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Hyperkyphosis and incident falls among community-dwelling older adults

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Philosophy

in

Public Health (Epidemiology)

by

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2017

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The Dissertation of Corinne Rae McDaniels-Davidson is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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2017

DEDICATION

To my amazing and supportive husband Jesse,
my loving and patient daughter Abigail,
my family who have stood behind me for decades as I pursued my dreams,
my colleagues who have been in my corner for over a decade,
and my mentors who have pushed and encouraged me.

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LIST OF ACRONYMS

3MS	Teng Modified Mini-Mental Status exam
BMD	Bone mineral density
BMI	Body mass index
DAG	Directed acyclic graph
DXA	Dual-energy X-ray absorptiometry
GEE	Generalized estimating equations
KFBS	Kyphosis, Falls, and Balance Study
KI	Kyphotic Index
MMSE	Mini-Mental Status Exam
MrOS	Osteoporotic Fractures in Men Study
OWD	Occiput-to-wall distance
SOF	Study of Osteoporotic Fractures
TUG	Timed up-and-go test

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ABSTRACT OF THE DISSERTATION

Hyperkyphosis and incident falls among community-dwelling older adults

by

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Doctor of Philosophy in Public Health (Epidemiology)

University of California, San Diego, 2017
San Diego State University, 2017

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Background: Falls are a common cause of morbidity among older adults. Although many fall risk factors are well understood, it is unknown whether a common geriatric condition, hyperkyphosis, increases fall risk.

Objectives: This dissertation research sought to determine whether older persons with worse degrees of kyphosis may be at increased risk of falls.

Methods: Three longitudinal cohorts of older adults (aged ≥65) were used, each with different kyphosis measures, to examine the association between degree of kyphosis and fall risk. Study 1 examined whether four measures of kyphosis (Debrunner kyphometer, flexicurve ruler, Cobb angle, and block method) increased the odds of an incident fall over one year of monthly falls follow-up in a mixed-gender sample of 72 individuals (mean age=78). Studies 2 and 3 each prospectively examined two different measures of kyphosis and incident falls over three years of tri-annual follow-up through multivariable modeling with GEEs. Study 2 included 2,346 men with the Cobb angle measure of kyphosis (mean age=74) and 2,929 men with block-measured kyphosis (mean age=79) from the Osteoporotic Fractures in Men Study (MrOS). Study 3 used data from 1,162 women with the Cobb angle measure (mean age=69) and 610 women with the flexicurve measure of kyphosis (mean age=73) from the Study of Osteoporotic Fractures in Women (SOF).

Results: In Study 1, all four measures of kyphosis conferred a 2-3 fold increase per SD in the odds of a fall over the following year (64% of participants fell over one year). In Studies 2 and 3, Cobb angle was not associated with fall risk in either MrOS or SOF. The blocks method was predictive of fall risk in MrOS (RR=1.11 per SD; 95% CI=1.06, 1.17) and KI was predictive of fall risk in SOF (RR=1.22 per SD; 95% CI=1.07, 1.40).

Conclusion: All three studies provide evidence that increased kyphosis predicts greater fall risk in older persons. The Cobb angle measure, however, appears to be least related to falls, possibly because it is a measure limited to the mid to lower thoracic spine whereas the block and flexicurve methods include curvature in the lower cervical and entire thoracic spine.

CHAPTER 1: INTRODUCTION

OVERVIEW

The aging of the baby boomer generation has brought about a significant shift in the demography of the United States (US). Spanning 50 years between 1960 and 2010, the US population increased by 72%, while the population of older adults (aged 65 and older) in the US increased more than 140%.[1] By 2020, it is expected that there will be over 40 million older adults living in the US.[1] With these staggering increases in the older population in particular, increased attention to geriatric health concerns, societal burden, and cost-containment have become research priorities.

Falls among older adults are particularly concerning, both from a personal and public health perspective. Falls can precipitate a rapid loss of independence in older adults, both in terms of physical function and living situation.[2,3] These disruptions in life circumstance can have an untold emotional impact on the older adult. In addition, the public health significance cannot be understated; it has been projected that by 2020 the cost of falls in the US in 2015 dollars will exceed $51 billion.[4] While studies of the causes, consequences, and prevention of falls in older adults have been ongoing for decades, studies of the impact of hyperkyphosis (excessive forward curvature of the thoracic spine; one hypothesized cause of falls and other adverse health outcomes) have only recently been undertaken. If this easily identifiable phenotype were shown to increase fall risk, it might add a simple tool for primary care providers to use

when screening their older patients for falls interventions. Moreover, if it were shown that hyperkyphosis increases fall risk through its impact on balance in the older adult, it would present an opportunity for proven interventions for those at risk of falls.

HYPERKYPHOSIS

Hyperkyphosis is an accentuated forward curvature in the back or thoracic spine, resulting in stooped or flexed posture.[5] Prevalence estimates vary due to the lack of consensus in measurement technique or diagnostic cut-points. In population-based cohorts, prevalence has been as high as 44%[6] in men by one measurement method and 30%[7] in women by another measurement method.

Broadly, hyperkyphosis has been associated with poor health outcomes and mortality. Sequelae include impaired pulmonary function, diminished physical function, and increased fracture risk.[6,8-10] Hyperkyphosis has also been shown to be associated with reduced lower extremity strength and impaired balance.[11-14] In terms of mortality, one study found that those with hyperkyphosis had 1.4 times greater rate of mortality compared to non-hyperkyphotic individuals.[6] Another study of mortality reported that among women with prevalent vertebral fractures, those with hyperkyphosis were at an increased risk for mortality.[15]

The excessive curvature can be brought about by many causal mechanisms. Both vertebral body and disc deformities have been shown to correspond to the angle of kyphosis.[16-19] One large study reported that those with

vertebral fractures had significantly higher age-adjusted Cobb angle (one measure of kyphosis) than those without vertebral fractures, though fewer than 40% of men and women in the highest quartile of Cobb angle had prevalent vertebral fractures, underscoring the diversity of causal mechanisms for the condition.[20] Degenerative disc disease, or the deterioration of the intervertebral discs over time, is thought to account for part of the variability in hyperkyphosis measures as well. Together with vertebral morphology, disc morphology accounted for 85% of the variability in kyphosis in one small study.[18] Spinal muscle weakness and paraspinal muscle density have also been shown to be associated with hyperkyphosis in older men and women.[7,21]

In addition to these intuitive causes related to spinal bodies, muscle, and discs, several other factors may contribute to increased kyphosis in older adults. Increasing age,[7,14,22,23] lower BMD,[7,14,24-26] weight,[25] and body mass index (BMI)[6,7,21] have been associated with increased kyphosis in older men and women.

Approaches to measuring kyphosis include both standing and lying methods. Standing methods include the gold standard radiographic Cobb angle, flexicurve ruler, goniometer, inclinometer, Debrunner kyphometer, occiput-to-wall distance, and qualitative visual inspection. Lying measures include lateral spine radiographs to measure the Cobb angle and the blocks method.[5,27]

The Cobb angle is measured from either standing or lying lateral spine radiographs. Lines are drawn on the radiographs to extend the top plate of T4 (or T3 if necessary) and the bottom plate of T12 (or T11 if necessary) to isolate the

thoracic curvature. Lines perpendicular to each of these are then drawn. The Inferior angle of intersection between these perpendicular lines is referred to as the Cobb angle.[8,27] Various Cobb angle values have been used as cut points in the literature to define hyperkyphosis including those based on quartiles, percentiles, or round numbers. Cobb angle measures from standing radiographs are considered the gold standard; radiographs taken in the lying position likely underestimate the degree of kyphosis.[23]

The blocks method of measuring severity of hyperkyphosis was pioneered by the Rancho Bernardo Study[6] and has since been utilized in other clinical research settings.[14,28,29] With the subject lying supine on a flat surface, trained personnel place 1.7 cm blocks under the participant's head until a neutral head and neck position is achieved. Greater numbers of blocks indicate more severe hyperkyphosis.[6] Unlike the Cobb angle, this method may capture forward curvature in the back originating from places other than the thoracic spine. There is no consensus within the body of literature utilizing the blocks method on a cut point to define hyperkyphosis.

The kyphotic index is derived from standing measures taken with an architect's flexible ruler. The flexicurve ruler is molded to the curvature of the participant's spine and marked at the C7 spinous process and the L5-S1 interspace. It is then transferred to a sheet of paper where the curve is traced on the axis of a vertical line between the two marks. A line is then drawn from the furthest point in the thoracic curve to the vertical axis. The width of the line divided by the marked length of the vertical axis multiplied by 100 is the kyphotic

index.[27] This method of measurement may capture different elements of thoracic curvature because the measure includes the entirety of the thoracic spine, whereas the Cobb angle focuses on curvature between T4 and T12.

The Debrunner kyphometer appears similar to a protractor with a drawing compass attached. This device uses two four-bar linkages to transfer the relative angle between two blocks (placed on the T2 and T3 spinous processes and the L5-S1 interspace) to a common location so it can be read on a dial. This has the advantage of allowing a measurement of the kyphotic angle without requiring radiography.[27]

Previous research has documented agreement (intraclass correlation coefficient = 0.68) between standing Debrunner kyphometer and Cobb angle.[30] In another study of 72 older men and women, three measures were compared to the Cobb angle (lying lateral radiograph) using Spearman Rank correlation coefficients (ρ) or Pearson correlation coefficients (r); the blocks method (ρ=0.59), Debrunner kyphometer (r=0.61), and kyphotic index calculated from flexicurve ruler measurements (r=0.67) all demonstrated good correlation.[28]

FALLS IN OLDER ADULTS

Among older adults, the loss of independence is often a devastating life event from both a personal and public health perspective. Falls, which are thought to occur in about 30% of older adults annually,[31] can precipitate a rapid loss of independence. Among community-dwelling older adults, falls strongly predict both functional decline and skilled-nursing facility placement.[2,3] The

perceived consequences of falling are so great that fear of falling has been reported to cause activity restriction in up to 60% of community-dwelling older adults.[32] The public health impact is no less severe than the personal impact. As mentioned previously, costs associated with fall injuries are expected to exceed $51 billion (in 2015 dollars) by 2020.[4]

Risk factors for falling differ between community-dwelling older adults, institutionalized older adults, and working-age adults.[4] In the community-dwelling older adult population common risk factors include increasing age, female sex, psychotropic drug use, comorbidities, cognitive impairment, history of falls, lower extremity weakness, balance deficit, gait problems, vertigo, mobility limitations, and fear of falling.[33,34] Among older adults, education about fall risks and balance-related exercise has been shown to reduce risk of injurious falls.[35-37]

HYPERKYPHOSIS AND FALLS

Considering the relatively high prevalence estimates for hyperkyphosis in older adults, the dearth of published research related to it as a predictor of falls may be contributing to it being overlooked within the medical field as an important and easily identifiable risk factor. There have been several related studies with varying objectives and a wide spectrum of quality that have shed some light on the association. However, nearly all of the studies have used surrogate measures of hyperkyphosis, falls, or both.[11,12,38-42] In some cases this was due to limited availability of desired data; in other cases, the relation between hyperkyphosis and falls was not the intended aim of the research. Only

one published study of hyperkyphosis and falls was prospective and nature, though it's follow-up period was limited to 6-12 months.[43]

Chronologically, the first identified report was conducted by Balzini and colleagues[12] in 2003 using both a surrogate hyperkyphosis measure (occiput-to-wall distance, which is an indicator of flexed posture; OWD) and surrogate falls measure (Performance Oriented Mobility Assessment; POMA). Among the 60 women in this cross sectional study, relative to those with a mild OWD, those in the severe OWD category had reduced balance and gait scores on the POMA.

In 2005, Sinaki and colleagues[42] published a case-control study in older women with 12 hyperkyphotic participants (Cobb angle ≥50°) and 13 healthy controls. The researchers did not inquire about history of falls but rather administered a falls efficacy scale. The hyperkyphotic group had lower falls efficacy and more falls risk factors than the control group.

Two years later, Kado and colleagues[9] published a report of a cross sectional study of community-dwelling older adults with 753 men and 1130 women. Hyperkyphosis was measured with the blocks method and the falls measure was obtained in a questionnaire inquiring about the previous twelve months. Men requiring ≥2 blocks had higher odds of injurious falls over the previous twelve months though the association was explained by age in women.

Also in 2007, Greig and colleagues[41] published a cross sectional report of 22 osteoporotic women attempting to determine whether vertebral fractures or hyperkyphosis was associated with a measure of balance. Among this small

sample of osteoporotic women, they concluded that balance was related to vertebral fractures rather than hyperkyphosis.

The same year, Antonelli-Incalzi and colleagues[11] published a cross sectional study of 783 men and women examining surrogate measures of hyperkyphosis (OWD) and falls (balance, gait speed, and chair stands). The authors concluded that OWD was associated with gait speed in both men and women and with balance in women.

In 2010, Kasukawa and colleagues[44] published a cross sectional study of older adults with 23 men and 69 women. Degree of thoracic kyphosis was measured with a SpinalMouse® from T1-T12 and subjects were categorized into one of three groups: fallen in the past year, fear of falling in the past year, and no history of falls or fear of falling in the past year. No significant association was found between history of falls in the past year and thoracic hyperkyphosis.

The following year, Katzman and colleagues[13] published a cross sectional study of 3,180 women examining the association between a measure of hyperkyphosis (Debrunner Kyphometer) and the timed up-and-go test (TUG), a measure of functional mobility. The authors found greater kyphotic angles were associated with increased TUG times, indicating worsening balance.

Two years later, Eum and colleagues[40] published findings from the MOBILIZE Boston Study cohort. In a cross sectional study of 226 men and 394 women, the authors found that greater Kyphotic Index (KI; calculated from the flexicurve ruler) was significantly associated with decreased Short Physical Performance Battery (SPPB) score, indicating deficits in lower extremity mobility

performance. Interestingly, there were no associations between KI and balance measures (Berg Balance Score).

Similarly, de Groot and colleagues[39] published results from a cross sectional study of 17 men and 39 women found that those with Flexed Posture (FP; occiput-to-wall distance >5cm) had more variable, less structured gait patterns, implying that they are at higher risk for falling.

Finally, van der Jagt-Willems and colleagues[43] published the first manuscript examining hyperkyphosis and future falls, though the authors chose to analyze the prospectively collected data using logistic regression. This small study of 51 older men and women found that each standard deviation increase in Cobb angle doubled the odds of a fall during a varied follow-up period (6-12 months as the follow-up period was doubled from six to 12 months due to lack of fall outcomes).

Although the research suggests an association between hyperkyphosis and falls, which could lead to simple interventions to reduce falls, improve quality of life, and decrease public health costs, well-designed prospective studies are needed to confirm these associations. This dissertation research will seek to definitively answer whether hyperkyphosis is a risk factor for future falls.

In order to guide our research and analytic strategies, a Directed Acyclic Graph (Figure 1.1) was developed to visualize the causal pathways between, and potential confounders of, the hypothesized association of hyperkyphosis and falls. Because age, weight, and osteoporosis/BMD, are common ancestors of both hyperkyphosis and falls, they will be controlled for in all statistical models.

Lower extremity strength and balance are hypothesized to lie within the causal pathway, meaning they potentially mediate the association between hyperkyphosis and falls.

