Associations between bone fractures and post-traumatic stress disorder after the Great East Japan Earthquake in the older adult: a prospective cohort study from the Fukushima Health Management Survey

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Abstract

Background

Bone metabolism is known to be affected by psychological stress, and increased psychological stress could increase fracture risk. The purpose of this study was to clarify the effect of mental health deterioration caused by disaster on fracture risk in the older adult.

Methods

This study analyzed the responses of those who answered the Mental Health and Lifestyle Survey component of the Fukushima Health Management Survey conducted in 2011: a total of 13,768 people aged 65 or more who had no history of fractures at the time of the Great East Japan Earthquake. We were able to track the presence or absence of a fracture until 2016. The analysis included age, sex, physical factors, social factors, psychological factors, and lifestyle factors. A survival analysis was performed on the relationship between each item and the fracture. Then, univariate and multivariate Cox proportional hazard models were constructed to identify fracture risk factors.

Results

A total of 1,687 (12.3%) fractures occurred during the observation period. As a result of univariate and multivariate Cox proportional hazard models, those at high risk of post-traumatic stress disorder (PTSD) (PTSD checklists ≥ 44) (hazard ratio [HR]: 1.18; 95% confidence interval [CI]: 1.01–1.38; P = 0.039), history of cancer (HR: 1.58; 95% CI: 1.28–1.93; P < 0.001), history of stroke (HR: 1.33; 95% CI: 1.08–1.65; P = 0.009), history of heart disease (HR: 1.23; 95% CI: 1.05–1.45; P = 0.012), history of diabetes (HR: 1.21; 95% CI: 1.05–1.39; P = 0.007), and who reported being extremely dissatisfied with sleep or not being able to sleep at all (HR: 1.40; 95% CI: 1.04–1.89; P = 0.025), had a significant increase in fracture risk independent of age and sex.

Conclusions

The results of this study indicate that chronic psychological stress caused by the Great East Japan Earthquake could have contributed to increased fracture risk in the older adult. Therefore, understanding bone mineral density, offering active psychological care to reduce psychosocial stress, and providing sleep guidance are important for preventing fractures in older adult residents, particularly those in evacuation areas.

Background

The Great East Japan Earthquake of magnitude 9.0 occurred on March 11, 2011, with its epicenter at the sea floor 130 km off the southeast Oshika Peninsula, Miyagi Prefecture. The related accident at Fukushima Daiichi Nuclear Power Station (FDNPS) occurred in Fukushima Prefecture. Compared with natural disasters, man-made disasters have been found to be responsible for a higher occurrence of post-traumatic stress disorder (PTSD). In fact, surveys of evacuation zone inhabitants have indicated that the proportion of adults with a PTSD checklist (PCL) score higher than the cutoff value, reflecting the presence of traumatic symptoms (2011: 21.6%; 2012: 18.3%), was comparable with that of workers affected by the 9/11 World Trade Center attack. A survey of 240 evacuees in Hirono Town, Fukushima Prefecture, one of the evacuation areas, found that 66.8% had reported symptoms of depression and 53.5% had reported clinically relevant symptoms of PTSD. Thus, residents in evacuation areas such as those in Fukushima Prefecture could be at high risk of developing PTSD due to events related to the disaster.

A possible association between increased fracture risk and PTSD has recently been reported; therefore, residents in Fukushima evacuation areas who are at high risk of developing PTSD could also be at high risk of fractures. According to the
results of the 2013 Basic Survey on National Life published by the Japanese Ministry of Health, Labor, and Welfare, 11.8% were certified as requiring support or nursing care because of falls or broken bones, a major factor equivalent to stroke. In addition, Tanji et al. reported that those with higher psychological distress after an earthquake have a higher risk of requiring nursing care. If residents in evacuation areas in Fukushima Prefecture are at high risk of developing PTSD, the associated higher risk of increased fractures could affect the healthy life expectancy and quality of life (QOL) of similar residents in evacuation areas. In particular, an increase in fracture risk in the older adult would contribute to an increase in the number of those requiring support or nursing care. However, no study has examined the relationship between the risk of developing PTSD due to earthquake and fractures in older adult residents of evacuation areas such as Fukushima Prefecture. Therefore, to maintain and improve the healthy life expectancy and QOL of older adult residents in the Fukushima Prefecture evacuation area, the association between the risk of PTSD and fractures in these residents should be investigated.

This study used data on the older adult taken from the Fukushima Health Management Survey to investigate the association between the frequency of fractures and factors related to the Great East Japan Earthquake, including the risk of developing PTSD.

