertebral assessment. Baseline demographic, clinical, and other health information (including a timed up and go (TUG) test) were assessed at a clinic visit. Participants were followed monthly through email or postcard for 1 year, with falls outcomes confirmed through telephone interview.
Results Mean age was 77.8 (± 7.1) among the 52 women and 20 men. Over 12 months, 64% of participants experienced at least one incident fall and 35% experienced an injurious fall. Each standard deviation increase in kyphosis resulted in more than doubling the adjusted odds of an incident fall, even after adjusting for TUG. Odds of injurious falls were less consistent across measures; after adjusting for TUG, only the blocks method was associated with injurious falls.
Conclusions Each kyphosis measure was independently associated with incident falls. Findings were inconsistent for injurious falls; the blocks measure suggested the strongest association. If these findings are replicated, the blocks measure could be incorporated into office visits as a quick and efficient tool to identify patients at increased fall risk.

Keywords Falls · Hyperkyphosis · Kyphosis · Older adults

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Introduction

Falls are common in older adults and have broad economic, medical, and emotional ramifications [1]. It has been estimated that one third of those over the age of 65 experience a fall in any given year with the associated economic costs measured in tens of billions of dollars [2]. Falls are the most common cause of injury among community-dwelling older adults and are strongly associated with loss of independence due to both functional decline and skilled-nursing facility admission [3,

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4]. Emotionally, the fear of falling itself affects health behaviors through activity restriction [5], resulting in diminished quality of life and ultimately a decline in physical function [6].

Hyperkyphosis, accentuated forward curvature in the thoracic spine, is commonly seen in aged populations. Estimates of hyperkyphosis in community-dwelling older adults vary by measurement method but are thought to be as high as 40% [7, 8]. There are a variety of known and hypothesized causes, including vertebral fractures, vertebral disc deformities, degenerative disc disease, spinal muscle weakness, and low paraspinal muscle density, among others [9–15]. Sequelae include impaired pulmonary function, decreased physical function, elevated fracture risk, and an increased risk of mortality [7, 8, 16–18]. Many have hypothesized that hyperkyphosis may increase older adults' fall risk [19–21], potentially through diminished balance [17].

Few studies have directly examined hyperkyphosis and falls in older adults. Among those that did, most were cross-sectional or retrospective in design and had mixed results. Given that hyperkyphosis changes the center of gravity and is a risk factor for future fracture [22, 23], further investigation is warranted to determine whether hyperkyphosis predicts future falls. Therefore, we conducted a prospective study to determine whether community-dwelling older men and women with exaggerated kyphosis may be at increased risk for incident and injurious falls over a period of one year.

Methods

Participants

A convenience sample of 72 ambulatory older adults (52 women and 20 men) was recruited from the San Diego community to participate in a study on kyphosis, balance, and falls. Participants were recruited through the UCSD Stein Institute of Research on Aging Newsletter (https://healthsciences.ucsd.edu/research/aging/Documents/February%202014%20-%20Successful%20Aging%20Newsletter.pdf, page 2) and physician referral from within the UCSD Health System. Those age 65 and older who were able to stand and walk without assistance were eligible for the study; those with a mini mental status score under 26 and those who did not feel safe completing the study measures were excluded. Study enrollment was capped at 72 due to funding limitations. Volunteers exceeded the available participant slots; the first 72 study-eligible volunteers to schedule and attend their clinic visit were enrolled. After providing informed consent, participants completed a baseline clinic visit at the University of California, San Diego (UCSD) Exercise and Physical Activity Resource Center (EPARC).

The University of California, San Diego Human Research Protections Program approved the research protocol.

Measurement of kyphosis

Kyphosis was measured four different ways in this study, described previously by Tran et al. [24]. Briefly, two standing measures were taken; a Debrunner Kyphometer, a protractor-like device, was used to measure the angle of kyphosis between the interspace of T2-T3 and the interspace between T11-T12 and a flexicurve ruler was used to calculate the kyphotic index (KI), a function of thoracic spine width to length. Two lying measures were also taken; the Cobb angle was calculated from a GE Lunar dual-energy X-ray absorptiometry (DXA)-based vertebral fracture assessment (VFA; software version 14.10.022). A physician rheumatologist with expertise in spinal measurement identified vertebral body edges used to compute the Cobb angle (T4 and T12; T5 was used when T4 was unable to be clearly visualized). The blocks method was the discrete number of 1.7 cm blocks placed under a participant's head to achieve a neutral head and neck position while lying supine on the DXA table [24].