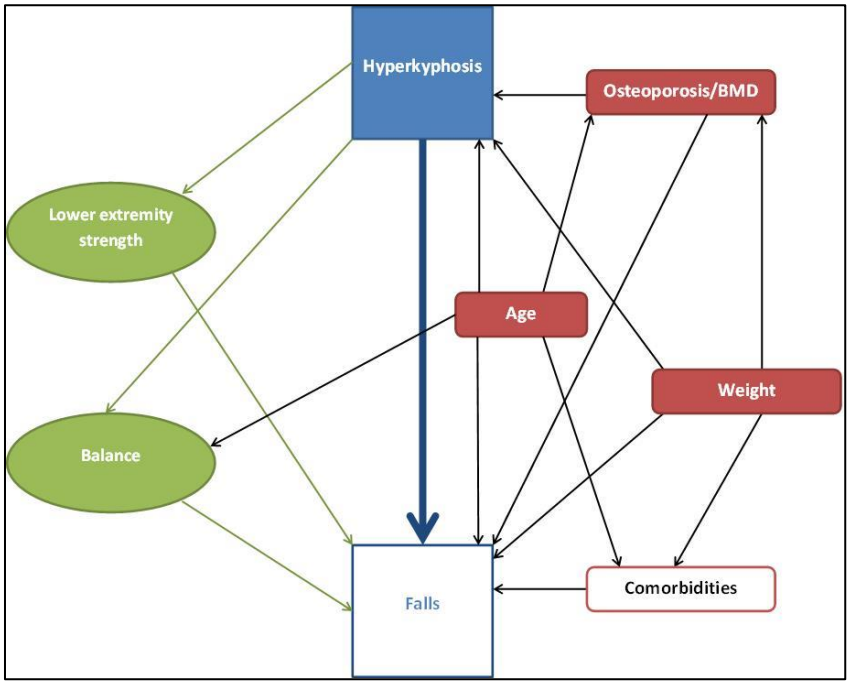


Figure 1.1: Directed Acyclic Graph: Hyperkyphosis and Falls

First, in a cohort of 72 older men and women, we will determine whether kyphosis as measured four different ways increases the odds of a fall over the following year with falls assessed monthly. Next, we will utilize data from two large population-based cohorts (one with only men and the other with only women) to determine whether two measures of kyphosis increase the risk of falls over three years. These long-term studies of the impact of kyphosis on fall risk are currently missing from the literature and are needed in order to advance our understanding of the association between hyperkyphosis and falls.

REFERENCES

1. U.S. Census Bureau. 65+ in the United States: 2010. In: Bureau USC, ed. Washington, DC: U.S. Government Printing Office; 2014.

2. Tinetti ME, Williams CS. The effect of falls and fall injuries on functioning in community-dwelling older persons. The journals of gerontology Series A, Biological sciences and medical sciences 1998;53:M112-9.

3. Tinetti ME, Williams CS. Falls, injuries due to falls, and the risk of admission to a nursing home. The New England journal of medicine 1997;337:1279-84.

4. Englander F, Hodson TJ, Terregrossa RA. Economic dimensions of slip and fall injuries. Journal of forensic sciences 1996;41:733-46.

5. Kado DM, Prenovost K, Crandall C. Narrative review: hyperkyphosis in older persons. Annals of internal medicine 2007;147:330-8.

6. 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. Journal of the American Geriatrics Society 2004;52:1662-7.

7. Katzman W, Cawthon P, Hicks GE, et al. Association of spinal muscle composition and prevalence of hyperkyphosis in healthy community-dwelling older men and women. The journals of gerontology Series A, Biological sciences and medical sciences 2012;67:191-5.

8. Kado DM, Duong T, Stone KL, et al. Incident vertebral fractures and mortality in older women: a prospective study. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2003;14:589-94.

9. 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. The journals of gerontology Series A, Biological sciences and medical sciences 2007;62:652-7.

10. Ryan SD, Fried LP. The impact of kyphosis on daily functioning. Journal of the American Geriatrics Society 1997;45:1479-86.

11. Antonelli-Incalzi R, Pedone C, Cesari M, Di Iorio A, Bandinelli S, Ferrucci L. Relationship between the occiput-wall distance and physical performance in the elderly: a cross sectional study. Aging clinical and experimental research 2007;19:207-12.

12. Balzini L, Vannucchi L, Benvenuti F, et al. Clinical characteristics of flexed posture in elderly women. Journal of the American Geriatrics Society 2003;51:1419-26.

13. Katzman WB, Vittinghoff E, Kado DM. Age-related hyperkyphosis, independent of spinal osteoporosis, is associated with impaired mobility in older community-dwelling women. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2011;22:85-90.

14. Katzman WB, Harrison SL, Fink HA, et al. Physical function in older men with hyperkyphosis. The journals of gerontology Series A, Biological sciences and medical sciences 2015;70:635-40.

15. Kado DM, Browner WS, Palermo L, Nevitt MC, Genant HK, Cummings SR. Vertebral fractures and mortality in older women: a prospective study. Study of Osteoporotic Fractures Research Group. Archives of internal medicine 1999;159:1215-20.

16. De Smet AA, Robinson RG, Johnson BE, Lukert BP. Spinal compression fractures in osteoporotic women: patterns and relationship to hyperkyphosis. Radiology 1988;166:497-500.

17. Geusens P, Vosse D, van der Heijde D, et al. High prevalence of thoracic vertebral deformities and discal wedging in ankylosing spondylitis patients with hyperkyphosis. The Journal of rheumatology 2001;28:1856-61.

18. Goh S, Price RI, Leedman PJ, Singer KP. The relative influence of vertebral body and intervertebral disc shape on thoracic kyphosis. Clin Biomech (Bristol, Avon) 1999;14:439-48.

19. Manns RA, Haddaway MJ, McCall IW, Cassar Pullicino V, Davie MW. The relative contribution of disc and vertebral morphometry to the angle of kyphosis in asymptomatic subjects. Clinical radiology 1996;51:258-62.

20. Schneider DL, von Muhlen D, Barrett-Connor E, Sartoris DJ. Kyphosis does not equal vertebral fractures: the Rancho Bernardo study. The Journal of rheumatology 2004;31:747-52.

21. Katzman WB, Miller-Martinez D, Marshall LM, Lane NE, Kado DM. Kyphosis and paraspinal muscle composition in older men: a cross-sectional study for the Osteoporotic Fractures in Men (MrOS) research group. BMC musculoskeletal disorders 2014;15:19.

22. Ensrud KE, Black DM, Harris F, Ettinger B, Cummings SR. Correlates of kyphosis in older women. The Fracture Intervention Trial Research Group. Journal of the American Geriatrics Society 1997;45:682-7.

23. 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. The journals of gerontology Series A, Biological sciences and medical sciences 2013;68:976-83.

24. Huang MH, Barrett-Connor E, Greendale GA, Kado DM. Hyperkyphotic posture and risk of future osteoporotic fractures: the Rancho Bernardo study. Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research 2006;21:419-23.

25. 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. Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research 2013;28:179-87.

26. Kado DM, Miller-Martinez D, Lui LY, et al. Hyperkyphosis, kyphosis progression, and risk of non-spine fractures in older community dwelling women: the study of osteoporotic fractures (SOF). Journal of bone and mineral research :

the official journal of the American Society for Bone and Mineral Research 2014;29:2210-6.

27. Katzman WB, Wanek L, Shepherd JA, Sellmeyer DE. Age-related hyperkyphosis: its causes, consequences, and management. The Journal of orthopaedic and sports physical therapy 2010;40:352-60.

28. Tran TH, Wing D, Davis A, et al. Correlations among four measures of kyphosis in older adults. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2015.

29. Greendale GA, Huang MH, Karlamangla AS, Seeger L, Crawford S. Yoga decreases kyphosis in senior women and men with adult-onset hyperkyphosis: results of a randomized controlled trial. Journal of the American Geriatrics Society 2009;57:1569-79.

30. Kado DM, Christianson L, Palermo L, Smith-Bindman R, Cummings SR, Greendale GA. Comparing a supine radiologic versus standing clinical measurement of kyphosis in older women: the Fracture Intervention Trial. Spine 2006;31:463-7.

31. Bergen G SM, Burns ER. Falls and fall injuries among adults aged ≥65 Years — United States, 2014. PreventionMorbidity and Mortality Weekly Report 2016;65:1-6.

32. Deshpande N, Metter EJ, Lauretani F, Bandinelli S, Guralnik J, Ferrucci L. Activity restriction induced by fear of falling and objective and subjective measures of physical function: a prospective cohort study. Journal of the American Geriatrics Society 2008;56:615-20.

33. Deandrea S, Lucenteforte E, Bravi F, Foschi R, La Vecchia C, Negri E. Review Article: Risk Factors for Falls in Community-dwelling Older People: "A Systematic Review and Meta-analysis". Epidemiology 2010;21:658-68.

34. Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. Age and ageing 2006;35 Suppl 2:ii37-ii41.

35. Clemson L, Cumming RG, Kendig H, Swann M, Heard R, Taylor K. The effectiveness of a community-based program for reducing the incidence of falls in the elderly: a randomized trial. Journal of the American Geriatrics Society 2004;52:1487-94.

36. Guse CE, Peterson DJ, Christiansen AL, Mahoney J, Laud P, Layde PM. Translating a Fall Prevention Intervention Into Practice: A Randomized Community Trial. American journal of public health 2015:e1-e7.

37. Province MA, Hadley EC, Hornbrook MC, et al. The effects of exercise on falls in elderly patients. A preplanned meta-analysis of the FICSIT Trials. Frailty and Injuries: Cooperative Studies of Intervention Techniques. Jama 1995;273:1341-7.

38. Choi CJ, Lim HW, Park MK, Cho JG, Im GJ, Chae SW. Does the kyphotic change decrease the risk of fall? Clinical and experimental otorhinolaryngology 2011;4:118-21.

39. de Groot MH, van der Jagt-Willems HC, van Campen JP, Lems WF, Beijnen JH, Lamoth CJ. A flexed posture in elderly patients is associated with impairments in postural control during walking. Gait & posture 2014;39:767-72.

40. Eum R, Leveille SG, Kiely DK, Kiel DP, Samelson EJ, Bean JF. Is kyphosis related to mobility, balance, and disability? American journal of physical medicine & rehabilitation / Association of Academic Physiatrists 2013;92:980-9.

41. Greig AM, Bennell KL, Briggs AM, Wark JD, Hodges PW. Balance impairment is related to vertebral fracture rather than thoracic kyphosis in individuals with osteoporosis. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2007;18:543-51.

42. Sinaki M, Brey RH, Hughes CA, Larson DR, Kaufman KR. Balance disorder and increased risk of falls in osteoporosis and kyphosis: significance of kyphotic posture and muscle strength. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2005;16:1004-10.

43. van der Jagt-Willems HC, de Groot MH, van Campen JP, Lamoth CJ, Lems WF. Associations between vertebral fractures, increased thoracic kyphosis, a flexed posture and falls in older adults: a prospective cohort study. BMC geriatrics 2015;15:34.

44. Kasukawa Y, Miyakoshi N, Hongo M, et al. Relationships between falls, spinal curvature, spinal mobility and back extensor strength in elderly people. Journal of bone and mineral metabolism 2010;28:82-7.

CHAPTER 2: KYPHOSIS AND INCIDENT FALLS AMONG COMMUNITY-DWELLING OLDER ADULTS

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ABSTRACT

OBJECTIVES: To determine the association between four measures of kyphosis and incident and injurious falls in older persons. DESIGN: Prospective cohort study. SETTING: La Jolla, California. PARTICIPANTS: Community dwelling adults aged 65 and older (n=72). MEASUREMENTS: Participants had kyphosis assessed four ways. Two standing measures included a flexicurve ruler placed against the participant's back to derive a kyphotic index and the Debrunner kyphometer, a protractor used to measure the kyphotic angle in degrees. Two lying measures were completed including 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 one year, with falls outcomes confirmed through telephone interview. RESULTS: Mean age was 77.8 (± 7.1) among the 52 women and 20 men. Over twelve months, 64% of participants experienced at least one incident fall and 35% experienced an injurious fall. For each standard deviation increase in kyphosis, adjusted odds of an incident fall more than doubled, even after adjusting for TUG time. Odds of injurious falls were less consistent across measures; after adjusting for TUG, only the blocks method was associated with injurious falls. CONCLUSION: Each kyphosis measure was independently associated with incident falls. Findings were less consistent for injurious falls, with the blocks measure suggesting the

strongest association. The blocks measure could be incorporated into office visits as a quick and efficient tool to identify patients at increased fall risk.

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.[3,4] 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]

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 were excluded. 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, described previously by Tran et al.[24] Briefly, two standing measures were taken; a Debrunner Kyphometer was used to measure the angle of kyphosis and a flexicurve ruler was used to

calculate the Kyphotic Index (KI). 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). 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]

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. 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.

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 (TUG), the time (in seconds) it takes to rise from a seated position, walk 10 feet 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 2.1). 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 (Table 2.2).

Table 2.1: Participant characteristics by incident and injurious fall occurrence (n=72)

Characteristics, n (%) or mean ± SD	Incident fall		*p*-value[a]	Injurious fall		*p*-value[a]	All (N=72)
	No (N=26)	Yes (N=46)		No (N=47)	Yes (N=25)		
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

[a] P-values for continuous data from independent samples t-test. P-values for categorical data from Pearson chi-square test. SD= standard deviation; BMD= bone mineral density; TUG= timed up-and-go test

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 2.1). 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 2.1). 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.

Table 2.2: Characteristics of Fallers Over One 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).

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]. 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

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 8 (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.

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 one year per SD increase (Table 2.3). 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 only minimally attenuated, reduced from 2.11 to 2.01 for Cobb angle and from 3.20 to 3.05 for blocks.

Table 2.3: 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**

[a]Adjusted for sex, age, weight, and total hip BMD; *Statistically significant at α=0.05; SD: Standard deviation, OR: Odds ratio, CI: Confidence interval

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 2.4, 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 one 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.

Table 2.4: 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**

[a]Adjusted for sex, age, weight, and total hip BMD; Statistically significant at α=0.05; SD: Standard deviation, OR: Odds ratio, CI: Confidence interval

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 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 two plausible explanations for our study findings. The first is that TUG test serves as a functional performance test. 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 second 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.

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.

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REFERENCES

1. O'Loughlin JL, Robitaille Y, Boivin JF, Suissa S. Incidence of and risk factors for falls and injurious falls among the community-dwelling elderly. American journal of epidemiology 1993;137:342-54.

2. Englander F, Hodson TJ, Terregrossa RA. Economic dimensions of slip and fall injuries. Journal of forensic sciences 1996;41:733-46.

3. Tinetti ME, Williams CS. Falls, injuries due to falls, and the risk of admission to a nursing home. The New England journal of medicine 1997;337:1279-84.

4. Tinetti ME, Williams CS. The effect of falls and fall injuries on functioning in community-dwelling older persons. The journals of gerontology Series A, Biological sciences and medical sciences 1998;53:M112-9.

5. Deshpande N, Metter EJ, Lauretani F, Bandinelli S, Guralnik J, Ferrucci L. Activity restriction induced by fear of falling and objective and subjective measures of physical function: a prospective cohort study. Journal of the American Geriatrics Society 2008;56:615-20.

6. Salkeld G, Cameron ID, Cumming RG, et al. Quality of life related to fear of falling and hip fracture in older women: a time trade off study. BMJ 2000;320:341-6.

7. Kado DM, Duong T, Stone KL, et al. Incident vertebral fractures and mortality in older women: a prospective study. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2003;14:589-94.

