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Association of Kyphotic Posture with Loss of Independence and Mortality Among Community-Dwelling Older Adults: The Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS)

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Abstract

Objectives: This study aimed to investigate the association between kyphotic posture and future loss of independence (LOI) and mortality in community-dwelling older adults.

Design: Prospective cohort study.

Setting: Two Japanese municipalities.

Participants: We enrolled 2,193 independent community-dwelling older adults aged ≥65 years at the time of their baseline health check-up in 2008. Kyphotic posture was evaluated using the wall-occiput test (WOT) and classified into three categories: non-kyphotic, mild (>0 and ≤4 cm), and severe (>4 cm).

Primary and secondary outcome measures: The primary outcome was mortality, whereas the secondary outcomes were LOI (new long-term care insurance certification levels 1–5) and a composite of LOI and mortality. A Cox proportional hazards model was used to estimate the adjusted hazard ratios (aHR).

Results: Of the 2,193 subjects enrolled, 1,621 were included in the primary analysis; among these, 272 (17%) and 202 (12%) were diagnosed with mild and severe kyphotic posture, respectively. After a median follow-up of 5.8 years, the aHRs for mortality were 1.17 (95% confidence interval [CI], 0.70–1.96) and 1.99 (95% CI, 1.20–3.30) in the mild and severe kyphotic posture groups, respectively. In the secondary analysis, a consistent association was observed for LOI (mild: aHR, 1.70; 95% CI, 1.13–2.55; severe: aHR, 2.08; 95% CI, 1.39–3.10) and the LOI–mortality composite (mild: aHR, 1.27; 95% CI, 0.90–1.79; severe: aHR, 1.83; 95% CI, 1.31–2.56).

Conclusion: Kyphotic posture was associated with LOI and mortality in community-dwelling older adults. Identifying the population with kyphotic posture using the WOT might help improve community health.

Strengths and limitations of this study:

- We demonstrated the association of kyphotic posture with loss of independence and mortality based on subjects from a general population.
- A high tracking ratio (98.5%) was achieved, which minimized the risk of information bias.
- We did not adjust for osteoporosis, a factor that might be associated with loss of independence and mortality through mechanisms other than kyphotic postures, such as fractures of the long bones.

Introduction

Kyphosis is described as an abnormal posture that develops because of the failure of the posture maintenance mechanism. When standing, lordotic segments (i.e., the cervical and lumbar spine) and kyphotic segments (i.e., the thoracic spine) must balance the occiput over the pelvic axis in an energy-efficient position. As the center of gravity of the trunk shifts forward via kyphosis in one segment of the spine, the other spinal segments, pelvis, hip joint, and knee joint cooperatively compensate to maintain overall sagittal balance.[1] Failure of this compensatory mechanism fails, the posture becomes kyphosis, giving rise to various health problems.[2,3] A kyphotic posture is common among older individuals, with a reported prevalence of 20–40%,[4] and is expected to increase as the population ages. Hence, the extent to which a kyphotic posture affects health is a serious concern.

Kyphotic posture reportedly has several deleterious effects on the afflicted individual's health, including a decline in physical function,[5] impairment in pulmonary function,[6,7] pain,[8] gastroesophageal reflux disease,[9] poor quality of life,[10] and accidental falls.[11,12] Therefore, there has been a growing concern regarding the association between kyphotic posture and serious health-related outcomes, such as loss of independence (LOI) and mortality.

Three previous studies have reported the association of kyphotic posture with LOI and mortality. First, Kado et al. demonstrated the association between cervicothoracic kyphosis and mortality.[13] As kyphosis was measured in the supine position rather than in the standing position, the evaluation of the kyphotic posture was not precise. In another study, Kado et al. reported an association of thoracic hyperkyphosis in the standing position with mortality in older women.[14] However, these two studies could not yield an assessment on whether the kyphotic posture was a risk factor for mortality in men. Okura et al. showed that kyphotic posture is related to LOI and mortality.[15] However, there was a potential bias since the study was passed on self-reported data from participants to determine kyphotic posture. Moreover, the researchers only controlled for age and gender as potential confounders. Furthermore, none of these studies adjusted for lumbar degenerative disease and back pain, which are strongly associated with kyphotic posture.

To address these concerns, we conducted a prospective cohort study to examine whether a kyphotic posture in the standing position was associated with LOI and mortality in community-dwelling men and women.

Materials and methods

Study Design and Population

This prospective observational study analyzed data from the Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS), a population-based study involving residents from two towns in Japan. The LOHAS evaluated the effect of locomotive dysfunction on healthcare outcomes, including quality of life, medical costs, and occurrence of LOI and mortality. The LOHAS comprised approximately 70% of all the National Health Insurance and Late-Stage Elderly Health Insurance beneficiaries in that region. Details of the study have been described elsewhere.[16]

Study Participants

Independent community-dwelling older adults aged ≥65 years without any long-term care insurance (LTCI) certification [17] at the time of their baseline health check-up in 2008 were enrolled. Those in whom kyphotic posture could not be determined due to missing data were excluded. Participants were observed starting from the baseline check-up in 2008 until March 2014.

This study was approved by certified institutional review boards (R1730 and 673) of the participating institutions, and all participants provided written informed consent before participation.

Definition of Kyphotic Posture

Kyphotic posture was defined using the wall-occiput test (WOT) at the time of musculoskeletal examination in 2008. The WOT is a semi-quantitative technique used to assess head forward posture in the standing position as well as thoracic vertebral fractures.[18,19] The WOT reflects not only thoracic hyperkyphosis, but also a loss of cervical and lumbar lordosis.

The distance (measured in cm) between the occiput prominence and the wall was measured using a tape while the participants were standing with both of their heels and sacrum against the wall and their head positioned such that an imaginary line from the lateral corner of the eye to the superior point of the auricle was parallel to the floor. In accordance with previous studies,[12,20] we divided the participants into the following three groups based on the degree of kyphosis: none, mild (>0, ≤4 cm), and severe (>4 cm).

Outcomes

The primary outcome was the mortality rate. Data on mortality and its causes were collected from death certificates provided by the Ministry of Health, Labour, and Welfare of Japan. The secondary outcome was the development of LOI, which was defined as a new LTCI certification of level 1–5 (i.e., a condition requiring any support for daily living). Information on LTCI certification status was obtained from the local government annually. The use of public data allowed us to access all outcome data, except for those participants who moved outside the target area.

Baseline Covariates

The following baseline covariates were analyzed as potential confounders for the relationship between kyphotic posture and mortality: age, sex, body mass index (categorized as <18.5, ≥18.5 and <25, and ≥25 kg/m^2, respectively), present smoking habits, lumbar spinal stenosis (LSS), low back pain (requiring treatment and lasting for more than 24 hours), health status (self-reported health: good, very good, or excellent vs. poor or very poor), stroke history, and handgrip strength (dominant hand). LSS was diagnosed using a validated diagnostic support tool for LSS.[21]

Statistical Analysis

The baseline characteristics of the participants were expressed as the presence or absence and the degree of kyphotic posture, using medians and interquartile ranges. Additionally, numbers and percentages were used for dichotomous variables.

The cumulative incidence method and log-rank test were employed to compare the intervals between the baseline and predetermined endpoint. Time 0 was considered as the date of each baseline check-up in 2008. Participants were censored after moving out of the target area or on March 31, 2014. After ascertaining that the proportional hazards assumption had not been violated, a Cox proportional hazards model with adjustment for possible confounders (i.e., the baseline covariates mentioned above) was used to investigate the association between the kyphotic posture and mortality. We conducted a sensitivity analysis with multiple imputations by chained equations of missing covariates, which included all variables (including outcomes) in the prediction model to generate 20 imputed datasets.

We performed four secondary analyses. First, we focused on LOI as a secondary outcome.

In that model, participants were censored after moving out of the target area, upon mortality, or on March 31, 2014. Second, we employed another Cox proportional hazard model to evaluate the composite outcome of LOI and mortality. Both models included the same covariates as those in the primary analysis. Third, we performed a subgroup analysis stratified by sex for the primary outcome of mortality. Finally, we analyzed cause-specific mortality in each group, similar to a previous study.[22] Four causes of death were evaluated: cancer, cardiovascular disease, respiratory disease, and others.

Statistical analyses were performed using Stata version 15.1 (StataCorp LLC, College Station, Texas, USA).

Patient and public involvement

There was no patient and public involvement.

Results

Baseline Characteristics

A total of 2,293 eligible participants from the 2008 LOHAS were identified. After excluding 100 subjects who did not undergo the WOT, a total of 2,193 participants were retained. The primary analysis included 1,621 participants without missing covariates. Fig. 1 shows the flow of subjects in this study.

Of the 1,621 participants enrolled in this study, 272 (17%) and 202 (12%) were diagnosed with mild and severe kyphotic posture, respectively (Table 1). The median age of all participants was 72 years, 61% were female, and 75% had good health status. The average age, proportion of overweight participants, and the proportion of participants with LSS and low back pain were high in the mild and severe kyphotic posture groups. The proportion of participants with good health status and average handgrip strength were low in these groups.

TABLE 1. Baseline Characteristics of Participants Without Missing Covariates

	Total	Kyphotic Posture		
		None	Mild (>0, ≤4 cm)	Severe (> 4 cm)
	n = 1621	*n* = 1147 (71)	*n* = 272 (17)	*n* = 202 (12)
Age, years	72 (68–76)	71 (67–74)	74 (70–78)	76 (72–80)
Sex, female	981 (61)	698 (61)	146 (54)	137 (68)
Body mass index, kg/m^2				
<18.5	57 (4)	43 (4)	7 (3)	7 (3)
≤18.5, <25	1042 (64)	756 (66)	175 (64)	111 (55)
≥25	522 (32)	348 (30)	90 (33)	84 (42)
Smoking habit	151 (9)	105 (9)	31 (11)	15 (7)
Lumbar spinal stenosis	274 (17)	175 (15)	53 (19)	46 (23)
Low back pain	131 (8)	84 (7)	25 (9)	22 (11)
Self-reported good health status	1221 (75)	878 (77)	197 (72)	146 (72)
Stroke history	87 (5)	54 (5)	15 (6)	18 (9)
Handgrip strength, kgw	26 (22–34.5)	27 (22–35)	26 (21.25–35)	22 (18.5–28)

Note. Data are presented as n (%) and mean (interquartile range).

Primary Analysis and Sensitivity Analysis

The cumulative mortality rates according to the degree of kyphosis are presented in Fig. 2. After a median follow-up of 5.8 years, participants with mild and severe kyphotic posture showed higher cumulative mortality rates (8% and 13%, respectively) than those without kyphotic posture (5%). The tracking ratio at the end of the study was 98.5%. The mortality rates were 0.008 per year in the non-kyphotic posture group, 0.014 per year in the mild kyphotic posture group, and 0.023 per year in the severe kyphotic posture group (Table 2), with the log-rank test indicating a difference among the groups (P <0.001). Cox regression analysis showed that participants with mild and severe kyphotic posture had higher rates of mortality than those without kyphotic posture, with adjusted hazard ratios (aHRs) of 1.17 (95% confidence interval [CI], 0.70–1.96), and 1.99 (95% CI, 1.20–3.30) respectively. A sensitivity analysis using imputed datasets revealed results similar to those of the primary analysis (aHR, 1.15 [95% CI, 0.71–1.87] and 2.15 [95% CI, 1.35–3.41], respectively; Supplementary table 1).

TABLE 2. Cox Proportional Hazards Model of Mortality According to the Degree of Kyphosis

	Number of Participants	Mortality	Occurrence Rate/Year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1147	54 (5)	0.008	Ref.	Ref.
Mild	272	22 (8)	0.014	1.74 (1.06, 2.85)	1.17 (0.70, 1.96)
Severe	202	26 (13)	0.023	2.83 (1.77, 4.52)	1.99 (1.20, 3.30)

Note. Data are presented as n (%).

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, health status, stroke history, and handgrip strength.

Secondary Analysis

The rates of LOI were 0.013 per year in the non-kyphotic posture group, 0.036 per year in the mild kyphotic posture group, and 0.048 per year in the severe kyphotic posture group (Table 3). Overall, subjects with mild and severe kyphotic posture had higher rates of LOI than those without kyphotic posture (aHR, 1.70 [95% CI, 1.13–2.55] and 2.08 [95% CI, 1.39–3.10], respectively).

TABLE 3. Cox Proportional Hazards Model of Loss of Independence According to the Degree of Kyphosis

	Number of Participants	Loss of Independence	Occurrence Rate/Year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1147	82 (7)	0.013	Ref.	Ref.
Mild	272	38 (14)	0.026	2.38 (1.61–3.52)	1.70 (1.13–2.55)
Severe	202	51 (25)	0.048	3.63 (2.52–5.22)	2.08 (1.39–3.10)

Note: Data are presented as n (%).

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, health status, stroke history, and handgrip strength.

Consistent results were obtained for the composite outcome of LOI and mortality (Table 4). Participants with mild and severe kyphotic posture had higher rates of LOI and mortality than those without kyphotic posture (aHR, 1.27 [95% CI, 0.90–1.79] and 1.83 [95% CI, 1.31–2.56], respectively).

TABLE 4. Cox Proportional Hazards Model of Loss of Independence and Mortality According to the Degree of Kyphosis

	Number of Participants	Loss of Independence and Mortality	Occurrence Rate/Year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1147	122 (11)	0.02	Ref.	Ref.
Mild	272	52 (19)	0.033	1.78 (1.28–2.50)	1.27 (0.90–1.79)
Severe	202	60 (30)	0.062	2.93 (2.16–3.98)	1.83 (1.31–2.56)

Note. Data are presented as n (%).

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, health status, history of stroke, and handgrip strength.

We conducted a subgroup analysis stratified by sex, which indicated that males had a higher cumulative rate of mortality (10%, 0.018 per year) than females (4%, 0.007 per year). Male sex also showed a more pronounced association between kyphotic posture and mortality (Table 5).

TABLE 5. Cox Proportional Hazards Model of Mortality According to the Degree of Kyphosis Stratified by sex

	Number of Subjects	Mortality	Occurrence Rate/Year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]

Male	640	64 (10)	0.018		
Kyphotic posture					
None	449	32 (7)	0.013	Ref.	Ref.
Mild	126	19 (15)	0.028	2.19 (1.24, 3.87)	1.64 (0.91, 2.95)
Severe	65	13 (20)	0.037	2.97 (1.56, 5.65)	2.31 (1.17, 4.56)
Female	981	38 (4)	0.007		
Kyphotic posture					
None	698	22 (3)	0.006	Ref.	Ref.
Mild	146	3 (2)	0.004	0.64 (0.19, 2.15)	0.50 (0.15, 1.73)
Severe	137	13 (9)	0.017	3.10 (1.56, 6.14)	1.55 (0.70, 3.45)

Note. Data are presented as n (%).