Each participant had Debrunner Kyphometer (ICC = 0.993) and flexicurve ruler (ICC = 0.933) measures conducted by at least two clinic staff to assess inter-rater reliability. A random sample of 20 VFAs was used to evaluate Cobb angle inter-rater reliability (ICC = 0.968), with staff blinded to each other's results. Inter-rater reliability for the blocks was not assessed, though it has performed well in past studies [24].

Ascertainment of falls outcomes

Participants were contacted monthly by postcard or email (as individually elected at the beginning of the study) to ascertain the number of incident falls and fall injuries. Incident falls were defined as any event where the participant fell all the way down to the floor or ground, or fell and hit an object like a chair or stair. Injurious falls were self-reported by each participant and include those incident falls where the participant responded that they sustained an injury as a result of the fall. Those reporting a fall were phoned by the study coordinator to gather further information about the falls and injuries including the cause(s), time of day, location, assistance required, and injury characteristics. Types of injuries included bruises, bleeding, sprains, strains, broken or fractured bones, blows to the head, concussions, and "other," as defined by the participants. Non-responders were also contacted by telephone. All participants remained in the study for the entire 12 month duration and had complete monthly follow-up data despite occasional response delays.

Other measurements

Participants were interviewed by study staff to ascertain age, sex, and other demographic and health history information. Body weight was measured on a calibrated digital scale. Total hip bone mineral density (BMD; g/cm^2) was measured by DXA using a GE Lunar Prodigy Advance densitometer (Madison, WI). Mobility and function were assessed using the timed up-and-go test, the time (in seconds) it takes to rise from a seated position, walk 10 ft at a normal pace, walk back, and return to a seated position.

Statistical analyses

The falls outcome variables were dichotomized into yes/no for any incident fall and any injurious fall. All kyphosis predictor variables remained continuous as their distributions were not significantly skewed.

To test the hypothesis that kyphosis is associated with falls outcomes, we built logistic regression models for each measure of kyphosis to obtain unadjusted odds ratios (OR) with 95% confidence intervals (CI) per standard deviation (SD) increase in the measures. Based on a priori decisions about modeling, each model was then adjusted for age, sex, weight, and BMD. In an attempt to determine whether a measure of mobility and function mediated the associations between kyphosis and falls outcomes, all models were further adjusted for TUG.

All hypothesis tests were two-sided. Analyses were conducted using SPSS version 23 (IBM Corp., Armonk, NY) and SAS version 9.4 (SAS Institute, Inc., Cary, NC).

Results

The mean age of the study cohort was 77.8 ± 7.1 years; men were older (80.5 ± 7.7 years) than women (76.8 ± 6.7 years). Of the 72 men and women in our study, 64% experienced an incident fall and 35% experienced an injurious fall over the 12 months of follow-up (Table 1).

Bivariate analyses showed no significant differences in age, sex, weight, BMD, or TUG time between those who did and did not experience an incident fall (Table 1). However, regardless of the kyphosis measure used, participants with greater kyphosis were more likely to report an incident fall, with all but the blocks measure of kyphosis demonstrating statistical significance ($p < 0.05$) in bivariate analyses. Compared to those who suffered injurious falls, there were no differences with regards to age, sex, weight, BMD, or TUG time in those who did not experience an injurious fall (Table 1). But, those with greater block and Debrunner measured kyphosis were more likely to report an injurious fall while the flexicurve and Cobb angle measures of kyphosis were not significantly different between the groups.

Characteristics of those with hyperkyphosis

Each of the four measures of kyphosis was dichotomized; those with Debrunner kyphometer ≥ 54, Flexicurve ruler ≥ 17, Cobb angle ≥ 50, and blocks ≥ 4 were classified as hyperkyphotic by that measure, consistent with previous analyses in this study [25]. Using these cutoffs, 18% of the sample was hyperkyphotic by Debrunner kyphometer, 25% by Flexicurve ruler, 30% by Cobb angle, and 40%

Table 1 Participant characteristics by incident and injurious fall occurrence (n = 72)