8. 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. Journal of the American Geriatrics Society 2004;52:1662-7.

9. De Smet AA, Robinson RG, Johnson BE, Lukert BP. Spinal compression fractures in osteoporotic women: patterns and relationship to hyperkyphosis. Radiology 1988;166:497-500.

10. Geusens P, Vosse D, van der Heijde D, et al. High prevalence of thoracic vertebral deformities and discal wedging in ankylosing spondylitis patients with hyperkyphosis. The Journal of rheumatology 2001;28:1856-61.

11. Goh S, Price RI, Leedman PJ, Singer KP. The relative influence of vertebral body and intervertebral disc shape on thoracic kyphosis. Clin Biomech (Bristol, Avon) 1999;14:439-48.

12. Katzman W, Cawthon P, Hicks GE, et al. Association of spinal muscle composition and prevalence of hyperkyphosis in healthy community-dwelling older men and women. The journals of gerontology Series A, Biological sciences and medical sciences 2012;67:191-5.

13. Katzman WB, Miller-Martinez D, Marshall LM, Lane NE, Kado DM. Kyphosis and paraspinal muscle composition in older men: a cross-sectional study for the Osteoporotic Fractures in Men (MrOS) research group. BMC musculoskeletal disorders 2014;15:19.

14. Manns RA, Haddaway MJ, McCall IW, Cassar Pullicino V, Davie MW. The relative contribution of disc and vertebral morphometry to the angle of kyphosis in asymptomatic subjects. Clinical radiology 1996;51:258-62.

15. Schneider DL, von Muhlen D, Barrett-Connor E, Sartoris DJ. Kyphosis does not equal vertebral fractures: the Rancho Bernardo study. The Journal of rheumatology 2004;31:747-52.

16. Kado DM, Browner WS, Palermo L, Nevitt MC, Genant HK, Cummings SR. Vertebral fractures and mortality in older women: a prospective study. Study of Osteoporotic Fractures Research Group. Archives of internal medicine 1999;159:1215-20.

17. 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. The journals of gerontology Series A, Biological sciences and medical sciences 2007;62:652-7.

18. Ryan SD, Fried LP. The impact of kyphosis on daily functioning. Journal of the American Geriatrics Society 1997;45:1479-86.

19. de Groot MH, van der Jagt-Willems HC, van Campen JP, Lems WF, Beijnen JH, Lamoth CJ. A flexed posture in elderly patients is associated with impairments in postural control during walking. Gait & posture 2014;39:767-72.

20. Eum R, Leveille SG, Kiely DK, Kiel DP, Samelson EJ, Bean JF. Is kyphosis related to mobility, balance, and disability? American journal of physical medicine & rehabilitation / Association of Academic Physiatrists 2013;92:980-9.

21. Katzman WB, Wanek L, Shepherd JA, Sellmeyer DE. Age-related hyperkyphosis: its causes, consequences, and management. The Journal of orthopaedic and sports physical therapy 2010;40:352-60.

22. Huang MH, Barrett-Connor E, Greendale GA, Kado DM. Hyperkyphotic posture and risk of future osteoporotic fractures: the Rancho Bernardo study. Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research 2006;21:419-23.

23. Kado DM, Miller-Martinez D, Lui LY, et al. Hyperkyphosis, kyphosis progression, and risk of non-spine fractures in older community dwelling women: the study of osteoporotic fractures (SOF). Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research 2014;29:2210-6.

24. Tran TH, Wing D, Davis A, et al. Correlations among four measures of kyphosis in older adults. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2015.

25. Yamamoto J BJ, Davis A, Wing D, Nichols J, Kado D. Trunk lean mass and its association with 3 measures of kyphosis in older community dwelling persons. Journal of the American Geriatrics Society 2015;63(Suppl 1).

26. van der Jagt-Willems HC, de Groot MH, van Campen JP, Lamoth CJ, Lems WF. Associations between vertebral fractures, increased thoracic kyphosis, a flexed posture and falls in older adults: a prospective cohort study. BMC geriatrics 2015;15:34.

27. Kasukawa Y, Miyakoshi N, Hongo M, et al. Relationships between falls, spinal curvature, spinal mobility and back extensor strength in elderly people. Journal of bone and mineral metabolism 2010;28:82-7.

28. Antonelli-Incalzi R, Pedone C, Cesari M, Di Iorio A, Bandinelli S, Ferrucci L. Relationship between the occiput-wall distance and physical performance in the elderly: a cross sectional study. Aging clinical and experimental research 2007;19:207-12.

29. Balzini L, Vannucchi L, Benvenuti F, et al. Clinical characteristics of flexed posture in elderly women. Journal of the American Geriatrics Society 2003;51:1419-26.

30. Choi CJ, Lim HW, Park MK, Cho JG, Im GJ, Chae SW. Does the kyphotic change decrease the risk of fall? Clinical and experimental otorhinolaryngology 2011;4:118-21.

31. Greig AM, Bennell KL, Briggs AM, Wark JD, Hodges PW. Balance impairment is related to vertebral fracture rather than thoracic kyphosis in individuals with osteoporosis. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2007;18:543-51.

32. Katzman WB, Vittinghoff E, Ensrud K, Black DM, Kado DM. Increasing kyphosis predicts worsening mobility in older community-dwelling women: a prospective cohort study. Journal of the American Geriatrics Society 2011;59:96-100.

33. Sinaki M, Brey RH, Hughes CA, Larson DR, Kaufman KR. Balance disorder and increased risk of falls in osteoporosis and kyphosis: significance of kyphotic posture and muscle strength. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2005;16:1004-10.

34. Hannan MT, Gagnon MM, Aneja J, et al. Optimizing the tracking of falls in studies of older participants: comparison of quarterly telephone recall with monthly falls calendars in the MOBILIZE Boston Study. American journal of epidemiology 2010;171:1031-6.

35. Ganz DA, Higashi T, Rubenstein LZ. Monitoring falls in cohort studies of community-dwelling older people: effect of the recall interval. Journal of the American Geriatrics Society 2005;53:2190-4.

CHAPTER 3: KYPHOSIS AND 3-YEAR FALL RISK IN COMMUNITY-DWELLING OLDER MEN

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ABSTRACT

PURPOSE: To determine whether two methods of measuring kyphosis are able to prospectively predict fall risk among community-dwelling older men over three years of follow-up. METHODS: Within the Osteoporotic Fractures in Men Study (MrOS), we conducted two three-year prospective studies of 2,346 and 2,928 men. The first group of men had kyphosis measured by Cobb angle at visit 1, while the second group of men had kyphosis assessed with the blocks method at visit 3; both groups self-reported falls tri-annually for three years after kyphotic assessment. Poisson regression with GEE was used to obtain relative risks (RR) of falls. RESULTS: The fall rate over three years among the visit 1 sample (mean age 74±6 years) was 651/1,000 person-years. There was no association between Cobb angle at visit 1 and subsequent falls over three years in adjusted models (RR=1.04, 95% CI=0.95, 1.14).The fall rate among the visit 3 sample (mean age 79±5 years) was 839/1,000 person years. In adjusted models, the risk of falls was increased by 11% for each standard deviation increase (1.4 blocks) in the number of blocks required to achieve a neutral head and neck position (RR=1.11, 95% CI= 1.06, 1.17). CONCLUSION: Although Cobb angle did not predict falls in community-dwelling older men over three years, the blocks method of measuring kyphosis was predictive of falls in this population. This difference could be due to the Cobb angle's focus on thoracic kyphosis only, whereas the blocks method may capture abnormal thoracic *and* cervical spine curvature.

INTRODUCTION

As the United States population continues to age, more attention has been brought to the causes of morbidity and mortality unique to older adults. Falls, for example, increase with age and result in the most common fatal and non-fatal injuries among older adults.[1,2] In a recent national survey, 26.5% of men aged 65 and older reported experiencing a fall in the preceding 12 months and more than 8% had experienced a fall injury.[1] Because falls pose a serious risk to the health of older adults, it is vital to understand, and potentially mitigate, the conditions and characteristics that increase fall risk.

While many fall risk factors are well understood, some potential risk markers are emerging. Commonly accepted risk factors for falls in community-dwelling adults include increasing age, female sex, psychotropic drug use, comorbidities, cognitive impairment, history of falls, lower extremity weakness, balance deficit, gait problems, vertigo, mobility limitations, and fear of falling.[2,3] Some studies have suggested a link between hyperkyphosis and increased fall risk.[4-8]

Hyperkyphosis is a common condition among older adults, classically presenting as forward curvature in the upper spine.[9] It has been associated with negative outcomes in older men including impaired lower extremity physical function,[10] reduced physical function,[11] impaired balance or gait,[6,7,12,13] and mortality.[14] Although estimates of prevalence vary by measurement method and cut point;[11,14,15] hyperkyphosis may affect as many as 44% of community-dwelling older men.[16] Results from mixed-gender cross sectional studies

examining the association between hyperkyphosis and falls have been mixed,[4,17] though two small prospective studies recently demonstrated increased fall risk with increasing kyphosis.[5,18]

To further investigate the relationship between hyperkyphosis and fall risk, we examined the association prospectively in two large study samples of older adult men, each with different kyphosis measures, within the Osteoporotic Fractures in Men study (MrOS). We hypothesized that greater kyphosis would result in a higher risk of falls over three years among community-dwelling older men.

METHODS

Subjects

Between 2000 and 2002, the Osteoporotic Fractures in Men Study (MrOS) enrolled 5,994 participants at clinical sites across the United States in Birmingham, AL; Minneapolis, MN; Palo Alto, CA; Pittsburgh, PA; Portland, OR; and San Diego, CA. Enrollees were community-dwelling, ambulatory men aged 65 and older. This observational longitudinal cohort study was designed to study the risk factors for and sequelae of fractures in older men.[19] Surviving participants were recalled periodically for additional follow-up clinic visits. Two separate cohorts (from clinic visit 1 and clinic visit 3) are the focus of the current study.

The Visit 1 sample is comprised of a sample of those who attended the first MrOS visit between 2000 and 2002. Of the 5,994 Visit 1 participants, Cobb

angle measurements of kyphosis were available for 2,351. These 2,351 men were randomly selected for Cobb measurements for a previous study[20] from a group of 5,229 who had attended both Visit 1 and Visit 2 and had lateral spine radiographs taken at both visits. For the purposes of this study, five participants of those 2,351 with Cobb angle measures were excluded due to lack of follow-up data leaving 2,346 in the Visit 1 sample.

Between 2006 and 2009, 4,681 participants returned for Visit 3. Kyphosis was assessed using the blocks method in a portion of visit participants due to delays in funding, implementation, and validation of the measure across all six study sites. Only those attending Visit 3 in the later phase of Visit 3 had the blocks measure (n=2,931).[10] Of these, three participants were excluded from the present analysis due to lack of follow-up data, leaving 2,928 in the Visit 3 sample.

The Institutional Review Boards at each of the six study centers approved the MrOS protocol; written informed consent was obtained from all participants.

Kyphosis measures

In the Visit 1 sample, Cobb angle of kyphosis was calculated from baseline digital lateral-lying thoracic spine radiographs, as previously described by Katzman and colleagues.[21] Trained study personnel calculated the Cobb angle by placing digitized points marking the top plate of the T4 vertebrae and the bottom plate of T12 vertebrae. Optasia software was then used to connect the points and determine the angle of intersection. When T4 and/or T12 were

unable to be visualized, T5 and T11 were used. The greater the Cobb angle, the greater the degree of kyphosis in that individual.

Kyphosis at Visit 3 was assessed with the blocks method pioneered by the Rancho Bernardo Study,[14] as previously described by Katzman and colleagues.[10] Due to hyperextension of the neck, hyperkyphotic individuals are unable to lie flat comfortably. While lying supine, 1.7 cm blocks were placed under the participant's occiput, as needed, until a neutral head and neck position was achieved. The number of blocks required to achieve the neutral position was recorded as the blocks measure, and corresponds to the severity of kyphosis.

Ascertainment of falls

After each study visit, participants were mailed one-page questionnaires every four months (tri-annually) to assess incident falls. Participants who reported falling in the preceding four months were asked to indicate the number of times (1, 2, 3, 4, or 5+). Those not responding to the questionnaires received follow-up telephone calls. Falls data from nine questionnaires (covering three years) after the in-person visit for each participant was included in the present study.

Clinic-based measures

Clinical measures were taken at both clinic visits. Height and weight were measured using a Harpenden Stadiometer (Holtain Ltd., Crymych, Dyfed, UK) and balance beam or digital scale, respectively. Body mass index (BMI) was calculated as the participant's weight in kilograms divided by height in meters

squared. Total hip bone mineral density (BMD) was measured by dual-energy X-ray absorptiometry (DXA) using Hologic QDR 4500 densitometers at all study sites. Lower extremity strength was assessed through two performance tests: the time required to stand five times from a chair, and six meter usual pace walking speed. The Teng Modified Mini-Mental State Exam (3MS) was administered to assess cognitive function; higher scores (0-100) indicate better cognitive function.

Study surveys

In addition, participants were surveyed at both visits about their age; race (white or non-white); smoking status (ever or never); alcohol intake (calculated drinks per week); use of medications with sedative effects including benzodiazepines, opioid analgesics, and SSRI or tricyclic antidepressants; history of osteoporosis (yes or no); comorbidities (yes or no) including diabetes, Parkinson disease, or history of stroke; falls in the previous year (yes or no); trouble with dizziness (yes or no); and self-assessed quality of health (good/excellent or fair/poor/very poor).

Statistical analysis

The same statistical methods were employed for both study samples. Descriptive statistics (mean, standard deviation [SD] or frequency, percent) were computed for each study sample. Univariable and multivariable Poisson regression models with generalized estimating equations (GEE) were used to model the number of falls per four month interval over three years in these

longitudinal samples. Each study subject contributed up to nine time points as the outcome. Poisson regression was chosen to model the counts of fall events and GEE was chosen to account for repeated participant fall counts (up to nine per individual).

In univariable analyses, relative risks (RR) and 95% confidence intervals (CI) adjusted for clinical site were reported for each covariate per SD for continuous covariates. In adjusted models the main predictor was Cobb angle of kyphosis for the Visit 1 sample and blocks measure of kyphosis for the Visit 3 sample. All multivariable models were minimally adjusted for age, weight, and BMD based on hypotheses about the causal pathways between hyperkyphosis and future falls. Variables that were thought to potentially confound the association between kyphosis and falls were added to the minimally adjusted model one-by-one and remained in the model if the main effect RR changed by ≥|10%|. Adjusted RRs, 95% CIs, and p-values (Wald test) were reported for each variable in the multivariable models (per SD for continuous variables). We conducted sensitivity analyses with the final models by running them as overdispersed Poisson models with the total number of falls over three years as the dependent variable; the same results were achieved. SAS software version 9.4 (SAS Institute, Cary, NC) was used for all analyses.

RESULTS

Visit 1 sample

Characteristics of the 2,346 men in the Visit 1 sample are found in Table 3.1. Mean age of the Visit 1 sample was 73.6 ± 5.9 years and mean Cobb angle was 38.6 ± 11.4°. Mean BMI was 27.4 ± 3.8 kg/m^2 and mean BMD was 0.955 ± 0.139 g/cm^2. More than half (64%) of the sample reported that they were past or current smokers and participants imbibed a mean of 4.7 ± 7.4 alcoholic drinks per week. Most (91%) reported not using medications with sedative effects, 4% reported having been told they had osteoporosis, and 17% reported one of the three comorbidities assessed. Twenty percent of the men reported a fall in the previous year and 27% reported trouble with dizziness. In terms of physical function, the mean chair stand time was 11.2 ± 3.4 sec and the average walking speed at usual pace was 1.20 ± 0.23 m/sec. Cognitive function was high with a mean 3MS score of 93.1 ± 6.4. Lastly, most (86%) assessed their health as *good* or *excellent*.