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, body mass index, smoking habit, lumbar spinal stenosis, low back pain, health status, stroke history, and handgrip strength.

The causes of mortality in each group are presented in Fig. 3. The rate of mortality due to respiratory diseases was higher in the severe kyphotic posture group (6 [16%] vs. 5 [7%] in the non-kyphotic posture group and 2 [7%] in the mild kyphotic posture group).

Discussion

In the present study, we explored the association between kyphotic posture and mortality using data from a relatively large sample. The kyphotic posture detected with the WOT appeared to affect mortality in a way not explained by age, sex, body mass index, smoking, LSS, low back pain, health status, history of stroke, and handgrip strength. Furthermore, a dose-response relationship was observed in the association; the presence of severe kyphotic posture was related to a two-fold increase in the risk of mortality than non-kyphotic posture. Additionally, kyphotic posture was associated with LOI, and the association between kyphotic posture and mortality was more pronounced in men.

Kado et al. reported that cervicothoracic kyphosis measured in the supine position was associated with mortality in older men and women; they did not observe any sex-specific differences in their study.[13] They also showed that the degree of thoracic hyperkyphosis in the standing position had a predictive value for mortality among older women, in addition to osteoporotic vertebral fractures (OVFs).[14] Our results were similar to those from previous studies, which showed that kyphotic posture was associated with mortality. Additionally, we believe that the present study has the advantage of using the WOT, which measures kyphosis in the standing position and reflects overall sagittal balance. To properly assess the degree of kyphosis, subjects should be in the standing position with their hips and knees fully extended to negate the compensatory mechanisms [23]. With the subjects in the supine position, kyphotic posture may be corrected by a non-physiologic hyper-extensive force so that the degree of kyphosis is consistently underestimated. Furthermore, as described above, kyphotic posture develops due to the failure of the posture maintenance mechanism. When evaluating kyphotic posture, it is necessary to focus not only on one segment, such as the thoracic spine, but also on the alignment of the whole spine.

In the subgroup analysis by sex, the association between kyphotic posture and mortality seemed to be more pronounced in men, although no clear sex difference in mortality was shown in the present study. Sex differences in the prevalence of vertebral fractures have been reported, [24,25] and the nature of kyphosis may differ between men and women. Further studies that subcategorize kyphosis by vertebral fractures might reveal sex differences categorized by kyphotic posture.

Explanations and Implications

We hypothesized two possible explanations for the association between kyphotic posture and mortality. First, we considered that mortality is an outcome of locomotive dysfunction. Several previous studies have reported that kyphotic posture is associated with locomotive dysfunction.[5,11,12,26,27] According to Tominaga et al., severe kyphotic posture measured by the WOT is associated with an increased incidence of falls in men.[12] Katzman et al. indicated an association of cervicothoracic kyphosis in the supine position with impaired lower extremity physical function among older men.[27] Hence, the effect of kyphotic posture might be prominent in men and associated with increased mortality. Early mortality may also be attributable to another possible mechanism. Multiple previous studies have shown that kyphotic posture may be associated with worse health, including diminished pulmonary function.[6,7] Notably, a previous report suggested that those with kyphotic posture were more likely to die of a pulmonary cause.[13] Although no statistical comparison was performed due to a lack of power, our study showed that the proportion of respiratory deaths among those with severe kyphotic posture was high.

The results of the present study suggest that kyphotic posture is a clinically important finding, and further studies on the effects of the prevention and treatment of kyphotic posture are needed. Noticeably, our study demonstrates that the WOT is helpful in predicting serious healthcare outcomes. Among men, those with mild and severe kyphotic posture identified by WOT were shown to have a 2.2-fold and 3-fold increased risk of mortality, respectively. The WOT is easy, inexpensive, and does not require special skills or devices, making it an attractive clinical tool for the identification of high-risk population. Approximately 40% of older adults with the worst degrees of kyphosis have underlying OVFs,[24,25] and OVFs are widely thought to be a major factor contributing to the development of kyphotic posture. Therefore, osteoporosis treatment may help prevent kyphotic posture via a reduction in the occurrence of OVFs. In addition to structural changes in the vertebral column, back extensor weakness is also associated with a kyphotic posture.[28-30] Despite limited evidence, some reports suggest that exercise may modestly improve back extensor muscle strength [31].

Strengths and Limitations

The present study has significant strengths. First, we demonstrated the association of kyphotic posture with LOI and mortality in a community-dwelling population. We believe that the present study is valuable in investigating the longitudinal development of serious healthcare outcomes based on samples from a general population. Second, we used public data, which provided us with reliable and complete information on outcomes, except for participants who moved out of the target area. As relocation was rare, a high tracking ratio (98.5%) was achieved, which minimized the risk of information bias.

Nevertheless, this study has several limitations. First, we did not adjust our dataset for osteoporosis. We did not adjust for OVFs because we were interested not only in kyphosis independent of OVFs, but in overall kyphotic postures, including the ones caused by OVFs. However, osteoporosis may be associated with LOI and mortality through other mechanisms. Second, the WOT does not distinguish rigid kyphosis from flexible kyphosis. To evaluate spinal flexibility, evaluations in both the standing and supine positions need to be performed. The WOT also does not identify participants who can maintain good non-kyphotic posture only for a short

309 period during measurement. No evaluation method has overcome this problem, and the
310 development of a new method, such as continuous posture analysis, is warranted. Finally,
311 attributing causation is difficult because of other unmeasured confounders, including subclinical
312 diseases. It should be noted that the present study does not provide evidence to support surgical
313 interventions to correct kyphosis. Surgical reconstruction should not be routinely performed in
314 elderly individuals with a typical high-risk profile.

315

316 **Conclusions**

317 Kyphotic posture is associated with LOI and mortality. Therefore, identifying older people with
318 kyphotic posture using the WOT in the community might help identify high-risk populations that
319 would benefit from healthcare interventions.

References

1. Schwab F, Lafage V, Boyce R, et al. Gravity line analysis in adult volunteers: age-related correlation with spinal parameters, pelvic parameters, and foot position. *Spine (Phila Pa 1976)*. 2006;31:959–67.
2. Farcy JP, Schwab FJ. Management of flatback and related kyphotic decompensation syndromes. *Spine (Phila Pa 1976)*. 1997;229:2452–7.
3. Ailon T, Shaffrey CI, Lenke LG, et al. Progressive spinal kyphosis in the aging population. *Neurosurgery*. 2015;774:164–72.
4. Kado DM, Prenovost K, Crandall C. Narrative review: hyperkyphosis in older persons. *Ann Intern Med*. 2007;147:330–8.
5. Eum R, Leveille SG, Kiely DK, et al. Is kyphosis related to mobility, balance, and disability? *Am J Phys Med Rehabil*. 2013;92:980–9.
6. Culham EG, Jimenez HA, King CE. Thoracic kyphosis, rib mobility, and lung volumes in normal women and women with osteoporosis. *Spine (Phila Pa 1976)*. 1994;19:1250–5.
7. Lee SJ, Chang JY, Ryu YJ, et al. Clinical features and outcomes of respiratory complications in patients with thoracic hyperkyphosis. *Lung*. 2015;193:1009–15.
8. Ensrud KE, Black DM, Harris F, et al. Correlates of kyphosis in older women. The Fracture Intervention Trial Research Group. *J Am Geriatr Soc*. 1997;45:682–7.
9. Imagama S, Ando K, Kobayashi K, et al. Increase in lumbar kyphosis and spinal inclination, declining back muscle strength, and sarcopenia are risk factors for onset of GERD: a 5-year prospective longitudinal cohort study. *Eur Spine J*. 2019;28:2619–28.
10. Imagama S, Hasegawa Y, Matsuyama Y, et al. Influence of sagittal balance and physical

ability associated with exercise on quality of life in middle-aged and elderly people. *Arch Osteoporos*. 2011;6:13–20.

11. McDaniels-Davidson C, Davis A, Wing D, et al. Kyphosis and incident falls among community-dwelling older adults. *Osteoporos Int*. 2018;29:163–9.

12. Tominaga R, Fukuma S, Yamazaki S, et al. Relationship between kyphotic posture and falls in community-dwelling men and women: the Locomotive Syndrome and Health Outcome in Aizu Cohort Study. *Spine (Phila Pa 1976)*. 2016;41:1232–8.

13. Kado DM, Huang MH, Karlamangla AS, et al. Hyperkyphotic posture predicts mortality in older community-dwelling men and women: a prospective study. *J Am Geriatr Soc.* 2004;52:1662–7.

14. Kado DM, Lui LY, Ensrud KE, et al. Hyperkyphosis predicts mortality independent of vertebral osteoporosis in older women. *Ann Intern Med.* 2009;150:681–7.

15. Okura M, Ogita M, Yamamoto M, et al. Self-assessed kyphosis and chewing disorders predict disability and mortality in community-dwelling older adults. *J Am Med Dir Assoc*. 2017;18:550.e1–6.

16. Otani K, Takegami M, Fukumori N, et al. Locomotor dysfunction and risk of cardiovascular disease, quality of life, and medical costs: design of the Locomotive Syndrome and Health Outcome in Aizu Cohort Study (LOHAS) and baseline characteristics of the study population. *J Orthop Sci.* 2012;17:261–71.

17. Campbell JC, Ikegami N. Long-term care insurance comes to Japan. *Health Aff (Millwood)*. 2000;19:26–39.

18. Green AD, Colon-Emeric CS, Bastian L, et al. Does this woman have osteoporosis? *JAMA*. 2004;292:2890–900.

19. Ziebart C, Adachi JD, Ashe MC, et al. Exploring the association between number, severity, location of fracture, and occiput-to-wall distance. *Arch Osteoporos*. 2019;14:27.

20. Siminoski K, Warshawski RS, Jen H, et al. The accuracy of clinical kyphosis examination for detection of thoracic vertebral fractures: comparison of direct and indirect kyphosis measures. *J Musculoskelet Neuronal Interact*. 2011;11:249–56.

21. Konno S, Kikuchi S, Tanaka Y, et al. A diagnostic support tool for lumbar spinal stenosis: a self-administered, self-reported history questionnaire. *BMC Musculoskelet Disord*. 2007;8:102.

22. Yamazaki H, Kamitani T, Matsui T, et al. Association of low alanine aminotransferase with loss of independence or death: a 5-year population-based cohort study. *J Gastroenterol Hepatol*. 2019;34:1793–9.

23. Horton WC, Brown CW, Bridwell KH, et al. Is there an optimal patient stance for obtaining a lateral 36" radiograph? A critical comparison of three techniques. *Spine (Phila Pa 1976)*. 2005;30:427–33.

24. Schneider DL, von Muhlen D, Barrett-Connor E, et al. Kyphosis does not equal vertebral fractures: the Rancho Bernardo study. *J Rheumatol.* 2004;31:747–52.

25. Kado DM, Browner WS, Palermo L, et al. Vertebral fractures and mortality in older women: a prospective study. Study of Osteoporotic Fractures Research Group. *Arch Intern Med*. 1999;159:1215–20.

26. Kado DM, Huang MH, Barrett-Connor E, et al. Hyperkyphotic posture and poor physical functional ability in older community-dwelling men and women: the Rancho Bernardo study. *J Gerontol A Biol Sci Med Sci*. 2005;60:633–7.

27. Katzman WB, Harrison SL, Fink HA, et al. Physical function in older men with

hyperkyphosis. *J Gerontol A Biol Sci Med Sci*. 2015;70:635–40.

28. Sinaki M, Itoi E, Rogers JW, et al. Correlation of back extensor strength with thoracic kyphosis and lumbar lordosis in estrogen-deficient women. *Am J Phys Med Rehabil*. 1996;75:370–4.

29. Laroche M, Delisle MB, Aziza R, et al. Is camptocormia a primary muscular disease? *Spine (Phila Pa 1976)*. 1995;20:1011–6.

30. Menezes-Reis R, Bonugli GP, Salmon CEG, et al. Relationship of spinal alignment with muscular volume and fat infiltration of lumbar trunk muscles. *PLoS One*. 2018;13:e0200198.

31. Bansal S, Katzman WB, Giangregorio LM. Exercise for improving age-related hyperkyphotic posture: a systematic review. *Arch Phys Med Rehabil*. 2014;95:129–40.

Figure legends

Fig. 1. Flow diagram of eligible participants.

WOT: wall-occiput test; LOHAS: Locomotive Syndrome and Health Outcomes in Aizu Cohort Study

Fig. 2. Cumulative incidence of mortality. Subjects were divided into the following three groups according to the degree of kyphotic posture: none, mild (> 0, ≤ 4 cm), and severe (> 4 cm).

Fig. 3. Cause-specific deaths in each group. Subjects were divided into the following three groups according to the degree of kyphosis: non-kyphotic, mild (> 0, ≤ 4 cm), and severe (> 4 cm).

Footnotes

Contributors: Conception and design of the study: YH, TK, SF, YY; Acquisition of data: MS, KO, SK, MT; Analysis and interpretation of data: YH, TK, SF, YY; Drafting the article or revising it critically for important intellectual content: YH, TK, MS, KO, SK, MT, SF, YY; Final approval of the version to be submitted: YH, TK, MS, KO, SK, MT, SF, YY.

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Competing interests: None declared.