**Methods**

**Study group**

Following the Great East Japan Earthquake, the Japanese government declared that the area outside the 20 km radius of the Fukushima Daiichi power plant, where the total radiation dose (cumulative radiation dose) was expected to reach >20 mSv/year, was the “planned evacuation area”; the area within a 20- to 30 km radius was the “area prepared for emergency evacuation”; and the area within a 20 km radius was the “caution zone.” Accordingly, the Japanese government evacuated residents from 13 cities, towns, and villages (all areas within Hirono-machi, Naraha-machi, Tomioka-machi, Kawauchi-mura, Okuma-machi, Futaba-machi, Namie-machi, Katsurao-mura, litate-mura, part of Tamura City, part of Minami-soma City, part of Kawamata-machi, and part of Date-city).

Since January 18, 2012, the Fukushima Health Management Survey has been conducted to evaluate the impact of radiation and to determine the health status of Fukushima residents, considering the diffusion of radioactive substances and evacuation due to the accident at FDNPS, which could subsequently help prevent illnesses, detect illnesses early, and provide early treatment for maintaining and improving the future health of the residents. Among the individuals who completed the Fukushima Health Management Survey, including the Mental Health and Lifestyle Survey component, were those who had been residing in the 13 towns that had to be evacuated because of the Great East Japan Earthquake (individuals with registered residency). Some 180,604 were aged ≥15 years (individuals born before April 1, 1995), of whom 27,066 were aged ≥65 years (men: 11,795; women: 15,271) and had completed the 2011 edition of the registered questionnaire (valid responses were obtained from 73,431 individuals, with a response rate of 40.7% and a mean age of 56.4 years), which comprised the sample for the present study. According to the questionnaire on “History of fractures after age 50,” as of 2011, 19,844 individuals (men: 9,297; women: 10,547; mean age: 75.2 ± 7.0 years) were confirmed to have had no recent history of fractures. Based on a questionnaire on fractures from 2012 to 2016, the occurrence of fractures was determined. Excluding 6,076 individuals whose fracture occurrence could not be tracked until 2016, 13,768 patients (men: 6,632; women: 7,136) were ultimately targeted (with a mean age of 74.5 ± 6.6 years and a mean follow-up period of 3.75 ± 1.48 person-years) (Fig. 1).

The analysis includes age, sex, physical factors (history of fractures, cancer, stroke, heart disease, diabetes, dyslipidemia, hepatic disorder, high blood pressure, and thyroid disease), social factors (experience of earthquake, tsunami, nuclear power plant accident [heard the explosion], need for assistance, change in employment status, and change in residence), psychological factors (history of mental illness, PCL), and lifestyle factors (history of smoking, history of drinking, sleep satisfaction levels, and exercise habits) in the items of the self-administered questionnaire used in the 2011 Mental Health and Lifestyle Survey.
Fracture Determination

In the Mental Health and Lifestyle Survey, questions regarding the presence or absence of fractures differ depending on the year, and the incidence of fractures was determined by combining the questions.

The presence or absence of fractures in 2011 and 2012 was confirmed by responding to a question on "A history of fractures after age 50." In 2013, in addition to the above question, a combination of answers regarding whether “a fracture was diagnosed by a physician within the past year” had been used to determine the presence or absence of fracture. In 2014 and 2015, the presence or absence of fractures had been determined based on only the answer to “fractures within 1 year.” In 2016, the incidence of fractures had been determined by a question on “History of fractures after the age of 50.”

Trauma Reaction Evaluation

The presence or absence of a trauma reaction was evaluated using PCL\textsuperscript{11−12}; those with a total PCL score of 44 or more were defined as being at high risk of PTSD.

History Of Disease

Residents were asked whether they had a history of cancer, stroke, heart disease, hypertension, diabetes, dyslipidemia, hepatic disorder, thyroid disease, or mental illness.

Lifestyle

The questionnaire section on smoking habits comprised three choices: never smoked, former smoker, or current smoker. The section on drinking habits also comprised three choices: never drinks or rarely drinks (less than once a month), former drinker, or current drinker (more than once a month). The question regarding the sleep satisfaction component comprised four choices: satisfied with sleep, slightly unsatisfied with sleep, quite unsatisfied with sleep, and very dissatisfied with sleep or does not sleep at all. Furthermore, the question regarding the exercise habits component comprised four choices: almost daily, two to four times a week, approximately once a week, or almost never.

Experience Of The Great East Japan Earthquake

The question regarding the experience of the Great East Japan Earthquake involved individuals responding to whether they had experienced the earthquake, tsunami, and nuclear power plant accident (heard the explosion).

