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Research Article

Severity of Kyphosis and Decline in Lung Function: The Framingham Study

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Abstract

Background: Hyperkyphosis reduces the amount of space in the chest, mobility of the rib cage, and expansion of the lungs. Decline in pulmonary function may be greater in persons with more severe kyphosis; however, no prospective studies have assessed this association. We conducted a longitudinal study to quantify the impact of kyphosis severity on decline in pulmonary function over 16 years in women and men.
Methods: Participants included a convenience sample of 193 women and 82 men in the Framingham Study original cohort (mean age: 63 years; range: 50–79 years), who had measurements of kyphosis angle from lateral spine radiographs obtained in 1972–1976 and forced expiratory volume in 1 second (FEV_1) from spirometry taken four times over 16 (±1.87) years from 1972 through 1988.
Results: Kyphosis severity was associated with greater decline in FEV_1 in women but not in men. Adjusted mean change in FEV_1 over 16 years was −162, −245, and −261 mL (trend, $p = .02$) with increasing tertile of kyphosis angle in women and −372, −297, and −257 mL (trend, $p = .20$) in men, respectively.
Conclusions: This longitudinal study found that kyphosis severity increased subsequent decline in pulmonary function in women but not in men. Reasons for an association between kyphosis and pulmonary function in women but in not men may be due, at least in part, to the small number of men in our study. Nevertheless, our findings suggest that preventing or slowing kyphosis progression may reduce the burden of pulmonary decline in older adults.

Keywords: Spine—Aging—Posture—Hunchback—Respiratory function

An accentuated anterior curvature of the thoracic spine, clinically referred to as hyperkyphosis, is a common spinal deformity manifested as a hunched posture. Despite a lack of a standardized definition of hyperkyphosis, prevalence is estimated to be between 20 and 40% among older adults (1,2). Hyperkyphosis causes anterior displacement of the center of mass of the trunk, reducing postural control (3). Consequently, individuals with hyperkyphosis have increased risk of falls (4–6), fractures (7,8), and physical function impairments (3,9–11) and reduced quality of life (12).

In addition, hyperkyphosis reduces the amount of space in the chest, mobility of the rib cage, and expansion of the lungs. However, there are few studies that have evaluated the effects of hyperkyphosis on airway restriction (13–16). Further, these investigations were cross-sectional studies that included small samples of clinical patients, who were predominately older women with vertebral fracture. Although vertebral fracture is a risk factor for hyperkyphosis (17,18), most individuals with hyperkyphosis have no evidence of vertebral fracture (19,20). Thus, the impact of hyperkyphosis on pulmonary function decline in older adults is unknown. Therefore, we conducted a longitudinal study to determine the association between severity of thoracic kyphosis and decline in pulmonary function over 16 years in women and men.

Methods

Participants and Study Design

Participants were members of the Framingham Heart Study, a population-based cohort of 5,209 participants (2,873 women and 2,336 men), aged 28–62 years, established in 1948 in Framingham, MA. Every 2 years, cohort members underwent standardized physical examinations and completed structured questionnaires administered by physician examiners (21). Participants in the current study were a convenience sample of 193 women and 82 men, who were part of a longitudinal study of incidence of vertebral fracture (22). The vertebral fracture study included 704 cohort members, who had baseline lateral spine radiographs obtained in 1972–1976 and subsequently in 1992–1993. For the current study, we used baseline assessments of participant characteristics, collected at clinical examinations at the time of, or closest in time to, the baseline radiographs that were used to measure kyphosis. For the primary outcome of the study, we used four repeated assessments of lung function collected over 16 years from 1972 through 1988 (23). Written informed consent was obtained from participants, in accordance with the protocols approved by the Institutional Review Boards at Boston University and Hebrew SeniorLife.