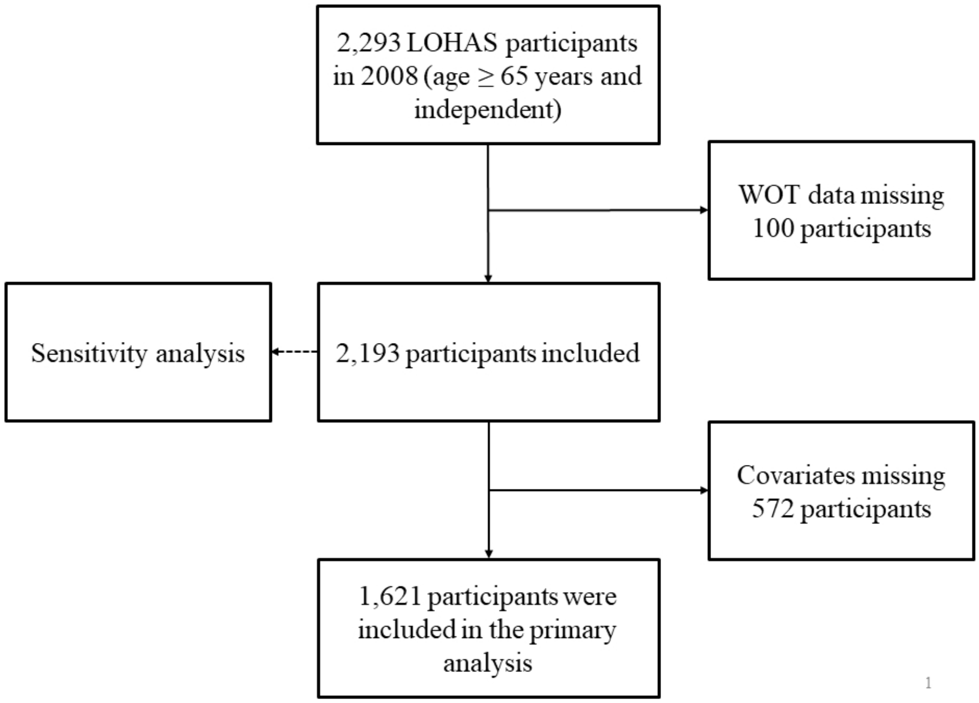

Fig. 1. Flow diagram of eligible participants.
WOT: wall-occiput test; LOHAS: Locomotive Syndrome and Health Outcomes in Aizu Cohort Study

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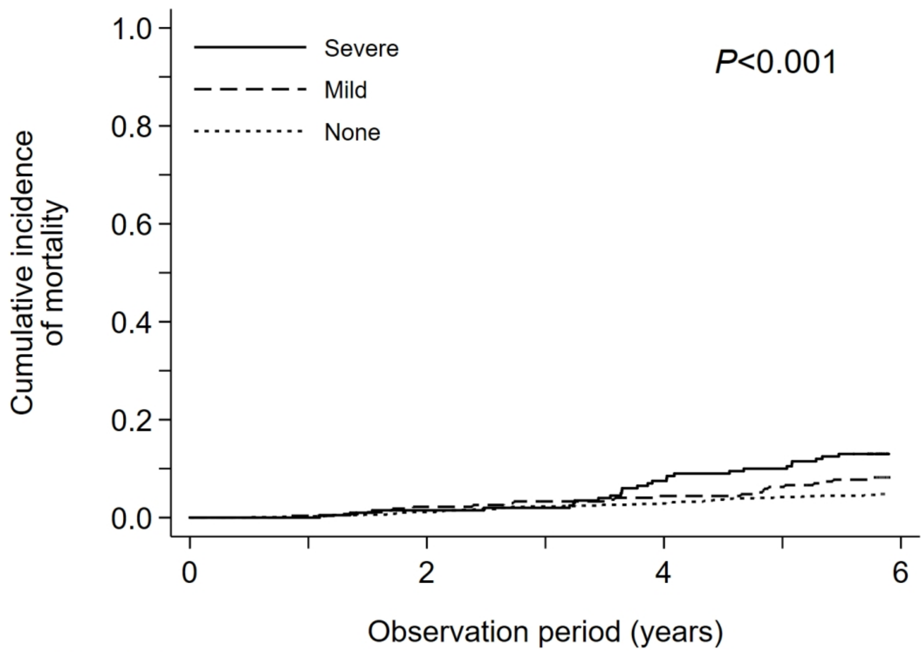

Number at risk

None	1147	1143	1131	1117	1104	1086
Mild	272	271	266	262	259	254
Severe	202	201	197	196	185	180

Fig. 2. Cumulative incidence of mortality. Subjects were divided into the following three groups according to the degree of kyphotic posture: none, mild (> 0, ≤ 4 cm), and severe (> 4 cm).

549x475mm (72 x 72 DPI)

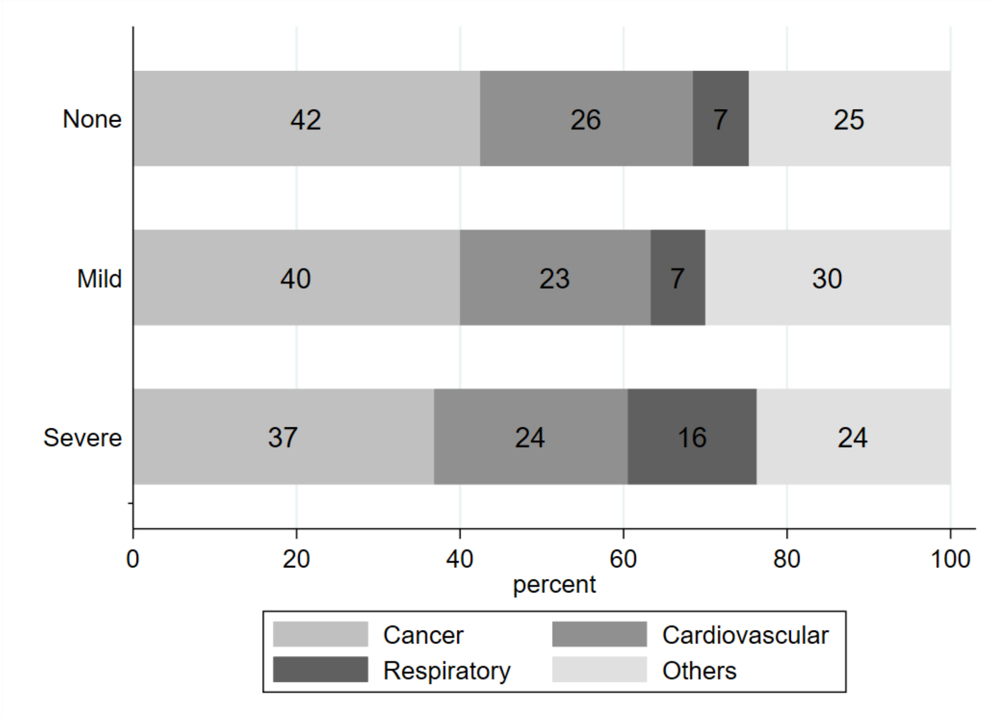

Fig. 3. Cause-specific deaths in each group. Participants were divided into the following three groups according to the degree of kyphosis: None, Mild (> 0, ≤ 4 cm), and Severe (> 4 cm).

366x266mm (72 x 72 DPI)

Supplemental Material 1

Supplemental material for: "Association of Kyphotic Posture with Loss of Independence and Mortality Among Community-Dwelling Older Adults: The Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS)"

Supplemental Table 1. Sensitivity Analysis with Multiple Imputation for Mortality According to the Degree of Kyphosis

	Number of Participants	Mortality	Occurrence Rate/Year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1525	73 (5)	0.009	Ref.	Ref.
Mild	369	30 (8)	0.015	1.72 (1.13–2.64)	1.19 (0.77–1.84)
Severe	299	38 (13)	0.023	2.76 (1.86–4.08)	1.80 (1.17–2.77)

Note: Data are presented as n (%).

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, health status, history of stroke, and handgrip strength.

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	6
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	No
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8
		(*b*) Describe any methods used to examine subgroups and interactions	9
		(*c*) Explain how missing data were addressed	8
		(*d*) If applicable, explain how loss to follow-up was addressed	8
		(*e*) Describe any sensitivity analyses	8
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	9
		(b) Give reasons for non-participation at each stage	9
		(c) Consider use of a flow diagram	9
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	9
		(b) Indicate number of participants with missing data for each variable of interest	No
		(c) Summarise follow-up time (eg, average and total amount)	10
Outcome data	15*	Report numbers of outcome events or summary measures over time	11

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11
		(*b*) Report category boundaries when continuous variables were categorized	-
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	12
Discussion			
Key results	18	Summarise key results with reference to study objectives	14
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	17
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	16
Generalisability	21	Discuss the generalisability (external validity) of the study results	17
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	24

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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Association of kyphotic posture with loss of independence and mortality in a community-based prospective cohort study: The Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS)

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Association of kyphotic posture with loss of independence and mortality in a community-based prospective cohort study: The Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS)

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Abstract

Objectives: This study aimed to investigate the association between kyphotic posture and future loss of independence (LOI) and mortality in community-dwelling older adults.

Design: Prospective cohort study.

Setting: Two Japanese municipalities.

Participants: We enrolled 2,193 independent community-dwelling older adults aged ≥65 years at the time of their baseline health check-up in 2008. Kyphotic posture was evaluated using the wall-occiput test (WOT) and classified into three categories: non-kyphotic, mild (>0 and ≤4 cm), and severe (>4 cm).

Primary and secondary outcome measures: The primary outcome was mortality and the secondary outcomes were LOI (new long-term care insurance certification levels 1–5) and a composite of LOI and mortality. A Cox proportional hazards model was used to estimate the adjusted hazard ratios (aHRs).

Results: Of the 2,193 subjects enrolled, 1,621 were included in the primary analysis. Among these, 272 (17%) and 202 (12%) were diagnosed with mild and severe kyphotic posture, respectively. The median follow-up time was 5.8 years. Compared to the non-kyphotic group, the aHRs for mortality were 1.17 (95% confidence interval [CI], 0.70–1.96) and 1.99 (95% CI, 1.20–3.30) in the mild and severe kyphotic posture groups, respectively. In the secondary analysis, a consistent association was observed for LOI (mild: aHR, 1.70; 95% CI, 1.13–2.55; severe: aHR, 2.08; 95% CI, 1.39–3.10) and the LOI–mortality composite (mild: aHR, 1.27; 95% CI, 0.90–1.79; severe: aHR, 1.83; 95% CI, 1.31–2.56).

Conclusion: Kyphotic posture was associated with LOI and mortality in community-dwelling older adults. Identifying the population with kyphotic posture using the WOT might help improve

community health.

Strengths and limitations of this study:

- The results were obtained from a relatively large cohort of a community-based population.
- Only 1.5% (31) of the 2,193 participants included in the study were lost to follow up due to change of residence from the target area, which minimized the risk of information bias.
- We did not adjust for osteoporosis, a factor that might be associated with loss of independence and mortality through mechanisms other than kyphotic postures, such as fractures of the long bones.
- The wall-occiput test does not distinguish rigid kyphosis from flexible kyphosis.
- Attributing causation is difficult because of other unmeasured confounders, including subclinical diseases.

Introduction

Kyphosis is described as an abnormal posture that develops because of the failure of the posture maintenance mechanism. When standing, lordotic segments (i.e., the cervical and lumbar spine) and kyphotic segments (i.e., the thoracic spine) must balance the occiput over the pelvic axis in an energy-efficient position. As the centre of gravity of the trunk shifts forward due to kyphosis in one segment of the spine, the other spinal segments, pelvis, hip joint, and knee joint cooperatively compensate to maintain overall sagittal balance.[1] Failure of this compensatory mechanism results in kyphotic posture, leading to various health problems.[2,3] A kyphotic posture is common among older individuals, with a reported prevalence of 20–40%,[4] and is expected to increase as the population ages. Hence, the extent to which a kyphotic posture affects health is a serious concern.

Several deleterious effects of kyphotic posture on the afflicted individual's health have been reported, including a decline in physical function,[5] impairment in pulmonary function,[6,7] pain,[8] gastroesophageal reflux disease,[9] poor quality of life,[10,11] and accidental falls.[12,13] Therefore, there has been a growing concern regarding the association between kyphotic posture and serious health-related outcomes, such as loss of independence (LOI) and mortality.

Three previous studies reported an association of kyphotic posture with LOI and mortality. First, Kado et al. demonstrated the association between cervicothoracic kyphosis and mortality.[14] It should be noted that, as kyphosis was measured in the supine position rather than in the standing position, the evaluation of the kyphotic posture was not precise. In another study, Kado et al. reported an association of thoracic hyperkyphosis in the standing position with mortality in older women.[15] Nonetheless, these two studies could not assess whether the kyphotic posture was a risk factor for mortality in men. Okura et al. showed that kyphotic posture is related to LOI and mortality.[16] However, there was a potential bias in this study, as the determination of kyphotic posture was based on self-reported data from participants. Moreover, the researchers only controlled for age and sex as potential confounders. Furthermore, none of these studies adjusted for lumbar degenerative disease and back pain, which are strongly associated with kyphotic posture.

To address these concerns, we conducted a prospective cohort study to examine whether a kyphotic posture in the standing position was associated with LOI and mortality in community-dwelling men and women.

Materials and methods

Study Design and Population

This prospective observational study analyzed data from the Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS), a population-based study involving residents from two towns in Japan. The LOHAS evaluated the effect of locomotive dysfunction on healthcare outcomes, including quality of life, medical costs, and occurrence of LOI and mortality. The LOHAS comprised approximately 70% of all the National Health Insurance and Late-Stage Elderly Health Insurance beneficiaries in that region. Details of the study have been described elsewhere.[17]

Study Participants

Independent community-dwelling older adults aged ≥65 years without any long-term care insurance (LTCI) certification [18] at the time of their baseline health check-up in 2008 were enrolled. Those in whom kyphotic posture could not be determined due to missing data were excluded. Participants were observed starting from the baseline check-up in 2008 until March 2014. This study was approved by certified institutional review boards (R1730 and 673) of the participating institutions, and all participants provided written informed consent before participation.

Definition of Kyphotic Posture

Kyphotic posture was defined using the wall-occiput test (WOT) at the time of musculoskeletal examination in 2008. The WOT is a semi-quantitative technique used to assess head forward posture in the standing position as well as thoracic vertebral fractures.[19,20] The WOT reflects not only thoracic hyperkyphosis, but also a loss of cervical and lumbar lordosis.

The distance (in cm) between the occiput prominence and the wall was measured using a tape while the participants were standing with both of their heels and sacrum against the wall and their head positioned such that an imaginary line from the lateral corner of the eye to the superior point of the auricle was parallel to the floor. In accordance with previous studies,[13,21] we divided the participants into the following three groups based on the degree of kyphosis: none, mild (>0, ≤4 cm), and severe (>4 cm).

Outcomes

The primary outcome was the time to mortality. Data on mortality and its causes were collected from death certificates provided by the Ministry of Health, Labour, and Welfare of Japan. The secondary outcome was the development of LOI, which was defined as a new LTCI certification of level 1–5 (i.e., a condition requiring any support for daily living). Information on LTCI certification status was obtained from the local government annually. The use of public data allowed us to access all outcome data, except for those participants who changed their residence outside the target area.

Baseline Covariates

The following baseline covariates were analysed as potential confounders for the relationship between kyphotic posture and mortality: age, sex, body mass index (categorized as <18.5, ≥18.5 and <25, and ≥25 kg/m^2), present smoking habits, lumbar spinal stenosis (LSS), low back pain (requiring treatment and lasting for more than 24 h), good health status (self-reported health: good, very good, or excellent), stroke history, and handgrip strength (dominant hand). LSS was diagnosed using a validated diagnostic support tool for specifically designed for this purpose.[22] Handgrip strength was measured using a digital dynamometer (Takei Scientific Instruments Co., Ltd, Japan).