Participants in the Visit 1 sample returned an average of 8.75 questionnaires (of nine) sent every four months to assess falls; 91% had complete follow-up with all nine questionnaires returned. Among the 2,346 men in the study, 1,184 (50%) had one or more falls over three years, 741 (32%) had two or more falls, 489 (21%) had three or more falls, and 31 (<2%) had 20+ falls. Figure 3.1 shows the cumulative number of falls over three years after Visit 1. In total, subjects experienced 4,462 falls over 6,854.67 person-years of follow-up in

the three years after Visit 1, giving a fall rate of 651 falls per 1,000 person-years in the Visit 1 sample.

Table 3.1: Visit 1 Sample Characteristics and Univariable Risks of Falls Over 3 Years Using Poisson Regression (n=2,346)

	Distribution	Univariable Risks of Falls Over 3 Years Using Poisson Regression[a]		
Variable	**Mean ± SD or N (%)**	**RR per SD**	**95% CI**	**p-value**
Age, *years*	73.6 ± 5.9	**1.28**	**1.18, 1.38**	**<.001**
Race/ethnicity				
non-white	246 (10)		REF	
white	2100 (90)	1.02	0.74, 1.40	.900
Height, *cm*	174.2 ± 6.8	**0.92**	**0.84, 0.99**	**.046**
Weight, *kg*	83.4 ± 13.3	1.04	0.96, 1.13	.297
Body mass index, kg/m^2	27.4 ± 3.8	**1.10**	**1.02, 1.20**	**.019**
Cobb angle, *degrees*	38.6 ± 11.4	1.07	0.98, 1.17	.139
Total hip BMD, g/cm^2	0.955 ± 0.139	0.93	0.85, 1.00	.070
Smoking status				
never	850 (36)		REF	
past or current	1496 (64)	0.90	0.76, 1.07	.228
Drinks per week	4.7 ± 7.4	0.95	0.87, 1.03	.206
Medication[b] use				
no	2137 (91)		REF	
yes	209 (9)	**2.29**	**1.84, 2.86**	**<.001**
Ever had osteoporosis				
no	2254 (96)		REF	
yes	92 (4)	**1.44**	**1.01, 2.04**	**.043**
Comorbidities[c]				
no	1942 (83)		REF	
yes	404 (17)	**1.71**	**1.40, 2.09**	**<.001**
Fallen in the past year				
no	1871 (80)		REF	
yes	475 (20)	**3.46**	**2.94, 4.06**	**<.001**
Trouble with dizziness				
no	1715 (73)		REF	
yes	631 (27)	**1.75**	**1.47, 2.08**	**<.001**
Chair stand time, *sec*	11.2 ± 3.4	**1.23**	**1.14, 1.32**	**<.001**
Walking speed, *m/sec*	1.20 ± 0.23	**0.74**	**0.67, 0.81**	**<.001**
Teng 3MS Exam score[d]	93.1 ± 6.4	**0.85**	**0.79, 0.91**	**<.001**
Self-rated quality of health				
good or excellent	2001 (85)		REF	
fair or poor or very poor	344 (15)	**1.94**	**1.57, 2.39**	**<.001**

[a] All models adjusted for site; [b] Medications include benzodiazepines, opioid analgesics, and SSRI or tricyclic antidepressants; [c] Comorbidities include Parkinson disease, diabetes, or history of stroke; [d] Teng Modified Mini-Mental Status Exam

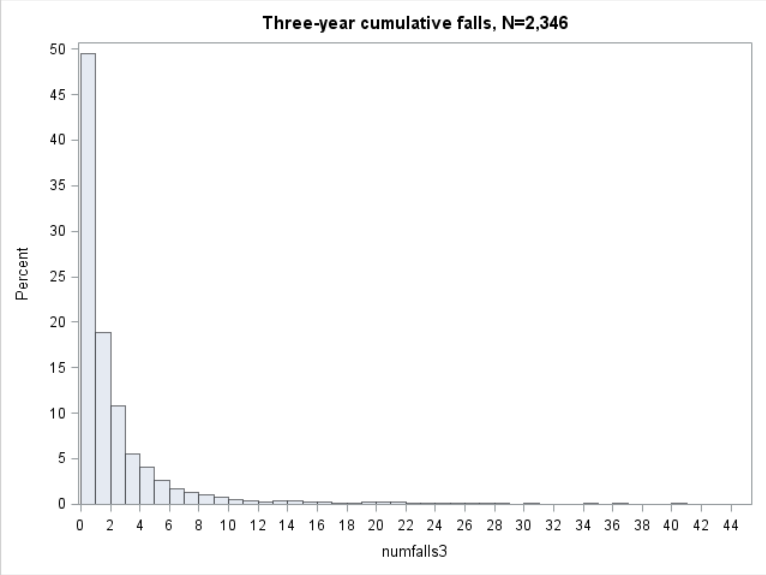


Figure 3.1: Cumulative Falls Over Three Years Post-Visit 1

Univariable risk of falls over three years were calculated for each Visit 1 characteristic using Poisson regression models with GEE to compute RRs and 95% CIs (adjusted for clinic site; Table 3.1). Increasing age, shorter height, higher BMI, use of medications with sedative effects, history of osteoporosis, history of assessed comorbidities, having fallen in the previous year, experiencing trouble with dizziness, greater chair stand time, slower walking speed, lower 3MS score, and poorer self-assessed quality of health were all associated with an increase in the risk of falls over three years in univariable models. Race, weight, Cobb angle of kyphosis, total hip BMD, smoking status, and alcohol consumption did not significantly increase the univariable risk of falls among the Visit 1 sample.

In multivariable Poisson models, Cobb angle was not significantly associated with falls over three years after adjustment for site, age, weight, and

total hip BMD (Table 3.2). The RR for each SD increase in Cobb angle was 1.04 (95% CI = 0.95, 1.14). Increasing age (RR=1.30, 95% CI=1.19, 1.42) and greater weight (RR=1.15, 95% CI=1.05, 1.27) were both significantly associated with increased risk of falls over three years in the adjusted model. None of the assessed covariates were considered to be statistical confounders by our *a priori* definition.

Table 3.2: Multivariable Risk of Falls Over 3 Years Using Poisson Regression with GEE[a] in the Visit 1 Sample (n=2,346)

Variable	RR per SD	95% CI	p-value
Cobb angle of kyphosis, *degrees*	1.04	0.95, 1.14	.432
Age, *years*	**1.30**	**1.19, 1.42**	**<.001**
Weight, *kg*	**1.15**	**1.05, 1.27**	**.003**
Total hip BMD, g/cm^2	0.93	0.85, 1.02	.108

[a] Model adjusted for site

The final Visit 1 multivariable model was adapted to an overdispersed Poisson model in order to predict risk of falls for an average member of the sample. The natural log of the number of years at risk for each participant was used as an offset. This resulted in a fall rate of 0.62 falls per man-year, given mean Cobb angle; age; weight; and BMD (and controlling for study site). This rate is slightly lower than the calculated crude rate of 0.65 falls per man-year.

Visit 3 sample

Characteristics of the 2,928 men in the Visit 3 sample are found in Table 3.3. Among those with the blocks measure at Visit 3, mean age was 79.2 ± 5.2 years, most (89%) were white, and participants required a mean of 2.6 ± 1.4 blocks to achieve a neutral head position while supine. Mean height was 173.2 ±

6.9 cm, weight was 81.4 ± 13.5 kg, and BMI was 27.1 ± 3.9 kg/cm^2. DXA-assessed mean BMD was 0.939 ± 0.148. More than half of the sample (60%) identified as past or current smokers, participants drank an average of 4.1 ± 6.2 alcoholic beverages per week, and 15% used medications with sedative effects. Eight percent reported having been diagnosed with osteoporosis and 23% reported comorbidities including Parkinson disease, history of stroke, or diabetes. Nearly a third (30%) recalled falling at least once in the previous year and 28% reported problems with dizziness. It took participants an average of 11.8 ± 3.8 sec to rise from a seated position five times and they had a mean usual-pace walking speed of 1.23 ± 0.24 m/sec. Participants' cognitive function was good with a mean score of 92.0 ± 7.1 on the 3MS and most (86%) self-assessed their health as *good* or *excellent*.

Participants in the Visit 3 sample returned an average of 8.6 ± 1.4 tri-annual falls questionnaires of the nine sent in the three years after Visit 3, and 89% returned all nine questionnaires. Among the 2,928 men in the analysis, 1,598 (55%) had at least one fall over the three years, 1,070 (37%) had two or more falls, 764 (26%) had three or more falls, and 49 participants (<2%) had 20+ falls. Figure 3.2 shows the cumulative falls over the three years after Visit 3. Participants experienced 7,039 falls over 8,385 person-years of follow-up, yielding a fall rate of 839/1,000 person-years over three years.

Table 3.3: Visit 3 Sample Characteristics and Univariable Risks of Falls Over 3 Years Using Poisson Regression (n=2,928)

	Distribution	Univariable Risks of Falls Over 3 Years Using Poisson Regression[a]		
Variable	**Mean ± SD or N (%)**	**RR per SD**	**95% CI**	**p-value**
Age, *years*	79.2 ± 5.2	**1.26**	**1.20, 1.32**	**<.001**
Race/ethnicity				
non-white	330 (11)		REF	
white	2598 (89)	**1.40**	**1.17, 1.67**	**<.001**
Height, *cm*	173.2 ± 6.9	0.97	0.92, 1.02	.247
Weight, *kg*	81.4 ± 13.5	0.99	0.94, 1.05	.800
Body mass index, kg/m^2	27.1 ± 3.9	1.01	0.96, 1.06	.753
Blocks measure of kyphosis	2.6 ± 1.4	**1.17**	**1.11, 1.23**	**<.001**
Total hip BMD, g/cm^2	0.939 ± 0.148	**0.92**	**0.87, 0.97**	**.003**
Smoking status				
never	1164 (40)		REF	
past or current	1762 (60)	0.97	0.88, 1.07	.565
Drinks per week	4.1 ± 6.2	0.98	0.93, 1.03	.391
Medication[b] use				
no	2491 (85)		REF	
yes	437 (15)	**1.77**	**1.58, 1.99**	**<.001**
Ever had osteoporosis				
no	2704 (92)		REF	
yes	224 (8)	**1.41**	**1.19, 1.65**	**<.001**
Comorbidities[c]				
no	2269 (77)		REF	
yes	659 (23)	**1.32**	**1.18, 1.47**	**<.001**
Fallen in the past year				
no	2041 (70)		REF	
yes	887 (30)	**3.19**	**2.92, 3.49**	**<.001**
Trouble with dizziness				
no	2102 (72)		REF	
yes	826 (28)	**1.71**	**1.55, 1.89**	**<.001**
Chair stand time, *sec*	11.8 ± 3.8	**1.21**	**1.17, 1.26**	**<.001**
Walking speed, *m/sec*	1.23 ± 0.24	**0.74**	**0.70, 0.78**	**<.001**
Teng 3MS Exam score[d]	92.0 ± 7.1	**0.90**	**0.86, 0.94**	**<.001**
Self-rated quality of health				
good or excellent	2514 (86)		REF	
fair or poor or very poor	411 (14)	**1.53**	**1.35, 1.73**	**<.001**

[a] All models adjusted for site; [b] Medications include benzodiazepines, opioid analgesics, and SSRI or tricyclic antidepressants; [c] Comorbidities include Parkinson disease, diabetes, or history of stroke; [d] Teng Modified Mini-Mental Status Exam

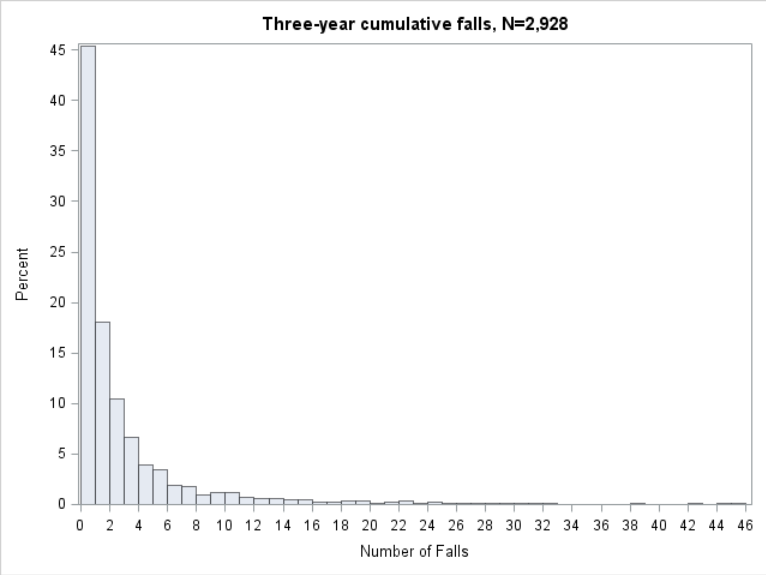


Figure 3.2: Cumulative Falls Over Three Years Post-Visit 3

In univariable analyses (Table 3.3), we found increasing age, identifying as racially white, increasing blocks measure of kyphosis, lower total hip BMD, medication use with sedative effects, ever having osteoporosis, having one of three identified comorbidities, recalling a fall in the preceding year, reporting trouble with dizziness, higher chair stand time, slower usual-speed walking pace, lower 3MS exam score, and lower rated quality of health to be associated with fall risk over three years in Poisson regression models with GEE (adjusted for clinic site only). All RRs were in the expected direction. Height, weight, BMI, smoking status, and alcohol consumption were not significantly associated with increased risk for falls in these analyses.

In the multivariable model, kyphosis as measured by the blocks method was associated with falls over three years. For each standard deviation increase in the blocks measure of kyphosis assessed at Visit 3, the adjusted risk of falls

over increased by 11% (RR=1.11, 95% CI=1.06, 1.17) after adjustment for clinic site, age, weight, and total hip BMD (Table 3.4). Increasing age (RR=1.324, 95% CI=1.18, 1.30) and greater weight (RR=1.06, 95% CI=1.01, 1.12) were also both significantly associated with increased risk of falls over three years in the adjusted model. None of the assessed covariates were considered to be statistical confounders by our *a priori* criteria.

Table 3.4: Multivariable Risk of Falls Over 3 Years Using Poisson Regression with GEE[a] in the Visit 3 Sample (n=2,928)

Variable	RR per SD	95% CI	p-value
Blocks measure of kyphosis	**1.11**	**1.06, 1.17**	**<.001**
Age, *years*	**1.24**	**1.18, 1.30**	**<.001**
Weight, *kg*	**1.06**	**1.01, 1.12**	**.032**
Total hip BMD, g/cm^2	0.945	0.90, 1.00	.065

[a] Model adjusted for site

The final Visit 3 multivariable model was adapted to an overdispersed Poisson model in order to predict risk of falls for an average member of the sample. The offset was equal to the ln(number of years at risk). This resulted in a fall rate of 0.80 falls per man-year, given mean blocks; age; weight; and BMD (and controlling for study site). This rate is slightly lower than the calculated crude rate of 0.84 falls per man-year.

