

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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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 2193 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 HRs (aHRs).

Results Of the 2193 subjects enrolled, 1621 were included in the primary analysis. Among these, 272 (17%) and 202 (12%) were diagnosed with mild and severe kyphotic postures, respectively. The median follow-up time was 5.8 years. Compared with the non-kyphotic group, the aHRs for mortality were 1.17 (95% CI 0.70 to 1.96) and 1.99 (95% CI 1.20 to 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 to 2.55; severe: aHR 2.08, 95% CI 1.39 to 3.10) and the LOI-mortality composite (mild: aHR 1.27, 95% CI 0.90 to 1.79; severe: aHR 1.83, 95% CI 1.31 to 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.

INTRODUCTION

Kyphosis is described as an abnormal posture that develops because of the failure of the

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 2193 participants included in the study were lost to follow-up due to change of residence from the target area, which minimised 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.

posture maintenance mechanism. When standing, lordotic segments (ie, the cervical and lumbar spine) and kyphotic segments (ie, 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 gastro-oesophageal 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 analysed the 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 health-care 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) certification¹⁸ 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.

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 semiquantitative technique used to assess head forward posture in the standing position as well as thoracic vertebral fractures.^{19,20} The WOT reflects thoracic hyperkyphosis and a loss of cervical and lumbar lordosis.

The distance (in centimetres) 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 ($>0, \leq 4$ 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 levels 1–5 (ie, 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 (categorised as <18.5 , ≥ 18.5 and <25 , and ≥ 25 kg/m²), present smoking habits, lumbar spinal stenosis (LSS), low back pain (requiring treatment and lasting for more than 24 hours), good health status (self-reported health: good, very good or excellent), stroke history and hand grip strength (dominant hand). LSS was diagnosed using a validated diagnostic support tool specifically designed for this purpose.²² Hand grip strength was measured using a digital dynamometer (Takei Scientific Instruments, 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 IQRs. 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 31 March 2014. After confirming that the proportional hazards assumption had not been violated, a Cox proportional hazards model with adjustment for

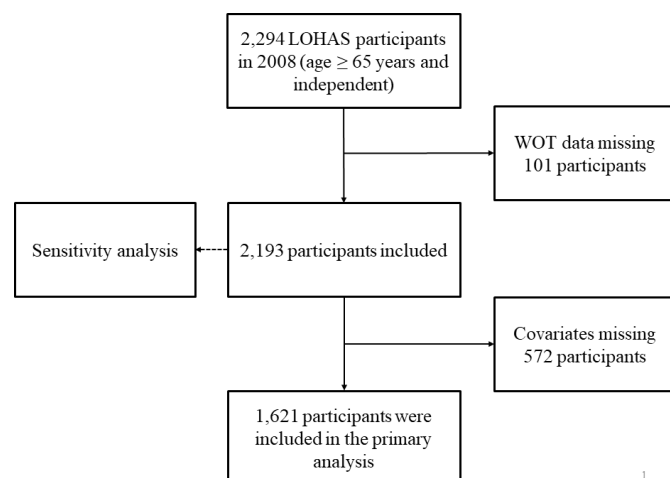


Figure 1 Flow diagram of eligible participants. LOHAS, Locomotive Syndrome and Health Outcomes in Aizu Cohort Study; WOT, wall-occiput test.

possible confounders (ie, age, sex, body mass index, smoking habit, LSS, low back pain, good health status, stroke history and hand grip 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 data sets.

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, on mortality or on 31 March 2014. Second, we employed another Cox proportional hazards 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 analysed the 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 V.15.1 (StataCorp, College Station, Texas, USA).

Patient and public involvement

There was no patient and public involvement in this study.

RESULTS

Baseline characteristics

A total of 2294 eligible participants from the 2008 LOHAS were identified. After excluding 101 subjects who did not undergo the WOT, a total of 2193 participants were retained. The primary analysis included 1621 participants without missing covariates. Figure 1 shows the flow diagram of subjects in this study.

Of the 1621 participants enrolled in this study, 272 (17%) and 202 (12%) were diagnosed with mild and severe kyphotic postures, 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/m²) and the proportion of participants with LSS and low back pain were high in the mild and severe kyphotic posture groups compared with the non-kyphotic posture group. The proportions of participants with good health status and average hand grip strength were low in these groups.