Statistical Analysis

The baseline characteristics of the participants were expressed as the presence or absence and the degree of kyphotic posture, using medians and interquartile ranges. Additionally, absolute and relative frequencies were used for dichotomous or categorical variables.

The cumulative incidence method and log-rank test were applied to compare the intervals between the baseline and date of mortality. The date of each baseline check-up in 2008 was considered as Time 0. Participants were censored after changing their residence out of the target area or on March 31, 2014. After confirming that the proportional hazards assumption had not been violated, a Cox proportional hazards model with adjustment for possible confounders (i.e., age, sex, body mass index, smoking habit, LSS, low back pain, good health status, stroke history, and handgrip strength) was used to investigate the association between the kyphotic posture and mortality. We conducted a sensitivity analysis with multiple imputations by chained equations of missing covariates, which included all variables (including outcomes) in the prediction model to generate 20 imputed datasets.

We performed four secondary analyses. First, we focused on LOI as a secondary outcome. In that model, participants were censored after moving out of the target area, upon mortality, or on March 31, 2014. Second, we employed another Cox proportional hazard model to evaluate the composite outcome of LOI and mortality. Both models included the same covariates as those in the primary analysis. For these secondary analyses, we performed sensitivity analyses using multiple imputations as in the main analysis. Third, we performed a subgroup analysis stratified by sex for the primary outcome of mortality. Finally, we analyzed cause-specific mortality in each group, as in a previous study.[23] Four causes of death were evaluated: cancer, cardiovascular disease, respiratory disease, and others.

Statistical analyses were performed using Stata version 15.1 (StataCorp LLC, College Station, Texas, USA).

Patient and public involvement

There was no patient and public involvement in this study.

Results

Baseline Characteristics

A total of 2,294 eligible participants from the 2008 LOHAS were identified. After excluding 101 subjects who did not undergo the WOT, a total of 2,193 participants were retained. The primary analysis included 1,621 participants without missing covariates. Fig. 1 shows the flow diagram of subjects in this study.

Of the 1,621 participants enrolled in this study, 272 (17%) and 202 (12%) were diagnosed with mild and severe kyphotic posture, respectively (Table 1). The median age of all participants was 72 years, 61% were female, and 75% had good health status. The average age, the proportion of overweight participants (body mass index ≥25 kg/m^2), and the proportion of participants with LSS and low back pain were high in the mild and severe kyphotic posture groups compared to the non-kyphotic posture group. The proportions of participants with good health status and average handgrip strength were low in these groups.

TABLE 1. Baseline characteristics of participants without missing covariates

	Total	Kyphotic posture		
		None	Mild (>0, ≤4 cm)	Severe (>4 cm)
	n = 1621	*n* = 1147 (71)	*n* = 272 (17)	*n* = 202 (12)
Age, years	72 (68–76)	71 (67–74)	74 (70–78)	76 (72–80)
Female sex	981 (61)	698 (61)	146 (54)	137 (68)
Body mass index, kg/m^2				
<18.5	57 (4)	43 (4)	7 (3)	7 (3)
≤18.5, <25	1042 (64)	756 (66)	175 (64)	111 (55)
≥25	522 (32)	348 (30)	90 (33)	84 (42)
Smoking habit	151 (9)	105 (9)	31 (11)	15 (7)

Lumbar spinal stenosis	274 (17)	175 (15)	53 (19)	46 (23)
Low back pain	131 (8)	84 (7)	25 (9)	22 (11)
Good health status	1221 (75)	878 (77)	197 (72)	146 (72)
Stroke history	87 (5)	54 (5)	15 (6)	18 (9)
Handgrip strength, kgw	26 (22–34.5)	27 (22–35)	26 (21.25–35)	22 (18.5–28)

Note. Data are presented as n (%) or median and interquartile range.

Primary Analysis and Sensitivity Analysis

The cumulative mortality rates according to the degree of kyphosis are presented in Fig. 2. The median follow-up time was 5.8 years. The participants with mild and severe kyphotic posture showed higher cumulative mortality rates (8% and 13%, respectively) than those without kyphotic posture (5%). The tracking ratio at the end of the study was 98.5%. The mortality rates were 0.008 per year in the non-kyphotic posture group, 0.014 per year in the mild kyphotic posture group, and 0.023 per year in the severe kyphotic posture group (Table 2), with the log-rank test indicating a difference among the groups (P <0.001). Cox regression analysis showed that participants with mild and severe kyphotic posture had higher rates of mortality than those without kyphotic posture, with adjusted hazard ratios (aHRs) of 1.17 (95% confidence interval [CI], 0.70–1.96), and 1.99 (95% CI, 1.20–3.30), respectively. A sensitivity analysis using imputed datasets revealed similar results to those of the primary analysis (aHR, 1.15 [95% CI, 0.71–1.87] and 2.15 [95% CI, 1.35–3.41], respectively; Supplementary Table 1).

TABLE 2. Cox proportional hazards model of mortality according to the degree of kyphosis

	Number of participants	Frequency of mortality	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1147	54	0.008	Ref.	Ref.
Mild	272	22	0.014	1.74 (1.06, 2.85)	1.17 (0.70, 1.96)
Severe	202	26	0.023	2.83 (1.77, 4.52)	1.99 (1.20, 3.30)

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, stroke history, and handgrip strength.

Secondary Analysis

The rates of LOI were 0.013 per year in the non-kyphotic posture group, 0.036 per year in the mild kyphotic posture group, and 0.048 per year in the severe kyphotic posture group (Table 3). Overall, subjects with mild and severe kyphotic posture had higher rates of LOI than those without kyphotic posture (aHR, 1.70 [95% CI, 1.13–2.55] and 2.08 [95% CI, 1.39–3.10], respectively). A sensitivity analysis using imputed datasets revealed similar results (aHR, 1.47 [95% CI, 1.03–2.10] and 1.74 [95% CI, 1.25–2.43], respectively; Supplementary Table 2).

TABLE 3. Cox Proportional Hazards Model of Loss of Independence According to the Degree of Kyphosis

	Number of participants	Frequency of loss of independence	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1147	82	0.013	Ref.	Ref.
Mild	272	38	0.026	2.38 (1.61–3.52)	1.70 (1.13–2.55)
Severe	202	51	0.048	3.63 (2.52–5.22)	2.08 (1.39–3.10)

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, stroke history, and handgrip strength.

Consistent results were obtained for the composite outcome of LOI and mortality (Table 4). Participants with mild and severe kyphotic posture had higher rates of LOI and mortality than those without kyphotic posture (aHR, 1.27 [95% CI, 0.90–1.79] and 1.83 [95% CI, 1.31–2.56], respectively). A sensitivity analysis using imputed datasets revealed similar results (aHR, 1.26 [95% CI, 0.93–1.69] and 1.63 [95% CI, 1.23–2.16], respectively; Supplementary Table 3).

TABLE 4. Cox proportional hazards model of loss of independence and mortality according to the degree of kyphosis

	Number of participants	Frequency of loss of independence	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]

		and mortality[b]			
Kyphotic posture					
None	1147	122	0.02	Ref.	Ref.
Mild	272	52	0.033	1.78 (1.28–2.50)	1.27 (0.90–1.79)
Severe	202	60	0.062	2.93 (2.16–3.98)	1.83 (1.31–2.56)

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, history of stroke, and handgrip strength.

[b]Composite of loss of independence and mortality.

We conducted a subgroup analysis stratified by sex, which indicated that men had a higher cumulative rate of mortality (10%, 0.018 per year) than women (4%, 0.007 per year). Male sex also showed a more pronounced association between kyphotic posture and mortality (Table 5).

TABLE 5. Cox proportional hazards model of mortality according to the degree of kyphosis stratified by sex

	Number of participants	Frequency of mortality	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Male	640	64	0.018		
Kyphotic posture					
None	449	32	0.013	Ref.	Ref.

Mild	126	19	0.028	2.19 (1.24, 3.87)	1.64 (0.91, 2.95)
Severe	65	13	0.037	2.97 (1.56, 5.65)	2.31 (1.17, 4.56)
Female	981	38	0.007		
Kyphotic posture					
None	698	22	0.006	Ref.	Ref.
Mild	146	3	0.004	0.64 (0.19, 2.15)	0.50 (0.15, 1.73)
Severe	137	13	0.017	3.10 (1.56, 6.14)	1.55 (0.70, 3.45)

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, stroke history, and handgrip strength.

The causes of mortality in each group are presented in Fig. 3. Although the frequencies were very low, the rate of mortality due to respiratory diseases was higher in the severe kyphotic posture group (6 [16%] vs. 5 [7%] in the non-kyphotic posture group and 2 [7%] in the mild kyphotic posture group).

Discussion

In the present study, we explored the association between kyphotic posture and mortality using data from a relatively large sample. The kyphotic posture detected with the WOT appeared to affect mortality in a way not explained by age, sex, body mass index, smoking habit, LSS, low back pain, good health status, history of stroke, or handgrip strength. Furthermore, the association was stronger in the severe kyphotic posture group; the presence of severe kyphotic posture was related to a two-fold increase in the hazards of mortality in relation to the non-kyphotic posture.

254 Additionally, kyphotic posture was associated with LOI, and the association between kyphotic posture and mortality was more pronounced in men.

256 Kado et al. reported that cervicothoracic kyphosis measured in the supine position was associated with mortality in older men and women. Notably, they did not observe any sex-specific differences in their study.[14] They also showed that the degree of thoracic hyperkyphosis in the standing position, in addition to osteoporotic vertebral fractures (OVFs), had a predictive value for mortality among older women.[15] Our results were similar to those from previous studies showing that kyphotic posture is associated with mortality. Additionally, we believe that the present study has the advantage of using the WOT, which measures kyphosis in the standing position and reflects overall sagittal balance. To accurately assess the degree of kyphosis, subjects should be in the standing position with their hips and knees fully extended to prevent compensatory mechanisms [24]. With the subjects in the supine position, kyphotic posture may be corrected by a non-physiologic hyper-extensive force, leading to a consistent underestimation of the degree of kyphosis. Furthermore, as described above, kyphotic posture develops due to the failure of the posture maintenance mechanism. When evaluating kyphotic posture, it is necessary to focus not only on one segment, such as the thoracic spine, but also on the alignment of the whole spine.

270 In the subgroup analysis by sex, the association between kyphotic posture and mortality seemed to be more pronounced in men, although no clear sex difference in mortality was found in the present study. Sex differences in the prevalence of vertebral fractures have been reported, [25,26] and the nature of the kyphosis may differ between men and women. Further studies that subcategorize kyphosis by vertebral fractures might reveal sex differences in kyphotic posture.

276 ***Explanations and Implications***

We hypothesized two possible explanations for the association between kyphotic posture and mortality. First, we considered that mortality is an outcome of locomotive dysfunction. Further, several previous studies have reported that kyphotic posture is associated with locomotive dysfunction.[5,12,13,27,28] According to Tominaga et al., severe kyphotic posture measured by the WOT is associated with an increased incidence of falls in men.[13] Katzman et al. indicated an association of cervicothoracic kyphosis in the supine position with impaired lower extremity physical function among older men.[28] Hence, the effect of kyphotic posture might be prominent and associated with increased mortality in men. Early mortality may also be attributable to other mechanisms. Multiple previous studies have shown that kyphotic posture may be associated with worse health, including diminished pulmonary function.[6,7] Notably, a previous report suggested that individuals with kyphotic posture are more likely to die of a pulmonary cause.[14] Although no statistical comparison was performed due to a lack of power, our results suggest that the proportion of respiratory deaths among those with severe kyphotic posture is high.

The results of the present study also suggest that kyphotic posture is a clinically important finding, and that further studies are required to fully explore the effects of the prevention and treatment of kyphotic posture. Noticeably, our study demonstrates that the WOT is helpful in predicting serious healthcare outcomes. Among men, those with mild and severe kyphotic posture identified by WOT had a 2.2-fold and 3-fold increased hazards of mortality, respectively. The WOT is easy, inexpensive, and does not require special skills or devices, making it an attractive clinical tool for the identification of high-risk individuals. As approximately 40% of older adults with severe kyphosis reported to have underlying OVFs,[24] OVFs are widely thought to be a major factor contributing to the development of kyphotic posture. Therefore, osteoporosis treatment may help prevent kyphotic posture via a reduction in the occurrence of OVFs. In addition to structural changes in the vertebral column, back extensor weakness is also associated with kyphotic posture.[29-31] Despite the limited evidence, some reports suggest that exercise may modestly improve back extensor muscle strength [32].

Strengths and Limitations

The present study has significant strengths. First, we demonstrated the association of kyphotic posture with LOI and mortality in a community-dwelling population. We believe that the present study is a valuable contribution in that it investigated the longitudinal development of serious healthcare outcomes based on samples from a general population. Second, we used public data, which provided us with reliable and complete information on outcomes, except for participants who changed their residence out of the target area. As relocation was rare, a high tracking ratio (98.5%) was achieved, which minimized the risk of information bias.

Nevertheless, this study also has several limitations. First, we did not adjust our dataset for osteoporosis. We did not adjust for OVFs because we were interested not only in kyphosis independent of OVFs, but in overall kyphotic postures, including the ones caused by OVFs. However, osteoporosis may be associated with LOI and mortality through other mechanisms. Second, the measurement of kyphotic posture may not be sufficiently precise. The WOT does not allow to distinguish rigid kyphosis from flexible kyphosis. To evaluate spinal flexibility, evaluations in both the standing and supine positions need to be performed. The WOT also does not identify participants who can maintain good non-kyphotic posture only for a short period during measurement. No evaluation method has overcome this problem, and the development of a new method, such as continuous posture analysis, is warranted. Furthermore, we did not use X-rays or inclinometer to assess kyphotic posture, and so it was not possible to determine the cause of the posture. However, we believe that the absence of spinal parameters such as kyphotic angle does not introduce a serious bias, as our focus is on the resulting kyphosis posture, not on its cause. Finally, attributing causation is difficult because of other unmeasured confounders, including subclinical diseases. It should be noted that the present study does not provide evidence to support surgical interventions to correct kyphosis. Surgical reconstruction should not be routinely performed in elderly individuals with a typical high-risk profile.

Conclusions

This study suggests that kyphotic posture is associated with LOI and mortality. Therefore, identifying community-dwelling older people with kyphotic posture using the WOT might help identify high-risk populations that would benefit from healthcare interventions.

