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# BMJ Open

## 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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| Journal:                      | <i>BMJ Open</i>  |
| Manuscript ID                 | bmjopen-2021-052421  |
| Article Type:                 | Original research  |
| Date Submitted by the Author: | 15-Apr-2021  |
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| Keywords:                     | Spine < ORTHOPAEDIC & TRAUMA SURGERY, Musculoskeletal disorders < ORTHOPAEDIC & TRAUMA SURGERY, PUBLIC HEALTH, GERIATRIC MEDICINE  |
|                               |  |

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5 2 **Community-Dwelling Older Adults: The Locomotive Syndrome and Health Outcomes in**  
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7 3 **Aizu Cohort Study (LOHAS)**  
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35 **Word count:** 2699 words

1  
2  
3 **37 Abstract**  
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5 **38 Objectives:** This study aimed to investigate the association between kyphotic posture and future  
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8 **39** loss of independence (LOI) and mortality in community-dwelling older adults.  
9

10 **40 Design:** Prospective cohort study.  
11

12 **41 Setting:** Two Japanese municipalities.  
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14 **42 Participants:** We enrolled 2,193 independent community-dwelling older adults aged  $\geq 65$  years at  
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16  
17 **43** the time of their baseline health check-up in 2008. Kyphotic posture was evaluated using the wall-  
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19 **44** occiput test (WOT) and classified into three categories: non-kyphotic, mild ( $>0$  and  $\leq 4$  cm), and  
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21 **45** severe ( $>4$  cm).  
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23

24 **46 Primary and secondary outcome measures:** The primary outcome was mortality, whereas the  
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26 **47** secondary outcomes were LOI (new long-term care insurance certification levels 1–5) and a  
27  
28 **48** composite of LOI and mortality. A Cox proportional hazards model was used to estimate the  
29  
30 **49** adjusted hazard ratios (aHR).  
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33 **50 Results:** Of the 2,193 subjects enrolled, 1,621 were included in the primary analysis; among these,  
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35 **51** 272 (17%) and 202 (12%) were diagnosed with mild and severe kyphotic posture, respectively.  
36  
37 **52** After a median follow-up of 5.8 years, the aHRs for mortality were 1.17 (95% confidence interval  
38  
39 **53** [CI], 0.70–1.96) and 1.99 (95% CI, 1.20–3.30) in the mild and severe kyphotic posture groups,  
40  
41 **54** respectively. In the secondary analysis, a consistent association was observed for LOI (mild: aHR,  
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43 **55** 1.70; 95% CI, 1.13–2.55; severe: aHR, 2.08; 95% CI, 1.39–3.10) and the LOI–mortality composite  
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45 **56** (mild: aHR, 1.27; 95% CI, 0.90–1.79; severe: aHR, 1.83; 95% CI, 1.31–2.56).  
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49 **57 Conclusion:** Kyphotic posture was associated with LOI and mortality in community-dwelling  
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51 **58** older adults. Identifying the population with kyphotic posture using the WOT might help improve  
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54 **59** community health.  
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**61 Strengths and limitations of this study:**

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

68

## 70 **Introduction**

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

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

86 Three previous studies have reported the association of kyphotic posture with LOI and  
87 mortality. First, Kado et al. demonstrated the association between cervicothoracic kyphosis and  
88 mortality.[13] As kyphosis was measured in the supine position rather than in the standing position,  
89 the evaluation of the kyphotic posture was not precise. In another study, Kado et al. reported an  
90 association of thoracic hyperkyphosis in the standing position with mortality in older women.[14]  
91 However, these two studies could not yield an assessment on whether the kyphotic posture was a  
92 risk factor for mortality in men. Okura et al. showed that kyphotic posture is related to LOI and



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3 93 mortality.[15] However, there was a potential bias since the study was passed on self-reported data  
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5 94 from participants to determine kyphotic posture. Moreover, the researchers only controlled for age  
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8 95 and gender as potential confounders. Furthermore, none of these studies adjusted for lumbar  
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10 96 degenerative disease and back pain, which are strongly associated with kyphotic posture.

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12 97 To address these concerns, we conducted a prospective cohort study to examine whether  
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15 98 a kyphotic posture in the standing position was associated with LOI and mortality in community-  
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17 99 dwelling men and women.  
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19 100

## 101 **Materials and methods**

### 102 *Study Design and Population*

103 This prospective observational study analyzed data from the Locomotive Syndrome and Health  
104 Outcomes in Aizu Cohort Study (LOHAS), a population-based study involving residents from two  
105 towns in Japan. The LOHAS evaluated the effect of locomotive dysfunction on healthcare  
106 outcomes, including quality of life, medical costs, and occurrence of LOI and mortality. The  
107 LOHAS comprised approximately 70% of all the National Health Insurance and Late-Stage  
108 Elderly Health Insurance beneficiaries in that region. Details of the study have been described  
109 elsewhere.[16]  
110

### 111 *Study Participants*

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

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3 116 This study was approved by certified institutional review boards (R1730 and 673) of the  
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5 117 participating institutions, and all participants provided written informed consent before  
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7 118 participation.  
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### 12 120 *Definition of Kyphotic Posture*

14 121 Kyphotic posture was defined using the wall-occiput test (WOT) at the time of musculoskeletal  
15 122 examination in 2008. The WOT is a semi-quantitative technique used to assess head forward  
16 123 posture in the standing position as well as thoracic vertebral fractures.[18,19] The WOT reflects  
17 124 not only thoracic hyperkyphosis, but also a loss of cervical and lumbar lordosis.  
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24 125 The distance (measured in cm) between the occiput prominence and the wall was  
25 126 measured using a tape while the participants were standing with both of their heels and sacrum  
26 127 against the wall and their head positioned such that an imaginary line from the lateral corner of the  
27 128 eye to the superior point of the auricle was parallel to the floor. In accordance with previous  
28 129 studies,[12,20] we divided the participants into the following three groups based on the degree of  
29 130 kyphosis: none, mild ( $>0, \leq 4$  cm), and severe ( $>4$  cm).  
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### 40 132 *Outcomes*

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42 133 The primary outcome was the mortality rate. Data on mortality and its causes were collected from  
43 134 death certificates provided by the Ministry of Health, Labour, and Welfare of Japan. The secondary  
44 135 outcome was the development of LOI, which was defined as a new LTCI certification of level 1–  
45 136 5 (i.e., a condition requiring any support for daily living). Information on LTCI certification status  
46 137 was obtained from the local government annually. The use of public data allowed us to access all  
47 138 outcome data, except for those participants who moved outside the target area.  
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### 140 *Baseline Covariates*

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

147

### 148 *Statistical Analysis*

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

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

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

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3 162 In that model, participants were censored after moving out of the target area, upon mortality, or on  
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5 163 March 31, 2014. Second, we employed another Cox proportional hazard model to evaluate the  
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8 164 composite outcome of LOI and mortality. Both models included the same covariates as those in  
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10 165 the primary analysis. Third, we performed a subgroup analysis stratified by sex for the primary  
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12 166 outcome of mortality. Finally, we analyzed cause-specific mortality in each group, similar to a  
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15 167 previous study.[22] Four causes of death were evaluated: cancer, cardiovascular disease,  
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17 168 respiratory disease, and others.

19 169 Statistical analyses were performed using Stata version 15.1 (StataCorp LLC, College  
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21  
22 170 Station, Texas, USA).

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### 26 172 *Patient and public involvement*

28 173 There was no patient and public involvement.

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31 174

## 33 175 **Results**

### 35 176 *Baseline Characteristics*

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38 177 A total of 2,293 eligible participants from the 2008 LOHAS were identified. After excluding 100  
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40 178 subjects who did not undergo the WOT, a total of 2,193 participants were retained. The primary  
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42 179 analysis included 1,621 participants without missing covariates. Fig. 1 shows the flow of subjects  
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45 180 in this study.

47 181 Of the 1,621 participants enrolled in this study, 272 (17%) and 202 (12%) were diagnosed  
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49 182 with mild and severe kyphotic posture, respectively (Table 1). The median age of all participants  
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51 183 was 72 years, 61% were female, and 75% had good health status. The average age, proportion of  
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54 184 overweight participants, and the proportion of participants with LSS and low back pain were high

185 in the mild and severe kyphotic posture groups. The proportion of participants with good health  
 186 status and average handgrip strength were low in these groups.

187

188 **TABLE 1.** Baseline Characteristics of Participants Without Missing Covariates

|                                    | Total           | Kyphotic Posture     |                     |                     |
|------------------------------------|-----------------|----------------------|---------------------|---------------------|
|                                    |                 | None                 | Mild (>0, ≤4 cm)    | Severe (> 4 cm)     |
|                                    | <i>n</i> = 1621 | <i>n</i> = 1147 (71) | <i>n</i> = 272 (17) | <i>n</i> = 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 <sup>2</sup> |                 |                      |                     |                     |
| <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).

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### 190 ***Primary Analysis and Sensitivity Analysis***

191 The cumulative mortality rates according to the degree of kyphosis are presented in Fig. 2. After

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3 192 a median follow-up of 5.8 years, participants with mild and severe kyphotic posture showed higher  
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5 193 cumulative mortality rates (8% and 13%, respectively) than those without kyphotic posture (5%).  
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8 194 The tracking ratio at the end of the study was 98.5%. The mortality rates were 0.008 per year in  
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10 195 the non-kyphotic posture group, 0.014 per year in the mild kyphotic posture group, and 0.023 per  
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12 196 year in the severe kyphotic posture group (Table 2), with the log-rank test indicating a difference  
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15 197 among the groups ( $P < 0.001$ ). Cox regression analysis showed that participants with mild and  
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17 198 severe kyphotic posture had higher rates of mortality than those without kyphotic posture, with  
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19 199 adjusted hazard ratios (aHRs) of 1.17 (95% confidence interval [CI], 0.70–1.96), and 1.99 (95%  
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21 200 CI, 1.20–3.30) respectively. A sensitivity analysis using imputed datasets revealed results similar  
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23  
24 201 to those of the primary analysis (aHR, 1.15 [95% CI, 0.71–1.87] and 2.15 [95% CI, 1.35–3.41],  
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26 202 respectively; Supplementary table 1).  
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31 204 **TABLE 2.** Cox Proportional Hazards Model of Mortality According to the Degree of Kyphosis

|                  | Number of<br>Participants | Mortality | Occurrence<br>Rate/Year | Unadjusted HR<br>(95% CI) | Adjusted HR<br>(95% CI) <sup>a</sup> |
|------------------|---------------------------|-----------|-------------------------|---------------------------|--------------------------------------|
| 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)                    |

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46 Note. Data are presented as n (%).

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

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50 <sup>a</sup>Estimated from a Cox regression model adjusted for age, sex, body mass index, smoking habit, lumbar spinal  
51  
52 stenosis, low back pain, health status, stroke history, and handgrip strength.  
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54 205

206 **Secondary Analysis**

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

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

|                  | Number of<br>Participants | Loss of<br>Independence | Occurrence<br>Rate/Year | Unadjusted HR<br>(95% CI) | Adjusted HR<br>(95% CI) <sup>a</sup> |
|------------------|---------------------------|-------------------------|-------------------------|---------------------------|--------------------------------------|
| 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.

<sup>a</sup>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.

214  
 215 Consistent results were obtained for the composite outcome of LOI and mortality (Table 4).  
 216 Participants with mild and severe kyphotic posture had higher rates of LOI and mortality than  
 217 those without kyphotic posture (aHR, 1.27 [95% CI, 0.90–1.79] and 1.83 [95% CI, 1.31–2.56],  
 218 respectively).

219

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

|                  | Number of<br>Participants | Loss of<br>Independence<br>and Mortality | Occurrence<br>Rate/Year | Unadjusted HR<br>(95% CI) | Adjusted HR<br>(95% CI) <sup>a</sup> |
|------------------|---------------------------|--|-------------------------|---------------------------|--------------------------------------|
| 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.

<sup>a</sup>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.

222  
 223 We conducted a subgroup analysis stratified by sex, which indicated that males had a  
 224 higher cumulative rate of mortality (10%, 0.018 per year) than females (4%, 0.007 per year). Male  
 225 sex also showed a more pronounced association between kyphotic posture and mortality (Table  
 226 5).

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

|  | Number of<br>Subjects | Mortality | Occurrence<br>Rate/Year | Unadjusted HR<br>(95% CI) | Adjusted HR<br>(95% CI) <sup>a</sup> |
|--|-----------------------|-----------|-------------------------|---------------------------|--------------------------------------|
|--|-----------------------|-----------|-------------------------|---------------------------|--------------------------------------|



|                  |     |         |       |                   |                   |
|------------------|-----|---------|-------|-------------------|-------------------|
| 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.