Characteristics, n (%) or mean ± SD	Incident fall			Injurious fall			All (n = 72)
	No (n = 26)	Yes (n = 46)	p value[a]	No (n = 47)	Yes (n = 25)	p value[a]	
			Sex				
Women	17 (65)	35 (76)	.414	35 (75)	17 (68)	.589	52 (72)
Men	9 (35)	11 (24)		12 (25)	8 (32)		20 (28)
Age, years	78.5 ± 6.8	77.4 ± 7.3	.523	78.0 ± 6.6	77.5 ± 8.2	.797	77.8 ± 7.1
Debrunner kyphometer, deg	39.6 ± 12.0	47.3 ± 10.9	.008	42.3 ± 11.7	48.7 ± 11.2	.031	44.5 ± 11.8
Flexicurve ruler, kyphotic index	12.1 ± 3.9	14.9 ± 5.2	.019	13.3 ± 4.5	14.9 ± 5.6	.207	13.9 ± 4.9
Cobb angle, deg	37.4 ± 13.0	44.7 ± 11.4	.015	41.2 ± 13.0	43.6 ± 11.1	.450	42.0 ± 12.4
Blocks, number	2.7 ± 1.3	3.4 ± 1.5	.052	2.9 ± 1.4	3.7 ± 1.5	.039	3.2 ± 1.5
Total hip BMD, g/cm^2	0.89 ± 0.15	0.89 ± 0.15	.986	0.90 ± 0.13	0.87 ± 0.17	.475	0.89 ± 0.15
Weight, kg	67.8 ± 14.9	69.5 ± 15.1	.631	67.8 ± 13.5	70.9 ± 17.4	.442	68.9 ± 14.9
TUG time, sec	7.9 ± 2.2	7.8 ± 1.5	.921	7.7 ± 1.8	8.1 ± 1.6	.380	7.9 ± 1.7

SD standard deviation, *BMD* bone mineral density, *TUG* timed up-and-go test

[a] p values for continuous data from independent samples t test. p values for categorical data from Pearson chi-square test

Table 2 Characteristics of fallers over 1 year by sex

Fall characteristics, *n* (%) or mean ± SD	Women (*n* = 52)	Men (*n* = 20)	All (*n* = 72)
Number of falls	1.2 ± 1.4	1.1 ± 1.8	1.2 ± 1.5
0	17 (33)	9 (45)	26 (36)
1	20 (39)	8 (40)	28 (39)
2	10 (19)	1 (5)	11 (15)
3	3 (6)	1 (5)	4 (6)
4+	2 (4)	1 (5)	3 (4)
> 1 fall in same month	4 (8)	1 (5)	5 (7)
	Women with falls (*n* = 35)	Men with falls (*n* = 11)	All fallers (*n* = 46)
Fall location(s)			
Fell only inside home	10 (29)	1 (9)	11 (24)
Fell only outside near home	5 (14)	3 (27)	8 (17)
Fell only elsewhere	13 (37)	2 (18)	15 (33)
Fell in multiple locations	4 (11)	4 (36)	8 (17)
Did not report	3 (9)	1 (9)	4 (9)
	Women with fall injuries (*n* = 17)	Men with fall injuries (*n* = 8)	All injured (*n* = 25)
Fall injury			
Bruise or bleeding	8 (47)	4 (50)	12 (48)
Sprain or strain	0 (0)	1 (13)	1 (4)
Bone fracture	3 (18)	0 (0)	3 (12)
Blow to head or concussion	0 (0)	0 (0)	0 (0)
Other[a]	3 (18)	2 (25)	5 (20)
Multiple injuries[b]	3 (18)	1 (13)	4 (16)

[a] Other injuries reported included rotator cuff, ribs, skinned knee, scrapes, and not specified

[b] Four individuals reported multiple injuries over the year of follow-up including bruising or bleeding (*n* = 4), fractures (*n* = 2), concussion (*n* = 1), and sprain or strain (*n* = 1)

by blocks. Bivariate analyses showed no significant differences in BMD, weight, or TUG time between those who were hyperkyphotic and those who were not by each of the four measures. Age was significantly associated with the Debrunner kyphometer and the blocks measure. For each standard deviation increase in age, participants had 2.1 times greater odds (95% CI = 1.1, 4.0) of being classified as hyperkyphotic by Debrunner kyphometer and 3.7 times greater odds (95% CI = 1.9, 7.1) of being classified hyperkyphotic by blocks.

Characteristics of fallers

Because men and women tend to experience falls differently, Table 2 presents fall characteristics by sex. Fifteen (29%) women and three (15%) men fell more than once during that time period; five participants (7%) fell multiple times within the same month. Eleven of 43 fallers (24%) fell inside their home, eight (17%) fell outside near their home, 15 (33%) fell at another location (either indoors or outdoors), and eight (17%) fell in multiple locations (four participants did not report fall location). Most (48%) of the individuals with fall injuries reported bruising or bleeding. Three (12%) fractures were reported and four individuals (16%) reported multiple injuries including bruising or bleeding, fractures, concussions, and sprains/strains (Table 2).