References

1. Schwab F, Lafage V, Boyce R, et al. Gravity line analysis in adult volunteers: age-related correlation with spinal parameters, pelvic parameters, and foot position. *Spine (Phila Pa 1976)*. 2006;31:959–67.
2. Farcy JP, Schwab FJ. Management of flatback and related kyphotic decompensation syndromes. *Spine (Phila Pa 1976)*. 1997;229:2452–7.
3. Ailon T, Shaffrey CI, Lenke LG, et al. Progressive spinal kyphosis in the aging population. *Neurosurgery*. 2015;774:164–72.
4. Kado DM, Prenovost K, Crandall C. Narrative review: hyperkyphosis in older persons. *Ann Intern Med*. 2007;147:330–8.
5. Eum R, Leveille SG, Kiely DK, et al. Is kyphosis related to mobility, balance, and disability? *Am J Phys Med Rehabil*. 2013;92:980–9.
6. Culham EG, Jimenez HA, King CE. Thoracic kyphosis, rib mobility, and lung volumes in normal women and women with osteoporosis. *Spine (Phila Pa 1976)*. 1994;19:1250–5.
7. Lee SJ, Chang JY, Ryu YJ, et al. Clinical features and outcomes of respiratory complications in patients with thoracic hyperkyphosis. *Lung*. 2015;193:1009–15.
8. Ensrud KE, Black DM, Harris F, et al. Correlates of kyphosis in older women. The Fracture Intervention Trial Research Group. *J Am Geriatr Soc*. 1997;45:682–7.
9. Imagama S, Ando K, Kobayashi K, et al. Increase in lumbar kyphosis and spinal inclination, declining back muscle strength, and sarcopenia are risk factors for onset of GERD: a 5-year prospective longitudinal cohort study. *Eur Spine J*. 2019;28:2619–28.
10. Imagama S, Hasegawa Y, Matsuyama Y, et al. Influence of sagittal balance and physical

ability associated with exercise on quality of life in middle-aged and elderly people. *Arch Osteoporos*. 2011;6:13–20.

11. Langella F, Villafañe JH, Lafage V, et al. Xipho-pubic angle (XPA) correlates with patient's reported outcomes in a population of adult spinal deformity: results from a multi-center cohort study. *Eur Spine J*. 2018;27:670−77.

12. McDaniels-Davidson C, Davis A, Wing D, et al. Kyphosis and incident falls among community-dwelling older adults. *Osteoporos Int*. 2018;29:163–9.

13. Tominaga R, Fukuma S, Yamazaki S, et al. Relationship between kyphotic posture and falls in community-dwelling men and women: the Locomotive Syndrome and Health Outcome in Aizu Cohort Study. *Spine (Phila Pa 1976)*. 2016;41:1232–8.

14. Kado DM, Huang MH, Karlamangla AS, et al. Hyperkyphotic posture predicts mortality in older community-dwelling men and women: a prospective study. *J Am Geriatr Soc.* 2004;52:1662–7.

15. Kado DM, Lui LY, Ensrud KE, et al. Hyperkyphosis predicts mortality independent of vertebral osteoporosis in older women. *Ann Intern Med.* 2009;150:681–7.

16. Okura M, Ogita M, Yamamoto M, et al. Self-assessed kyphosis and chewing disorders predict disability and mortality in community-dwelling older adults. *J Am Med Dir Assoc*. 2017;18:550.e1–6.

17. Otani K, Takegami M, Fukumori N, et al. Locomotor dysfunction and risk of cardiovascular disease, quality of life, and medical costs: design of the Locomotive Syndrome and Health Outcome in Aizu Cohort Study (LOHAS) and baseline characteristics of the study population. *J Orthop Sci.* 2012;17:261–71.

18. Campbell JC, Ikegami N. Long-term care insurance comes to Japan. *Health Aff (Millwood)*. 2000;19:26–39.

19. Green AD, Colon-Emeric CS, Bastian L, et al. Does this woman have osteoporosis? *JAMA*. 2004;292:2890–900.

20. Ziebart C, Adachi JD, Ashe MC, et al. Exploring the association between number, severity, location of fracture, and occiput-to-wall distance. *Arch Osteoporos*. 2019;14:27.

21. Siminoski K, Warshawski RS, Jen H, et al. The accuracy of clinical kyphosis examination for detection of thoracic vertebral fractures: comparison of direct and indirect kyphosis measures. *J Musculoskelet Neuronal Interact*. 2011;11:249–56.

22. Konno S, Kikuchi S, Tanaka Y, et al. A diagnostic support tool for lumbar spinal stenosis: a self-administered, self-reported history questionnaire. *BMC Musculoskelet Disord*. 2007;8:102.

23. Yamazaki H, Kamitani T, Matsui T, et al. Association of low alanine aminotransferase with loss of independence or death: a 5-year population-based cohort study. *J Gastroenterol Hepatol*. 2019;34:1793–9.

24. Horton WC, Brown CW, Bridwell KH, et al. Is there an optimal patient stance for obtaining a lateral 36" radiograph? A critical comparison of three techniques. *Spine (Phila Pa 1976)*. 2005;30:427–33.

25. Schneider DL, von Muhlen D, Barrett-Connor E, et al. Kyphosis does not equal vertebral fractures: the Rancho Bernardo study. *J Rheumatol.* 2004;31:747–52.

26. Kado DM, Browner WS, Palermo L, et al. Vertebral fractures and mortality in older women: a prospective study. Study of Osteoporotic Fractures Research Group. *Arch Intern Med*. 1999;159:1215–20.

27. Kado DM, Huang MH, Barrett-Connor E, et al. Hyperkyphotic posture and poor physical functional ability in older community-dwelling men and women: the Rancho Bernardo study. *J Gerontol A Biol Sci Med Sci*. 2005;60:633–7.

28. Katzman WB, Harrison SL, Fink HA, et al. Physical function in older men with hyperkyphosis. *J Gerontol A Biol Sci Med Sci*. 2015;70:635–40.

29. Sinaki M, Itoi E, Rogers JW, et al. Correlation of back extensor strength with thoracic kyphosis and lumbar lordosis in estrogen-deficient women. *Am J Phys Med Rehabil*. 1996;75:370–4.

30. Laroche M, Delisle MB, Aziza R, et al. Is camptocormia a primary muscular disease? *Spine (Phila Pa 1976)*. 1995;20:1011–6.

31. Menezes-Reis R, Bonugli GP, Salmon CEG, et al. Relationship of spinal alignment with muscular volume and fat infiltration of lumbar trunk muscles. *PLoS One*. 2018;13:e0200198.

32. Bansal S, Katzman WB, Giangregorio LM. Exercise for improving age-related hyperkyphotic posture: a systematic review. *Arch Phys Med Rehabil*. 2014;95:129–40.

Figure Legends

Fig. 1. Flow diagram of eligible participants.

WOT: wall-occiput test; LOHAS: Locomotive Syndrome and Health Outcomes in Aizu Cohort Study

Fig. 2. Cumulative incidence of mortality. Subjects were divided into the following three groups according to the degree of kyphotic posture: None, Mild (> 0, ≤ 4 cm), and Severe (> 4 cm). The P-value was calculated using log-rank test.

Fig. 3. Cause-specific deaths in each group. Participants were divided into the following three groups according to the degree of kyphosis: None, Mild (> 0, ≤ 4 cm), and Severe (> 4 cm).

Footnotes

Contributors: Conception and design of the study: YH, TK, SF, and YY; Acquisition of data: MS, KO, SK, and MT; Analysis and interpretation of data: YH, TK, SF, and YY; Drafting the article or revising it critically for important intellectual content: YH, TK, MS, KO, SK, MT, SF, and YY; Final approval of the version to be submitted: YH, TK, MS, KO, SK, MT, SF, and YY.

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Data availability statement: The data presented in the study are not currently available. Additional unpublished data is still being analysed for another research project.

Competing interests: None declared.

Ethics approval: This study was approved by the institutional Review Boards of Fukushima Medical University and Kyoto University Graduate School and Faculty of Medicine of Kyoto University Hospital (No. 673 and R1730, respectively).

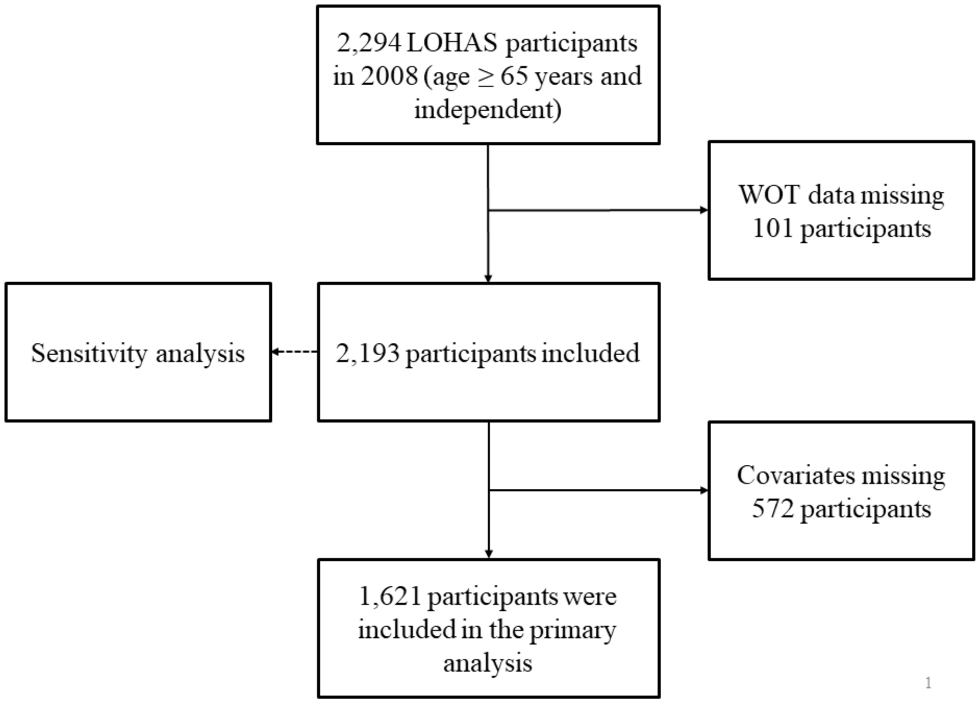

Fig. 1. Flow diagram of eligible participants.
WOT: wall-occiput test; LOHAS: Locomotive Syndrome and Health Outcomes in Aizu Cohort Study

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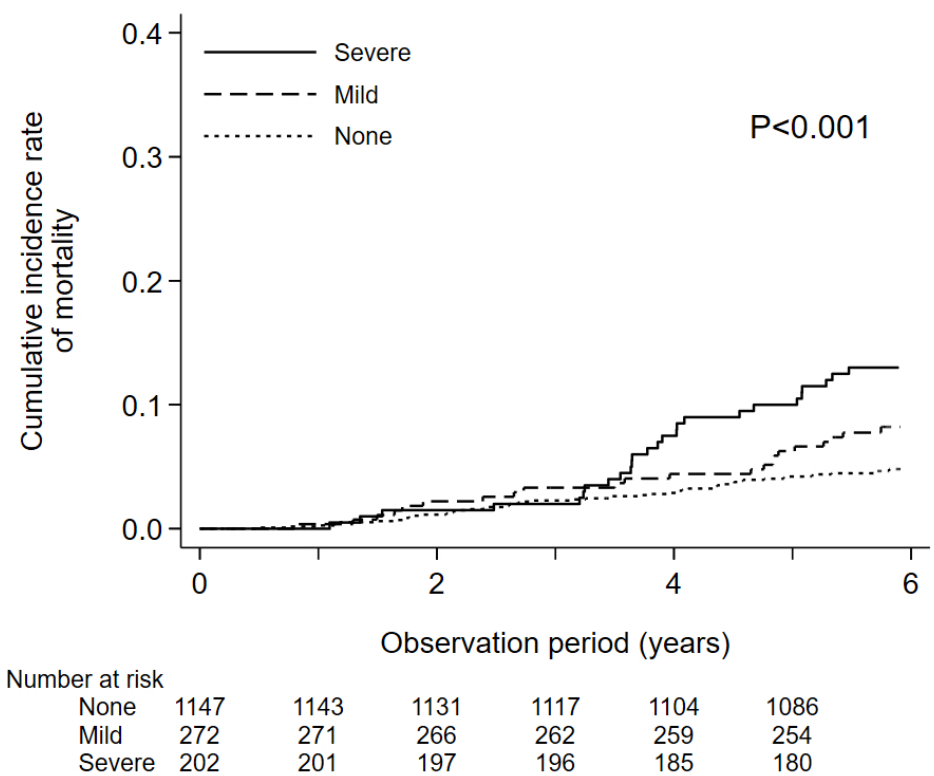

Fig. 2. Cumulative incidence of mortality. Subjects were divided into the following three groups according to the degree of kyphotic posture: None, Mild (> 0, ≤ 4 cm), and Severe (> 4 cm).
The P-value was calculated using log-rank test.

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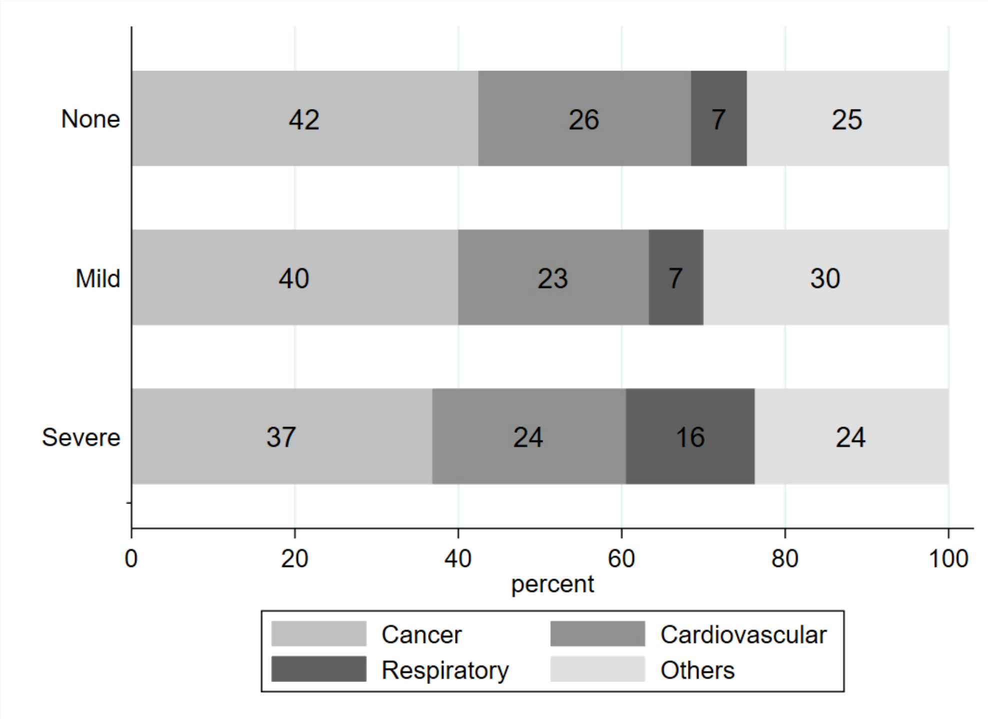

Fig. 3. Cause-specific deaths in each group. Participants were divided into the following three groups according to the degree of kyphosis: None, Mild (> 0, ≤ 4 cm), and Severe (> 4 cm).