<sup>a</sup>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.

230

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

234

## 235 Discussion

236 In the present study, we explored the association between kyphotic posture and mortality using  
 237 data from a relatively large sample. The kyphotic posture detected with the WOT appeared to  
 238 affect mortality in a way not explained by age, sex, body mass index, smoking, LSS, low back  
 239 pain, health status, history of stroke, and handgrip strength. Furthermore, a dose-response

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3 240 relationship was observed in the association; the presence of severe kyphotic posture was related  
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5 241 to a two-fold increase in the risk of mortality than non-kyphotic posture. Additionally, kyphotic  
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7 242 posture was associated with LOI, and the association between kyphotic posture and mortality was  
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9 243 more pronounced in men.

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11  
12 244 Kado et al. reported that cervicothoracic kyphosis measured in the supine position was  
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14 245 associated with mortality in older men and women; they did not observe any sex-specific  
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16 246 differences in their study.[13] They also showed that the degree of thoracic hyperkyphosis in the  
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18 247 standing position had a predictive value for mortality among older women, in addition to  
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20 248 osteoporotic vertebral fractures (OVFs).[14] Our results were similar to those from previous  
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22 249 studies, which showed that kyphotic posture was associated with mortality. Additionally, we  
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24 250 believe that the present study has the advantage of using the WOT, which measures kyphosis in  
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26 251 the standing position and reflects overall sagittal balance. To properly assess the degree of  
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28 252 kyphosis, subjects should be in the standing position with their hips and knees fully extended to  
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30 253 negate the compensatory mechanisms [23]. With the subjects in the supine position, kyphotic  
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32 254 posture may be corrected by a non-physiologic hyper-extensive force so that the degree of  
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34 255 kyphosis is consistently underestimated. Furthermore, as described above, kyphotic posture  
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36 256 develops due to the failure of the posture maintenance mechanism. When evaluating kyphotic  
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38 257 posture, it is necessary to focus not only on one segment, such as the thoracic spine, but also on  
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40 258 the alignment of the whole spine.

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43 259 In the subgroup analysis by sex, the association between kyphotic posture and mortality  
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45 260 seemed to be more pronounced in men, although no clear sex difference in mortality was shown  
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47 261 in the present study. Sex differences in the prevalence of vertebral fractures have been reported,  
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49 262 [24,25] and the nature of kyphosis may differ between men and women. Further studies that

263 subcategorize kyphosis by vertebral fractures might reveal sex differences categorized by kyphotic  
264 posture.

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### 266 *Explanations and Implications*

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

280 The results of the present study suggest that kyphotic posture is a clinically important  
281 finding, and further studies on the effects of the prevention and treatment of kyphotic posture are  
282 needed. Noticeably, our study demonstrates that the WOT is helpful in predicting serious  
283 healthcare outcomes. Among men, those with mild and severe kyphotic posture identified by WOT  
284 were shown to have a 2.2-fold and 3-fold increased risk of mortality, respectively. The WOT is  
285 easy, inexpensive, and does not require special skills or devices, making it an attractive clinical

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3 286 tool for the identification of high-risk population. Approximately 40% of older adults with the  
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5 287 worst degrees of kyphosis have underlying OVFs,[24,25] and OVFs are widely thought to be a  
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7 288 major factor contributing to the development of kyphotic posture. Therefore, osteoporosis  
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9 289 treatment may help prevent kyphotic posture via a reduction in the occurrence of OVFs. In addition  
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11 290 to structural changes in the vertebral column, back extensor weakness is also associated with a  
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13 291 kyphotic posture.[28-30] Despite limited evidence, some reports suggest that exercise may  
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15 292 modestly improve back extensor muscle strength [31].  
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### 21 294 ***Strengths and Limitations***

23  
24 295 The present study has significant strengths. First, we demonstrated the association of kyphotic  
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26 296 posture with LOI and mortality in a community-dwelling population. We believe that the present  
27  
28 297 study is valuable in investigating the longitudinal development of serious healthcare outcomes  
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30 298 based on samples from a general population. Second, we used public data, which provided us with  
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32 299 reliable and complete information on outcomes, except for participants who moved out of the  
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34 300 target area. As relocation was rare, a high tracking ratio (98.5%) was achieved, which minimized  
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36 301 the risk of information bias.  
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40 302 Nevertheless, this study has several limitations. First, we did not adjust our dataset for  
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42 303 osteoporosis. We did not adjust for OVFs because we were interested not only in kyphosis  
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44 304 independent of OVFs, but in overall kyphotic postures, including the ones caused by OVFs.  
45  
46 305 However, osteoporosis may be associated with LOI and mortality through other mechanisms.  
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48 306 Second, the WOT does not distinguish rigid kyphosis from flexible kyphosis. To evaluate spinal  
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50 307 flexibility, evaluations in both the standing and supine positions need to be performed. The WOT  
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52 308 also does not identify participants who can maintain good non-kyphotic posture only for a short  
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3 309 period during measurement. No evaluation method has overcome this problem, and the  
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5 310 development of a new method, such as continuous posture analysis, is warranted. Finally,  
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7 311 attributing causation is difficult because of other unmeasured confounders, including subclinical  
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9 312 diseases. It should be noted that the present study does not provide evidence to support surgical  
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11 313 interventions to correct kyphosis. Surgical reconstruction should not be routinely performed in  
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13 314 elderly individuals with a typical high-risk profile.  
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## 19 316 **Conclusions**

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21 317 Kyphotic posture is associated with LOI and mortality. Therefore, identifying older people with  
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23 318 kyphotic posture using the WOT in the community might help identify high-risk populations that  
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25 319 would benefit from healthcare interventions.  
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3 404 **Figure legends**  
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5 405 **Fig. 1.** Flow diagram of eligible participants.  
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8 406 WOT: wall-occiput test; LOHAS: Locomotive Syndrome and Health Outcomes in Aizu Cohort  
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12 408 **Fig. 2.** Cumulative incidence of mortality. Subjects were divided into the following three groups  
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14 409 according to the degree of kyphotic posture: none, mild ( $> 0, \leq 4$  cm), and severe ( $> 4$  cm).  
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17 410 **Fig. 3.** Cause-specific deaths in each group. Subjects were divided into the following three groups  
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19 411 according to the degree of kyphosis: non-kyphotic, mild ( $> 0, \leq 4$  cm), and severe ( $> 4$  cm).  
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3 413 **Footnotes**  
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5 414 **Contributors:** Conception and design of the study: YH, TK, SF, YY; Acquisition of data: MS,  
6  
7 415 KO, SK, MT; Analysis and interpretation of data: YH, TK, SF, YY; Drafting the article or revising  
8  
9 416 it critically for important intellectual content: YH, TK, MS, KO, SK, MT, SF, YY; Final approval  
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11 417 of the version to be submitted: YH, TK, MS, KO, SK, MT, SF, YY.  
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14 418 **Funding:** This research received no specific grant from any funding agency in the public,  
15  
16 419 commercial or not-for-profit sectors.  
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19 420 **Data availability statement:** The data presented in the study are not currently available separately.  
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21 421 Additional unpublished data is still being analyzed for another research project.  
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24 422 **Competing interests:** None declared.  
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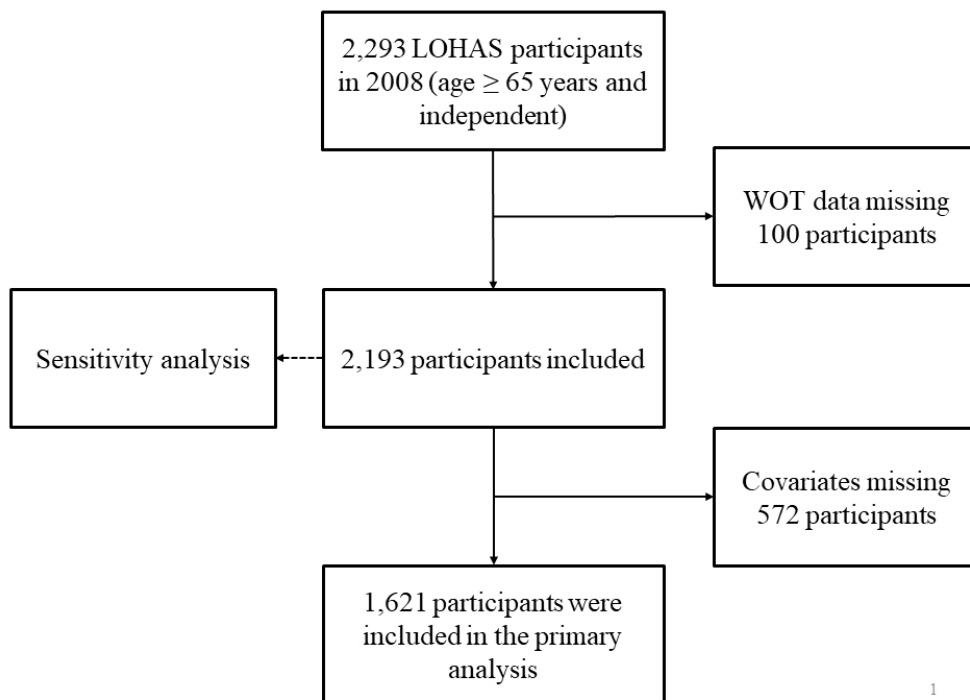
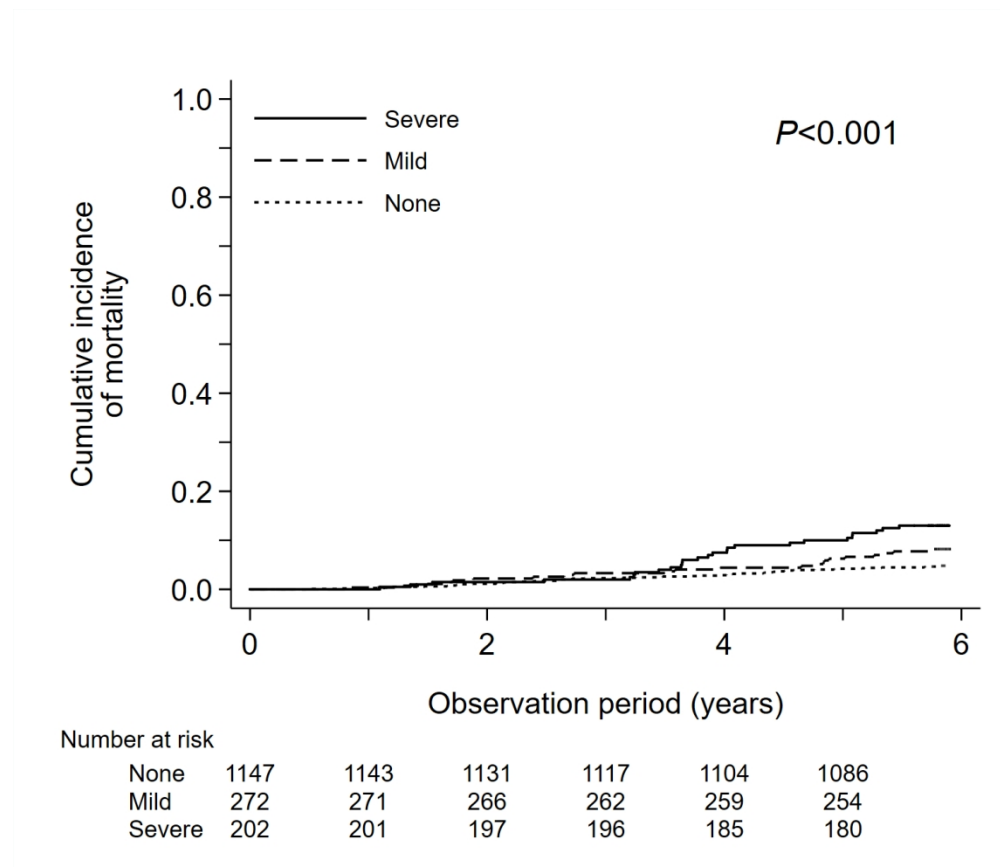


Fig. 1. Flow diagram of eligible participants.  
WOT: wall-occiput test; LOHAS: Locomotive Syndrome and Health Outcomes in Aizu Cohort Study

254x190mm (96 x 96 DPI)



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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 ( $> 0, \leq 4$  cm), and severe ( $> 4$  cm).