Table 1 Baseline characteristics of participants without missing covariates

	Kyphotic posture			
	Total n=1621	None n=1147 (71)	Mild (>0, ≤4 cm) n=272 (17)	Severe (>4 cm) 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)
Hand grip strength (kgw)	26 (22–34.5)	27 (22–35)	26 (21.25–35)	22 (18.5–28)

Data are presented as n (%) or median and IQR.

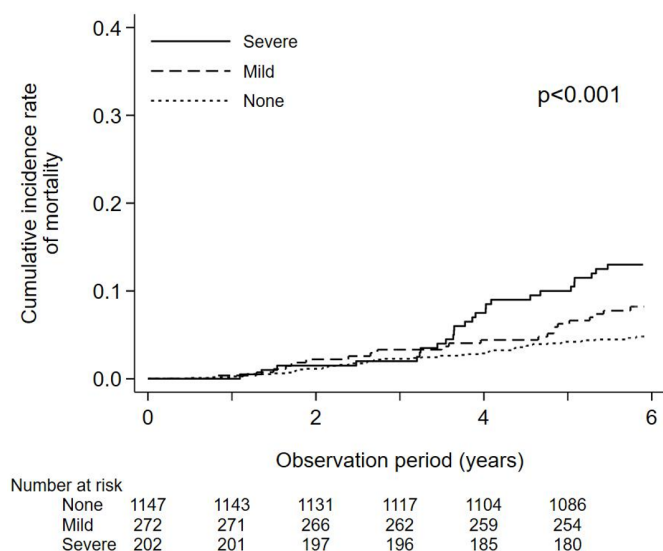


Figure 2 Cumulative incidence of mortality. Subjects were divided into the following three groups according to the degree of kyphotic posture: none, mild ($>0, \leq 4$ cm) and severe (>4 cm). The p value was calculated using log-rank test.

Primary analysis and sensitivity analysis

The cumulative mortality rates according to the degree of kyphosis are presented in figure 2. The median follow-up time was 5.8 years. The participants with mild and severe kyphotic postures 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 postures had higher rates of mortality than those without kyphotic posture, with adjusted HRs (aHRs) of 1.17 (95% CI 0.70 to 1.96) and 1.99 (95% CI 1.20 to 3.30), respectively. A sensitivity analysis using imputed data sets revealed similar results to those of the primary analysis (aHR 1.15 (95% CI 0.71 to 1.87) and 2.15 (95% CI 1.35 to 3.41), respectively; online supplemental table 1).

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 postures had higher rates of LOI than those without kyphotic posture (aHR 1.70 (95% CI 1.13 to 2.55) and 2.08 (95% CI 1.39 to 3.10), respectively). A sensitivity analysis using imputed data sets revealed similar results (aHR 1.47 (95% CI 1.03 to 2.10) and 1.74 (95% CI 1.25 to 2.43), respectively; online supplemental table 2).

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

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).

The causes of mortality in each group are presented in figure 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 hand grip strength. Furthermore, the association was stronger in the severe kyphotic posture group; the presence of severe kyphotic posture was related to a twofold increase in the hazards of mortality in relation to the non-kyphotic posture. Additionally, kyphotic posture was associated

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

	Participants (n)	Frequency of mortality	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)*
Kyphotic posture					
None	1147	54	0.008	Ref	Ref
Mild	272	22	0.014	1.74 (1.06 to 2.85)	1.17 (0.70 to 1.96)
Severe	202	26	0.023	2.83 (1.77 to 4.52)	1.99 (1.20 to 3.30)

*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 hand grip strength.

Table 3 Cox proportional hazards model of loss of independence according to the degree of kyphosis

	Participants (n)	Frequency of loss of independence	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)*
Kyphotic posture					
None	1147	82	0.013	Ref	Ref
Mild	272	38	0.026	2.38 (1.61 to 3.52)	1.70 (1.13 to 2.55)
Severe	202	51	0.048	3.63 (2.52 to 5.22)	2.08 (1.39 to 3.10)

*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 hand grip strength.

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-physiological hyperextensive 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 on one segment, such as the thoracic spine, and 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 subcategorise kyphosis by vertebral fractures might reveal sex differences in kyphotic posture.

Explanations and implications

We hypothesised 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.

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

	Participants (n)	Frequency of loss of independence and mortality*	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)†
Kyphotic posture					
None	1147	122	0.02	Ref	Ref
Mild	272	52	0.033	1.79 (1.28 to 2.50)	1.27 (0.90 to 1.79)
Severe	202	60	0.062	2.93 (2.16 to 3.98)	1.83 (1.31 to 2.56)

*Composite of loss of independence and mortality.