DISCUSSSION

In this study, kyphosis measured by the blocks method was predictive of falls over three years in older adult men. For every 1.4 block (SD) increase, there was an 11% increase in the risk of falls over three years in adjusted models. However, kyphosis measured by the Cobb angle was not associated with risk of

falls over three years in this population. These seemingly disparate results could indicate that in men, the increase in fall risk is associated with upper spine curvature, including the thoracic and cervical spine, captured by blocks method but not with the Cobb angle measure, which isolates thoracic curvature (from T4 to T12) only. Indeed, Tran and colleagues found that among three measures of kyphosis, the blocks method had the lowest correlation with Cobb angle (r_s=0.63).[22]

Past research has produced mixed results about the relationship between kyphosis and falls. In a small study of 51 men and women, Cobb angle was predictive of incident falls over 6-12 months. [5] This study, however, was limited by varied follow-up time and the underrepresentation of men (n=12/51). Similar to our results, a study of 92 men and women found that thoracic kyphosis measured with the SpinalMouse®, a computerized handheld device rolled along a subject's spine to analyze curvature, was not associated with recall of falls from the previous year.[17]

In terms of the blocks measure and falls, one large retrospective study of community-dwelling older men and women found the blocks measure was associated with falls in the previous year among community-dwelling older men.[4] In a recent study examining four measures of kyphosis at baseline and following participants monthly to assess falls, we found that both the blocks measure and the Cobb angle were predictive of a 2-3 fold increase in the odds of an incident fall over the following year (with monthly falls ascertainment), although this study was also limited by a small proportion of men (n=20/72).[18]

The men in the Visit 3 sample were nearly six years older than the men in the Visit 1 sample, so differences could be expected in the two cohorts due to aging. Participants in the Visit 3 sample were, on average, 1 cm shorter, 2 kg lighter, drank slightly less, and may have been somewhat healthier (lower assessed medication use, lower osteoporosis diagnoses, and fewer assessed comorbidities). They also had slightly higher chair stand times, slightly slower walking speeds, and reported more falls in the preceding year. The cohorts differed, too, in univariable analyses. Race, height, and BMI were not significantly associated with fall risk in the Visit 1 sample, but were in the Visit 3 sample. These differences could be due to selection bias in the Visit 3 convenience sample, or they could be due to age.

Strengths of this study include: the large sample sizes, prospective ascertainment of falls, and analytic strategy to incorporate these repeated falls measures. Participant response to the tri-annual questionnaires was excellent; post-Visit 1 there was an average of 2.9 ± 0.5 years of follow-up and post-Visit 3 there was an average of 2.9 ± 0.3 years of follow-up (of 3 possible). Our fall rates were similar to those in the published literature; fall rates post-Visit 3 (0.84/person-year) were similar to those reported among men in the MOBILIZE Boston study (0.92/person-year) with similar mean ages (post-Visit 3 mean age = 79 ± 5; MOBILIZE mean age = 78 ± 5).[23] Our rates were higher than those found in men through the 2014 Behavioral Risk Factor Surveillance System (0.66/person-year), though these were calculated based on 12-month recall.[1]

This study has some limitations. Although the Visit 1 sample was randomly selected, they were only selected from the 87% of original study participants who had both Visit 1 and Visit 2 lateral radiographs, and so may not be representative of the entire Visit 1 sample. The Visit 3 sample must be considered a convenience sample, due to the late initiation of the blocks measure during the window of time the visits were taking place. In addition, because the measures were taken in different participants at different time points (when the participants were different ages), we cannot directly compare them. Lastly, fall rates may be underestimates due to recall bias as the four-month recall for falls ascertainment may have missed lesser falls that would have been captured through monthly follow-up.

In the largest and longest prospective study of kyphosis and incident falls in community-dwelling older men to date, we found that the blocks method but not the Cobb angle was predictive of falls over three years. These results add to the growing body of literature about the simple, yet predictive, blocks measure of kyphosis. The differences in the two measures' ability to predict falls is notable. As there is no standard measurement for kyphosis, future research should assess forward leaning posture through multiple measures simultaneously and assess incident falls as frequently as possible.

Acknowledgments: Chapter 3, in full, will be prepared for submission to a TBD journal for publication of material. Co-Authors include Jeanne F Nichols, Florin

Vaida, Caroline Macera, Suzanne P Lindsay, and Deborah M Kado. The dissertation author is the primary author of this material.

REFERENCES

1. Bergen G SM, Burns ER. Falls and fall injuries among adults aged ≥65 Years — United States, 2014. PreventionMorbidity and Mortality Weekly Report 2016;65:1-6.

2. Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. Age and ageing 2006;35 Suppl 2:ii37-ii41.

3. Deandrea S, Lucenteforte E, Bravi F, Foschi R, La Vecchia C, Negri E. Review Article: Risk Factors for Falls in Community-dwelling Older People: "A Systematic Review and Meta-analysis". Epidemiology 2010;21:658-68.

4. 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. The journals of gerontology Series A, Biological sciences and medical sciences 2007;62:652-7.

5. van der Jagt-Willems HC, de Groot MH, van Campen JP, Lamoth CJ, Lems WF. Associations between vertebral fractures, increased thoracic kyphosis, a flexed posture and falls in older adults: a prospective cohort study. BMC geriatrics 2015;15:34.

6. de Groot MH, van der Jagt-Willems HC, van Campen JP, Lems WF, Beijnen JH, Lamoth CJ. A flexed posture in elderly patients is associated with impairments in postural control during walking. Gait & posture 2014;39:767-72.

7. Eum R, Leveille SG, Kiely DK, Kiel DP, Samelson EJ, Bean JF. Is kyphosis related to mobility, balance, and disability? American journal of physical medicine & rehabilitation / Association of Academic Physiatrists 2013;92:980-9.

8. Sinaki M, Brey RH, Hughes CA, Larson DR, Kaufman KR. Balance disorder and increased risk of falls in osteoporosis and kyphosis: significance of kyphotic posture and muscle strength. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2005;16:1004-10.

9. Kado DM, Prenovost K, Crandall C. Narrative review: hyperkyphosis in older persons. Annals of internal medicine 2007;147:330-8.

10. Katzman WB, Harrison SL, Fink HA, et al. Physical function in older men with hyperkyphosis. The journals of gerontology Series A, Biological sciences and medical sciences 2015;70:635-40.

11. Ryan SD, Fried LP. The impact of kyphosis on daily functioning. Journal of the American Geriatrics Society 1997;45:1479-86.

12. Antonelli-Incalzi R, Pedone C, Cesari M, Di Iorio A, Bandinelli S, Ferrucci L. Relationship between the occiput-wall distance and physical performance in the elderly: a cross sectional study. Aging clinical and experimental research 2007;19:207-12.

13. Balzini L, Vannucchi L, Benvenuti F, et al. Clinical characteristics of flexed posture in elderly women. Journal of the American Geriatrics Society 2003;51:1419-26.

14. 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. Journal of the American Geriatrics Society 2004;52:1662-7.

15. Katzman W, Cawthon P, Hicks GE, et al. Association of spinal muscle composition and prevalence of hyperkyphosis in healthy community-dwelling older men and women. The journals of gerontology Series A, Biological sciences and medical sciences 2012;67:191-5.

16. 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. The journals of gerontology Series A, Biological sciences and medical sciences 2005;60:633-7.

17. Kasukawa Y, Miyakoshi N, Hongo M, et al. Relationships between falls, spinal curvature, spinal mobility and back extensor strength in elderly people. Journal of bone and mineral metabolism 2010;28:82-7.

18. McDaniels-Davidson C, Davis A, Wing D, Nichols JF, Kado DM. Kyphosis and Incident Falls among Community-dwelling Older Adults. In: American Geriatrics Society Annual Meeting. Long Beach, CA; 2016.

19. 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. Contemporary clinical trials 2005;26:569-85.

20. Katzman WB, Parimi N, Mansoori Z, et al. Cross-sectional and Longitudinal Associations of Diffuse Idiopathic Skeletal Hyperostosis (DISH) and Thoracic Kyphosis in Older Men and Women. Arthritis care & research 2016.

21. Katzman WB, Miller-Martinez D, Marshall LM, Lane NE, Kado DM. Kyphosis and paraspinal muscle composition in older men: a cross-sectional study for the Osteoporotic Fractures in Men (MrOS) research group. BMC musculoskeletal disorders 2014;15:19.

22. Tran TH, Wing D, Davis A, et al. Correlations among four measures of kyphosis in older adults. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2015.

23. Duckham RL, Procter-Gray E, Hannan MT, Leveille SG, Lipsitz LA, Li W. Sex differences in circumstances and consequences of outdoor and indoor falls in older adults in the MOBILIZE Boston cohort study. BMC geriatrics 2013;13:133.

CHAPTER 4: KYPHOSIS AND 3-YEAR FALL RISK IN COMMUNITY-DWELLING OLDER WOMEN

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ABSTRACT

PURPOSE: To determine whether degree of hyperkyphosis, as measured by the Cobb angle and by kyphotic index (KI), independently predict risk of falls over three years in community-dwelling older women. METHODS: Two separate prospective analyses were conducted within the Study of Osteoporotic Fractures, a multi-site observational study of risk factors for osteoporotic fractures in women. The first utilized Cobb angle measures from a subset of Visit 1 participants (n=1,162); the second utilized KI data derived from standing flexicurve measures on a subset of Visit 2 participants (n=610). Both groups were followed tri-annually for three years to assess falls. Poisson regression with GEE was used to calculate relative risk (RR) of falls per standard deviation (SD) increase in kyphosis measure. RESULTS: The fall rate over three years in the Visit 1 sample (mean age 69.3 ± 3.9 years) was 400/1,000 woman-years and 450/1,000 woman-years in the Visit 2 sample (mean age 72.8 ± 4.7). Cobb angle of kyphosis was not significantly associated with falls in the Visit 1 sample in adjusted models (RR=1.06, 95% CI=0.95, 1.17). Kyphosis measured by the KI was associated with a 23% increased risk of falls per SD increase in the measure in adjusted models (RR=1.22, 95% CI=1.07, 1.40). CONCLUSION: Higher KI, a standing measure of postural kyphosis, increased the risk of future falls. When added to the body of literature about the sequelae of hyperkyphosis, it underscores the need for both awareness of the condition among healthcare providers who care for older persons and research into its prevention and treatment.

INTRODUCTION

Falls in older women are of grave concern to the health care community and to the women themselves. In a recent national survey, more than 30% of community-dwelling women aged ≥65 reported a fall in the preceding year.[1] Falls can precipitate a rapid loss of independence in otherwise healthy individuals through functional decline and nursing home placement.[2,3] Indeed, the fear of falling itself has been cited as causing activity restriction in up to 60% of community-dwelling older adults[4] and 80% of older women surveyed in one study reportedly preferred death to a "bad hip fracture and subsequent admission to a nursing home."[5] In addition to the physical and emotional tolls of falls, the monetary costs of falls in the United States have been projected reach the tens of billions of dollars by 2020.[6]

The causes of falls are complex and multi-factorial, though commonly cited risk factors include advancing age, female sex, history of falls, psychotropic drug use, comorbidities, cognitive impairment, history of falls, lower extremity weakness, balance problems, gait deficits, dizziness, impaired mobility, and fear of falling.[7,8] It has also been proposed that postural hyperkyphosis may increase risk of future falls.[9-13]

Hyperkyphosis, or forward curvature of the thoracic spine, is thought to be common among older adults.[14-16] It has been associated with several poor health outcomes including impaired pulmonary function,[17] diminished physical function,[11,18] increased fracture risk,[19] and mortality.[20,21] Estimates in older

women vary by study, measurement method, and definition. In one large study of 70-79 year olds, 30% of white women were hyperkyphotic (Cobb angle >40°).[15]

The present study seeks to determine whether two measures of hyperkyphosis are able to prospectively predict falls in community-dwelling older women. We hypothesize that greater kyphosis as measured by the Cobb angle and the kyphotic index will be associated with an increase in the risk of falls over three years in women from the Study of Osteoporotic Fractures (SOF).

METHODS

Subjects

Between 1986 and 1988, the Study of Osteoporotic Fractures (SOF) enrolled 9,704 white women from study sites in Baltimore, MD; Minneapolis, MN; Monongahela Valley, PA; and Portland, OR. This multi-center, prospective, observational study of women age 65 and older was designed to identify risk factors for osteoporotic fractures in this population. Those with bilateral hip replacements or who could not walk without assistance were excluded from enrollment.[22] Surviving participants were then recalled periodically for additional follow-up clinic visits. Two separate cohorts (the Visit 1 sample and the Visit 2 sample) form the focus of the current study.

The Visit 1 sample is comprised of a sample of those who completed the baseline clinic visit between October 1986 and October 1988 (n=9,704) and were then followed at four month intervals for three years. The sample includes participants that had Cobb angle of kyphosis derived from lateral radiographs

obtained at Visit 1 for a previous study.[23] In that study, Kado and colleagues randomly sampled 1,000 participants who had lateral thoracic spine radiographs taken at Visit 1 and again 15 years later. They randomly sampled an additional 200 Visit 1 participants that had radiographs from the baseline visit but not 15 years later to account for survival bias, though four of those were removed due to unreadable Cobb angle. The Visit 1 sample includes 1,162 participants who had been previously randomly sampled to have kyphosis measured (33 of the original 1,000 randomly sampled had radiographs that did not permit Cobb angle derivation and one lacked the falls outcome and so were excluded).

The Visit 2 sample is comprised of a sample of those who participated in the second clinic visit between January 1989 and December 1990 (8,098 surviving study participants) and were similarly followed at four month intervals for three years. The first consecutive 150-200 participants from each clinic site (n=610) were selected to have kyphosis measured with a flexicurve ruler to calculate the kyphotic index.[21] These 610 participants are included in a separate analysis and are referred to as the Visit 2 sample.

The Institutional Review Boards at each of the four study centers approved the SOF protocol; written informed consent was obtained from all participants.

Kyphosis measures

In the Visit 1 sample, Cobb angle of kyphosis was calculated from recumbent lateral thoracic spine radiographs obtained during the baseline clinic

visit, as previously described by Kado and colleagues.[23] Markers indicating the superior endplate of the T4 vertebral body and the inferior endplate of T12 were marked on the images using a translucent digitizer (GTCO, Rockville, MD) and cursor. The coordinates for each point were marked on a 0.1mm resolution grid. The computerized digitization program then constructed lines perpendicular to the endplates; their intersection was the Cobb angle of kyphosis. When T4 and T12 were unable to be visualized, T5 and T11 were used. The greater the Cobb angle, the greater the degree of kyphosis in that individual.

In the Visit 2 sample, the kyphotic index was calculated from measurements done on a subset of participants, as previously described by Kado and colleagues.[21] An architect's flexible ruler (flexicurve) was placed against the participant's spine while standing with the upper end immediately below the C7 spinous process and the lower end at the S2 spinous process. The outline of the molded ruler was traced using a digital scanner; this outline was used to define a vertical line representing the length of the upper back curve (l). The horizontal distance between that line and the maximum curvature of the ruler was then assessed (w). The kyphotic index was calculated as 100 times the length of the upper back curve divided by the maximum curvature width (100 x l/w). The greater the kyphotic index, the greater the degree of kyphosis in that individual.