549x475mm (72 x 72 DPI)

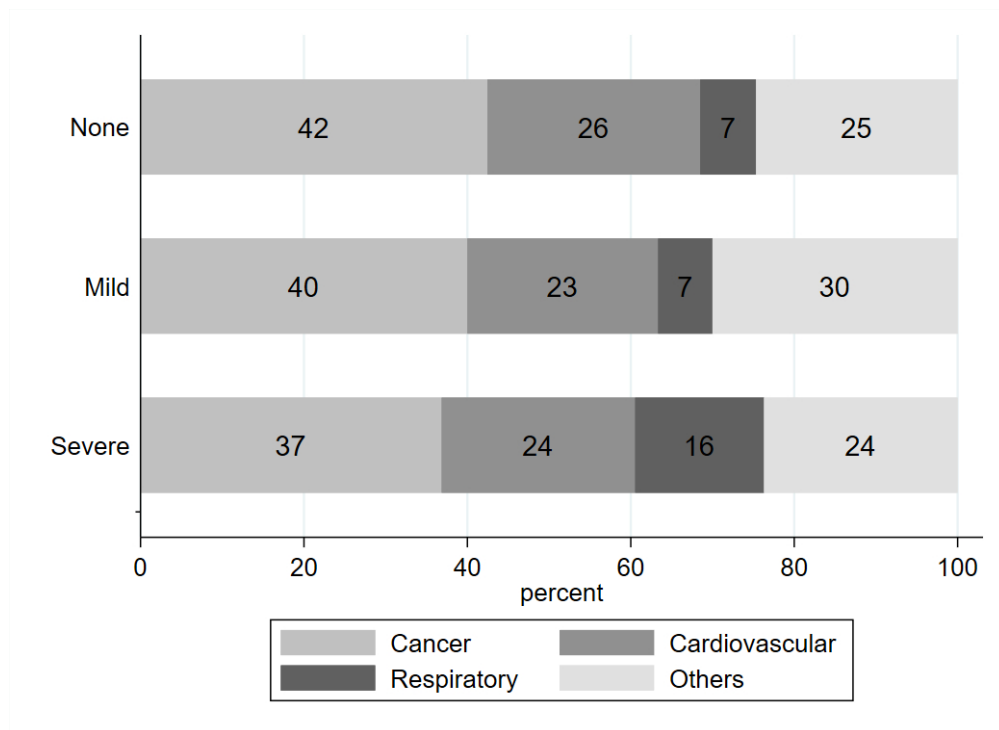


Fig. 3. Cause-specific deaths in each group. Participants were divided into the following three groups according to the degree of kyphosis: None, Mild (> 0, ≤ 4 cm), and Severe (> 4 cm).

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<br>Participants | Mortality | Occurrence<br>Rate/Year | Unadjusted HR<br>(95% CI) | Adjusted HR<br>(95% CI) <sup>a</sup> |
|------------------|---------------------------|-----------|-------------------------|---------------------------|--------------------------------------|
| 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.

<sup>a</sup>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 |
|---------------------------|---------|---|---------|
| <b>Title and abstract</b> | 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       |
| <b>Introduction</b>       |         |   |         |
| 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       |
| <b>Methods</b>            |         |   |         |
| 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       |
| <b>Results</b>            |         |   |         |
| 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      |



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|----|--------------------------|----|--|----|
| 1  | 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 |
| 2  |                          |    | (b) Report category boundaries when continuous variables were categorized  | -  |
| 3  |                          |    | (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period   | -  |
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| 9  | Other analyses           | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses   | 12 |
| 10 |                          |    |  |    |
| 11 | <b>Discussion</b>        |    |  |    |
| 12 |                          |    |  |    |
| 13 | Key results              | 18 | Summarise key results with reference to study objectives   | 14 |
| 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 |
| 15 |                          |    |  |    |
| 16 | Interpretation           | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence                                   | 16 |
| 17 |                          |    |  |    |
| 18 |                          |    |  |    |
| 19 | Generalisability         | 21 | Discuss the generalisability (external validity) of the study results  | 17 |
| 20 |                          |    |  |    |
| 21 | <b>Other information</b> |    |  |    |
| 22 | 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 |
| 23 |                          |    |  |    |
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26 \*Give information separately for exposed and unexposed groups.

27  
28 **Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and  
29 published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely  
30 available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at  
31 <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is  
32 available at <http://www.strobe-statement.org>.  
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# 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)

|                                 |   |
|---------------------------------|---|
| Journal:                        | <i>BMJ Open</i>   |
| Manuscript ID                   | bmjopen-2021-052421.R1  |
| Article Type:                   | Original research   |
| Date Submitted by the Author:   | 20-Nov-2021   |
| Complete List of Authors:       | Hijkata, Yasukazu; Kyoto University Graduate School of Medicine Faculty of Medicine, Department of Healthcare Epidemiology<br>Kamitani, Tsukasa; Kyoto University Graduate School of Medicine Faculty of Medicine, Department of Healthcare Epidemiology<br>Sekiguchi, Miho; Fukushima Medical University School of Medicine, Department of Orthopedic Surgery<br>Otani, Koji; Fukushima Medical University School of Medicine, Department of Orthopedic Surgery<br>Konno, Shin-ichi; Fukushima Medical University School of Medicine, Department of Orthopedic Surgery<br>Takegami, Misa; National Cerebral and Cardiovascular Center, Preventive Medicine and Epidemiology Informatics<br>Fukuhara, Shunichi; Fukushima Kenritsu Ika Daigaku, Department of General Medicine, Shirakawa Satellite for Teaching And Research (STAR); Kyoto University Graduate School of Medicine Faculty of Medicine, Section of Clinical Epidemiology, Department of Community Medicine<br>Yamamoto, Yosuke; Kyoto University Graduate School of Medicine Faculty of Medicine, Department of Healthcare Epidemiology |
| <b>Primary Subject Heading</b>: | Geriatric medicine  |
| Secondary Subject Heading:      | Public health   |
| Keywords:                       | Spine < ORTHOPAEDIC & TRAUMA SURGERY, Musculoskeletal disorders < ORTHOPAEDIC & TRAUMA SURGERY, PUBLIC HEALTH, GERIATRIC MEDICINE   |
|                                 |   |

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3 1 **Association of kyphotic posture with loss of independence and mortality in a community-**  
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5 2 **based prospective cohort study: The Locomotive Syndrome and Health Outcomes in Aizu**  
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7 3 **Cohort Study (LOHAS)**  
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35 **Word count:** 2915 words

## 36 Abstract

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

39 **Design:** Prospective cohort study.

40 **Setting:** Two Japanese municipalities.

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

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

49 **Results:** Of the 2,193 subjects enrolled, 1,621 were included in the primary analysis. Among these,  
50 272 (17%) and 202 (12%) were diagnosed with mild and severe kyphotic posture, respectively.  
51 The median follow-up time was 5.8 years. Compared to the non-kyphotic group, the aHRs for  
52 mortality were 1.17 (95% confidence interval [CI], 0.70–1.96) and 1.99 (95% CI, 1.20–3.30) in  
53 the mild and severe kyphotic posture groups, respectively. In the secondary analysis, a consistent  
54 association was observed for LOI (mild: aHR, 1.70; 95% CI, 1.13–2.55; severe: aHR, 2.08; 95%  
55 CI, 1.39–3.10) and the LOI–mortality composite (mild: aHR, 1.27; 95% CI, 0.90–1.79; severe:  
56 aHR, 1.83; 95% CI, 1.31–2.56).

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

59 community health.

60

61 **Strengths and limitations of this study:**

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

## 72 Introduction

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

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

88 Three previous studies reported an association of kyphotic posture with LOI and mortality.  
89 First, Kado et al. demonstrated the association between cervicothoracic kyphosis and  
90 mortality.[14] It should be noted that, as kyphosis was measured in the supine position rather than  
91 in the standing position, the evaluation of the kyphotic posture was not precise. In another study,  
92 Kado et al. reported an association of thoracic hyperkyphosis in the standing position with  
93 mortality in older women.[15] Nonetheless, these two studies could not assess whether the  
94 kyphotic posture was a risk factor for mortality in men. Okura et al. showed that kyphotic posture



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3 95 is related to LOI and mortality.[16] However, there was a potential bias in this study, as the  
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5 96 determination of kyphotic posture was based on self-reported data from participants. Moreover,  
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7  
8 97 the researchers only controlled for age and sex as potential confounders. Furthermore, none of  
9  
10 98 these studies adjusted for lumbar degenerative disease and back pain, which are strongly associated  
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12 99 with kyphotic posture.  
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14  
15 100 To address these concerns, we conducted a prospective cohort study to examine whether  
16  
17 101 a kyphotic posture in the standing position was associated with LOI and mortality in community-  
18  
19 102 dwelling men and women.  
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## 23 24 104 **Materials and methods**

### 25 26 105 *Study Design and Population*

27  
28 106 This prospective observational study analyzed data from the Locomotive Syndrome and Health  
29  
30 107 Outcomes in Aizu Cohort Study (LOHAS), a population-based study involving residents from two  
31  
32 108 towns in Japan. The LOHAS evaluated the effect of locomotive dysfunction on healthcare  
33  
34 109 outcomes, including quality of life, medical costs, and occurrence of LOI and mortality. The  
35  
36 110 LOHAS comprised approximately 70% of all the National Health Insurance and Late-Stage  
37  
38 111 Elderly Health Insurance beneficiaries in that region. Details of the study have been described  
39  
40 112 elsewhere.[17]  
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### 46 47 114 *Study Participants*

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49 115 Independent community-dwelling older adults aged  $\geq 65$  years without any long-term care  
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51 116 insurance (LTCI) certification [18] at the time of their baseline health check-up in 2008 were  
52  
53 117 enrolled. Those in whom kyphotic posture could not be determined due to missing data were  
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2  
3 118 excluded. Participants were observed starting from the baseline check-up in 2008 until March 2014.  
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5 119 This study was approved by certified institutional review boards (R1730 and 673) of the  
6  
7  
8 120 participating institutions, and all participants provided written informed consent before  
9  
10 121 participation.  
11

12 122

### 13 14 123 *Definition of Kyphotic Posture*

15  
16  
17 124 Kyphotic posture was defined using the wall-occiput test (WOT) at the time of musculoskeletal  
18  
19 125 examination in 2008. The WOT is a semi-quantitative technique used to assess head forward  
20  
21 126 posture in the standing position as well as thoracic vertebral fractures.[19,20] The WOT reflects  
22  
23  
24 127 not only thoracic hyperkyphosis, but also a loss of cervical and lumbar lordosis.  
25

26 128 The distance (in cm) between the occiput prominence and the wall was measured using a  
27  
28 129 tape while the participants were standing with both of their heels and sacrum against the wall and  
29  
30  
31 130 their head positioned such that an imaginary line from the lateral corner of the eye to the superior  
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33 131 point of the auricle was parallel to the floor. In accordance with previous studies,[13,21] we  
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35 132 divided the participants into the following three groups based on the degree of kyphosis: none,  
36  
37 133 mild ( $>0, \leq 4$  cm), and severe ( $>4$  cm).  
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### 41 42 135 *Outcomes*

43  
44 136 The primary outcome was the time to mortality. Data on mortality and its causes were collected  
45  
46 137 from death certificates provided by the Ministry of Health, Labour, and Welfare of Japan. The  
47  
48 138 secondary outcome was the development of LOI, which was defined as a new LTCI certification  
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51 139 of level 1–5 (i.e., a condition requiring any support for daily living). Information on LTCI  
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54 140 certification status was obtained from the local government annually. The use of public data  
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3 141 allowed us to access all outcome data, except for those participants who changed their residence  
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5 142 outside the target area.  
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10 144 ***Baseline Covariates***

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12 145 The following baseline covariates were analysed as potential confounders for the relationship  
13  
14 146 between kyphotic posture and mortality: age, sex, body mass index (categorized as  $<18.5$ ,  $\geq 18.5$   
15  
16 147 and  $<25$ , and  $\geq 25$  kg/m<sup>2</sup>), present smoking habits, lumbar spinal stenosis (LSS), low back pain  
17  
18 148 (requiring treatment and lasting for more than 24 h), good health status (self-reported health: good,  
19  
20 149 very good, or excellent), stroke history, and handgrip strength (dominant hand). LSS was  
21  
22 150 diagnosed using a validated diagnostic support tool for specifically designed for this purpose.[22]  
23  
24 151 Handgrip strength was measured using a digital dynamometer (Takei Scientific Instruments Co.,  
25  
26 152 Ltd, Japan).  
27  
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29

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31 153  
32  
33 154 ***Statistical Analysis***

34  
35 155 The baseline characteristics of the participants were expressed as the presence or absence and the  
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37 156 degree of kyphotic posture, using medians and interquartile ranges. Additionally, absolute and  
38  
39 157 relative frequencies were used for dichotomous or categorical variables.  
40

41  
42 158 The cumulative incidence method and log-rank test were applied to compare the intervals  
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44 159 between the baseline and date of mortality. The date of each baseline check-up in 2008 was  
45  
46 160 considered as Time 0. Participants were censored after changing their residence out of the target  
47  
48 161 area or on March 31, 2014. After confirming that the proportional hazards assumption had not  
49  
50 162 been violated, a Cox proportional hazards model with adjustment for possible confounders (i.e.,  
51  
52 163 age, sex, body mass index, smoking habit, LSS, low back pain, good health status, stroke history,  
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3 164 and handgrip strength) was used to investigate the association between the kyphotic posture and  
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5 165 mortality. We conducted a sensitivity analysis with multiple imputations by chained equations of  
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7  
8 166 missing covariates, which included all variables (including outcomes) in the prediction model to  
9  
10 167 generate 20 imputed datasets.