Kyphosis Angle

Kyphosis angle (degrees) was measured at baseline from lateral spine radiographs. A single trained reader used an adjustable triangle to determine the angle resulting from lines drawn from the superior border of T4 and the inferior border of T12. A larger kyphosis angle corresponds to a more pronounced forward curvature of the thoracic spine. The intraclass correlation coefficient estimating the intra-rater reliability was .97 (95% confidence interval: 0.93–0.99) for 30 participants, chosen at random, and measured in duplicate.

Spirometry

Lung function was assessed by spirometry at four clinic visits conducted in 1972–1976, 1979–1982, 1981–1984, and 1985–1988 (23) using a 6-L water-sealed bell spirometer (Warren E. CoIlins, Braintree, MA), with the participant standing and wearing nose clips (24,25). In earlier examinations, three spirometry maneuvers were performed, and the forced vital capacity (FVC) and the forced expiratory volume in 1 second (FEV_1) from the acceptable maneuver with the highest FVC were used for analysis. For the 1985–1988 examination, spirometry maneuvers were repeated until at least three acceptable spirograms were obtained, and the highest values of FVC and FEV_1 from among all acceptable maneuvers were used, in accordance with contemporary guidelines (26). For the first three of these examinations, the FVC and the FEV_1 were measured by hand using back extrapolation. For the 1985–1988 examination, the FVC and FEV_1 were measured by an Eagle II microprocessor interfaced with the spirometer. Primary outcomes included FEV_1 (L), the volume of air exhaled in the first second of forced expiration, and FVC (L), the total amount of air exhaled. Because findings were similar for both FEV_1 and FVC, we present results only for FEV_1.

Other Variables

We examined potential confounding factors associated with pulmonary function and/or kyphosis based on previous research (18,24). Height, to the nearest 0.25 inch, and weight, to the nearest 0.5 pound, were measured using a stadiometer and balance beam scale, respectively. Body mass index (kg/m^2) was calculated from height and weight. Isometric grip strength of the right hand (one trial), to the nearest kilogram, was measured using an adjustable handheld dynamometer. Smoking, alcohol consumption, and physical activity were assessed by questionnaires, administered by trained interviewers. Smoking status was classified as current versus former/never. Alcohol consumption in ounces per week was computed by multiplying the average amount of alcohol in a single drink of beer, wine, or spirits by the average number of reported drinks per week. Physical activity index was calculated from the average number of hours per day participants reported sleeping and performing sedentary, slight, moderate, and heavy levels of physical activity during work and leisure time (27). The hours spent at each level of activity were multiplied by a weight based on the oxygen consumption required for that activity and summed to create an index of physical activity. Prevalent vertebral fracture from T4 to T12 was assessed from baseline spine radiographs using a semi-quantitative method and defined as any vertebral body graded at least mildly deformed (20–25% reduction or more in any vertebral height) (28).

Statistical Analysis

We used linear mixed effects regression models, with unstructured correlation matrices and robust variance, to estimate age-adjusted and multivariable-adjusted mean decline in FEV_1 (based on four repeated measures over 16 years) according to sex-specific tertiles of baseline kyphosis angle (Tertile 1 = low). The p value for the test for trend was obtained by entering into the model an ordinal variable with each level representing a tertile of kyphosis angle. Multiply-adjusted models included baseline age (years), height (cm), weight (kg), prevalent vertebral fracture (yes/no), current smoking (yes/no), and physical activity (index). Additional covariates (such as grip strength and alcohol consumption) as well as time-varying covariates (smoking) did not change results and therefore were not retained in multivariable models. We repeated the analysis considering kyphosis angle as a continuous variable, but results were consistent with those for kyphosis angle as categorized by tertiles. Analysis was conducted separately for women and men using Statistical Analysis Software, version 9.3 (SAS Institute, Cary, NC).

Results

Participants included 275 cohort members (193 women and 82 men) with a mean baseline age of 63 years and range 50 to 79 years. Mean kyphosis angle was 40° (range 4–76°) in women and 34° (range 6–80°) in men (Table 1).