366x266mm (72 x 72 DPI)

Supplementary Material 1

Supplemental material for: "Association of kyphotic posture with loss of independence and mortality in a community-based prospective cohort study: The Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS)"

Supplementary Table 1. Sensitivity analysis with multiple imputation for mortality according to the degree of kyphosis

	Number of participants	Frequency of mortality	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1525	73	0.009	Ref.	Ref.
Mild	369	30	0.015	1.72 (1.13–2.64)	1.19 (0.77–1.84)
Severe	299	38	0.023	2.76 (1.86–4.08)	1.80 (1.17–2.77)

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, history of stroke, and handgrip strength.

Supplementary Material 2

Supplemental material for: "Association of kyphotic posture with loss of independence and mortality in a community-based prospective cohort study: The Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS)"

Supplementary Table 2. Sensitivity analysis with multiple imputation for loss of independence according to the degree of kyphosis

	Number of participants	Frequency of loss of independence	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1525	114	0.015	Ref.	Ref.
Mild	369	47	0.018	2.10 (1.49–2.97)	1.47 (1.03–2.10)
Severe	299	73	0.045	3.33 (2.46–4.49)	1.74 (1.25–2.43)

Abbreviations: HR = hazard ratio; CI = confidence interval.

a Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, stroke history, and handgrip strength.

Supplementary Material 3

Supplemental material for: "Association of kyphotic posture with loss of independence and mortality in a community-based prospective cohort study: The Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS)"

Supplementary Table 3. Sensitivity analysis with multiple imputation for loss of independence and mortality according to the degree of kyphosis

	Number of Participants	Frequency of loss of independence and mortality	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1525	176	0.021	Ref.	Ref.
Mild	369	65	0.033	1.78 (1.33–2.37)	1.26 (0.93–1.69)
Severe	299	93	0.06	2.78 (2.16–3.59)	1.63 (1.23–2.16)

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, stroke history, and handgrip strength.

[b]Composite outcome of loss of independence and mortality.

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	6
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	No
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8
		(*b*) Describe any methods used to examine subgroups and interactions	9
		(*c*) Explain how missing data were addressed	9
		(*d*) If applicable, explain how loss to follow-up was addressed	8
		(*e*) Describe any sensitivity analyses	9
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	9
		(b) Give reasons for non-participation at each stage	9
		(c) Consider use of a flow diagram	10
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	9
		(b) Indicate number of participants with missing data for each variable of interest	No
		(c) Summarise follow-up time (eg, average and total amount)	11
Outcome data	15*	Report numbers of outcome events or summary measures over time	11

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	12
		(*b*) Report category boundaries when continuous variables were categorized	-
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11
Discussion			
Key results	18	Summarise key results with reference to study objectives	15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	18
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	16
Generalisability	21	Discuss the generalisability (external validity) of the study results	18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	25

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

BMJ Open

Association of kyphotic posture with loss of independence and mortality in a community-based prospective cohort study: The Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS)

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Association of kyphotic posture with loss of independence and mortality in a community-based prospective cohort study: The Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS)

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Word count: 3002 words

Abstract

Objectives: This study aimed to investigate the association between kyphotic posture and future loss of independence (LOI) and mortality in community-dwelling older adults.

Design: Prospective cohort study.

Setting: Two Japanese municipalities.

Participants: We enrolled 2,193 independent community-dwelling older adults aged ≥65 years at the time of their baseline health check-up in 2008. Kyphotic posture was evaluated using the wall-occiput test (WOT) and classified into three categories: non-kyphotic, mild (>0 and ≤4 cm), and severe (>4 cm).

Primary and secondary outcome measures: The primary outcome was mortality and the secondary outcomes were LOI (new long-term care insurance certification levels 1–5) and a composite of LOI and mortality. A Cox proportional hazards model was used to estimate the adjusted hazard ratios (aHRs).

Results: Of the 2,193 subjects enrolled, 1,621 were included in the primary analysis. Among these, 272 (17%) and 202 (12%) were diagnosed with mild and severe kyphotic posture, respectively. The median follow-up time was 5.8 years. Compared to the non-kyphotic group, the aHRs for mortality were 1.17 (95% confidence interval [CI], 0.70–1.96) and 1.99 (95% CI, 1.20–3.30) in the mild and severe kyphotic posture groups, respectively. In the secondary analysis, a consistent association was observed for LOI (mild: aHR, 1.70; 95% CI, 1.13–2.55; severe: aHR, 2.08; 95% CI, 1.39–3.10) and the LOI–mortality composite (mild: aHR, 1.27; 95% CI, 0.90–1.79; severe: aHR, 1.83; 95% CI, 1.31–2.56).

Conclusion: Kyphotic posture was associated with LOI and mortality in community-dwelling older adults. Identifying the population with kyphotic posture using the WOT might help improve

community health.

Strengths and limitations of this study:

- The results were obtained from a relatively large cohort of a community-based population.
- Only 1.5% (31) of the 2,193 participants included in the study were lost to follow up due to change of residence from the target area, which minimized the risk of information bias.
- We did not adjust for osteoporosis, a factor that might be associated with loss of independence and mortality through mechanisms other than kyphotic postures, such as fractures of the long bones.
- The wall-occiput test does not distinguish rigid kyphosis from flexible kyphosis.
- Attributing causation is difficult because of other unmeasured confounders, including subclinical diseases.

Introduction

Kyphosis is described as an abnormal posture that develops because of the failure of the posture maintenance mechanism. When standing, lordotic segments (i.e., the cervical and lumbar spine) and kyphotic segments (i.e., the thoracic spine) must balance the occiput over the pelvic axis in an energy-efficient position. As the centre of gravity of the trunk shifts forward due to kyphosis in one segment of the spine, the other spinal segments, pelvis, hip joint, and knee joint cooperatively compensate to maintain overall sagittal balance.[1] Failure of this compensatory mechanism results in kyphotic posture, leading to various health problems.[2,3] A kyphotic posture is common among older individuals, with a reported prevalence of 20–40%,[4] and is expected to increase as the population ages. Hence, the extent to which a kyphotic posture affects health is a serious concern.

Several deleterious effects of kyphotic posture on the afflicted individual's health have been reported, including a decline in physical function,[5] impairment in pulmonary function,[6,7] pain,[8] gastroesophageal reflux disease,[9] poor quality of life,[10,11] and accidental falls.[12,13] Therefore, there has been a growing concern regarding the association between kyphotic posture and serious health-related outcomes, such as loss of independence (LOI) and mortality.

Three previous studies reported an association of kyphotic posture with LOI and mortality. First, Kado et al. demonstrated the association between cervicothoracic kyphosis and mortality.[14] It should be noted that, as kyphosis was measured in the supine position rather than in the standing position, the evaluation of the kyphotic posture was not precise. In another study, Kado et al. reported an association of thoracic hyperkyphosis in the standing position with mortality in older women.[15] Nonetheless, these two studies could not assess whether the kyphotic posture was a risk factor for mortality in men. Okura et al. showed that kyphotic posture is related to LOI and mortality.[16] However, there was a potential bias in this study, as the determination of kyphotic posture was based on self-reported data from participants. Moreover, the researchers only controlled for age and sex as potential confounders. Furthermore, none of these studies adjusted for lumbar degenerative disease and back pain, which are strongly associated with kyphotic posture.

To address these concerns, we conducted a prospective cohort study to examine whether a kyphotic posture in the standing position was associated with LOI and mortality in community-dwelling men and women.

Materials and methods

Study Design and Population

This prospective observational study analyzed data from the Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS), a population-based study involving residents from two towns in Japan. The LOHAS evaluated the effect of locomotive dysfunction on healthcare outcomes, including quality of life, medical costs, and occurrence of LOI and mortality. The LOHAS comprised approximately 70% of all the National Health Insurance and Late-Stage Elderly Health Insurance beneficiaries in that region. Details of the study have been described elsewhere.[17]

Study Participants

Independent community-dwelling older adults aged ≥65 years without any long-term care insurance (LTCI) certification [18] at the time of their baseline health check-up in 2008 were enrolled. Those in whom kyphotic posture could not be determined due to missing data were excluded. Participants were observed starting from the baseline check-up in 2008 until March 2014. This study was approved by certified institutional review boards (R1730 and 673) of the participating institutions, and all participants provided written informed consent before participation.

Definition of Kyphotic Posture

Kyphotic posture was defined using the wall-occiput test (WOT) at the time of musculoskeletal examination in 2008. The WOT is a semi-quantitative technique used to assess head forward posture in the standing position as well as thoracic vertebral fractures.[19,20] The WOT reflects not only thoracic hyperkyphosis, but also a loss of cervical and lumbar lordosis.

The distance (in cm) between the occiput prominence and the wall was measured using a tape while the participants were standing with both of their heels and sacrum against the wall and their head positioned such that an imaginary line from the lateral corner of the eye to the superior point of the auricle was parallel to the floor. In accordance with previous studies,[13,21] we divided the participants into the following three groups based on the degree of kyphosis: none, mild (>0, ≤4 cm), and severe (>4 cm).

Outcomes

The primary outcome was the time to mortality. Data on mortality and its causes were collected from death certificates provided by the Ministry of Health, Labour, and Welfare of Japan. The secondary outcome was the development of LOI, which was defined as a new LTCI certification of level 1–5 (i.e., a condition requiring any support for daily living). Information on LTCI certification status was obtained from the local government annually. The use of public data allowed us to access all outcome data, except for those participants who changed their residence outside the target area.

Baseline Covariates

The following baseline covariates were analysed as potential confounders for the relationship between kyphotic posture and mortality: age, sex, body mass index (categorized as <18.5, ≥18.5 and <25, and ≥25 kg/m^2), present smoking habits, lumbar spinal stenosis (LSS), low back pain (requiring treatment and lasting for more than 24 h), good health status (self-reported health: good, very good, or excellent), stroke history, and handgrip strength (dominant hand). LSS was diagnosed using a validated diagnostic support tool specifically designed for this purpose.[22] Handgrip strength was measured using a digital dynamometer (Takei Scientific Instruments Co., Ltd, Japan).

Statistical Analysis

The baseline characteristics of the participants were expressed as the presence or absence and the degree of kyphotic posture, using medians and interquartile ranges. Additionally, absolute and relative frequencies were used for dichotomous or categorical variables.

The cumulative incidence method and log-rank test were applied to compare the intervals between the baseline and date of mortality. The date of each baseline check-up in 2008 was considered as Time 0. Participants were censored after changing their residence out of the target area or on March 31, 2014. After confirming that the proportional hazards assumption had not been violated, a Cox proportional hazards model with adjustment for possible confounders (i.e., age, sex, body mass index, smoking habit, LSS, low back pain, good health status, stroke history, and handgrip strength) was used to investigate the association between the kyphotic posture and mortality. We conducted a sensitivity analysis with multiple imputations by chained equations of missing covariates, which included all variables (including outcomes) in the prediction model to generate 20 imputed datasets.

We performed four secondary analyses. First, we focused on LOI as a secondary outcome. In that model, participants were censored after moving out of the target area, upon mortality, or on March 31, 2014. Second, we employed another Cox proportional hazard model to evaluate the composite outcome of LOI and mortality. Both models included the same covariates as those in the primary analysis. For these secondary analyses, we performed sensitivity analyses using multiple imputations as in the main analysis. Third, we performed a subgroup analysis stratified by sex for the primary outcome of mortality. Finally, we analyzed cause-specific mortality in each group, as in a previous study.[23] Four causes of death were evaluated: cancer, cardiovascular disease, respiratory disease, and others.

Statistical analyses were performed using Stata version 15.1 (StataCorp LLC, College Station, Texas, USA).

Patient and public involvement

There was no patient and public involvement in this study.

Results

Baseline Characteristics

A total of 2,294 eligible participants from the 2008 LOHAS were identified. After excluding 101 subjects who did not undergo the WOT, a total of 2,193 participants were retained. The primary analysis included 1,621 participants without missing covariates. Fig. 1 shows the flow diagram of subjects in this study.

Of the 1,621 participants enrolled in this study, 272 (17%) and 202 (12%) were diagnosed with mild and severe kyphotic posture, respectively (Table 1). The median age of all participants was 72 years, 61% were female, and 75% had good health status. The average age, the proportion of overweight participants (body mass index ≥25 kg/m^2), and the proportion of participants with LSS and low back pain were high in the mild and severe kyphotic posture groups compared to the non-kyphotic posture group. The proportions of participants with good health status and average handgrip strength were low in these groups.

TABLE 1. Baseline characteristics of participants without missing covariates

	Total	Kyphotic posture		
		None	Mild (>0, ≤4 cm)	Severe (>4 cm)
	n = 1621	*n* = 1147 (71)	*n* = 272 (17)	*n* = 202 (12)
Age, years	72 (68–76)	71 (67–74)	74 (70–78)	76 (72–80)
Female sex	981 (61)	698 (61)	146 (54)	137 (68)
Body mass index, kg/m^2				
<18.5	57 (4)	43 (4)	7 (3)	7 (3)
≤18.5, <25	1042 (64)	756 (66)	175 (64)	111 (55)
≥25	522 (32)	348 (30)	90 (33)	84 (42)
Smoking habit	151 (9)	105 (9)	31 (11)	15 (7)

Lumbar spinal stenosis	274 (17)	175 (15)	53 (19)	46 (23)
Low back pain	131 (8)	84 (7)	25 (9)	22 (11)
Good health status	1221 (75)	878 (77)	197 (72)	146 (72)
Stroke history	87 (5)	54 (5)	15 (6)	18 (9)
Handgrip strength, kgw	26 (22–34.5)	27 (22–35)	26 (21.25–35)	22 (18.5–28)

Note. Data are presented as n (%) or median and interquartile range.

Primary Analysis and Sensitivity Analysis

The cumulative mortality rates according to the degree of kyphosis are presented in Fig. 2. The median follow-up time was 5.8 years. The participants with mild and severe kyphotic posture showed higher cumulative mortality rates (8% and 13%, respectively) than those without kyphotic posture (5%). The tracking ratio at the end of the study was 98.5%. The mortality rates were 0.008 per year in the non-kyphotic posture group, 0.014 per year in the mild kyphotic posture group, and 0.023 per year in the severe kyphotic posture group (Table 2), with the log-rank test indicating a difference among the groups (p <0.001). Cox regression analysis showed that participants with mild and severe kyphotic posture had higher rates of mortality than those without kyphotic posture, with adjusted hazard ratios (aHRs) of 1.17 (95% confidence interval [CI], 0.70–1.96), and 1.99 (95% CI, 1.20–3.30), respectively. A sensitivity analysis using imputed datasets revealed similar results to those of the primary analysis (aHR, 1.15 [95% CI, 0.71–1.87] and 2.15 [95% CI, 1.35–3.41], respectively; Supplementary Table 1).