11  
12 168 We performed four secondary analyses. First, we focused on LOI as a secondary outcome.  
13  
14 169 In that model, participants were censored after moving out of the target area, upon mortality, or on  
15  
16  
17 170 March 31, 2014. Second, we employed another Cox proportional hazard model to evaluate the  
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19 171 composite outcome of LOI and mortality. Both models included the same covariates as those in  
20  
21 172 the primary analysis. For these secondary analyses, we performed sensitivity analyses using  
22  
23 173 multiple imputations as in the main analysis. Third, we performed a subgroup analysis stratified  
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25  
26 174 by sex for the primary outcome of mortality. Finally, we analyzed cause-specific mortality in each  
27  
28 175 group, as in a previous study.[23] Four causes of death were evaluated: cancer, cardiovascular  
29  
30  
31 176 disease, respiratory disease, and others.

32  
33 177 Statistical analyses were performed using Stata version 15.1 (StataCorp LLC, College  
34  
35 178 Station, Texas, USA).

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37  
38 179

### 39 40 180 *Patient and public involvement*

41  
42 181 There was no patient and public involvement in this study.

43  
44  
45 182

## 46 47 183 **Results**

### 48 49 184 *Baseline Characteristics*

50  
51 185 A total of 2,294 eligible participants from the 2008 LOHAS were identified. After excluding 101  
52  
53  
54 186 subjects who did not undergo the WOT, a total of 2,193 participants were retained. The primary

187 analysis included 1,621 participants without missing covariates. Fig. 1 shows the flow diagram of  
 188 subjects in this study.

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

196  
 197 **TABLE 1.** Baseline characteristics of participants without missing covariates

|                                    | Total           | Kyphotic posture     |                           |                     |
|------------------------------------|-----------------|----------------------|---------------------------|---------------------|
|                                    |                 | None                 | Mild (>0, $\leq 4$<br>cm) | Severe (>4<br>cm)   |
|                                    | <i>n</i> = 1621 | <i>n</i> = 1147 (71) | <i>n</i> = 272 (17)       | <i>n</i> = 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 <sup>2</sup> |                 |                      |                           |                     |
| <18.5                              | 57 (4)          | 43 (4)               | 7 (3)                     | 7 (3)               |
| $\leq 18.5$ , <25                  | 1042 (64)       | 756 (66)             | 175 (64)                  | 111 (55)            |
| $\geq 25$                          | 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.

198

### 199 *Primary Analysis and Sensitivity Analysis*

200 The cumulative mortality rates according to the degree of kyphosis are presented in Fig. 2. The  
 201 median follow-up time was 5.8 years. The participants with mild and severe kyphotic posture  
 202 showed higher cumulative mortality rates (8% and 13%, respectively) than those without kyphotic  
 203 posture (5%). The tracking ratio at the end of the study was 98.5%. The mortality rates were 0.008  
 204 per year in the non-kyphotic posture group, 0.014 per year in the mild kyphotic posture group, and  
 205 0.023 per year in the severe kyphotic posture group (Table 2), with the log-rank test indicating a  
 206 difference among the groups ( $P < 0.001$ ). Cox regression analysis showed that participants with  
 207 mild and severe kyphotic posture had higher rates of mortality than those without kyphotic posture,  
 208 with adjusted hazard ratios (aHRs) of 1.17 (95% confidence interval [CI], 0.70–1.96), and 1.99  
 209 (95% CI, 1.20–3.30), respectively. A sensitivity analysis using imputed datasets revealed similar  
 210 results to those of the primary analysis (aHR, 1.15 [95% CI, 0.71–1.87] and 2.15 [95% CI, 1.35–  
 211 3.41], respectively; Supplementary Table 1).

212

213 **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) <sup>a</sup> |
|------------------|------------------------|------------------------|----------------------|------------------------|-----------------------------------|
| 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.

<sup>a</sup>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.

214

### 215 *Secondary Analysis*

216 The rates of LOI were 0.013 per year in the non-kyphotic posture group, 0.036 per year in the mild  
 217 kyphotic posture group, and 0.048 per year in the severe kyphotic posture group (Table 3). Overall,  
 218 subjects with mild and severe kyphotic posture had higher rates of LOI than those without kyphotic  
 219 posture (aHR, 1.70 [95% CI, 1.13–2.55] and 2.08 [95% CI, 1.39–3.10], respectively). A sensitivity  
 220 analysis using imputed datasets revealed similar results (aHR, 1.47 [95% CI, 1.03–2.10] and 1.74  
 221 [95% CI, 1.25–2.43], respectively; Supplementary Table 2).

222

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

|                  | Number of participants | Frequency of loss of independence | Occurrence rate/year | Unadjusted HR (95% CI) | Adjusted HR (95% CI) <sup>a</sup> |
|------------------|------------------------|-----------------------------------|----------------------|------------------------|-----------------------------------|
| 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.

<sup>a</sup>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.

225  
226 Consistent results were obtained for the composite outcome of LOI and mortality (Table 4).  
227 Participants with mild and severe kyphotic posture had higher rates of LOI and mortality than  
228 those without kyphotic posture (aHR, 1.27 [95% CI, 0.90–1.79] and 1.83 [95% CI, 1.31–2.56],  
229 respectively). A sensitivity analysis using imputed datasets revealed similar results (aHR, 1.26  
230 [95% CI, 0.93–1.69] and 1.63 [95% CI, 1.23–2.16], respectively; Supplementary Table 3).

231  
232 **TABLE 4.** Cox proportional hazards model of loss of independence and mortality according to  
233 the degree of kyphosis

|  | Number of participants | Frequency of loss of independence | Occurrence rate/year | Unadjusted HR (95% CI) | Adjusted HR (95% CI) <sup>a</sup> |
|--|------------------------|-----------------------------------|----------------------|------------------------|-----------------------------------|
|--|------------------------|-----------------------------------|----------------------|------------------------|-----------------------------------|



and mortality<sup>b</sup>

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.

<sup>a</sup>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.

<sup>b</sup>Composite of loss of independence and mortality.

234

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

238

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

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

14

|                  |     |    |       |                   |                   |
|------------------|-----|----|-------|-------------------|-------------------|
| 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.

<sup>a</sup>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.

241  
242 The causes of mortality in each group are presented in Fig. 3. Although the frequencies  
243 were very low, the rate of mortality due to respiratory diseases was higher in the severe kyphotic  
244 posture group (6 [16%] vs. 5 [7%] in the non-kyphotic posture group and 2 [7%] in the mild  
245 kyphotic posture group).

## 247 Discussion

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

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3 254 Additionally, kyphotic posture was associated with LOI, and the association between kyphotic  
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5 255 posture and mortality was more pronounced in men.  
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7  
8 256 Kado et al. reported that cervicothoracic kyphosis measured in the supine position was  
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10 257 associated with mortality in older men and women. Notably, they did not observe any sex-specific  
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12 258 differences in their study.[14] They also showed that the degree of thoracic hyperkyphosis in the  
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14 259 standing position, in addition to osteoporotic vertebral fractures (OVFs), had a predictive value for  
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16 260 mortality among older women.[15] Our results were similar to those from previous studies  
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18 261 showing that kyphotic posture is associated with mortality. Additionally, we believe that the  
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20 262 present study has the advantage of using the WOT, which measures kyphosis in the standing  
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22 263 position and reflects overall sagittal balance. To accurately assess the degree of kyphosis, subjects  
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24 264 should be in the standing position with their hips and knees fully extended to prevent compensatory  
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26 265 mechanisms [24]. With the subjects in the supine position, kyphotic posture may be corrected by  
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28 266 a non-physiologic hyper-extensive force, leading to a consistent underestimation of the degree of  
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30 267 kyphosis. Furthermore, as described above, kyphotic posture develops due to the failure of the  
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32 268 posture maintenance mechanism. When evaluating kyphotic posture, it is necessary to focus not  
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34 269 only on one segment, such as the thoracic spine, but also on the alignment of the whole spine.  
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40 270 In the subgroup analysis by sex, the association between kyphotic posture and mortality  
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42 271 seemed to be more pronounced in men, although no clear sex difference in mortality was found in  
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44 272 the present study. Sex differences in the prevalence of vertebral fractures have been reported,  
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46 273 [25,26] and the nature of the kyphosis may differ between men and women. Further studies that  
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48 274 subcategorize kyphosis by vertebral fractures might reveal sex differences in kyphotic posture.  
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### 52 53 276 *Explanations and Implications*

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3 277 We hypothesized two possible explanations for the association between kyphotic posture and  
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5 278 mortality. First, we considered that mortality is an outcome of locomotive dysfunction. Further,  
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8 279 several previous studies have reported that kyphotic posture is associated with locomotive  
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10 280 dysfunction.[5,12,13,27,28] According to Tominaga et al., severe kyphotic posture measured by  
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12 281 the WOT is associated with an increased incidence of falls in men.[13] Katzman et al. indicated  
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14 282 an association of cervicothoracic kyphosis in the supine position with impaired lower extremity  
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16 283 physical function among older men.[28] Hence, the effect of kyphotic posture might be prominent  
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18 284 and associated with increased mortality in men. Early mortality may also be attributable to other  
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20 285 mechanisms. Multiple previous studies have shown that kyphotic posture may be associated with  
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22 286 worse health, including diminished pulmonary function.[6,7] Notably, a previous report suggested  
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24 287 that individuals with kyphotic posture are more likely to die of a pulmonary cause.[14] Although  
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26 288 no statistical comparison was performed due to a lack of power, our results suggest that the  
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31 289 proportion of respiratory deaths among those with severe kyphotic posture is high.

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33 290 The results of the present study also suggest that kyphotic posture is a clinically important  
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35 291 finding, and that further studies are required to fully explore the effects of the prevention and  
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37 292 treatment of kyphotic posture. Noticeably, our study demonstrates that the WOT is helpful in  
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39 293 predicting serious healthcare outcomes. Among men, those with mild and severe kyphotic posture  
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41 294 identified by WOT had a 2.2-fold and 3-fold increased hazards of mortality, respectively. The  
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43 295 WOT is easy, inexpensive, and does not require special skills or devices, making it an attractive  
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45 296 clinical tool for the identification of high-risk individuals. As approximately 40% of older adults  
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47 297 with severe kyphosis reported to have underlying OVFs,[24] OVFs are widely thought to be a  
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49 298 major factor contributing to the development of kyphotic posture. Therefore, osteoporosis  
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51 299 treatment may help prevent kyphotic posture via a reduction in the occurrence of OVFs. In addition

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3 300 to structural changes in the vertebral column, back extensor weakness is also associated with  
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5 301 kyphotic posture.[29-31] Despite the limited evidence, some reports suggest that exercise may  
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7 302 modestly improve back extensor muscle strength [32].  
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### 11 12 304 *Strengths and Limitations*

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14 305 The present study has significant strengths. First, we demonstrated the association of kyphotic  
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16 306 posture with LOI and mortality in a community-dwelling population. We believe that the present  
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18 307 study is a valuable contribution in that it investigated the longitudinal development of serious  
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20 308 healthcare outcomes based on samples from a general population. Second, we used public data,  
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22 309 which provided us with reliable and complete information on outcomes, except for participants  
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24 310 who changed their residence out of the target area. As relocation was rare, a high tracking ratio  
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26 311 (98.5%) was achieved, which minimized the risk of information bias.  
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31 312 Nevertheless, this study also has several limitations. First, we did not adjust our dataset  
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33 313 for osteoporosis. We did not adjust for OVFs because we were interested not only in kyphosis  
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35 314 independent of OVFs, but in overall kyphotic postures, including the ones caused by OVFs.  
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37 315 However, osteoporosis may be associated with LOI and mortality through other mechanisms.  
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39 316 Second, the measurement of kyphotic posture may not be sufficiently precise. The WOT does not  
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41 317 allow to distinguish rigid kyphosis from flexible kyphosis. To evaluate spinal flexibility,  
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43 318 evaluations in both the standing and supine positions need to be performed. The WOT also does  
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45 319 not identify participants who can maintain good non-kyphotic posture only for a short period  
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47 320 during measurement. No evaluation method has overcome this problem, and the development of a  
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49 321 new method, such as continuous posture analysis, is warranted. Furthermore, we did not use X-  
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51 322 rays or inclinometer to assess kyphotic posture, and so it was not possible to determine the cause  
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3 323 of the posture. However, we believe that the absence of spinal parameters such as kyphotic angle  
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5 324 does not introduce a serious bias, as our focus is on the resulting kyphosis posture, not on its cause.  
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8 325 Finally, attributing causation is difficult because of other unmeasured confounders, including  
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10 326 subclinical diseases. It should be noted that the present study does not provide evidence to support  
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12 327 surgical interventions to correct kyphosis. Surgical reconstruction should not be routinely  
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15 328 performed in elderly individuals with a typical high-risk profile.  
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### 19 330 **Conclusions**

21 331 This study suggests that kyphotic posture is associated with LOI and mortality. Therefore,  
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23 332 identifying community-dwelling older people with kyphotic posture using the WOT might help  
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26 333 identify high-risk populations that would benefit from healthcare interventions.  
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3 **418 Figure Legends**

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5 **419 Fig. 1.** Flow diagram of eligible participants.