Individuals with greater kyphosis were 2–3 years older and had two to three time greater prevalence of vertebral fracture than those

Table 1. Baseline Characteristics of Study Participants

Characteristic	Mean (*SD*) or *n* (%)	
	Women (*N* = 193)	Men (*N* = 82)
Age (years)	63 (5)	62 (5)
Height (cm)	158 (6)	172 (7)
Weight (kg)	64 (10)	80 (12)
Body mass index (kg/m^2)	26 (4)	27 (4)
Current smoker (%)	43 (22%)	19 (23%)
Alcohol consumption (oz/week)	2 (3)	6 (6)
Physical activity index (range 27–63)	34 (4)	37 (8)
Grip strength (kg)	27 (5)	50 (8)
Prevalent vertebral fracture (%)	35 (18%)	18 (22%)
Kyphosis angle (degrees; range 6–80°)	40 (13)	34 (14)

with less kyphosis (Table 2). However, there were little or no differences in height, weight, alcohol consumption, physical activity, or grip strength according to kyphosis angle. Frequency of current smokers appeared to increase with increasing tertile of kyphosis angle in women but to decrease with increasing tertile of kyphosis angle in men. However, these trends were not significant in either women or men.

At baseline, mean (±*SD*) FEV_1 was 2.06 L (±0.35) in women and 2.93 L (±0.49) in men. FEV_1 decreased with advancing age (Figure 1) and time from the first (1972–1976) through the fourth (1985–1988) assessment, which was on average 16 (±1.87) years (Figure 2). Mean decline in FEV_1 was 301 mL (±0.29) in women and 242 mL (±0.22) in men.

Age-adjusted mean decline in FEV_1 increased with severity of kyphosis in women: 161, 244, and 266 mL for Tertile 1 (lowest kyphosis angle), Tertile 2, and Tertile 3, respectively; trend, $p = .02$ (Table 3). Decline in FEV_1 did not increase with kyphosis angle in men but rather decreased (373, 299, and 252 mL for Tertile 1 through 3, respectively); however, the trend was not statistically significant ($p = .17$). Multivariable-adjusted estimates of decline in FEV_1 were similar to age-adjusted estimates. Finally, results for FVC (not shown) were similar to those for FEV_1 with decline in FVC increasing with tertile of kyphosis angle in women but not in men.

Discussion

This community-based study used radiographic measures of thoracic spine curvature and standardized pulmonary function testing to quantify change in lung function over 16 years in both women and men. We found that women with a more pronounced forward curvature of the thoracic spine had greater decline in lung function compared with women with a more erect posture. The association was independent of vertebral fracture and other potential confounders. Further, we observed an excess decline in FEV_1 of 100 mL over 16 years (6.3 mL/year) between women in the lowest and highest tertiles of kyphosis angle (FEV_1 = 161 and 261 mL, respectively). This amount is comparable with the average excess loss in FEV_1 associated with light smoking (less than 15 cigarettes per day) in women, estimated at 98 mL over 16 years (6.1 mL/year) (29).

No prospective studies have evaluated the impact of kyphosis severity on decline in lung function. However, our findings are consistent with cross-sectional studies that showed individuals with greater kyphosis have more severe pulmonary impairment (13–16). These cross-sectional studies were clinically based and included small numbers of older women with osteoporosis, or they compared lung function in patients with vertebral fractures to control patients. Di Bari and colleagues (30) conducted a cross-sectional study in a community-based sample of older women and men and

Table 2. Baseline Characteristics of Study Participants by Sex-specific Tertiles of Kyphosis Angle