Ascertainment of falls

Participants were asked to respond to short mailed questionnaires every four months during the study to assess incident falls. Falls were defined as "landing on the floor or ground, or falling and hitting an object like a table or chair."[22] Participants who reported falling in the preceding four months were asked to indicate the number of times they fell. Those not responding to the questionnaires received follow-up telephone calls.[22] Falls data representing three years (nine tri-annual questionnaires) after the baseline visit were included in the Visit 1 cohort analysis and falls data representing three years after the second visit were included in the Visit 2 sample analysis.

Clinic-based measures

Clinical measures were assessed at both Visit 1 and Visit 2. Visit 1 clinic measures included height and weight using a Harpenden stadiometer (Holtain, DyFed, UK) and balance beam; Body Mass Index (BMI) was calculated from height and weight. Prevalent vertebral fracture assessment was accomplished through lateral radiographs and calcaneal bone mineral density (BMD) was measured by single photon absorptiometry (OsteoAnalyzer; Dove Medical Systems). Cognitive function was assessed using the Short Mini Mental Status Exam, where higher scores (0-26) indicate better cognitive function. Physical performance and lower extremity strength were assessed with the chair stand (the time required to rise and stand five times from a chair) and speed of a 6-meter usual pace walk.

Visit 2 clinic measures included height, weight, and BMI. Total hip BMD was assessed by central DXA using QDR 1000 densitometers (Hologic, Bedford, MA, USA). Cognitive function was assessed using the Trail Making Test B, where participants are timed while asked to draw lines connecting sequentially numbered circles; higher times indicate poorer cognitive function. Physical performance and lower extremity strength were again assessed with the chair stand and 10 meter walking speed.

Study surveys

Participants at Visit 1 were surveyed about their age, smoking status, alcohol intake, medication use, comorbidities, falls and fainting episodes in the past year, and self-assessed health status. Participants at Visit 2 were surveyed about their age, smoking status, medication use, and falls in the past year.

Statistical analysis

The statistical methods were the same for both the Visit 1 sample and Visit 2 sample. Descriptive statistics (means and standard deviations or frequencies and percentages) were calculated for each study sample. Univariable and multivariable Poisson regression models with generalized estimating equations (GEE) were used to model the number of falls per four month interval over three years in these longitudinal cohorts. Each participant contributed up to nine time points as the outcome. GEE was chosen to account for the correlation between repeated falls assessments in participants. In univariable analyses, relative risks (RR) and 95% confidence intervals (CI) were

reported for each covariate (per standard deviation [SD] for continuous covariates) adjusted for study site. In multivariable models the main predictor was Cobb angle of kyphosis for the Visit 1 sample and kyphotic index for the Visit 2 sample. All multivariable models were minimally adjusted for age, weight, and BMD based on *a priori* hypotheses about the causal pathways between kyphosis and falls. Additional covariates considered to be potential confounders to the association between kyphosis and falls were statistically assessed one-at-a-time and remained in the model if the kyphosis RR changed by 10% or more. Relative Risks, 95% CIs, and p-values based on the Wald test were reported for each variable in the multivariable models (per SD change in continuous variables). Sensitivity analyses were undertaken where the final models from each cohort were also run as overdispersed Poisson models with total number of falls over three years as the dependent variable; results did not differ. SAS software version 9.4 (SAS Institute, Cary, NC) was used for all analyses.

RESULTS

Visit 1 sample

Characteristics of the Visit 1 sample are shown in Table 4.1. Mean age among the 1,162 women in the Visit 1 sample (which took place between 1986 and 1988) was 69.3 ± 3.9 years and their mean Cobb angle was 44.8 ± 12.0 degrees. Mean BMI was 26.4 ± 4.2, 15% had prevalent vertebral fractures, 62% were never-smokers, and they consumed an average of 2.1 ± 4.3 alcoholic drinks per week. Twenty percent of the cohort used medications that may

increase fall risk including benzodiazepines, barbiturates, hypnotic sedatives, antidepressants, antihistamines, or muscle relaxers; 5% had a history of Parkinson disease, diabetes, or stroke. More than a quarter (27%) reported that they had experienced a fall in the preceding 12 months and 4% reported fainting in the previous year; 90% rated their quality of health as *excellent* or *good*.

Table 4.1: Visit 1 Sample Characteristics and Univariable Risks of Falls Over 3 Years Using Poisson Regression (n=1,162)

	Distribution	Univariable Risks of Falls Over 3 Years Using Poisson Regression[a]		
Variable	**Mean ± SD or N (%)**	**RR per SD**	**95% CI**	**p-value**
Age, *years*	69.3 ± 3.9	1.06	0.97, 1.16	.228
Height, *cm*	160.1 ± 5.9	0.93	0.84, 1.02	.119
Weight, *kg*	67.6 ± 11.7	1.09	0.99, 1.20	.074
Body mass index, kg/m^2	26.4 ± 4.2	**1.11**	**1.01, 1.22**	**.029**
Cobb angle, *degrees*	44.8 ± 12.0	1.03	0.94, 1.14	.520
Prevalent vertebral fx				
no	983 (85%)		REF	
yes	179 (15%)	1.22	0.97, 1.54	.095
Calcaneal BMD, g/cm^2	0.418 ± 0.086	1.06	0.96, 1.17	.238
Smoking status				
never	721 (62%)		REF	
past or current	437 (38%)	0.95	0.79, 1.14	.584
Drinks per week	2.05 ± 4.28	0.99	0.91, 1.08	.799
Medication[b] use				
no	929 (80%)		REF	
yes	233 (20%)	1.21	0.95, 1.53	.119
Comorbidities[c]				
no	1100 (95%)		REF	
yes	62 (5%)	0.97	0.66, 1.41	.856
Fallen in the past year				
no	843 (73%)		REF	
yes	316 (27%)	**2.15**	**1.80, 2.57**	**<.001**
Fainted in the past year				
no	1114 (96%)		REF	
yes	47 (4%)	**1.79**	**1.26, 2.54**	**.001**
Chair stand time, *sec*	11.1 ± 3.3	1.09	0.96, 1.23	.174
Walking speed, *m/sec*	1.08 ± 0.20	0.98	0.86, 1.11	.727
Short MMS Exam score[d]	25.0 ± 1.5	0.92	0.83, 1.02	.112
Self-rated quality of health				
good or excellent	1049 (90%)		REF	
fair or poor or very poor	113 (10%)	**0.72**	**0.55, 0.94**	**.016**

[a] All models adjusted for site; [b] Medications include benzodiazepines, barbiturates, hypnotic sedatives, antidepressants, antihistamines, and muscle relaxers; [c] Comorbidities include Parkinson disease, diabetes, or history of stroke; [d] Short Mini Mental Status Exam; a test of cognitive function

Of the nine falls questionnaires (sent every four months) representing the three year period after Visit 1, participants returned an average of 8.95 ± 0.35 questionnaires; 1,127 participants (97%) had complete follow-up. The distribution of falls over three years after Visit 1 is shown in Figure 4.1. More than half (51%) of participants experienced a fall during the three year follow-up period; 264 (23%) experienced one fall; 145 (12%) experienced two falls; and 181 (16%) experienced three or more falls. In sum, participants experienced 1,396 falls over 3,467.33 person-years of follow-up, resulting in a fall rate of 0.40 falls per person-year in the Visit 1 sample.

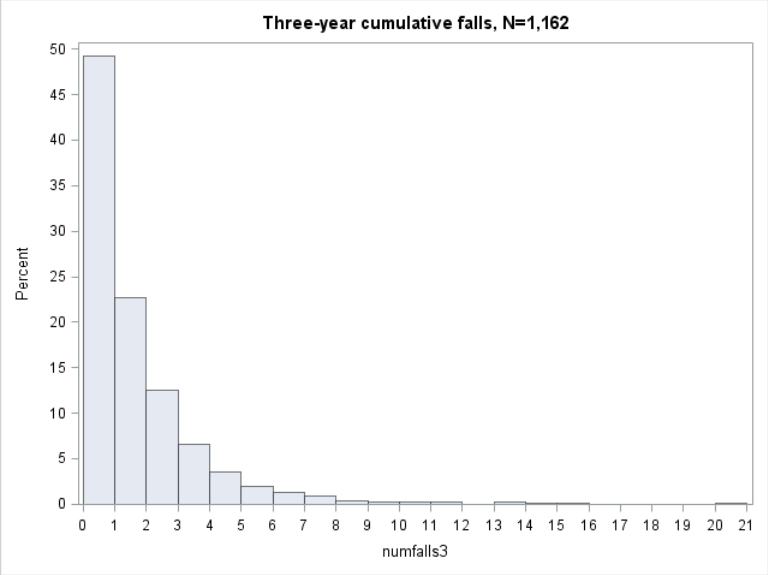


Figure 4.1: Cumulative Falls Over Three Years Post-Visit 1

Univariate relative risk (RR) of falls over three years were calculated for each variable in the Visit 1 sample using Poisson regression models with GEE, adjusting for clinic site. As seen in Table 4.1, BMI, reporting a fall in the past year, reporting fainting in the past year, and self-rated quality of health were all

significantly related to falls over three years in univariate models. All RRs for significant covariates were in the expected direction relative to falls with the exception of self-assessed health status; those who reported *fair*, *poor*, or *very poor* health were less likely to fall as compared to those who reported better health.

Results of multivariable modeling for the Visit 1 sample are shown in Table 4.2. Cobb angle of kyphosis was not associated with falls over three years in minimally adjusted multivariable models (RR=1.06 per SD increase in Cobb angle; 95% CI = 0.96, 1.16). Similarly, age, weight, and calcaneal BMD were not significantly related to falls over three years in adjusted models. Height, BMI, prevalent vertebral fractures, smoking status, alcohol consumption, medication use, comorbidities, falls in the previous year, fainting in the previous year, chair stand time, walking speed, Short Mini Mental Status Exam score, and self-rated quality of health were individually added to the base model and were determined not to confound the association between Cobb angle of kyphosis and falls.

Table 4.2: Multivariable Risk of Falls Over 3 Years Using Poisson Regression with GEE[a] in the Visit 1 Sample (n=1,162)

Variable	RR per SD	95% CI	p-value
Cobb angle of kyphosis, *degrees*	1.06	0.96, 1.16	.256
Age, *years*	1.05	0.95, 1.15	.340
Weight, *kg*	1.09	0.98, 1.21	.126
Calcaneal BMD, g/cm^2	1.02	0.92, 1.14	.704

[a] Model adjusted for site

Visit 2 sample

Characteristics of the Visit 2 sample are found in Table 3.1. Among the 610 women in the Visit 2 sample, whose clinic visit took place between 1989 and 1990, mean age was 72.8 ± 4.7 years. The average kyphotic index was 12.3 ± 3.4 and mean BMI was 26.3 ± 45 kg/m^2. Sixty percent of the cohort reported never smoking and 25% reported using sleeping or anxiety medications. More than 30% of the cohort reported a fall in the preceding 12 months. The average time to rise and stand five times from a chair was 12.6 ± 4.9 seconds and the mean walking speed during a 10 meter measured walk was 0.92 ± 0.22 meters per second.

Of the nine falls questionnaires (sent every four months) representing the three year period after Visit 2, participants returned an average of 8.78 ± 0.94 questionnaires; 555 participants (91%) had complete follow-up. Figure 4.2 shows the distribution of cumulative falls over the three years after Visit 2. Half (50%) of participants experienced a fall during the three year follow-up period; 140 (23%) experienced one fall; 63 (10%) experienced two falls; and 101 (17%) experienced three or more falls. In sum, participants experienced 804 falls over 1,785 person-years of follow-up, resulting in a fall rate of 0.45 falls per person-year in the Visit 2 sample.

Univariate RR of falls over three years were also calculated for each variable in the Visit 2 sample using Poisson regression models with GEE, adjusting for clinic site. As shown in Table 4.3, increasing age, higher kyphotic index, medication use, reporting a fall in the previous year, higher chair stand

time, and slower walking speed significantly increased the risk of falls over three years in univariate models.

Table 4.3: Visit 2 Sample Characteristics and Univariable Risks of Falls Over 3 Years Using Poisson Regression (n=610)

	Distribution	Univariable Risks of Falls Over 3 Years Using Poisson Regression[a]		
Variable	**Mean ± SD or N (%)**	**RR per SD**	**95% CI**	**p-value**
Age, *years*	72.8 ± 4.7	**1.36**	**1.18, 1.56**	**<.001**
Height, *cm*	159.2 ± 5.9	0.88	0.75, 1.03	.123
Weight, *kg*	66.5 ± 12.0	0.89	0.77, 1.03	.131
Body mass index, *kg/m^2*	26.3 ± 4.5	0.93	0.80, 1.08	.366
Kyphotic Index	12.3 ± 3.4	**1.23**	**1.06, 1.42**	**.005**
Total hip BMD, *g/cm^2*	0.763 ± 0.130	1.00	0.87, 1.14	.962
Smoking status				
never	363 (60%)		REF	
past or current	242 (40%)	0.80	0.60, 1.06	.123
Medication[b] use				
no	460 (75%)		REF	
yes	150 (25%)	**1.44**	**1.03, 2.01**	**.035**
Fallen in the past year				
no	409 (69%)		REF	
yes	187 (31%)	**2.01**	**1.52, 2.64**	**<.001**
Chair stand time, *sec*	12.6 ± 4.9	**1.28**	**1.13, 1.44**	**<.001**
Walking speed, *m/sec*	0.92 ± 0.22	**0.71**	**0.28, 0.86**	**<.001**
Trail Making Test B, *sec*	110.0 (32.8)	1.09	0.93, 1.27	.280

[a] All models adjusted for site; [b] Medications include those classified as sleeping or anxiety medications

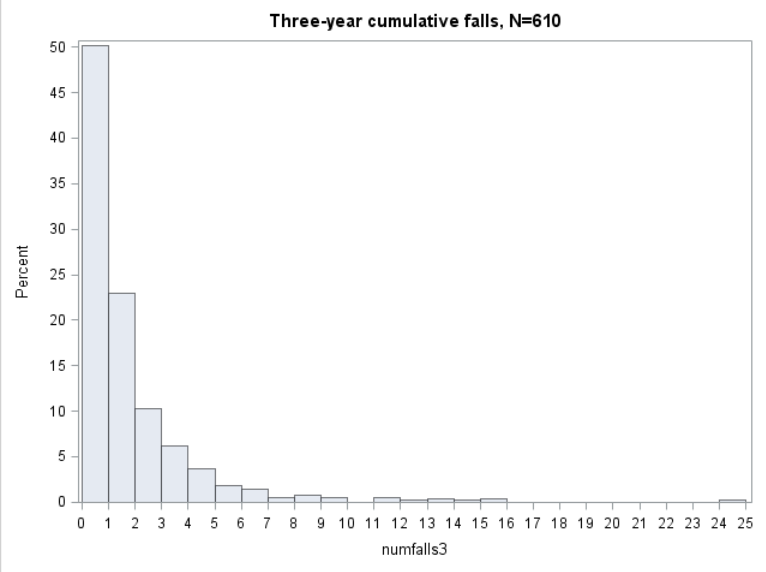


Figure 4.2: Cumulative Falls Over Three Years Post-Visit 2

Results of the Visit 2 sample multivariable modeling are found in Table 4.4. The kyphotic index (derived from the flexicurve measure) was associated with falls over three years in multivariable models. For each SD increase in the kyphotic index, the risk of falls increased by 22% (RR=1.22; 95% CI=1.07, 1.40) after adjusting for age, weight, and total hip BMD. Age was also significantly associated with risk of falls (RR=1.32 per SD increase in age; 95% CI=1.14, 1.54). Height, BMI, smoking status, medication use, falls in the preceding year, chair stand time, walking speed, and cognitive function (Trail Making Test B) were included in the minimally adjusted model one-at-a-time and were determined to not confound the association between kyphotic index and falls.