†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 hand grip strength.

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

	Participants (n)	Frequency of mortality	Occurrence rate/year	Unadjusted HR (95% CI)	Adjusted HR (95% CI)*
Male	640	64	0.018		
Kyphotic posture					
None	449	32	0.013	Ref	Ref
Mild	126	19	0.028	2.19 (1.24 to 3.87)	1.64 (0.91 to 2.95)
Severe	65	13	0.037	2.97 (1.56 to 5.65)	2.31 (1.17 to 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 to 2.15)	0.50 (0.15 to 1.73)
Severe	137	13	0.017	3.10 (1.56 to 6.14)	1.55 (0.70 to 3.45)

*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 hand grip strength.

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 postures identified by WOT had 2.2-fold and threefold 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 OVs,²⁴ OVs 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 OVs. 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 minimised the risk of information bias.

Nevertheless, this study also has several limitations. First, we did not adjust our data set for osteoporosis. We did not adjust for OVs because we were interested in kyphosis independent of OVs, and in overall kyphotic postures, including the ones caused by OVs. 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 the 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

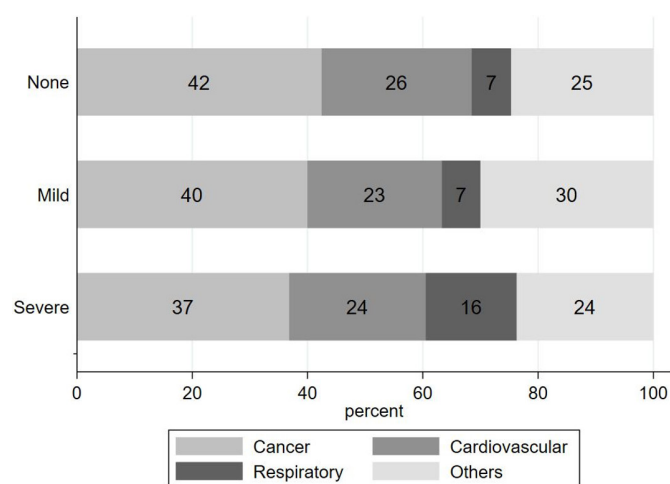


Figure 3 Cause-specific deaths in each group. Participants were divided into the following three groups according to the degree of kyphosis: none, mild (>0 , ≤ 4 cm) and severe (>4 cm).

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.

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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. YY is the guarantor of the work and accepts full responsibility for the presented content.

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Patient consent for publication Not required.

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REFERENCES

- Schwab F, Lafage V, Boyce R. Gravity line analysis in adult volunteers: age-related correlation with spinal parameters, pelvic parameters, and foot position. *Spine* 2006;31:959–67.
- Farcy JP, Schwab FJ. Management of flatback and related kyphotic decompensation syndromes. *Spine* 1997;22:2452–7.
- Ailon T, Shaffrey CI, Lenke LG, et al. Progressive spinal kyphosis in the aging population. *Neurosurgery* 2015;77 Suppl 4:S164–72.
- Kado DM, Prenovost K, Crandall C. Narrative review: hyperkyphosis in older persons. *Ann Intern Med* 2007;147:330–8.
- 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.
- Culham EG, Jimenez HA, King CE. Thoracic kyphosis, rib mobility, and lung volumes in normal women and women with osteoporosis. *Spine* 1994;19:1250–5.
- 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.
- 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.
- 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.
- 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.
- 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;27:670–7.
- McDaniels-Davidson C, Davis A, Wing D, et al. Kyphosis and incident falls among community-dwelling older adults. *Osteoporos Int* 2018;29:163–9.
- 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* 2016;41:1232–8.
- Kado DM, Huang M-H, 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.
- Kado DM, Lui L-Y, Ensrud KE, et al. Hyperkyphosis predicts mortality independent of vertebral osteoporosis in older women. *Ann Intern Med* 2009;150:681–7.
- 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.e1–550.e6.
- 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.
- Campbell JC, Ikegami N. Long-Term care insurance comes to Japan. *Health Aff* 2000;19:26–39.

- 19 Green AD, Colón-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-ichi, Kikuchi S-ichi, Tanaka Y, Konno S, Kikuchi S, *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* 2005;30:427–33.
- 25 Schneider DL, von Mühlen 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 M-H, 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* 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.

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.

^aEstimated 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.

^aEstimated 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.

^bComposite outcome of loss of independence and mortality.