Need For Assistance

The question regarding need for assistance involved individuals responding to whether they could eat, change clothes, use restrooms, and shop alone. Those who answered that assistance was required for any of the four items were defined as a group requiring assistance.

Changes In Employment Status

Regarding change in employment status (job change or unemployment) following the earthquake and accident, residents could respond with either “changed” or “unchanged.”
Changes In Housing And Evacuation

Residents could respond to the question regarding change in residence after the earthquake in one of the following ways: residing in a shelter, in temporary housing, renting a house or apartment, residing in a relative's house, residing in their own house, or other (free comment). The respondents who had lived in temporary or evacuation shelters immediately after the earthquake were defined as having changed their residence.

In addition, the residents of Tamura city, Minamisoma-city, Date-city, and Kawamata-towns whose current housing was not a temporary or evacuation center in 2011 were defined as the nonevacuee group. The others were defined as evacuee groups.

Statistical Analysis Methods

The statistical analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). The Kaplan–Meier method and the log-rank test were used to compare the difference in the incidence of fractures based on the answers for each item. In addition, univariate and multivariate Cox proportional hazard models were used to obtain crude and adjusted hazard ratios (HRs) and 95% confidence intervals (CIs) for the association between each factor and fractures. All the data are presented as the number of individuals (n), mean, standard deviation, or percentages. P < 0.05 was considered statistically significant.

Results

Participant characteristics

Table 1 lists the participant characteristics. The mean follow-up period for all participants was 3.75 ± 1.48 person-years. Some 1,687 (12.3%) participants experienced a fracture during the observation period.
Table 1
Participants’ characteristics.

| Factor                              | Classification | All participants (n = 13768) |
|-------------------------------------|----------------|------------------------------|
|                                     |                |                              |
|                                     |                | Mean | SD  |
| Age                                 | years          | 74.5 | 6.6 |
| Follow-up period                    | person-years   | 3.75 | 1.48 |
| Sex                                 |                |      |     |
| Men                                 |                | 6632 | 48.2|
| Women                               |                | 7136 | 51.8|
| PCL Scores                          |                |      |     |
| < 44                                |                | 9252 | 74.5|
| ≥ 44                                |                | 3174 | 25.5|
| Experience of evacuation            |                |      |     |
| No                                  |                | 6349 | 69.6|
| Yes                                 |                | 2774 | 30.4|
| Experience of earthquake            |                |      |     |
| No                                  |                | 962  | 7.0 |
| Yes                                 |                | 12806| 93.0|
| Experience of tsunami               |                |      |     |
| No                                  |                | 10604| 77.0|
| Yes                                 |                | 3164 | 23.0|
| Experience of a nuclear accident    |                |      |     |
| (explosion heard)                   |                |      |     |
| No                                  |                | 5463 | 39.7|
| Yes                                 |                | 8305 | 60.3|
| History of mental illness           |                |      |     |
| No                                  |                | 12289| 94.4|
| Yes                                 |                | 727  | 5.6 |
| Need for assistance                 |                |      |     |
| No                                  |                | 12240| 90.3|
| Yes                                 |                | 1315 | 9.7 |
| History of cancer                   |                |      |     |
| No                                  |                | 11763| 91.5|
| Yes                                 |                | 1094 | 8.5 |
| History of stroke                   |                |      |     |
| No                                  |                | 11640| 89.6|
| Yes                                 |                | 1353 | 10.4|
| History of heart disease            |                |      |     |
| No                                  |                | 10531| 96.6|
| Yes                                 |                | 375  | 3.4 |
| History of diabetes mellitus        |                |      |     |
| No                                  |                | 8611 | 66.5|
| Yes                                 |                | 4335 | 33.5|
| History of dyslipidemia             |                |      |     |
| No                                  |                | 6535 | 50.1|
| Yes                                 |                | 6507 | 49.9|
| History of hepatic disorder         |                |      |     |
| No                                  |                | 12468| 96.6|
### Table: Factors and Classifications