TABLE 2. Cox proportional hazards model of mortality according to the degree of kyphosis

	Number of participants	Frequency of mortality	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1147	54	0.008	Ref.	Ref.
Mild	272	22	0.014	1.74 (1.06, 2.85)	1.17 (0.70, 1.96)
Severe	202	26	0.023	2.83 (1.77, 4.52)	1.99 (1.20, 3.30)

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, stroke history, and handgrip strength.

Secondary Analysis

The rates of LOI were 0.013 per year in the non-kyphotic posture group, 0.026 per year in the mild kyphotic posture group, and 0.048 per year in the severe kyphotic posture group (Table 3). Overall, subjects with mild and severe kyphotic posture had higher rates of LOI than those without kyphotic posture (aHR, 1.70 [95% CI, 1.13–2.55] and 2.08 [95% CI, 1.39–3.10], respectively). A sensitivity analysis using imputed datasets revealed similar results (aHR, 1.47 [95% CI, 1.03–2.10] and 1.74 [95% CI, 1.25–2.43], respectively; Supplementary Table 2).

TABLE 3. Cox Proportional Hazards Model of Loss of Independence According to the Degree of Kyphosis

	Number of participants	Frequency of loss of independence	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1147	82	0.013	Ref.	Ref.
Mild	272	38	0.026	2.38 (1.61–3.52)	1.70 (1.13–2.55)
Severe	202	51	0.048	3.63 (2.52–5.22)	2.08 (1.39–3.10)

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, stroke history, and handgrip strength.

Consistent results were obtained for the composite outcome of LOI and mortality (Table 4). Participants with mild and severe kyphotic posture had higher rates of LOI and mortality than those without kyphotic posture (aHR, 1.27 [95% CI, 0.90–1.79] and 1.83 [95% CI, 1.31–2.56], respectively). A sensitivity analysis using imputed datasets revealed similar results (aHR, 1.26 [95% CI, 0.93–1.69] and 1.63 [95% CI, 1.23–2.16], respectively; Supplementary Table 3).

TABLE 4. Cox proportional hazards model of loss of independence and mortality according to the degree of kyphosis

	Number of participants	Frequency of loss of independence	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]

		and mortality[b]			
Kyphotic posture					
None	1147	122	0.02	Ref.	Ref.
Mild	272	52	0.033	1.79 (1.28–2.50)	1.27 (0.90–1.79)
Severe	202	60	0.062	2.93 (2.16–3.98)	1.83 (1.31–2.56)

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, history of stroke, and handgrip strength.

[b]Composite of loss of independence and mortality.

We conducted a subgroup analysis stratified by sex, which indicated that men had a higher cumulative rate of mortality (10%, 0.018 per year) than women (4%, 0.007 per year). Male sex also showed a more pronounced association between kyphotic posture and mortality (Table 5).

TABLE 5. Cox proportional hazards model of mortality according to the degree of kyphosis stratified by sex

	Number of participants	Frequency of mortality	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Male	640	64	0.018		
Kyphotic posture					
None	449	32	0.013	Ref.	Ref.

Mild	126	19	0.028	2.19 (1.24, 3.87)	1.64 (0.91, 2.95)
Severe	65	13	0.037	2.97 (1.56, 5.65)	2.31 (1.17, 4.56)
Female	981	38	0.007		
Kyphotic posture					
None	698	22	0.006	Ref.	Ref.
Mild	146	3	0.004	0.64 (0.19, 2.15)	0.50 (0.15, 1.73)
Severe	137	13	0.017	3.10 (1.56, 6.14)	1.55 (0.70, 3.45)

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, stroke history, and handgrip strength.

The causes of mortality in each group are presented in Fig. 3. Although the frequencies were very low, the rate of mortality due to respiratory diseases was higher in the severe kyphotic posture group (6 [16%] vs. 5 [7%] in the non-kyphotic posture group and 2 [7%] in the mild kyphotic posture group).

Discussion

In the present study, we explored the association between kyphotic posture and mortality using data from a relatively large sample. The kyphotic posture detected with the WOT appeared to affect mortality in a way not explained by age, sex, body mass index, smoking habit, LSS, low back pain, good health status, history of stroke, or handgrip strength. Furthermore, the association was stronger in the severe kyphotic posture group; the presence of severe kyphotic posture was related to a two-fold increase in the hazards of mortality in relation to the non-kyphotic posture.

Additionally, kyphotic posture was associated with LOI, and the association between kyphotic posture and mortality was more pronounced in men.

Kado et al. reported that cervicothoracic kyphosis measured in the supine position was associated with mortality in older men and women. Notably, they did not observe any sex-specific differences in their study.[14] They also showed that the degree of thoracic hyperkyphosis in the standing position, in addition to osteoporotic vertebral fractures (OVFs), had a predictive value for mortality among older women.[15] Our results were similar to those from previous studies showing that kyphotic posture is associated with mortality. Additionally, we believe that the present study has the advantage of using the WOT, which measures kyphosis in the standing position and reflects overall sagittal balance. To accurately assess the degree of kyphosis, subjects should be in the standing position with their hips and knees fully extended to prevent compensatory mechanisms [24]. With the subjects in the supine position, kyphotic posture may be corrected by a non-physiologic hyper-extensive force, leading to a consistent underestimation of the degree of kyphosis. Furthermore, as described above, kyphotic posture develops due to the failure of the posture maintenance mechanism. When evaluating kyphotic posture, it is necessary to focus not only on one segment, such as the thoracic spine, but also on the alignment of the whole spine.

In the subgroup analysis by sex, the association between kyphotic posture and mortality seemed to be more pronounced in men, although no clear sex difference in mortality was found in the present study. Sex differences in the prevalence of vertebral fractures have been reported, [25,26] and the nature of the kyphosis may differ between men and women. Further studies that subcategorize kyphosis by vertebral fractures might reveal sex differences in kyphotic posture.

Explanations and Implications

We hypothesized two possible explanations for the association between kyphotic posture and mortality. First, we considered that mortality is an outcome of locomotive dysfunction. Further, several previous studies have reported that kyphotic posture is associated with locomotive dysfunction.[5,12,13,27,28] According to Tominaga et al., severe kyphotic posture measured by the WOT is associated with an increased incidence of falls in men.[13] Katzman et al. indicated an association of cervicothoracic kyphosis in the supine position with impaired lower extremity physical function among older men.[28] Hence, the effect of kyphotic posture might be prominent and associated with increased mortality in men. Early mortality may also be attributable to other mechanisms. Multiple previous studies have shown that kyphotic posture may be associated with worse health, including diminished pulmonary function.[6,7] Notably, a previous report suggested that individuals with kyphotic posture are more likely to die of a pulmonary cause.[14] Although no statistical comparison was performed due to a lack of power, our results suggest that the proportion of respiratory deaths among those with severe kyphotic posture is high.

The results of the present study also suggest that kyphotic posture is a clinically important finding, and that further studies are required to fully explore the effects of the prevention and treatment of kyphotic posture. Noticeably, our study demonstrates that the WOT is helpful in predicting serious healthcare outcomes. Among men, those with mild and severe kyphotic posture identified by WOT had a 2.2-fold and 3-fold increased hazards of mortality, respectively. The WOT is easy, inexpensive, and does not require special skills or devices, making it an attractive clinical tool for the identification of high-risk individuals. As approximately 40% of older adults with severe kyphosis reported to have underlying OVFs,[24] OVFs are widely thought to be a major factor contributing to the development of kyphotic posture. Therefore, osteoporosis treatment may help prevent kyphotic posture via a reduction in the occurrence of OVFs. In addition to structural changes in the vertebral column, back extensor weakness is also associated with kyphotic posture.[29-31] Despite the limited evidence, some reports suggest that exercise may modestly improve back extensor muscle strength. [32]

Strengths and Limitations

The present study has significant strengths. First, we demonstrated the association of kyphotic posture with LOI and mortality in a community-dwelling population. We believe that the present study is a valuable contribution in that it investigated the longitudinal development of serious healthcare outcomes based on samples from a general population. Second, we used public data, which provided us with reliable and complete information on outcomes, except for participants who changed their residence out of the target area. As relocation was rare, a high tracking ratio (98.5%) was achieved, which minimized the risk of information bias.

Nevertheless, this study also has several limitations. First, we did not adjust our dataset for osteoporosis. We did not adjust for OVFs because we were interested not only in kyphosis independent of OVFs, but in overall kyphotic postures, including the ones caused by OVFs. However, osteoporosis may be associated with LOI and mortality through other mechanisms. Second, the measurement of kyphotic posture may not be sufficiently precise. The WOT does not allow to distinguish rigid kyphosis from flexible kyphosis. To evaluate spinal flexibility, evaluations in both the standing and supine positions need to be performed. The WOT also does not identify participants who can maintain good non-kyphotic posture only for a short period during measurement. No evaluation method has overcome this problem, and the development of a new method, such as continuous posture analysis, is warranted. Additionally, the WOT values may contain measurement errors due to denture wear and respiratory variability. Thus, measurement using WOT has some disadvantages. However, as mentioned above, it is a very simple method of measurement, which makes it possible to survey a relatively large number of the general population and has the advantage of easy clinical application. Another limitation in the measurement of kyphotic posture is the inability to identify the cause of the posture since it is not assessed using X-rays or inclinometer. However, we believe that the absence of spinal parameters such as kyphotic angle does not introduce a serious bias, as our focus is on the resulting kyphosis posture, not on its cause. Finally, attributing causation is difficult because of other unmeasured confounders, including subclinical diseases. In addition, since more than 10 years have passed since the baseline measurement in 2008, confounding factors may have changed due to lifestyle changes such as the spread of smartphones. It should be noted that the present study does not provide evidence to support surgical interventions to correct kyphosis. Surgical reconstruction should not be routinely performed in elderly individuals with a typical high-risk profile.

Conclusions

This study suggests that kyphotic posture is associated with LOI and mortality. Therefore, identifying community-dwelling older people with kyphotic posture using the WOT might help identify high-risk populations that would benefit from healthcare interventions.

References

1. Schwab F, Lafage V, Boyce R, et al. Gravity line analysis in adult volunteers: age-related correlation with spinal parameters, pelvic parameters, and foot position. *Spine (Phila Pa 1976)*. 2006;31:959–67.

2. Farcy JP, Schwab FJ. Management of flatback and related kyphotic decompensation syndromes. *Spine (Phila Pa 1976)*. 1997;229:2452–7.

3. Ailon T, Shaffrey CI, Lenke LG, et al. Progressive spinal kyphosis in the aging population. *Neurosurgery*. 2015;774:164–72.

4. Kado DM, Prenovost K, Crandall C. Narrative review: hyperkyphosis in older persons. *Ann Intern Med*. 2007;147:330–8.

5. Eum R, Leveille SG, Kiely DK, et al. Is kyphosis related to mobility, balance, and disability? *Am J Phys Med Rehabil*. 2013;92:980–9.

6. Culham EG, Jimenez HA, King CE. Thoracic kyphosis, rib mobility, and lung volumes in normal women and women with osteoporosis. *Spine (Phila Pa 1976)*. 1994;19:1250–5.

7. Lee SJ, Chang JY, Ryu YJ, et al. Clinical features and outcomes of respiratory complications in patients with thoracic hyperkyphosis. *Lung*. 2015;193:1009–15.

8. Ensrud KE, Black DM, Harris F, et al. Correlates of kyphosis in older women. The Fracture Intervention Trial Research Group. *J Am Geriatr Soc*. 1997;45:682–7.

9. Imagama S, Ando K, Kobayashi K, et al. Increase in lumbar kyphosis and spinal inclination, declining back muscle strength, and sarcopenia are risk factors for onset of GERD: a 5-year prospective longitudinal cohort study. *Eur Spine J*. 2019;28:2619–28.

10. Imagama S, Hasegawa Y, Matsuyama Y, et al. Influence of sagittal balance and physical

ability associated with exercise on quality of life in middle-aged and elderly people. *Arch Osteoporos*. 2011;6:13–20.

11. Langella F, Villafañe JH, Lafage V, et al. Xipho-pubic angle (XPA) correlates with patient's reported outcomes in a population of adult spinal deformity: results from a multi-center cohort study. *Eur Spine J*. 2018;27:670–77.

12. McDaniels-Davidson C, Davis A, Wing D, et al. Kyphosis and incident falls among community-dwelling older adults. *Osteoporos Int*. 2018;29:163–9.

13. Tominaga R, Fukuma S, Yamazaki S, et al. Relationship between kyphotic posture and falls in community-dwelling men and women: the Locomotive Syndrome and Health Outcome in Aizu Cohort Study. *Spine (Phila Pa 1976)*. 2016;41:1232–8.

14. Kado DM, Huang MH, Karlamangla AS, et al. Hyperkyphotic posture predicts mortality in older community-dwelling men and women: a prospective study. *J Am Geriatr Soc.* 2004;52:1662–7.

15. Kado DM, Lui LY, Ensrud KE, et al. Hyperkyphosis predicts mortality independent of vertebral osteoporosis in older women. *Ann Intern Med.* 2009;150:681–7.

16. Okura M, Ogita M, Yamamoto M, et al. Self-assessed kyphosis and chewing disorders predict disability and mortality in community-dwelling older adults. *J Am Med Dir Assoc*. 2017;18:550.e1–6.

17. Otani K, Takegami M, Fukumori N, et al. Locomotor dysfunction and risk of cardiovascular disease, quality of life, and medical costs: design of the Locomotive Syndrome and Health Outcome in Aizu Cohort Study (LOHAS) and baseline characteristics of the study population. *J Orthop Sci.* 2012;17:261–71.

18. Campbell JC, Ikegami N. Long-term care insurance comes to Japan. *Health Aff*

(Millwood). 2000;19:26–39.

19. Green AD, Colon-Emeric CS, Bastian L, et al. Does this woman have osteoporosis? *JAMA*. 2004;292:2890–900.

20. Ziebart C, Adachi JD, Ashe MC, et al. Exploring the association between number, severity, location of fracture, and occiput-to-wall distance. *Arch Osteoporos*. 2019;14:27.

21. Siminoski K, Warshawski RS, Jen H, et al. The accuracy of clinical kyphosis examination for detection of thoracic vertebral fractures: comparison of direct and indirect kyphosis measures. *J Musculoskelet Neuronal Interact*. 2011;11:249–56.