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7 **420** WOT: wall-occiput test; LOHAS: Locomotive Syndrome and Health Outcomes in Aizu Cohort

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9 **421** Study

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11 **422 Fig. 2.** Cumulative incidence of mortality. Subjects were divided into the following three groups

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13 according to the degree of kyphotic posture: None, Mild ( $> 0, \leq 4$  cm), and Severe ( $> 4$  cm).

14  
15 **423** The P-value was calculated using log-rank test.

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17 **424 Fig. 3.** Cause-specific deaths in each group. Participants were divided into the following three

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19 **425** groups according to the degree of kyphosis: None, Mild ( $> 0, \leq 4$  cm), and Severe ( $> 4$  cm).

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21 **426**

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3 427 **Footnotes**  
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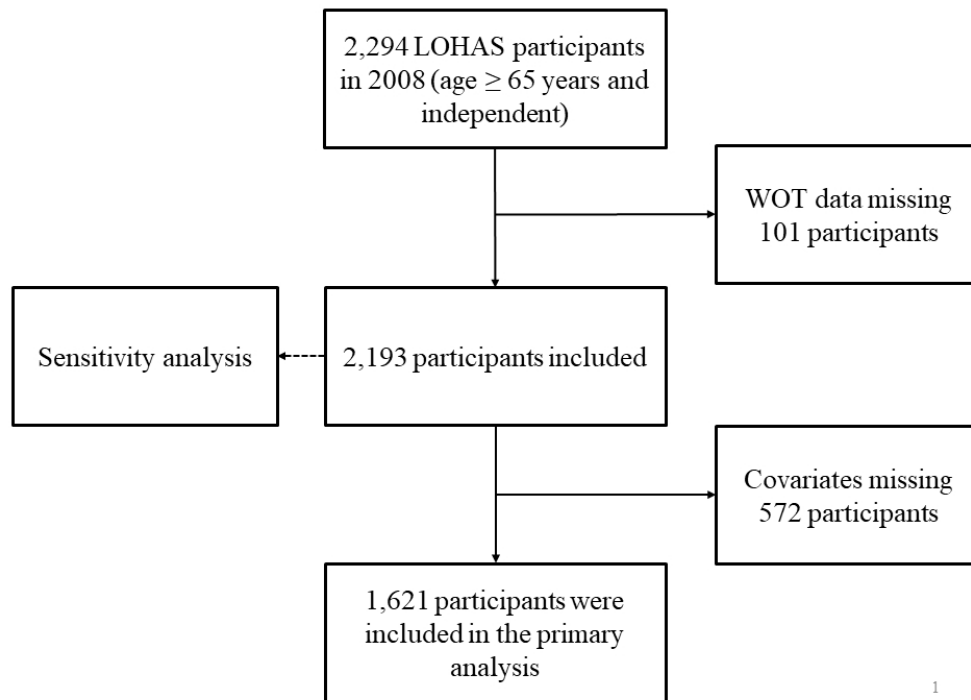
5 428 **Contributors:** Conception and design of the study: YH, TK, SF, and YY; Acquisition of data:  
6  
7 429 MS, KO, SK, and MT; Analysis and interpretation of data: YH, TK, SF, and YY; Drafting the  
8  
9 430 article or revising it critically for important intellectual content: YH, TK, MS, KO, SK, MT, SF,  
10  
11 431 and YY; Final approval of the version to be submitted: YH, TK, MS, KO, SK, MT, SF, and YY.  
12  
13

14 432 **Funding:** This research received no specific grant from any funding agency in the public,  
15  
16 433 commercial or not-for-profit sectors.  
17  
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19 434 **Data availability statement:** The data presented in the study are not currently available.  
20  
21 435 Additional unpublished data is still being analysed for another research project.  
22  
23

24 436 **Competing interests:** None declared.  
25

26 437 **Ethics approval:** This study was approved by the institutional Review Boards of Fukushima  
27  
28 438 Medical University and Kyoto University Graduate School and Faculty of Medicine of Kyoto  
29  
30 439 University Hospital (No. 673 and R1730, respectively).  
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31 Fig. 1. Flow diagram of eligible participants.  
32 WOT: wall-occiput test; LOHAS: Locomotive Syndrome and Health Outcomes in Aizu Cohort Study

33 254x190mm (96 x 96 DPI)

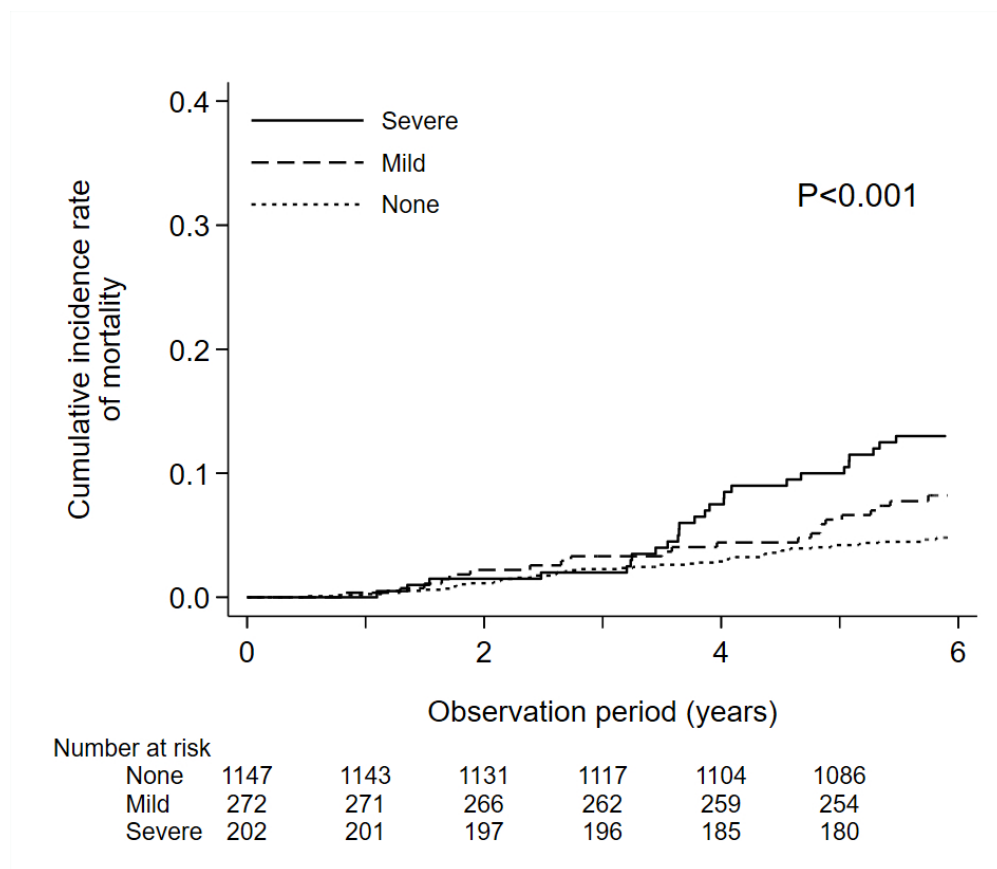


Fig. 2. Cumulative incidence of mortality. Subjects were divided into the following three groups according to the degree of kyphotic posture: None, Mild ( $> 0, \leq 4$  cm), and Severe ( $> 4$  cm). The P-value was calculated using log-rank test.

333x288mm (72 x 72 DPI)

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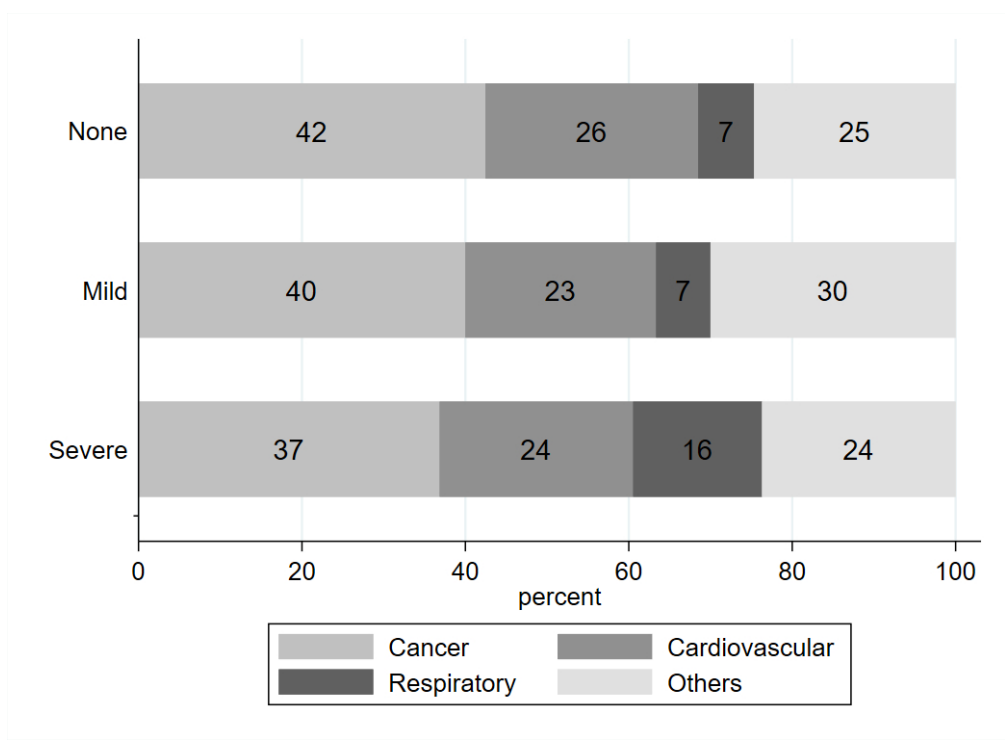


Fig. 3. Cause-specific deaths in each group. Participants were divided into the following three groups according to the degree of kyphosis: None, Mild (> 0, ≤ 4 cm), and Severe (> 4 cm).

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) <sup>a</sup> |
|------------------|------------------------|------------------------|----------------------|------------------------|-----------------------------------|
| 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.

<sup>a</sup>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) <sup>a</sup> |
|------------------|------------------------|-----------------------------------|----------------------|------------------------|-----------------------------------|
| 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.

<sup>a</sup> 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<br>Participants | Frequency of<br>loss of<br>independence<br>and mortality | Occurrence<br>rate/year | Unadjusted HR<br>(95% CI) | Adjusted HR<br>(95% CI) <sup>a</sup> |
|-------------------------|---------------------------|--|-------------------------|---------------------------|--------------------------------------|
| <b>Kyphotic posture</b> |                           |  |                         |                           |                                      |
| 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.

<sup>a</sup>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.