| Factor                  | Classification     | All participants (n = 13768) |
|-------------------------|--------------------|------------------------------|
|                         | Yes                | 433                          | 3.4 |
| History of hypertension | No                 | 3915                         | 29.2 |
|                         | Yes                | 9474                         | 70.8 |
| History of thyroid disease | No             | 12738                        | 96.9 |
|                         | Yes                | 405                          | 3.1 |
| Smoking habit           | never smoked       | 7984                         | 61.3 |
|                         | former smoker      | 3790                         | 29.1 |
|                         | current smoker     | 1261                         | 9.7 |
| Drinking habit          | never drinks or rarely drinks (less than once a month) | 7289 | 55.1 |
|                         | former drinker     | 763                          | 5.8 |
|                         | current drinker (more than once a month) | 5185 | 39.2 |
| Level of sleep satisfaction | satisfied with sleep | 4247                         | 42.3 |
|                         | slightly unsatisfied with sleep | 4013 | 40.0 |
|                         | quite unsatisfied with sleep | 1298 | 12.9 |
|                         | very dissatisfied with sleep or does not sleep at all | 484 | 4.8 |
| Exercise habit          | almost daily       | 3370                         | 25.6 |
|                         | 2 to 4 times a week | 4080                         | 31.1 |
|                         | approximately once a week | 1988 | 15.1 |
|                         | almost never       | 3701                         | 28.2 |
| Job change              | No                 | 6607                         | 55.3 |
|                         | Yes                | 5337                         | 44.7 |
| Loss of job             | No                 | 11968                        | 86.9 |
|                         | Yes                | 1800                         | 13.1 |
| Residential changes     | No                 | 8175                         | 62.2 |
|                         | Yes                | 4965                         | 37.8 |

Data are presented as numbers with percentage or mean with standard deviation.

SD: standard deviation, PCL: post-traumatic stress disorder checklist.