Associations between kyphosis measures and incident falls

In crude logistic regression models, three measures of kyphosis (Debrunner kyphometer, flexicurve ruler, and Cobb angle) were associated with roughly a two-fold increase in the risk of incident fall over 1 year per SD increase (Table 3). After adjustment for sex, age, weight, and total hip BMD, the association between each of the kyphosis measures was strengthened with ORs ranging from 2.11 per SD of Cobb angle to 3.20 per SD of blocks. Because it is thought that balance may be adversely affected by worsening kyphosis, we further adjusted for TUG time to assess whether accounting for its dynamic balance component might mediate the association between kyphosis and incident falls; the ORs per SD were

Table 3 Odds of incident fall by each measure of kyphosis (n = 72)

Modeled kyphosis measure (per SD)	Unadjusted models			Adjusted models[a]			Adj. models[a] + TUG time		
	OR	95% CI	p value	OR	95% CI	p value	OR	95% CI	p value
Debrunner kyphometer	2.03*	1.17, 3.52	.012	2.41*	1.28, 4.55	.006	2.16*	1.11, 4.21	.024
Flexicurve ruler	2.02*	1.10, 3.70	.024	2.55*	1.23, 5.29	.012	2.32*	1.09, 4.92	.028
Cobb angle	1.92*	1.11, 3.31	.019	2.11*	1.13, 3.96	.020	2.01*	1.06, 3.82	.033
Blocks	1.75	0.99, 3.11	.058	3.20*	1.38, 7.46	.007	3.05*	1.26, 7.36	.013

SD standard deviation, *OR* odds ratio, *CI* confidence interval

[a] Adjusted for sex, age, weight, and total hip BMD

*Statistically significant at $\alpha = 0.05$

only minimally attenuated, reduced from 2.11 to 2.01 for Cobb angle and from 3.20 to 3.05 for blocks.

Associations between kyphosis measures and injurious falls

While there was a trend that worse kyphosis was associated with future injurious falls, the results were less robust. As shown in Table 4, in crude logistic regression models, two measures of kyphosis (blocks method and Debrunner kyphometer) were associated with an increase in the risk of an injurious fall over 1 year. Additional adjustment for sex, age, weight, and total hip BMD strengthened the association. However, once models were further adjusted for TUG time only the blocks method remained statistically significant; with each SD increase in blocks there was a near tripling of risk for injurious fall.

Discussion

For each SD increase in kyphosis measure, adjusted odds of an incident fall more than doubled among the older adults in this study; notably, odds of an incident fall tripled for each SD increase in the blocks measure. These associations remained even after adjustment for TUG time, which was hypothesized to mediate the association between kyphosis and falls. These results have several implications: (1) Those with higher degrees of kyphosis are more likely to suffer a fall than their peers with less kyphosis; (2) all four measures of kyphosis are roughly equally able to predict odds of an incident fall; and (3) mobility and function as measured by the TUG test does not explain the association between kyphosis and falls.

The main findings of our study are in line with the only other prospective published report of kyphosis and falls [26], although poor participant retention limited the conclusiveness of the previous study's results. One large cross-sectional study found an association between the blocks measure and self-reported falls in the previous year among men only, though the authors noted that they lacked power to detect a significant association in women [17]. Another cross-sectional study of 92 persons found no association between a computer-assisted measure of kyphosis and self-reported falls in the previous year, and thus, the rationale for conducting the current prospective study was strong [27]. Herein, we report consistency across four different commonly used measures of kyphosis in predicting future falls. We have previously published that the correlations between these four different measures were strong, ranging

Table 4 Odds of injurious fall by each measure of kyphosis (n = 72)

Modeled kyphosis measure (per SD)	Unadjusted models			Adjusted models[a]			Adj. models[a] + TUG time		
	OR	95% CI	p value	OR	95% CI	p value	OR	95% CI	p value
Debrunner kyphometer	1.80*	1.04, 3.14	.037	2.02*	1.08, 3.80	.028	1.76	0.89, 3.47	.104
Flexicurve ruler	1.37	0.83, 2.26	.213	1.62	0.90, 2.92	.106	1.43	0.71, 2.90	.319
Cobb angle	1.21	0.74, 2.00	.445	1.37	0.78, 2.41	.276	1.35	0.75, 2.42	.322
Blocks	1.74*	1.01, 2.98	.045	2.41*	1.18, 4.92	.016	2.74*	1.18, 6.34	.019

SD standard deviation, *OR* odds ratio, *CI* confidence interval

[a] Adjusted for sex, age, weight, and total hip BMD

*Statistically significant at $\alpha = 0.05$

between 0.63 and 0.76, and our current study findings provide solid evidence of construct validity [24].