<sup>b</sup>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               |
|------------------------------|---------|--|-----------------------|
| <b>Title and abstract</b>    | 1       | (a) Indicate the study's design with a commonly used term in the title or the abstract<br>(b) Provide in the abstract an informative and balanced summary of what was done and what was found  | 3<br>3                |
| <b>Introduction</b>          |         |  |                       |
| 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                     |
| <b>Methods</b>               |         |  |                       |
| 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<br>(b) For matched studies, give matching criteria and number of exposed and unexposed  | 6<br>-                |
| Variables                    | 7       | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable   | 7                     |
| Data sources/<br>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<br>(b) Describe any methods used to examine subgroups and interactions<br>(c) Explain how missing data were addressed<br>(d) If applicable, explain how loss to follow-up was addressed<br>(e) Describe any sensitivity analyses | 8<br>9<br>9<br>8<br>9 |
| <b>Results</b>               |         |  |                       |
| 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<br>(b) Give reasons for non-participation at each stage<br>(c) Consider use of a flow diagram                        | 9<br>9<br>10          |
| Descriptive data             | 14*     | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders<br>(b) Indicate number of participants with missing data for each variable of interest<br>(c) Summarise follow-up time (eg, average and total amount)                         | 9<br>No<br>11         |
| Outcome data                 | 15*     | Report numbers of outcome events or summary measures over time   | 11                    |

|    |                          |    |  |    |
|----|--------------------------|----|--|----|
| 1  | 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 |
| 2  |                          |    | (b) Report category boundaries when continuous variables were categorized  | -  |
| 3  |                          |    | (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period   | -  |
| 4  |                          |    |  |    |
| 5  |                          |    |  |    |
| 6  |                          |    |  |    |
| 7  |                          |    |  |    |
| 8  |                          |    |  |    |
| 9  | Other analyses           | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses   | 11 |
| 10 |                          |    |  |    |
| 11 | <b>Discussion</b>        |    |  |    |
| 12 |                          |    |  |    |
| 13 | Key results              | 18 | Summarise key results with reference to study objectives   | 15 |
| 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   | 18 |
| 15 |                          |    |  |    |
| 16 | Interpretation           | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence                                   | 16 |
| 17 |                          |    |  |    |
| 18 |                          |    |  |    |
| 19 | Generalisability         | 21 | Discuss the generalisability (external validity) of the study results  | 18 |
| 20 |                          |    |  |    |
| 21 | <b>Other information</b> |    |  |    |
| 22 | 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 |
| 23 |                          |    |  |    |
| 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>.

# 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)

|                                 |   |
|---------------------------------|---|
| Journal:                        | <i>BMJ Open</i>   |
| Manuscript ID                   | bmjopen-2021-052421.R2  |
| Article Type:                   | Original research   |
| Date Submitted by the Author:   | 10-Feb-2022   |
| Complete List of Authors:       | Hijkata, Yasukazu; Kyoto University Graduate School of Medicine Faculty of Medicine, Department of Healthcare Epidemiology<br>Kamitani, Tsukasa; Kyoto University Graduate School of Medicine Faculty of Medicine, Department of Healthcare Epidemiology<br>Sekiguchi, Miho; Fukushima Medical University School of Medicine, Department of Orthopedic Surgery<br>Otani, Koji; Fukushima Medical University School of Medicine, Department of Orthopedic Surgery<br>Konno, Shin-ichi; Fukushima Medical University School of Medicine, Department of Orthopedic Surgery<br>Takegami, Misa; National Cerebral and Cardiovascular Center, Preventive Medicine and Epidemiology Informatics<br>Fukuhara, Shunichi; Fukushima Kenritsu Ika Daigaku, Department of General Medicine, Shirakawa Satellite for Teaching And Research (STAR); Kyoto University Graduate School of Medicine Faculty of Medicine, Section of Clinical Epidemiology, Department of Community Medicine<br>Yamamoto, Yosuke; Kyoto University Graduate School of Medicine Faculty of Medicine, Department of Healthcare Epidemiology |
| <b>Primary Subject Heading</b>: | Geriatric medicine  |
| Secondary Subject Heading:      | Public health   |
| Keywords:                       | Spine < ORTHOPAEDIC & TRAUMA SURGERY, Musculoskeletal disorders < ORTHOPAEDIC & TRAUMA SURGERY, PUBLIC HEALTH, GERIATRIC MEDICINE   |
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2  
3 1 **Association of kyphotic posture with loss of independence and mortality in a community-**  
4  
5 2 **based prospective cohort study: The Locomotive Syndrome and Health Outcomes in Aizu**  
6  
7 3 **Cohort Study (LOHAS)**  
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9 4

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11  
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35 **Word count:** 3002 words



## 36 Abstract

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

39 **Design:** Prospective cohort study.

40 **Setting:** Two Japanese municipalities.

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

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

49 **Results:** Of the 2,193 subjects enrolled, 1,621 were included in the primary analysis. Among these,  
50 272 (17%) and 202 (12%) were diagnosed with mild and severe kyphotic posture, respectively.  
51 The median follow-up time was 5.8 years. Compared to the non-kyphotic group, the aHRs for  
52 mortality were 1.17 (95% confidence interval [CI], 0.70–1.96) and 1.99 (95% CI, 1.20–3.30) in  
53 the mild and severe kyphotic posture groups, respectively. In the secondary analysis, a consistent  
54 association was observed for LOI (mild: aHR, 1.70; 95% CI, 1.13–2.55; severe: aHR, 2.08; 95%  
55 CI, 1.39–3.10) and the LOI–mortality composite (mild: aHR, 1.27; 95% CI, 0.90–1.79; severe:  
56 aHR, 1.83; 95% CI, 1.31–2.56).

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

59 community health.

60

61 **Strengths and limitations of this study:**

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

## 72 Introduction

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

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

88 Three previous studies reported an association of kyphotic posture with LOI and mortality.  
89 First, Kado et al. demonstrated the association between cervicothoracic kyphosis and  
90 mortality.[14] It should be noted that, as kyphosis was measured in the supine position rather than  
91 in the standing position, the evaluation of the kyphotic posture was not precise. In another study,  
92 Kado et al. reported an association of thoracic hyperkyphosis in the standing position with  
93 mortality in older women.[15] Nonetheless, these two studies could not assess whether the  
94 kyphotic posture was a risk factor for mortality in men. Okura et al. showed that kyphotic posture

1  
2  
3 95 is related to LOI and mortality.[16] However, there was a potential bias in this study, as the  
4  
5 96 determination of kyphotic posture was based on self-reported data from participants. Moreover,  
6  
7  
8 97 the researchers only controlled for age and sex as potential confounders. Furthermore, none of  
9  
10 98 these studies adjusted for lumbar degenerative disease and back pain, which are strongly associated  
11  
12 99 with kyphotic posture.  
13

14  
15 100 To address these concerns, we conducted a prospective cohort study to examine whether  
16  
17 101 a kyphotic posture in the standing position was associated with LOI and mortality in community-  
18  
19 102 dwelling men and women.  
20

21  
22 103

## 23 24 104 **Materials and methods**

### 25 26 105 *Study Design and Population*

27  
28 106 This prospective observational study analyzed data from the Locomotive Syndrome and Health  
29  
30 107 Outcomes in Aizu Cohort Study (LOHAS), a population-based study involving residents from two  
31  
32 108 towns in Japan. The LOHAS evaluated the effect of locomotive dysfunction on healthcare  
33  
34 109 outcomes, including quality of life, medical costs, and occurrence of LOI and mortality. The  
35  
36 110 LOHAS comprised approximately 70% of all the National Health Insurance and Late-Stage  
37  
38 111 Elderly Health Insurance beneficiaries in that region. Details of the study have been described  
39  
40 112 elsewhere.[17]  
41  
42  
43

44  
45 113

### 46 47 114 *Study Participants*

48  
49 115 Independent community-dwelling older adults aged  $\geq 65$  years without any long-term care  
50  
51 116 insurance (LTCI) certification [18] at the time of their baseline health check-up in 2008 were  
52  
53 117 enrolled. Those in whom kyphotic posture could not be determined due to missing data were  
54

1  
2  
3 118 excluded. Participants were observed starting from the baseline check-up in 2008 until March 2014.  
4  
5 119 This study was approved by certified institutional review boards (R1730 and 673) of the  
6  
7  
8 120 participating institutions, and all participants provided written informed consent before  
9  
10 121 participation.  
11

12 122

### 13 14 123 ***Definition of Kyphotic Posture***

15  
16  
17 124 Kyphotic posture was defined using the wall-occiput test (WOT) at the time of musculoskeletal  
18  
19 125 examination in 2008. The WOT is a semi-quantitative technique used to assess head forward  
20  
21 126 posture in the standing position as well as thoracic vertebral fractures.[19,20] The WOT reflects  
22  
23  
24 127 not only thoracic hyperkyphosis, but also a loss of cervical and lumbar lordosis.  
25

26 128 The distance (in cm) between the occiput prominence and the wall was measured using a  
27  
28 129 tape while the participants were standing with both of their heels and sacrum against the wall and  
29  
30  
31 130 their head positioned such that an imaginary line from the lateral corner of the eye to the superior  
32  
33 131 point of the auricle was parallel to the floor. In accordance with previous studies,[13,21] we  
34  
35 132 divided the participants into the following three groups based on the degree of kyphosis: none,  
36  
37 133 mild ( $>0, \leq 4$  cm), and severe ( $>4$  cm).  
38  
39

40 134

### 41 42 135 ***Outcomes***

43  
44 136 The primary outcome was the time to mortality. Data on mortality and its causes were collected  
45  
46 137 from death certificates provided by the Ministry of Health, Labour, and Welfare of Japan. The  
47  
48 138 secondary outcome was the development of LOI, which was defined as a new LTCI certification  
49  
50  
51 139 of level 1–5 (i.e., a condition requiring any support for daily living). Information on LTCI  
52  
53  
54 140 certification status was obtained from the local government annually. The use of public data  
55

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2  
3 141 allowed us to access all outcome data, except for those participants who changed their residence  
4  
5 142 outside the target area.  
6

7  
8 143

9  
10 144 ***Baseline Covariates***

11  
12 145 The following baseline covariates were analysed as potential confounders for the relationship  
13  
14 146 between kyphotic posture and mortality: age, sex, body mass index (categorized as  $<18.5$ ,  $\geq 18.5$   
15  
16 147 and  $<25$ , and  $\geq 25$  kg/m<sup>2</sup>), present smoking habits, lumbar spinal stenosis (LSS), low back pain  
17  
18 148 (requiring treatment and lasting for more than 24 h), good health status (self-reported health: good,  
19  
20 149 very good, or excellent), stroke history, and handgrip strength (dominant hand). LSS was  
21  
22 150 diagnosed using a validated diagnostic support tool specifically designed for this purpose.[22]  
23  
24 151 Handgrip strength was measured using a digital dynamometer (Takei Scientific Instruments Co.,  
25  
26 152 Ltd, Japan).  
27  
28  
29

30  
31 153

32  
33 154 ***Statistical Analysis***

34  
35 155 The baseline characteristics of the participants were expressed as the presence or absence and the  
36  
37 156 degree of kyphotic posture, using medians and interquartile ranges. Additionally, absolute and  
38  
39 157 relative frequencies were used for dichotomous or categorical variables.  
40

41  
42 158 The cumulative incidence method and log-rank test were applied to compare the intervals  
43  
44 159 between the baseline and date of mortality. The date of each baseline check-up in 2008 was  
45  
46 160 considered as Time 0. Participants were censored after changing their residence out of the target  
47  
48 161 area or on March 31, 2014. After confirming that the proportional hazards assumption had not  
49  
50 162 been violated, a Cox proportional hazards model with adjustment for possible confounders (i.e.,  
51  
52 163 age, sex, body mass index, smoking habit, LSS, low back pain, good health status, stroke history,  
53  
54  
55

1  
2  
3 164 and handgrip strength) was used to investigate the association between the kyphotic posture and  
4  
5 165 mortality. We conducted a sensitivity analysis with multiple imputations by chained equations of  
6  
7  
8 166 missing covariates, which included all variables (including outcomes) in the prediction model to  
9  
10 167 generate 20 imputed datasets.

11  
12 168 We performed four secondary analyses. First, we focused on LOI as a secondary outcome.  
13  
14 169 In that model, participants were censored after moving out of the target area, upon mortality, or on  
15  
16  
17 170 March 31, 2014. Second, we employed another Cox proportional hazard model to evaluate the  
18  
19 171 composite outcome of LOI and mortality. Both models included the same covariates as those in  
20  
21 172 the primary analysis. For these secondary analyses, we performed sensitivity analyses using  
22  
23 173 multiple imputations as in the main analysis. Third, we performed a subgroup analysis stratified  
24  
25  
26 174 by sex for the primary outcome of mortality. Finally, we analyzed cause-specific mortality in each  
27  
28 175 group, as in a previous study.[23] Four causes of death were evaluated: cancer, cardiovascular  
29  
30  
31 176 disease, respiratory disease, and others.