Table 4.4: Multivariable Risk of Falls Over 3 Years Using Poisson Regression with GEE[a] in the Visit 2 Sample (n=610)

Variable	RR per SD	95% CI	p-value
Kyphotic Index	**1.22**	**1.07, 1.40**	**.003**
Age, *years*	**1.32**	**1.14, 1.54**	**<.001**
Weight, *kg*	0.93	0.80, 1.09	.379
Total hip BMD, g/cm^2	1.08	0.94, 1.22	.270

[a] Model adjusted for site

The final Visit 2 multivariable model was adapted to an overdispersed Poisson model in order to predict risk of falls for an average member of the sample. The natural log of the number of years at risk for each woman was used as the offset. This resulted in a fall rate of 0.40 falls per woman-year, given mean kyphotic index; age; weight; and BMD (and controlling for study site). This rate is slightly lower than the calculated crude rate of 0.45 falls per woman-year.

DISCUSSION

In this large study of community-dwelling older women, increased kyphosis as measured by the kyphotic index was predictive of falls over three years, in line with our hypothesis. Specifically, each SD increase in the kyphotic index was associated with a 22% increase in the risk of falls over three years in adjusted models. Contrary to our hypothesis, though, kyphosis measured by the Cobb angle was not predictive of falls in a separate cohort within the same study.

The Cobb angle is a modified measure adapted from scoliosis assessments.[24] It is generally measured from thoracic spine radiographs, although the protocol for these radiographs was not developed with postural measures in mind. Although there has been demonstrated agreement between the kyphotic index and Cobb angle in the literature ($r_s = 0.684$, $p<.0001$),[25] it has been suggested that Cobb angle assessed from the lateral-lying position underestimates the degree of kyphosis[26], which would impact its utility as a measure of posture. Thus, perhaps only the most severely kyphotic individuals were captured by the assessment. The kyphotic index, a standing measure computed from measurements taken with an architect's flexible ruler, may be a more accurate measure of postural kyphosis. Alternatively, it is possible that while the Cobb angle strictly isolates thoracic curvature (T4-T12), the kyphotic index captures forward leaning posture related to thoracic kyphosis and lumbar lordosis (as the endpoints are the spinous process of C7 and the L5-S1 interspace). It may be that *stooped posture*, resulting from abnormal curvature in the cervical, thoracic, *or* lumbar spine is the main risk factor for falls and that

measuring the curvature in only one or two sections of the spine underestimates the overall risk.

The Cobb angle findings within the large Visit 1 sample contrast with those from a small study of 51 men and women where Cobb angle >50° was associated with a two-fold increase in the odds of a fall over the following year. However, the study's mean age was ten years older, had a higher proportion with prevalent vertebral fractures, and had a higher mean Cobb angle (51.2°) than the Visit 1 sample (44.8°). The current study's findings are also in contrast to our recently presented work from the Kyphosis, Falls, and Balance Study (KFBS), which also found Cobb angle to be associated with a two-fold increase in the odds of any fall over the following year in multivariable logistic regression models.[27] Mean age in the KFBS population of 72 men and women was 78 years, though the mean Cobb angle was 42.0°, nearly three degrees lower than our Visit 1 sample.

The kyphotic index findings within the Visit 2 sample of 610 community-dwelling women are in line, though weaker than, those of KFBS, which found a 2.5 fold increase in the odds of a fall for each standard deviation in kyphotic index. In addition to a mean age difference of +5 years, the mean kyphotic index in the KFBS sample of 13.9 was higher than the Visit 2 sample mean of 12.3.[27]

Differences were observed between the Visit 1 and Visit 2 samples. Interestingly, age was not significantly associated with univariate risk of falls in the Visit 1 sample, but was associated with falls in the Visit 2 sample, with an approximate difference of 3.5 years between the two cohorts. Similarly, walking

speed and timed chair stands were not associated with falls in the Visit 1 sample but were associated with risk of falls in the Visit 2 sample. These differences may be due to a threshold effect of worsening physical function with age or, more likely, due to survivor bias in the selection of the Visit 1 sample.

This study is the largest prospective examination of kyphosis and falls in community-dwelling older women to date. Strengths of the research include the prospective collection of falls data in the Visit 1 and Visit 2 samples, excellent participant retention, the examination of two different measures of kyphosis, and the analyses allowing repeated measures to be taken into account. The selection of participants is a limitation of this study. Within the Visit 1 sample, 1,000 of the 1,196 participants selected for Cobb angle measurements were chosen because they also had lateral spine radiographs 15 years later, making them the healthiest of the Visit 1 participants who may have had lower fall risk than those who did not survive 15 years.[26] Those in Visit 2 who had flexicurve measures may also differ from other Visit 2 participants as they were selected consecutively. Other limitations include the potential recall bias with the four-month falls recall, separate cohorts at different time points for the examination of the two measures of kyphosis, and variability in the measured covariates at these two different time points. In addition, our results are likely not generalizable to all community-dwelling older women as enrollment in SOF was limited to white women.

Although Cobb angle of kyphosis did not appear to be associated with falls in the relatively young Visit 1 sample, Cobb angle measures are available from

data collected at the 15-year SOF clinic visit. Since falls questionnaires continued throughout the study, replicating the analysis in this aged cohort could help to determine whether there is a threshold effect with age and the impacts of hyperkyphosis.

In conclusion, community-dwelling women with greater degrees of kyphosis as measured by the kyphotic index are at increased risk of falls, regardless of age, weight, and total hip BMD. This adds to the growing body of literature suggesting that kyphosis is an important independent risk factor for falls, and should be taken into account when assessing fall risk.

Acknowledgments: Chapter 4, in full, will be prepared for submission to a TBD journal for publication of material. Co-Authors include Jeanne F Nichols, Florin Vaida, Caroline Macera, Suzanne P Lindsay, and Deborah M Kado. The dissertation author is the primary author of this material.

REFERENCES

1. Bergen G SM, Burns ER. Falls and fall injuries among adults aged ≥65 Years — United States, 2014. PreventionMorbidity and Mortality Weekly Report 2016;65:1-6.

2. Tinetti ME, Williams CS. Falls, injuries due to falls, and the risk of admission to a nursing home. The New England journal of medicine 1997;337:1279-84.

3. Tinetti ME, Williams CS. The effect of falls and fall injuries on functioning in community-dwelling older persons. The journals of gerontology Series A, Biological sciences and medical sciences 1998;53:M112-9.

4. Deshpande N, Metter EJ, Lauretani F, Bandinelli S, Guralnik J, Ferrucci L. Activity restriction induced by fear of falling and objective and subjective measures of physical function: a prospective cohort study. Journal of the American Geriatrics Society 2008;56:615-20.

5. Salkeld G, Cameron ID, Cumming RG, et al. Quality of life related to fear of falling and hip fracture in older women: a time trade off study. BMJ 2000;320:341-6.

6. Englander F, Hodson TJ, Terregrossa RA. Economic dimensions of slip and fall injuries. Journal of forensic sciences 1996;41:733-46.

7. Deandrea S, Lucenteforte E, Bravi F, Foschi R, La Vecchia C, Negri E. Review Article: Risk Factors for Falls in Community-dwelling Older People: "A Systematic Review and Meta-analysis". Epidemiology 2010;21:658-68.

8. Rubenstein LZ. Falls in older people: epidemiology, risk factors and strategies for prevention. Age and ageing 2006;35 Suppl 2:ii37-ii41.

9. de Groot MH, van der Jagt-Willems HC, van Campen JP, Lems WF, Beijnen JH, Lamoth CJ. A flexed posture in elderly patients is associated with impairments in postural control during walking. Gait & posture 2014;39:767-72.

10. Eum R, Leveille SG, Kiely DK, Kiel DP, Samelson EJ, Bean JF. Is kyphosis related to mobility, balance, and disability? American journal of physical medicine & rehabilitation / Association of Academic Physiatrists 2013;92:980-9.

11. Sinaki M, Brey RH, Hughes CA, Larson DR, Kaufman KR. Balance disorder and increased risk of falls in osteoporosis and kyphosis: significance of kyphotic posture and muscle strength. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2005;16:1004-10.

12. 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. The journals of gerontology Series A, Biological sciences and medical sciences 2007;62:652-7.

13. van der Jagt-Willems HC, de Groot MH, van Campen JP, Lamoth CJ, Lems WF. Associations between vertebral fractures, increased thoracic kyphosis, a flexed posture and falls in older adults: a prospective cohort study. BMC geriatrics 2015;15:34.

14. 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. Journal of the American Geriatrics Society 2004;52:1662-7.

15. Katzman W, Cawthon P, Hicks GE, et al. Association of spinal muscle composition and prevalence of hyperkyphosis in healthy community-dwelling older men and women. The journals of gerontology Series A, Biological sciences and medical sciences 2012;67:191-5.

16. Ryan SD, Fried LP. The impact of kyphosis on daily functioning. Journal of the American Geriatrics Society 1997;45:1479-86.

17. Harrison RA, Siminoski K, Vethanayagam D, Majumdar SR. Osteoporosis-related kyphosis and impairments in pulmonary function: a systematic review. Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research 2007;22:447-57.

18. Sinaki M, Itoi E, Rogers JW, Bergstralh EJ, Wahner HW. Correlation of back extensor strength with thoracic kyphosis and lumbar lordosis in estrogen-deficient women. American journal of physical medicine & rehabilitation / Association of Academic Physiatrists 1996;75:370-4.

19. Kado DM, Miller-Martinez D, Lui LY, et al. Hyperkyphosis, kyphosis progression, and risk of non-spine fractures in older community dwelling women: the study of osteoporotic fractures (SOF). Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research 2014;29:2210-6.

20. Kado DM, Browner WS, Palermo L, Nevitt MC, Genant HK, Cummings SR. Vertebral fractures and mortality in older women: a prospective study. Study of Osteoporotic Fractures Research Group. Archives of internal medicine 1999;159:1215-20.

21. Kado DM, Lui LY, Ensrud KE, Fink HA, Karlamangla AS, Cummings SR. Hyperkyphosis predicts mortality independent of vertebral osteoporosis in older women. Annals of internal medicine 2009;150:681-7.

22. Faulkner KA, Cauley JA, Studenski SA, et al. Lifestyle predicts falls independent of physical risk factors. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2009;20:2025-34.

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. Journal of bone and mineral research : the official journal of the American Society for Bone and Mineral Research 2013;28:179-87.

24. Fon GT, Pitt MJ, Thies AC, Jr. Thoracic kyphosis: range in normal subjects. AJR American journal of roentgenology 1980;134:979-83.

25. Tran TH, Wing D, Davis A, et al. Correlations among four measures of kyphosis in older adults. Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA 2015.

26. 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. The journals of gerontology Series A, Biological sciences and medical sciences 2013;68:976-83.

27. McDaniels-Davidson C, Davis A, Wing D, Nichols JF, Kado DM. Kyphosis and Incident Falls among Community-dwelling Older Adults. In: American Geriatrics Society Annual Meeting. Long Beach, CA; 2016.

CHAPTER 5: DISCUSSION

AIMS

This dissertation research was undertaken to better understand falls among older adults within the context of hyperkyphosis. The following aims were addressed by this research: **Aim 1.** To determine whether four measures of kyphosis are associated with incident and injurious falls over one year among older adults in San Diego, CA. **Aim 2.** To determine whether a measure of lower extremity strength and balance mediates the association between hyperkyphosis and falls. **Aim 3.** To assess whether measures of kyphosis independently predict fall risk over three years in large US multi-site cohorts of older men and older women.

METHODOLOGIES

Cross sectional and prospective quantitative methods were used to investigate the association between hyperkyphosis and fall risk in the older adult population. Specifically, paper 1 (Kyphosis and incident falls among community-dwelling older adults) examined whether kyphosis measured four different ways in 72 older men and women increased the odds of any fall or any injurious fall within the following year using logistic regression models. Paper 1 also included a mediation analysis to determine whether, as has been hypothesized, balance and physical function lie within the causal pathway between hyperkyphosis and falls.

Paper 2 (Kyphosis and 3-year fall risk in community-dwelling older men) sought to ascertain whether two measures of kyphosis were able to predict fall risk over three years of tri-annual follow-up in large multi-site cohorts of older men. These analyses utilized generalized estimating equations with log links and Poisson distributions due to the repeated falls counts over nine time points, enabling the analysis of these correlated data.

Paper 3 (Kyphosis and 3-year fall risk in community-dwelling older women) utilized analyses similar to Paper 2 to determine whether two measures of kyphosis predicted fall risk over three years of tri-annual follow-up in large multi-site cohorts of older women.

IMPLICATIONS AND FURTHER INVESTIGATIONS

Implications of the investigations presented in each of the manuscripts as well as additional analyses that were undertaken to illuminate and clarify the association between hyperkyphosis and falls are found herein.

Paper 1

Results from the Kyphosis, Falls, and Balance Study (KFBS) on four measures of kyphosis on incident and injurious falls over the subsequent year revealed several interesting findings. First: in an older population (mean age 77.8 ± 7.1 years) of men and women, monthly falls follow-up yielded high reporting of both incident and injurious falls (64% and 35% of our population experienced at least one incident and one injurious fall, respectively; Table 2.1). These proportions are more than double those obtained through 12-month recall among

older adults; the most recent Behavioral Risk Factor Surveillance System Survey (BRFSS) found that only 29% of men and women aged ≥65 reported a fall, and just 11% reported an injurious fall in the preceding 12 months.[1] These disparate findings between monthly and annual falls recall are supported by others recommending daily or monthly recall intervals who have found that longer recall intervals specific for non-fallers, but are not sensitive for falls.[2,3]

Secondly, adjusted odds of at least one incident fall over the subsequent year at least doubled for each standard deviation (SD) increase in all kyphosis measures (Table 2.3). This consistency across all four measures, two standing and two lying, was marked. Further, adjusted odds of a fall during the follow-up period for each SD increase in Cobb angle (OR = 2.11; 95% CI = 1.13, 3.96) were nearly identical to what was reported in a similar study of older men and women with monthly falls ascertainment (OR = 2.13; 95% CI = 1.10, 4.51).[4] This suggests external validity for the association between Cobb angle and falls, which may be extended to the three other measures as well.

Lastly, contrary to our hypothesis, elements of balance and lower extremity function as measured by the timed up-and-go (TUG) test did not mediate the association between kyphosis and falls. We followed Baron and Kenny's steps for assessing mediation[5] and found that: 1) kyphosis was a significant predictor of falls (Table 2.3); 2) kyphosis was *not* a significant predictor of TUG time in regression models, though beta estimates approached significance (Table S.1); 3) TUG time was not a significant predictor of falls in logistic regression models (Table S.2); and 4) inclusion of TUG time in adjusted

logistic regression models with kyphosis measures only minimally attenuated the measure of association between kyphosis and falls (Table S.2).