	Baseline Kyphosis Angle (tertile)		
	Low[a]	Medium	High
Women (*N* = 193)	*n* = 64	*n* = 63	*n* = 66
Mean (*SD*), (degrees)	25 (7)	40 (4)	54 (7)
Range (degrees)	4–33	34–46	47–76
Characteristic	Mean (*SD*) or *n* (%)		
Age (years)	62 (5)	62 (4)	64 (5)
Height (cm)	158 (6)	159 (5)	158 (7)
Weight (kg)	63 (9)	65 (11)	64 (10)
Body mass index (kg/m²)	25 (3)	26 (4)	26 (3)
Current smokers (%)	11 (17%)	17 (27%)	15 (23%)
Alcohol consumption (oz/week)	3 (4)	3 (3)	2 (2)
Physical activity index (range 27–49)	34 (4)	34 (5)	33 (3)
Grip strength (kg)	27 (5)	27 (4)	27 (5)
Prevalent vertebral fracture (%)	5 (8%)	10 (16%)	20 (30%)
	Baseline Kyphosis Angle (tertile)		
	Low[a]	Medium	High
Men (*N* = 82)	*n* = 28	*n* = 27	*n* = 27
Mean (*SD*), (degrees)	19 (7)	34 (3)	49 (8)
Range (degrees)	6–28	29–39	40–80
Characteristic	Mean (*SD*) or *n* (%)		
Age (years)	60 (4)	63 (5)	63 (5)
Height (cm)	172 (6)	172 (6)	171 (8)
Weight (kg)	84 (11)	79 (11)	78 (14)
Body mass index (kg/m²)	28 (3)	27 (3)	27 (4)
Current smokers (%)	8 (29%)	6 (22%)	5 (19%)
Alcohol consumption (oz/week)	5 (5)	5 (5)	7 (7)
Physical activity index (range 27–63)	37 (7)	36 (7)	37 (9)
Grip strength (kg)	51 (7)	49 (7)	49 (8)
Prevalent vertebral fracture (%)	4 (15%)	8 (30%)	6 (22%)

Note: [a]Smallest (least severe) kyphosis angle.

also found that worse kyphosis, defined by occiput to wall distance and standing stature adjusted for tibia length, was associated with reduced FEV_1.

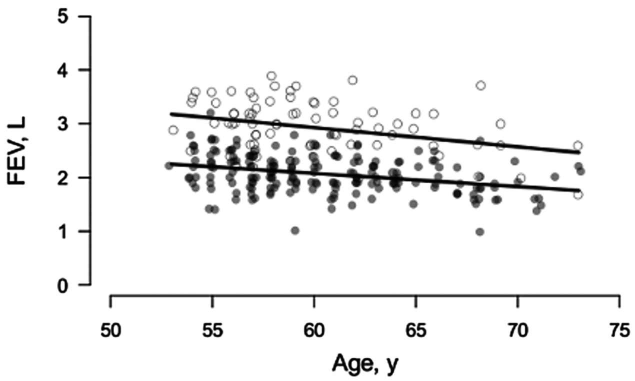

Figure 1. Forced expiratory volume in 1 second (FEV_1, L) according to baseline age (1972–1976) in women (closed circles) and men (open circles).

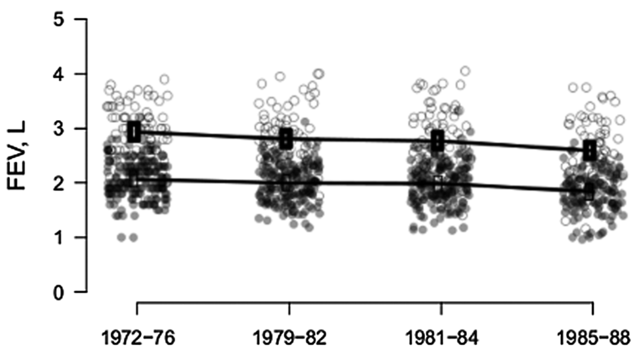

Figure 2. Forced expiratory volume in 1 second (FEV_1, L) over four assessments (1972–1988) in women (closed circles) and men (open circles).