32  
33 177 Statistical analyses were performed using Stata version 15.1 (StataCorp LLC, College  
34  
35 178 Station, Texas, USA).

36  
37  
38 179

### 39 40 180 *Patient and public involvement*

41  
42 181 There was no patient and public involvement in this study.

43  
44  
45 182

## 46 47 183 **Results**

### 48 49 184 *Baseline Characteristics*

50  
51 185 A total of 2,294 eligible participants from the 2008 LOHAS were identified. After excluding 101  
52  
53  
54 186 subjects who did not undergo the WOT, a total of 2,193 participants were retained. The primary

187 analysis included 1,621 participants without missing covariates. Fig. 1 shows the flow diagram of  
 188 subjects in this study.

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

196  
 197 **TABLE 1.** Baseline characteristics of participants without missing covariates

|                                    | Total           | Kyphotic posture     |                        |                     |
|------------------------------------|-----------------|----------------------|------------------------|---------------------|
|                                    |                 | None                 | Mild (>0, $\leq 4$ cm) | Severe (>4 cm)      |
|                                    | <i>n</i> = 1621 | <i>n</i> = 1147 (71) | <i>n</i> = 272 (17)    | <i>n</i> = 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 <sup>2</sup> |                 |                      |                        |                     |
| <18.5                              | 57 (4)          | 43 (4)               | 7 (3)                  | 7 (3)               |
| $\leq 18.5$ , <25                  | 1042 (64)       | 756 (66)             | 175 (64)               | 111 (55)            |
| $\geq 25$                          | 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.

198

### 199 *Primary Analysis and Sensitivity Analysis*

200 The cumulative mortality rates according to the degree of kyphosis are presented in Fig. 2. The  
 201 median follow-up time was 5.8 years. The participants with mild and severe kyphotic posture  
 202 showed higher cumulative mortality rates (8% and 13%, respectively) than those without kyphotic  
 203 posture (5%). The tracking ratio at the end of the study was 98.5%. The mortality rates were 0.008  
 204 per year in the non-kyphotic posture group, 0.014 per year in the mild kyphotic posture group, and  
 205 0.023 per year in the severe kyphotic posture group (Table 2), with the log-rank test indicating a  
 206 difference among the groups ( $p < 0.001$ ). Cox regression analysis showed that participants with  
 207 mild and severe kyphotic posture had higher rates of mortality than those without kyphotic posture,  
 208 with adjusted hazard ratios (aHRs) of 1.17 (95% confidence interval [CI], 0.70–1.96), and 1.99  
 209 (95% CI, 1.20–3.30), respectively. A sensitivity analysis using imputed datasets revealed similar  
 210 results to those of the primary analysis (aHR, 1.15 [95% CI, 0.71–1.87] and 2.15 [95% CI, 1.35–  
 211 3.41], respectively; Supplementary Table 1).

212

213 **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) <sup>a</sup> |
|------------------|------------------------|------------------------|----------------------|------------------------|-----------------------------------|
| 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.

<sup>a</sup>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.

214

### 215 *Secondary Analysis*

216 The rates of LOI were 0.013 per year in the non-kyphotic posture group, 0.026 per year in the mild  
 217 kyphotic posture group, and 0.048 per year in the severe kyphotic posture group (Table 3). Overall,  
 218 subjects with mild and severe kyphotic posture had higher rates of LOI than those without kyphotic  
 219 posture (aHR, 1.70 [95% CI, 1.13–2.55] and 2.08 [95% CI, 1.39–3.10], respectively). A sensitivity  
 220 analysis using imputed datasets revealed similar results (aHR, 1.47 [95% CI, 1.03–2.10] and 1.74  
 221 [95% CI, 1.25–2.43], respectively; Supplementary Table 2).

222

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

|                  | Number of participants | Frequency of loss of independence | Occurrence rate/year | Unadjusted HR (95% CI) | Adjusted HR (95% CI) <sup>a</sup> |
|------------------|------------------------|-----------------------------------|----------------------|------------------------|-----------------------------------|
| 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.

<sup>a</sup>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.

225  
226 Consistent results were obtained for the composite outcome of LOI and mortality (Table 4).  
227 Participants with mild and severe kyphotic posture had higher rates of LOI and mortality than  
228 those without kyphotic posture (aHR, 1.27 [95% CI, 0.90–1.79] and 1.83 [95% CI, 1.31–2.56],  
229 respectively). A sensitivity analysis using imputed datasets revealed similar results (aHR, 1.26  
230 [95% CI, 0.93–1.69] and 1.63 [95% CI, 1.23–2.16], respectively; Supplementary Table 3).

231  
232 **TABLE 4.** Cox proportional hazards model of loss of independence and mortality according to  
233 the degree of kyphosis

|  | Number of participants | Frequency of loss of independence | Occurrence rate/year | Unadjusted HR (95% CI) | Adjusted HR (95% CI) <sup>a</sup> |
|--|------------------------|-----------------------------------|----------------------|------------------------|-----------------------------------|
|--|------------------------|-----------------------------------|----------------------|------------------------|-----------------------------------|

and mortality<sup>b</sup>

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.

<sup>a</sup>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.

<sup>b</sup>Composite of loss of independence and mortality.

234

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

238

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

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

14

|                  |     |    |       |                   |                   |
|------------------|-----|----|-------|-------------------|-------------------|
| 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.

<sup>a</sup>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.

241  
242 The causes of mortality in each group are presented in Fig. 3. Although the frequencies  
243 were very low, the rate of mortality due to respiratory diseases was higher in the severe kyphotic  
244 posture group (6 [16%] vs. 5 [7%] in the non-kyphotic posture group and 2 [7%] in the mild  
245 kyphotic posture group).

## 247 Discussion

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

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3 254 Additionally, kyphotic posture was associated with LOI, and the association between kyphotic  
4  
5 255 posture and mortality was more pronounced in men.  
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7  
8 256 Kado et al. reported that cervicothoracic kyphosis measured in the supine position was  
9  
10 257 associated with mortality in older men and women. Notably, they did not observe any sex-specific  
11  
12 258 differences in their study.[14] They also showed that the degree of thoracic hyperkyphosis in the  
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14 259 standing position, in addition to osteoporotic vertebral fractures (OVFs), had a predictive value for  
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16 260 mortality among older women.[15] Our results were similar to those from previous studies  
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18 261 showing that kyphotic posture is associated with mortality. Additionally, we believe that the  
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20 262 present study has the advantage of using the WOT, which measures kyphosis in the standing  
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22 263 position and reflects overall sagittal balance. To accurately assess the degree of kyphosis, subjects  
23  
24 264 should be in the standing position with their hips and knees fully extended to prevent compensatory  
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26 265 mechanisms [24]. With the subjects in the supine position, kyphotic posture may be corrected by  
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28 266 a non-physiologic hyper-extensive force, leading to a consistent underestimation of the degree of  
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30 267 kyphosis. Furthermore, as described above, kyphotic posture develops due to the failure of the  
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32 268 posture maintenance mechanism. When evaluating kyphotic posture, it is necessary to focus not  
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34 269 only on one segment, such as the thoracic spine, but also on the alignment of the whole spine.  
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40 270 In the subgroup analysis by sex, the association between kyphotic posture and mortality  
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42 271 seemed to be more pronounced in men, although no clear sex difference in mortality was found in  
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44 272 the present study. Sex differences in the prevalence of vertebral fractures have been reported,  
45  
46 273 [25,26] and the nature of the kyphosis may differ between men and women. Further studies that  
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48 274 subcategorize kyphosis by vertebral fractures might reveal sex differences in kyphotic posture.  
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## 52 53 276 *Explanations and Implications*

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3 277 We hypothesized two possible explanations for the association between kyphotic posture and  
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5 278 mortality. First, we considered that mortality is an outcome of locomotive dysfunction. Further,  
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8 279 several previous studies have reported that kyphotic posture is associated with locomotive  
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10 280 dysfunction.[5,12,13,27,28] According to Tominaga et al., severe kyphotic posture measured by  
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12 281 the WOT is associated with an increased incidence of falls in men.[13] Katzman et al. indicated  
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14 282 an association of cervicothoracic kyphosis in the supine position with impaired lower extremity  
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16 283 physical function among older men.[28] Hence, the effect of kyphotic posture might be prominent  
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18 284 and associated with increased mortality in men. Early mortality may also be attributable to other  
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20 285 mechanisms. Multiple previous studies have shown that kyphotic posture may be associated with  
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22 286 worse health, including diminished pulmonary function.[6,7] Notably, a previous report suggested  
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24 287 that individuals with kyphotic posture are more likely to die of a pulmonary cause.[14] Although  
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26 288 no statistical comparison was performed due to a lack of power, our results suggest that the  
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31 289 proportion of respiratory deaths among those with severe kyphotic posture is high.

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33 290 The results of the present study also suggest that kyphotic posture is a clinically important  
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35 291 finding, and that further studies are required to fully explore the effects of the prevention and  
36  
37 292 treatment of kyphotic posture. Noticeably, our study demonstrates that the WOT is helpful in  
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39 293 predicting serious healthcare outcomes. Among men, those with mild and severe kyphotic posture  
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41 294 identified by WOT had a 2.2-fold and 3-fold increased hazards of mortality, respectively. The  
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43 295 WOT is easy, inexpensive, and does not require special skills or devices, making it an attractive  
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45 296 clinical tool for the identification of high-risk individuals. As approximately 40% of older adults  
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47 297 with severe kyphosis reported to have underlying OVFs,[24] OVFs are widely thought to be a  
48  
49 298 major factor contributing to the development of kyphotic posture. Therefore, osteoporosis  
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51 299 treatment may help prevent kyphotic posture via a reduction in the occurrence of OVFs. In addition

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3 300 to structural changes in the vertebral column, back extensor weakness is also associated with  
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5 301 kyphotic posture.[29-31] Despite the limited evidence, some reports suggest that exercise may  
6  
7 302 modestly improve back extensor muscle strength. [32]  
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10 303

### 12 304 *Strengths and Limitations*

14 305 The present study has significant strengths. First, we demonstrated the association of kyphotic  
15  
16 306 posture with LOI and mortality in a community-dwelling population. We believe that the present  
17  
18 307 study is a valuable contribution in that it investigated the longitudinal development of serious  
19  
20 308 healthcare outcomes based on samples from a general population. Second, we used public data,  
21  
22 309 which provided us with reliable and complete information on outcomes, except for participants  
23  
24 310 who changed their residence out of the target area. As relocation was rare, a high tracking ratio  
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26 311 (98.5%) was achieved, which minimized the risk of information bias.  
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30 312 Nevertheless, this study also has several limitations. First, we did not adjust our dataset  
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32 313 for osteoporosis. We did not adjust for OVFs because we were interested not only in kyphosis  
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34 314 independent of OVFs, but in overall kyphotic postures, including the ones caused by OVFs.  
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36 315 However, osteoporosis may be associated with LOI and mortality through other mechanisms.  
37  
38 316 Second, the measurement of kyphotic posture may not be sufficiently precise. The WOT does not  
39  
40 317 allow to distinguish rigid kyphosis from flexible kyphosis. To evaluate spinal flexibility,  
41  
42 318 evaluations in both the standing and supine positions need to be performed. The WOT also does  
43  
44 319 not identify participants who can maintain good non-kyphotic posture only for a short period  
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46 320 during measurement. No evaluation method has overcome this problem, and the development of a  
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48 321 new method, such as continuous posture analysis, is warranted. Additionally, the WOT values may  
49  
50 322 contain measurement errors due to denture wear and respiratory variability. Thus, measurement  
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3 323 using WOT has some disadvantages. However, as mentioned above, it is a very simple method of  
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5 324 measurement, which makes it possible to survey a relatively large number of the general  
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8 325 population and has the advantage of easy clinical application. Another limitation in the  
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10 326 measurement of kyphotic posture is the inability to identify the cause of the posture since it is not  
11  
12 327 assessed using X-rays or inclinometer. However, we believe that the absence of spinal parameters  
13  
14 328 such as kyphotic angle does not introduce a serious bias, as our focus is on the resulting kyphosis  
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16 329 posture, not on its cause. Finally, attributing causation is difficult because of other unmeasured  
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18 330 confounders, including subclinical diseases. In addition, since more than 10 years have passed  
19  
20 331 since the baseline measurement in 2008, confounding factors may have changed due to lifestyle  
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22 332 changes such as the spread of smartphones. It should be noted that the present study does not  
23  
24 333 provide evidence to support surgical interventions to correct kyphosis. Surgical reconstruction  
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26 334 should not be routinely performed in elderly individuals with a typical high-risk profile.  
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### 32 336 **Conclusions**

33 337 This study suggests that kyphotic posture is associated with LOI and mortality. Therefore,  
34  
35 338 identifying community-dwelling older people with kyphotic posture using the WOT might help  
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37  
38 339 identify high-risk populations that would benefit from healthcare interventions.  
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3 424 **Figure Legends**

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5 425 **Fig. 1.** Flow diagram of eligible participants.