Paper 2

Within the Osteoporotic Fractures in Men Study (MrOS), a sample of men from Visit 1 (taking place between 2000 and 2002) and a sample of men from Visit 3 (occurring between 2006 and 2009) revealed incongruent findings about measures of kyphosis and the risk for incident falls over three years. Among the 2,346 men in the Visit 1 sample mean age was 73.6 ± 5.9 years, mean Cobb angle was 38.6 ± 11.4°, and 50% reported at least one fall over the three years of tri-annual follow-up. In adjusted models, Cobb angle of kyphosis at Visit 1 was not significantly associated with risk of falls over three years. This lack of an association could have been due to several factors. First, this sample was younger overall than those studies that have found an association between Cobb angle and falls in mixed-gender older adults.[4,6] Second, the mean Cobb angle was lower than other published reports.[7] Third, the falls outcome measure may have been diluted due to recall bias in counting falls at 4-month intervals. Indeed, the fall rate obtained through this interval over three years of 0.65 falls/person-year was nearly identical to that obtained from annual falls recall among men in the 2014 BRFSS (0.66 falls/person-year).

Among the 2,928 men in the Visit 3 sample, mean age was 79.2 ± 5.2 years, mean number of blocks required to achieve a neutral head and neck position was 2.6 ± 1.4, and 55% reported at least one incident fall over three

years. In adjusted models, the blocks measure of kyphosis was predictive of fall risk over three years in men. For each 1.4 block (SD) increase, adjusted fall risk increased by 11% (RR=1.11, 95% CI=1.06, 1.17). While this finding was statistically significant, the measure of association was much lower than we found in Paper 1. This could have been due to differences between the two cohorts in kyphosis, sex, or falls recall. While the KFBS and MrOS Visit 3 samples were of similar age (mean 77.8 and 79.2 respectively), the KFBS cohort was more kyphotic (mean 3.2 blocks in KFBS and 2.6 blocks in MrOS Visit3). In addition, the KFBS cohort was mixed-gender while MrOS is composed only of men. Finally, as previously stated, KFBS subjects were followed monthly to assess falls whereas MrOS participants were queried only once every four months, suggesting recall bias within MrOS.

The analyses presented in this paper were completed with generalized estimating equations (GEE) with log link function and Poisson distribution. This allowed correlated, repeated falls count measures (which are assumed to be correlated) to be modeled as the response variable. Poisson models are ideal to model count data, but have a strict assumption about equity between the mean and variance of the response variable. When this assumption is not met the result is *overdispersion*, which leads to inaccurate standard errors, biasing significance tests away from the null hypothesis (type I error). To ensure the GEE models corrected for overdispersion, we conducted a sensitivity analysis where the final models were run as overdispersed Poisson models with the total number of falls (rather than repeated falls measures) as the response variable. Similar

results were obtained within the Visit 1 sample (Table S.3) and the Visit 3 cohort (Table S.4), leading us to confirm that the GEE models were appropriate and corrected for any overdispersion.

Paper 3

Similar to the results of Paper 2, two samples from different time points (one from the baseline study visit between 1986 and 1988 and the other from the second study visit between 1989 and 1990) within the Study of Osteoporotic Fractures in Women (SOF) yielded conflicting findings about the association between two measures of kyphosis and incident falls over three years.

The 1,162 women in the Visit 1 sample had a mean age of 69.3 ± 3.9 years, mean Cobb angle of 44.8 ± 12.0°, and 51% reported at least one fall over three years of tri-annual follow-up. In adjusted models, Cobb angle was not significantly associated with falls over the following three years. In fact, none of the variables in the final model (age, weight, or BMD) were associated with falls over three years.

These findings contrast with those found in other studies. This could have been due to selection bias within the cohort. Cobb angle measures were conducted for a previous study that was examining change over 15 years. This limited the available pool of Visit 1 participants because those eligible had to have survived 15 years after Visit 1 and been well enough to attend a study visit to have a lateral spine radiograph. Although the authors of that study attempted to reduce survivor bias with the addition of 196 women with only Visit 1

radiographs, those efforts may have not been successful.[8] This cohort of women was significantly younger (by 10.0 and 8.5 years) than other published reports that have found an association between Cobb angle and falls in mixed-gender older adults.[4,6] This sample of women also had a much lower fall rate (at 0.40 falls/person-year) than published reports, which may have been due to their being among the healthiest of the Visit 1 participants. Even with annual falls recall, the BRFSS reported a higher fall rate of 0.68 falls/person-year among women aged 65 and older.[1]

Among the 610 women in the Visit 2 sample, mean age was 72.8 ± 4.7 years, mean kyphotic index was 12.3 ± 3.4, and 50% experienced at least one fall over the following three years. For each SD (3.4) increase in kyphotic index in adjusted models, risk of falls increased by 22% (RR = 1.22; 95% CI = 1.07, 1.40). These results are in line with, though weaker than, those found in Paper 1 where each SD (4.9) increase in kyphotic index resulted in more than a 2.5-fold increase in the odds of a fall over the following year. The two populations differed otherwise as well; the KFBS population was older (mean age 77.8 ± 7.1 years), had greater kyphotic index (mean 13.9 ± 4.9), and had a greater proportion report a fall (64%) in one year than the SOF Visit 2 sample reported over three years.

The two SOF samples reported lower fall rates than the MrOS samples despite not having a capped falls reporting system that the MrOS tri-annual questionnaires contained. Whereas MrOS participants were asked to circle the number of times they fell (1, 2, 3, 4, or 5+), SOF participants were asked to

indicate an open-ended number. Perhaps the lack of visible response options reduced their recall.

To ensure that the GEE models were appropriate and managed any overdispersion in the response variables; we conducted sensitivity analyses as done in Paper 2. Each final GEE model was run as a multivariable Poisson regression with robust variance estimates (so called *sandwich* estimators of variance) with total number of falls over three years as the response variable. As in Paper 2, similar results were found with the Visit 1 sample (Table S.5) and Visit 2 sample (Table S.6), indicating GEE was an appropriate analytic strategy for falls within the SOF samples.

LIMITATIONS

The results of the three presented studies must be interpreted with some caution due to inherent limitations. Paper 1 may not be generalizable to the broad population of older adults since the analyses were based on a relatively small, homogenous, self-selected cohort where women outnumbered men by more than 2:1. Paper 3 was also based on a homogenous population in that only white women were originally enrolled into the study, hampering generalizability.

The samples of participants within Paper 3 also likely suffer from selection bias, specifically survivor bias, as one of the kyphosis measures (Cobb angle) was completed mostly for subjects with available radiographs at our time point of interest *and*15 years later and the other kyphosis measure (kyphotic index) was completed on a small proportion of consecutive clinic visit attendees. To a lesser

degree, survivor bias may have also influenced the selection of the Cobb angle measures completed for Paper 2, as these were done for a previous study on only those who had radiographs at our time point of interest and three years later.

Recall bias likely affected the results of Papers 2 and 3 to a significant degree, perhaps leading to an underestimation in effect sizes. As discussed, the assessment of falls at four month intervals likely results in an underestimation of falls in older adults and may actually represent only significant falls. Lastly, while the large population-based cohort studies that Papers 2 and 3 were set within provide timely and cost effective access to large sample sizes, they were not originally designed to assess kyphosis and falls.

Despite these limitations, all three studies offered prospectively collected falls data with excellent participant retention and allowed for multiple methods of kyphosis assessment. Papers 2 and 3 are the first to utilize prospective analytic techniques with very large sample sizes. Paper 1 was set within a study specifically designed to measure the effects of kyphosis on falls over time with the benefit of monthly falls reporting. It also successfully replicated results on the impact of the Cobb angle on future falls from a previous study also designed specifically to assess this association.[4]

CONCLUSIONS

In summary, increasing kyphosis appears to increase fall risk and injurious fall risk among community-dwelling older adults, though the mechanism may not

be through loss of lower extremity strength and reduced balance as hypothesized. Additionally, the results of this research indicate that different measures of kyphosis may be assessing elements of forward curvature in not just the thoracic spine, but also the cervical and/or lumbar spine. This dissertation also provided further evidence that monthly falls recall is ideal for tracking incident falls.

Future research might focus on 1) the mechanisms by which kyphosis increases fall risk so as to provide potential intervention points for falls risk reduction; 2) whether fall risk can be mitigated through reductions in kyphosis; and 3) developing consensus for age-based cut points to define hyperkyphosis with the various available measurement techniques. Also, future research into falls risk factors and developing tools to measure risk should include measures of kyphosis in addition to the well-established risk factors.

It is clear that health care professionals should be taking posture into account when assessing fall risk in their older, community-dwelling patients. Simple measurements such as the blocks method are non-invasive, confer no radiation risk, and could be conducted during routine office visits.

REFERENCES

1. Bergen G SM, Burns ER. Falls and fall injuries among adults aged ≥65 Years — United States, 2014. PreventionMorbidity and Mortality Weekly Report 2016;65:1-6.

2. Ganz DA, Higashi T, Rubenstein LZ. Monitoring falls in cohort studies of community-dwelling older people: effect of the recall interval. Journal of the American Geriatrics Society 2005;53:2190-4.

3. Hannan MT, Gagnon MM, Aneja J, et al. Optimizing the tracking of falls in studies of older participants: comparison of quarterly telephone recall with monthly falls calendars in the MOBILIZE Boston Study. American journal of epidemiology 2010;171:1031-6.

4. van der Jagt-Willems HC, de Groot MH, van Campen JP, Lamoth CJ, Lems WF. Associations between vertebral fractures, increased thoracic kyphosis, a flexed posture and falls in older adults: a prospective cohort study. BMC geriatrics 2015;15:34.

5. Baron RM, Kenny DA. The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. Journal of Personality and Social Psychology 1986;51:1173-82.

6. McDaniels-Davidson C, Davis A, Wing D, Nichols JF, Kado DM. Kyphosis and Incident Falls among Community-dwelling Older Adults. In: American Geriatrics Society Annual Meeting. Long Beach, CA; 2016.

7. Schneider DL, von Muhlen D, Barrett-Connor E, Sartoris DJ. Kyphosis does not equal vertebral fractures: the Rancho Bernardo study. The Journal of rheumatology 2004;31:747-52.

8. 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. The journals of gerontology Series A, Biological sciences and medical sciences 2013;68:976-83.

APPENDIX

SUPPLEMENTARY TABLES

Table S.1: Regression of Kyphosis Measures on TUG Time in the KFBS Study (n=72)

Modeled Kyphosis Measure	Beta Estimate	95% CI	*p-value*
Debrunner kyphometer	0.037	-0.002, 0.075	.060
Flexicurve ruler	0.094	-0.005, 0.194	.063
Cobb angle	0.031	-0.003, 0.064	.075
Blocks	0.260	-0.058, 0.578	.108

KFBS: Kyphosis, Falls, and Balance Study; CI: Confidence interval

Table S.2: Odds of Incident Fall by Each Measure of Kyphosis in the KFBS Study (n=72)

Modeled Kyphosis measure (per SD)	Adjusted Models[a]			Adj. Models[a] + TUG time		
	OR	95% CI	*p-value*	OR	95% CI	*p-value*
Debrunner kyphometer	**2.41***	**1.28, 4.55**	**.006**	**2.16***	**1.11, 4.21**	**.024**
TUG Time	--	--	--	0.84	0.41, 1.70	.621
Flexicurve ruler	**2.55***	**1.23, 5.29**	**.012**	**2.32***	**1.09, 4.92**	**.028**
TUG Time	--	--	--	0.84	0.42, 1.70	.632
Cobb angle	**2.11***	**1.13, 3.96**	**.020**	**2.01***	**1.06, 3.82**	**.033**
TUG Time	--	--	--	0.86	0.43, 1.74	.675
Blocks	**3.20***	**1.38, 7.46**	**.007**	**3.05***	**1.26, 7.36**	**.013**
TUG Time	--	--	--	1.11	0.53, 2.34	.782

[a]Adjusted for sex, age, weight, and total hip BMD; *Statistically significant at α=0.05; KFBS: Kyphosis, Falls, and Balance Study; SD: Standard deviation; OR: Odds ratio; CI: Confidence interval

Table S.3: Sensitivity Analysis for Overdispersion in the Visit 1 MrOS Sample Multivariable Models (n=2,346)

Variable in Model	Generalized Estimating Equations with Poisson Distribution			Poisson Regression with Robust Variance Estimator		
	RR	**95% CI**	***p-value***	**RR**	**95% CI**	***p-value***
Cobb angle of kyphosis, *degrees*	1.04	0.95, 1.14	.432	1.05	0.99, 1.12	.123
Age, *years*	**1.30**	**1.19, 1.42**	**<.001**	**1.26**	**1.19, 1.34**	**<.001**
Weight, *kg*	**1.15**	**1.05, 1.27**	**.003**	**1.53**	**1.08, 1.23**	**<.001**
Total hip BMD, g/cm^2	0.93	0.84, 1.02	.108	**0.93**	**0.87, 0.99**	**.046**

MrOS: Osteoporotic Fractures in Men Study; RR: Relative Risk; CI: Confidence interval

Table S.4: Sensitivity Analysis for Overdispersion in the Visit 3 MrOS Sample Multivariable Models (n=2,928)

Variable in Model	Generalized Estimating Equations with Poisson Distribution			Poisson Regression with Robust Variance Estimator		
	RR	**95% CI**	***p-value***	**RR**	**95% CI**	***p-value***
Blocks measure of kyphosis	**1.11**	**1.06, 1.17**	**<.001**	**1.16**	**1.10, 1.22**	**<.001**
Age, *years*	**1.24**	**1.18, 1.30**	**<.001**	**1.26**	**1.20, 1.34**	**<.001**
Weight, *kg*	**1.06**	**1.01, 1.12**	**.032**	**1.08**	**1.01, 1.15**	**.017**
Total hip BMD, g/cm^2	0.95	0.90, 1.00	.065	0.96	0.90, 1.02	.179

MrOS: Osteoporotic Fractures in Men Study; RR: Relative Risk; CI: Confidence interval

Table S.5: Sensitivity Analysis for Overdispersion in the Visit 1 SOF Sample Multivariable Models (n=1,162)

Variable in Model	Generalized Estimating Equations with Poisson Distribution			Poisson Regression with Robust Variance Estimator		
	RR	95% CI	*p-value*	RR	95% CI	*p-value*
Cobb angle of kyphosis, *degrees*	1.06	0.96, 1.17	.256	1.057	0.98, 1.14	.168
Age, *years*	1.05	0.95, 1.15	.340	1.041	0.96, 1.13	.325
Weight, *kg*	1.09	0.98, 1.21	.126	1.084	0.99, 1.18	.070
Total hip BMD, g/cm^2	1.02	0.92, 1.14	.704	1.021	0.93, 1.12	.666

SOF: Study of Osteoporotic Fractures in Women; RR: Relative Risk; CI: Confidence interval

Table S.5: Sensitivity Analysis for Overdispersion in the Visit 2 SOF Sample Multivariable Models (n=610)

Variable in Model	Generalized Estimating Equations with Poisson Distribution			Poisson Regression with Robust Variance Estimator		
	RR	95% CI	*p-value*	RR	95% CI	*p-value*
Kyphotic index	**1.22**	**1.07, 1.40**	**.003**	**1.22**	**1.08, 1.37**	**<.001**
Age, *years*	**1.32**	**1.14, 1.54**	**<.001**	**1.30**	**1.16, 1.44**	**<.001**
Weight, *kg*	0.93	0.80, 1.09	.379	0.94	0.82, 1.07	.347
Total hip BMD, g/cm^2	1.08	0.94, 1.22	.270	1.08	0.94, 1.24	.280

SOF: Study of Osteoporotic Fractures in Women; RR: Relative Risk; CI: Confidence interval