Restrictive ventilatory impairment due to reduced thoracic volume is a plausible mechanism to explain the effect of increasing kyphosis severity on declining pulmonary function. In addition, as the anterior curvature of the thoracic spine increases and posture becomes more hunched, mobility in the thoracic rib cage is reduced, restricting thoracic and lung expansion during a maximal inspiratory maneuver. Kyphosis severity may also reduce pulmonary function by thoracic muscle weakness. Katzman and colleagues (31) found that men with worse kyphosis had lower spinal muscle density than men with less thoracic curvature. Together, excessive kyphosis and muscle weakness may disrupt thoracic cage mechanics and lead to reduced lung function.

Limitations of this study include a small sample size, particularly in men, and a potential for survivor bias. Participants for this study were selected from a longitudinal study of 25-year incidence of vertebral fracture (22). Thus, participants in the current study may have under-represented individuals with the most severe kyphosis and/or pulmonary disease, because each of these conditions increase mortality in older adults (1,25). As a result, our study may have underestimated the magnitude of the association between kyphosis angle and FEV_1. Of note, the association between kyphosis angle and decline in FEV_1 observed in women in this study was not present in men. The lack of association between kyphosis angle and FEV_1 in men may have been due to survivor bias playing a larger role in men than in women in this study, because smoking and mortality were significantly higher in men than in women during the time (1970s–1980s) of this study (32,33). The lower frequency of current smokers in men than women in the mid- to high tertiles of kyphosis angle and higher frequency of current smokers in men than women in the lowest tertile of kyphosis angle suggest that the potential for survivor bias may have been greater in men than in women in our study (34). In addition, it is possible that changes in smoking status may have obscured an association between severity of kyphosis and lung function, particularly in men. However, including smoking as a time-varying covariate did not change our results. Finally, the small

Table 3. Decline in FEV_1 Over 16 Years of Follow-up, According to Sex-specific Tertiles of Baseline Kyphosis Angle

Women (*N* = 193)			Decline in FEV_1			
Baseline Kyphosis Angle			Age-Adjusted		Multiply-Adjusted[b]	
Tertile	Mean (*SD*), (degrees)	Range (degrees)	Mean (mL)	95% CI	Mean (mL)	95% CI
Low[a]	25 (7)	4–33	161	100–221	162	101–222
Medium	40 (4)	34–46	244	183–306	245	184–306
High	54 (7)	47–76	261	201–322	261	200–322
Test for trend	—	—	p = .02	—	p = .02	—
Men (*N* = 82)			**Decline in FEV_1**			
Baseline Kyphosis Angle			Age-Adjusted		Multiply-Adjusted[b]	
Tertile	Mean (*SD*), degrees	Range (degrees)	Mean (mL)	95% CI	Mean (mL)	95% CI
Low[a]	19 (7)	6–28	373	249–496	372	249–496
Medium	34 (3)	29–39	299	184–413	297	182–412
High	49 (8)	40–80	252	131–372	257	136–378
Test for trend	—	—	p = .17	—	p = .20	—

Notes: CI = confidence interval; FEV_1 = forced expiratory volume in 1 second.
[a]Smallest (least severe) kyphosis angle.
[b]Adjusted for age, height, weight, prevalent vertebral fracture, current smoking, and physical activity.

number of men may have also reduced the ability of our study to detect associations in this group.

Our study had several strengths. This investigation is the first prospective study of thoracic curvature in relation to subsequent decline in lung function and included both women and men. We used repeated measures of lung function over more than a decade, assessed by spirometry, the clinical standard. In addition, assessment of kyphosis angle and vertebral fracture was based on radiographs using validated, standardized procedures. Information on many important confounders was obtained from comprehensive clinical examinations.

The present study suggests that greater severity of kyphosis increases the risk of pulmonary function decline. Interventions to prevent or slow the progression of kyphosis (35,36) may mitigate subsequent pulmonary decline which is an important determinant of morbidity and mortality in older adults (37).

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