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7 426 WOT: wall-occiput test; LOHAS: Locomotive Syndrome and Health Outcomes in Aizu Cohort

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9 427 Study

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11 428 **Fig. 2.** Cumulative incidence of mortality. Subjects were divided into the following three groups

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13 429 according to the degree of kyphotic posture: None, Mild ( $> 0, \leq 4$  cm), and Severe ( $> 4$  cm).

14  
15 430 The p-value was calculated using log-rank test.

16  
17 431 **Fig. 3.** Cause-specific deaths in each group. Participants were divided into the following three

18  
19 432 groups according to the degree of kyphosis: None, Mild ( $> 0, \leq 4$  cm), and Severe ( $> 4$  cm).

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3 433 **Footnotes**  
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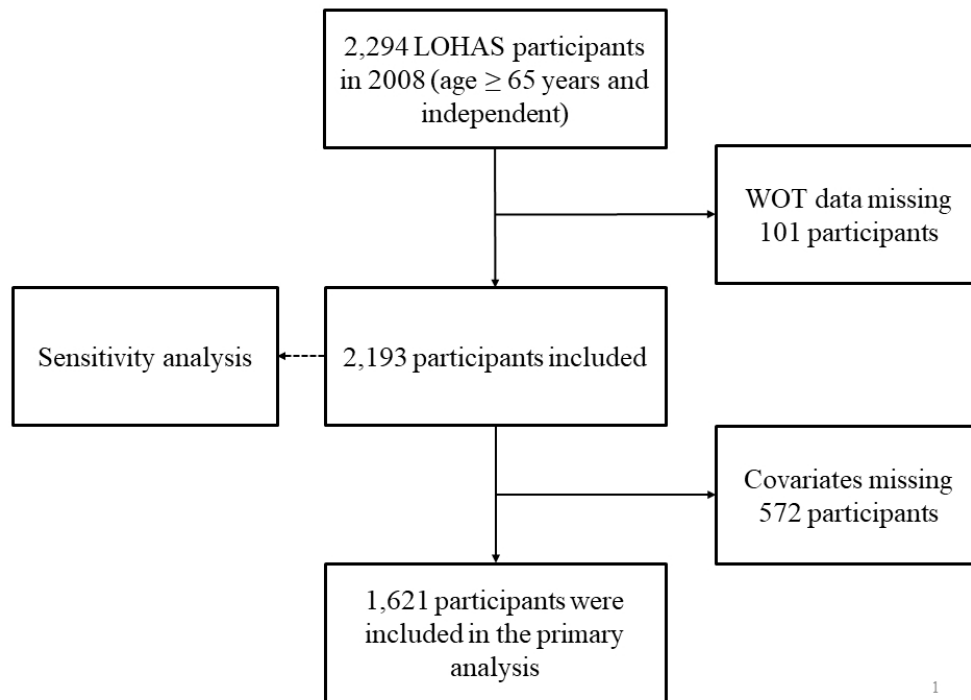
5 434 **Contributors:** Conception and design of the study: YH, TK, SF, and YY; Acquisition of data:  
6  
7 435 MS, KO, SK, and MT; Analysis and interpretation of data: YH, TK, SF, and YY; Drafting the  
8  
9 436 article or revising it critically for important intellectual content: YH, TK, MS, KO, SK, MT, SF,  
10  
11 437 and YY; Final approval of the version to be submitted: YH, TK, MS, KO, SK, MT, SF, and YY.  
12  
13

14 438 **Funding:** This research received no specific grant from any funding agency in the public,  
15  
16 439 commercial or not-for-profit sectors.  
17  
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19 440 **Data availability statement:** The data presented in the study are not currently available.  
20  
21 441 Additional unpublished data is still being analysed for another research project.  
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23

24 442 **Competing interests:** None declared.  
25

26 443 **Ethics approval:** This study was approved by the institutional Review Boards of Fukushima  
27  
28 444 Medical University and Kyoto University Graduate School and Faculty of Medicine of Kyoto  
29  
30 445 University Hospital (No. 673 and R1730, respectively).  
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31 Fig. 1. Flow diagram of eligible participants.  
32 WOT: wall-occiput test; LOHAS: Locomotive Syndrome and Health Outcomes in Aizu Cohort Study

33 254x190mm (96 x 96 DPI)



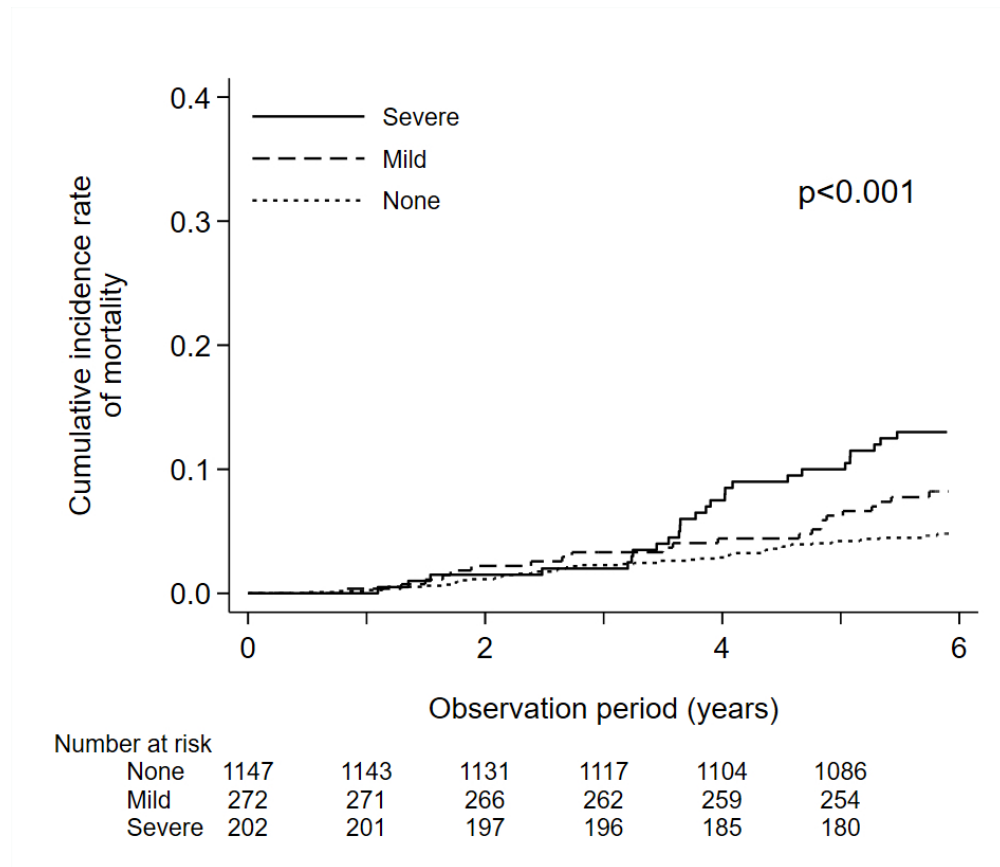


Fig. 2. Cumulative incidence of mortality. Subjects were divided into the following three groups according to the degree of kyphotic posture: None, Mild ( $> 0, \leq 4$  cm), and Severe ( $> 4$  cm). The p-value was calculated using log-rank test.

333x288mm (72 x 72 DPI)

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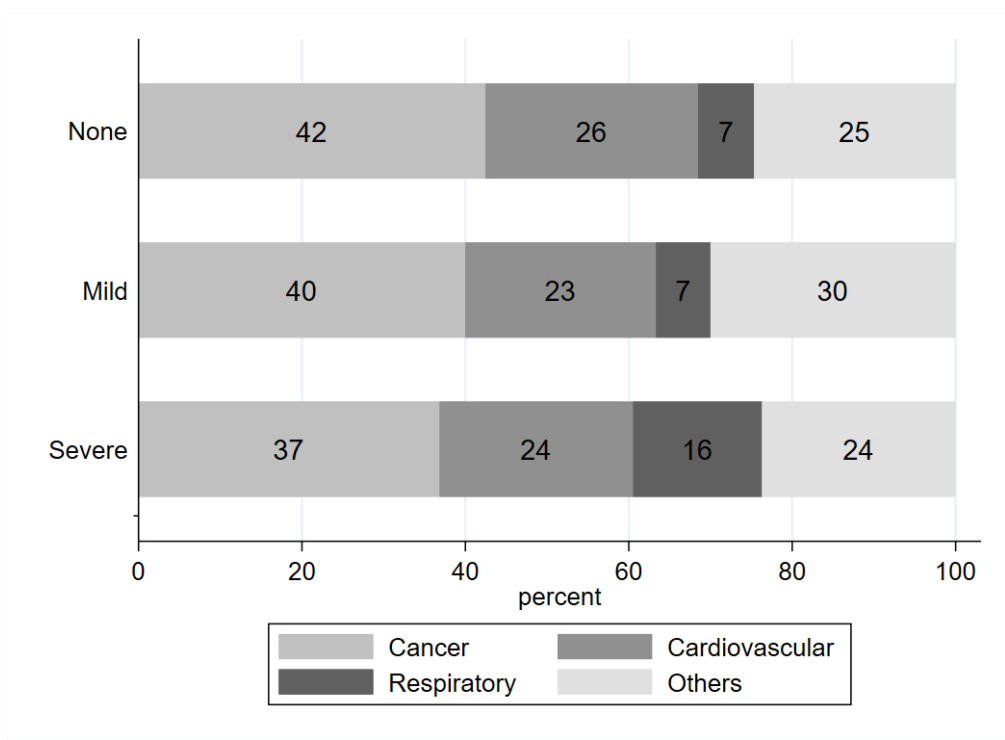


Fig. 3. Cause-specific deaths in each group. Participants were divided into the following three groups according to the degree of kyphosis: None, Mild (> 0, ≤ 4 cm), and Severe (> 4 cm).

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) <sup>a</sup> |
|------------------|------------------------|------------------------|----------------------|------------------------|-----------------------------------|
| 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.

<sup>a</sup>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) <sup>a</sup> |
|------------------|------------------------|-----------------------------------|----------------------|------------------------|-----------------------------------|
| 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.

<sup>a</sup> 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<br>Participants | Frequency of<br>loss of<br>independence<br>and mortality | Occurrence<br>rate/year | Unadjusted HR<br>(95% CI) | Adjusted HR<br>(95% CI) <sup>a</sup> |
|-------------------------|---------------------------|--|-------------------------|---------------------------|--------------------------------------|
| <b>Kyphotic posture</b> |                           |  |                         |                           |                                      |
| 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.

<sup>a</sup>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.

<sup>b</sup>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 |
|---------------------------|---------|---|---------|
| <b>Title and abstract</b> | 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       |
| <b>Introduction</b>       |         |   |         |
| 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       |
| <b>Methods</b>            |         |   |         |
| 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       |
| <b>Results</b>            |         |   |         |
| 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      |

|    |                          |    |  |    |
|----|--------------------------|----|--|----|
| 1  | 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 |
| 2  |                          |    | (b) Report category boundaries when continuous variables were categorized  | -  |
| 3  |                          |    | (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period   | -  |
| 4  |                          |    |  |    |
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| 6  |                          |    |  |    |
| 7  |                          |    |  |    |
| 8  |                          |    |  |    |
| 9  | Other analyses           | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses   | 11 |
| 10 |                          |    |  |    |
| 11 | <b>Discussion</b>        |    |  |    |
| 12 |                          |    |  |    |
| 13 | Key results              | 18 | Summarise key results with reference to study objectives   | 15 |
| 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   | 18 |
| 15 |                          |    |  |    |
| 16 | Interpretation           | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence                                   | 16 |
| 17 |                          |    |  |    |
| 18 |                          |    |  |    |
| 19 | Generalisability         | 21 | Discuss the generalisability (external validity) of the study results  | 18 |
| 20 |                          |    |  |    |
| 21 | <b>Other information</b> |    |  |    |
| 22 | 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 |
| 23 |                          |    |  |    |
| 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>.