22. Konno S, Kikuchi S, Tanaka Y, et al. A diagnostic support tool for lumbar spinal stenosis: a self-administered, self-reported history questionnaire. *BMC Musculoskelet Disord*. 2007;8:102.

23. Yamazaki H, Kamitani T, Matsui T, et al. Association of low alanine aminotransferase with loss of independence or death: a 5-year population-based cohort study. *J Gastroenterol Hepatol*. 2019;34:1793–9.

24. Horton WC, Brown CW, Bridwell KH, et al. Is there an optimal patient stance for obtaining a lateral 36" radiograph? A critical comparison of three techniques. *Spine (Phila Pa 1976)*. 2005;30:427–33.

25. Schneider DL, von Muhlen D, Barrett-Connor E, et al. Kyphosis does not equal vertebral fractures: the Rancho Bernardo study. *J Rheumatol.* 2004;31:747–52.

26. Kado DM, Browner WS, Palermo L, et al. Vertebral fractures and mortality in older women: a prospective study. Study of Osteoporotic Fractures Research Group. *Arch Intern Med*. 1999;159:1215–20.

27. Kado DM, Huang MH, Barrett-Connor E, et al. Hyperkyphotic posture and poor physical

functional ability in older community-dwelling men and women: the Rancho Bernardo study. *J Gerontol A Biol Sci Med Sci*. 2005;60:633–7.

28. Katzman WB, Harrison SL, Fink HA, et al. Physical function in older men with hyperkyphosis. *J Gerontol A Biol Sci Med Sci*. 2015;70:635–40.

29. Sinaki M, Itoi E, Rogers JW, et al. Correlation of back extensor strength with thoracic kyphosis and lumbar lordosis in estrogen-deficient women. *Am J Phys Med Rehabil*. 1996;75:370–4.

30. Laroche M, Delisle MB, Aziza R, et al. Is camptocormia a primary muscular disease? *Spine (Phila Pa 1976)*. 1995;20:1011–6.

31. Menezes-Reis R, Bonugli GP, Salmon CEG, et al. Relationship of spinal alignment with muscular volume and fat infiltration of lumbar trunk muscles. *PLoS One*. 2018;13:e0200198.

32. Bansal S, Katzman WB, Giangregorio LM. Exercise for improving age-related hyperkyphotic posture: a systematic review. *Arch Phys Med Rehabil*. 2014;95:129–40.

Figure Legends

Fig. 1. Flow diagram of eligible participants.

WOT: wall-occiput test; LOHAS: Locomotive Syndrome and Health Outcomes in Aizu Cohort Study

Fig. 2. Cumulative incidence of mortality. Subjects were divided into the following three groups according to the degree of kyphotic posture: None, Mild (> 0, ≤ 4 cm), and Severe (> 4 cm). The p-value was calculated using log-rank test.

Fig. 3. Cause-specific deaths in each group. Participants were divided into the following three groups according to the degree of kyphosis: None, Mild (> 0, ≤ 4 cm), and Severe (> 4 cm).

Footnotes

Contributors: Conception and design of the study: YH, TK, SF, and YY; Acquisition of data: MS, KO, SK, and MT; Analysis and interpretation of data: YH, TK, SF, and YY; Drafting the article or revising it critically for important intellectual content: YH, TK, MS, KO, SK, MT, SF, and YY; Final approval of the version to be submitted: YH, TK, MS, KO, SK, MT, SF, and YY.

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Competing interests: None declared.

Ethics approval: This study was approved by the institutional Review Boards of Fukushima Medical University and Kyoto University Graduate School and Faculty of Medicine of Kyoto University Hospital (No. 673 and R1730, respectively).

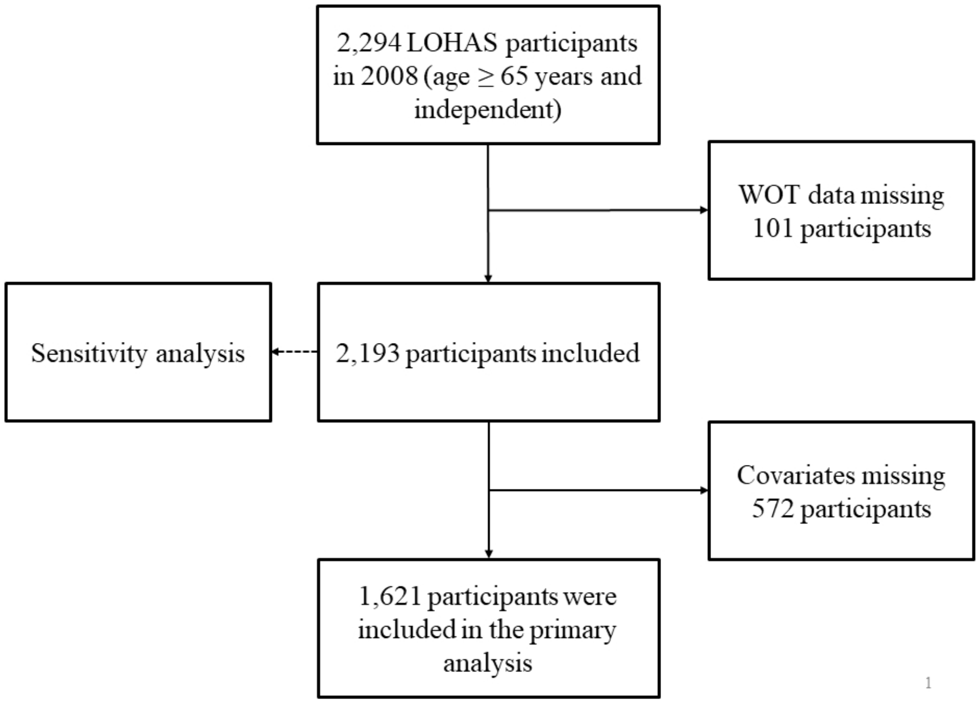

Fig. 1. Flow diagram of eligible participants.
WOT: wall-occiput test; LOHAS: Locomotive Syndrome and Health Outcomes in Aizu Cohort Study

254x190mm (96 x 96 DPI)

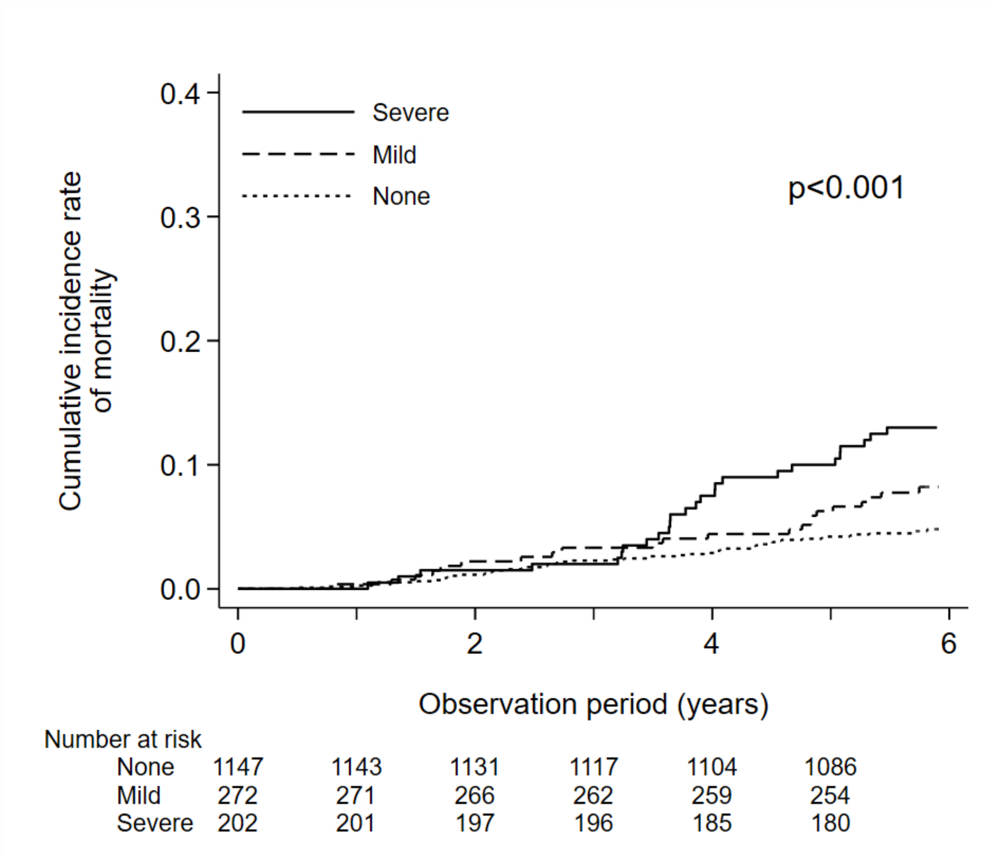

Fig. 2. Cumulative incidence of mortality. Subjects were divided into the following three groups according to the degree of kyphotic posture: None, Mild (> 0, ≤ 4 cm), and Severe (> 4 cm).The p-value was calculated using log-rank test.

333x288mm (72 x 72 DPI)

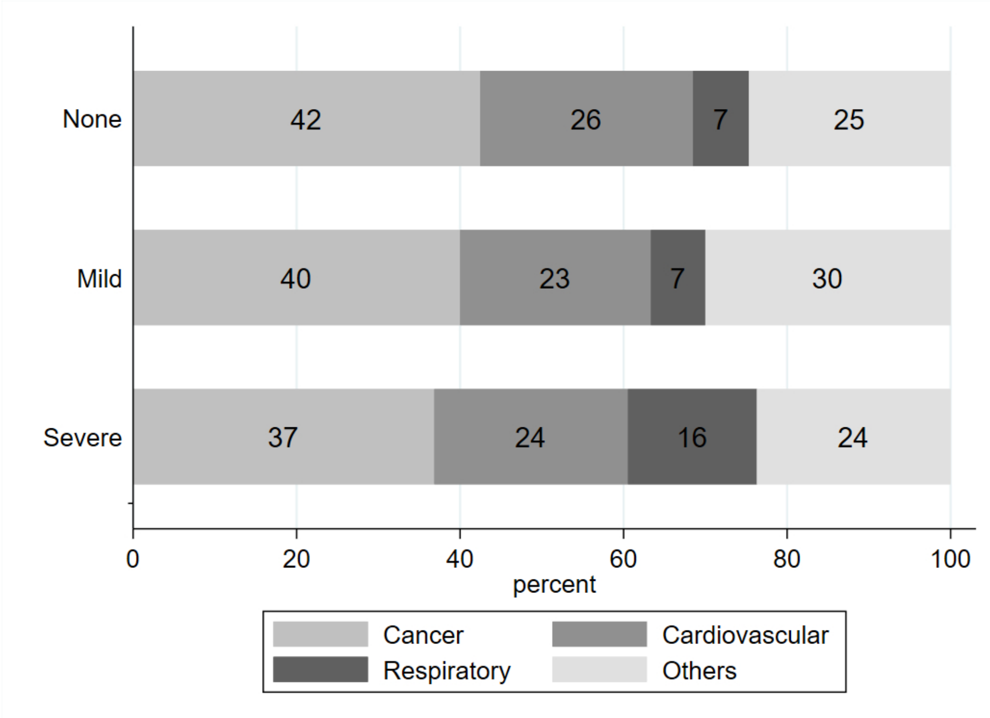

Fig. 3. Cause-specific deaths in each group. Participants were divided into the following three groups according to the degree of kyphosis: None, Mild (> 0, ≤ 4 cm), and Severe (> 4 cm).

366x266mm (72 x 72 DPI)

Supplementary Material 1

Supplemental material for: "Association of kyphotic posture with loss of independence and mortality in a community-based prospective cohort study: The Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS)"

Supplementary Table 1. Sensitivity analysis with multiple imputation for mortality according to the degree of kyphosis

	Number of participants	Frequency of mortality	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1525	73	0.009	Ref.	Ref.
Mild	369	30	0.015	1.72 (1.13–2.64)	1.19 (0.77–1.84)
Severe	299	38	0.023	2.76 (1.86–4.08)	1.80 (1.17–2.77)

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, history of stroke, and handgrip strength.

Supplementary Material 2

Supplemental material for: "Association of kyphotic posture with loss of independence and mortality in a community-based prospective cohort study: The Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS)"

Supplementary Table 2. Sensitivity analysis with multiple imputation for loss of independence according to the degree of kyphosis

	Number of participants	Frequency of loss of independence	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1525	114	0.015	Ref.	Ref.
Mild	369	47	0.018	2.10 (1.49–2.97)	1.47 (1.03–2.10)
Severe	299	73	0.045	3.33 (2.46–4.49)	1.74 (1.25–2.43)

Abbreviations: HR = hazard ratio; CI = confidence interval.
a Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, stroke history, and handgrip strength.

Supplementary Material 3

Supplemental material for: "Association of kyphotic posture with loss of independence and mortality in a community-based prospective cohort study: The Locomotive Syndrome and Health Outcomes in Aizu Cohort Study (LOHAS)"

Supplementary Table 3. Sensitivity analysis with multiple imputation for loss of independence and mortality according to the degree of kyphosis

	Number of Participants	Frequency of loss of independence and mortality	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)[a]
Kyphotic posture					
None	1525	176	0.021	Ref.	Ref.
Mild	369	65	0.033	1.78 (1.33–2.37)	1.26 (0.93–1.69)
Severe	299	93	0.06	2.78 (2.16–3.59)	1.63 (1.23–2.16)

Abbreviations: HR = hazard ratio; CI = confidence interval.

[a]Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal stenosis, low back pain, good health status, stroke history, and handgrip strength.

[b]Composite outcome of loss of independence and mortality.

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	5
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	6
		(*b*) For matched studies, give matching criteria and number of exposed and unexposed	-
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	7
Bias	9	Describe any efforts to address potential sources of bias	8
Study size	10	Explain how the study size was arrived at	No
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8
		(*b*) Describe any methods used to examine subgroups and interactions	9
		(*c*) Explain how missing data were addressed	9
		(*d*) If applicable, explain how loss to follow-up was addressed	8
		(*e*) Describe any sensitivity analyses	9
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	9
		(b) Give reasons for non-participation at each stage	9
		(c) Consider use of a flow diagram	10
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	9
		(b) Indicate number of participants with missing data for each variable of interest	No
		(c) Summarise follow-up time (eg, average and total amount)	11
Outcome data	15*	Report numbers of outcome events or summary measures over time	11

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	12
		(*b*) Report category boundaries when continuous variables were categorized	-
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	-
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	11
Discussion			
Key results	18	Summarise key results with reference to study objectives	15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	18
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	16
Generalisability	21	Discuss the generalisability (external validity) of the study results	18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	25

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.