In related literature, several reports of varying quality have been published that employed alternative measures for kyphosis and used balance as a surrogate outcome for falls [19, 20, 28–33]. These studies as a whole suggest that kyphosis adversely affects balance, and it is known that poor balance is a fall risk factor. For example, in several cross-sectional studies, occiput-to-wall distance (OWD) has been used as a measure of forward flexed posture where the participant stands with their feet and buttocks touching a wall; the distance between their occiput and the wall is measured and recorded as the OWD. Two studies found that OWD was associated with gait problems in both sexes; one of these also found that OWD was associated with poor balance in women [19, 28]. Similarly, a study of women with chronic back pain found OWD was associated with balance and gait issues, both of which could lead to increased fall risk [29]. Using the Debrunner Kyphometer as a measure of kyphosis, a large study of women found that greater quartiles of kyphotic angle were associated with longer TUG times in fully adjusted models [32], while a small study of women found that hyperkyphotic women had reduced gait velocity and reduced falls efficacy compared to women with normal kyphosis [33]. However, in contrast, two other published studies reported no association between kyphosis and the Berg Balance Score [20] and force plate measures of balance [31].

Similar to the two studies that reported no association with balance, in our study, none of the four measures of kyphosis were associated with TUG time, and TUG was similarly not associated with incident falls. These findings are somewhat counterintuitive as those who are most kyphotic would seem to be those who should have impaired mobility and be at increased fall risk. There are at least three plausible explanations for our study findings. The first is that the TUG test is primarily a functional performance test and is not a direct test of balance. Secondly, the mean TUG time in our study sample was on the lower end of age-specific normative values, suggesting the older men and women were high functioning and the test was not sensitive enough to detect impairments in this population. The third potential explanation is that perhaps fall risk in those with hyperkyphosis is really mediated by other related factors such as spinal muscle weakness and this characteristic would not necessarily be captured by the TUG.

Unlike the incident falls outcomes, we did not find consistent results with the injurious falls outcome. Although the magnitude of the associations were similar to those of incident falls, only blocks and Debrunner kyphometer were significantly associated with injurious falls. After further adjustment for TUG, only the blocks method was significant. This could have been due to lack of power as there were far fewer injurious falls ($n = 25$) among the cohort compared with incident falls ($n = 46$). The findings could also be due to the various components of kyphosis being measured by each method. For example, the blocks method likely captures kyphosis in the upper region of the spine, whereas the flexicurve and Cobb angle methods capture only thoracic kyphosis. Regardless, for each standard deviation increase in the so-called crude blocks method, odds of an injurious fall more than doubled.

It is worth noting that our cohort study showed substantially higher incidence of falls than those reported in other studies. It seems likely that our comparatively frequent falls assessment (once per month), complete follow-up, and older, engaged study population contributed to the higher incidence. Especially if non-injurious and without any consequences, the recall of falls in this age population may tend toward underreporting at less frequent intervals [34, 35]; thus, our study may provide a more realistic estimate of number of falls sustained in older persons living in the community.

Our study had several strengths including a prospective design with a full year of follow-up, monthly falls tracking, and 100% retention of all study subjects as well as multiple methods of assessing degree of kyphosis. Challenges include multiple statistical comparisons, a relatively small sample size, self-selection bias, the small proportion of men, and the relatively homogenous population of active, Caucasian older adults. Another limitation is that our study was designed to only examine the association between hyperkyphosis and falls; it is possible that our findings were due to an unmeasured condition co-occurring with hyperkyphosis. Although the study population was active and performed well on physical performance tests, most (65%) reported three or more current chronic conditions at the time of enrollment and more than half (58%) were taking three or more prescription medications (data not shown).

Although further studies with larger sample sizes are needed to confirm our findings, our results are encouraging. To date, no standardized fall intervention strategies have considered posture as an important factor, and yet, it is plausible that modifying posture could theoretically reduce fall risk. It is promising that a simple, inexpensive blocks test could be incorporated into older adults' primary care visits or included as part of routine osteoporosis screening to aid in the assessment of fall risk. Further research should incorporate large population-based samples and attempt to identify measurement-specific cut points for increased fall risk.

Compliance with ethical standards

Conflicts of interest None.

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