### Survival Analysis Results

The participants were divided into fracture and nonfracture groups, and the relationship between each factor and the incidence of fractures was examined.
As a result of the survival analysis, significant differences in fracture incidence in the older adult were found in relation to sex (P < 0.001), PTSD risk (P < 0.001), experience of earthquake (P = 0.013), history of mental illness (P < 0.001), need for assistance (P < 0.001), history of cancer (P < 0.001), history of stroke (P < 0.001), history of heart disease (P < 0.001), history of diabetes (P = 0.015), history of hepatic disorder (P = 0.048), smoking habits (P < 0.001), drinking habits (P < 0.001), sleep satisfaction (P < 0.001), and exercise habits (P = 0.005) (Table 2).
| Factor                        | Classification | Non bone fracture (n = 1,2081) | Incidence of bone fracture (n = 1,687) | P value |
|-------------------------------|----------------|---------------------------------|----------------------------------------|---------|
|                               |                | Mean | SD  | Mean | SD  |                  |
| Age                           | years          | 74.3 | 6.6 | 75.8 | 6.8 |                  |
| Follow-up period              | person-years   | 2.50 | 1.45 | 3.93 | 1.40 |                  |
| Sex                           |                |      |     |      |     |                  |
|                               | Men            | 6,015 | 49.8 | 617  | 36.6 | <.0001            |
|                               | Women          | 6,066 | 50.2 | 1,070 | 63.4 |                   |
| PCL Score                     | < 44           | 8,247 | 75.3 | 1,005 | 68.5 | <.0001            |
|                               | ≥ 44           | 2,711 | 24.7 | 463  | 31.5 |                   |
| Experience of evacuation      | No             | 5,596 | 69.7 | 753  | 68.5 | 0.487             |
|                               | Yes            | 2,427 | 30.3 | 347  | 31.5 |                   |
| Experience of earthquake      | No             | 829   | 6.9  | 133  | 7.9  | 0.013             |
|                               | Yes            | 11,252 | 93.1 | 1,554 | 92.1 |                   |
| Experience of tsunami         | No             | 9,293 | 76.9 | 1,311 | 77.7 | 0.951             |
|                               | Yes            | 2,788 | 23.1 | 376  | 22.3 |                   |
| Experience of nuclear accident (explosion heard) | No | 4,779 | 39.6 | 684  | 40.5 | 0.341             |
|                               | Yes            | 7,302 | 60.4 | 1,003 | 59.5 |                   |
| History of mental illness     | No             | 10,852 | 94.7 | 1,437 | 92.6 | <.0001            |
|                               | Yes            | 613   | 5.3  | 114  | 7.4  |                   |
| Need for assistance           | No             | 10,812 | 90.8 | 1,428 | 86.4 | <.0001            |
|                               | Yes            | 1,091 | 9.2  | 224  | 13.6 |                   |
| History of cancer             | No             | 10,376 | 91.8 | 1,387 | 89.1 | <.0001            |
|                               | Yes            | 924   | 8.2  | 170  | 10.9 |                   |
| History of stroke             | No             | 10,274 | 90.0 | 1,366 | 86.7 | <.0001            |
|                               | Yes            | 1,144 | 10.0 | 209  | 13.3 |                   |
| History of heart disease      | No             | 9,332 | 81.3 | 1,199 | 76.2 | <.0001            |
|                               | Yes            | 2,153 | 18.7 | 375  | 23.8 |                   |
| History of diabetes mellitus  | No             | 7,605 | 66.8 | 1,006 | 64.2 | 0.015             |
|                               | Yes            | 3,773 | 33.2 | 562  | 35.8 |                   |
| History of dyslipidemia       | No             | 5,762 | 50.3 | 773  | 48.8 | 0.659             |
|                               | Yes            | 5,697 | 49.7 | 810  | 51.2 |                   |
| History of hepatic disorder   | No             | 10,965 | 96.7 | 1,503 | 96.0 | 0.048             |
| Factor                           | Classification | Non bone fracture (n = 1,2081) | Incidence of bone fracture (n = 1,687) | P value  |
|---------------------------------|----------------|-------------------------------|---------------------------------------|----------|
|                                 |                | Yes                           | Yes                                   | 371      | 3.3 | 62   | 4.0 | 0.119 |
| History of hypertension         | No             | 3,456                         | 459                                   | 29.4     | 28.0 | 0.261 |
|                                 | Yes            | 8,291                         | 1,183                                 | 70.6     | 72.0 | 0.119 |
| History of thyroid disease      | No             | 11,234                        | 1,504                                 | 97.0     | 96.2 | 0.078 |
|                                 | Yes            | 346                           | 59                                    | 3.0      | 3.8  | 0.63  |
| Smoking habit                   | never smoked   | 6,922                         | 1,062                                 | 60.3     | 68.1 | < .0001 |
|                                 | former smoker  | 3,427                         | 363                                   | 29.9     | 23.3 |        |
|                                 | current smoker | 1,127                         | 134                                   | 9.8      | 8.6  |        |
| Drinking habit                  | never drinks or rarely drinks (less than once a month) | 6,326 | 963 | 60.4 | < .0001 |
|                                 | former drinker | 674                           | 89                                    | 5.8      | 5.6  |        |
|                                 | current drinker| 4,642                         | 543                                   | 39.9     | 34.0 |        |
| Level of sleep satisfaction     | satisfied with sleep | 3,796 | 451 | 36.6 | < .0001 |
|                                 | slightly unsatisfied with sleep | 3,500 | 513 | 41.7 |        |
|                                 | quite unsatisfied with sleep | 1,116 | 182 | 14.8 |        |
|                                 | very dissatisfied with sleep or does not sleep at all | 399 | 85 | 6.9 |        |
| Exercise habit                  | almost daily   | 2,989                         | 381                                   | 25.9     | 24.0 | 0.005 |
|                                 | 2 to 4 times a week | 3,595 | 485 | 30.5 |        |
|                                 | approximately once a week | 1,748 | 240 | 15.1 |        |
|                                 | almost never   | 3,217                         | 484                                   | 27.9     | 30.4 |        |
| Job change                      | No             | 5,831                         | 776                                   | 55.3     | 55.4 | 0.500 |
|                                 | Yes            | 4,712                         | 625                                   | 44.7     | 44.6 |        |
| Loss of job                     | No             | 10,491                        | 1,477                                 | 86.8     | 87.6 | 0.054 |
|                                 | Yes            | 1,590                         | 210                                   | 13.2     | 12.4 |        |
| Residential changes             | No             | 7,200                         | 975                                   | 62.3     | 61.4 | 0.820 |
|                                 | Yes            | 4,353                         | 612                                   | 37.7     | 38.6 |        |
| Factor | Classification | Non bone fracture (n = 1,2081) | Incidence of bone fracture (n = 1,687) | P value |
|--------|----------------|--------------------------------|-------------------------------------|---------|
|        |                |                                |                                     |         |

Data are presented as a number with a percentage or a mean with standard deviation.

The interval scale between the bone fracture and no bone fracture group groups was tested using the log-rank test.

SD: standard deviation, PCL: post-traumatic stress disorder checklist.

p < 0.05 was considered statistically significant.

**Univariate And Multivariate Cox Proportional Hazard Models**

Univariate and multivariate Cox proportional hazard models were performed for each factor, with significant differences in the survival analysis to identify the association between psychological indicators and fracture frequency in the older adult (Table 3).
Table 3
The results of univariate and multivariate Cox proportional hazard models.

| Factors                        | Classification | Crude HR (95% CI) | P value | Adjusted HR (95% CI) | P value |
|--------------------------------|----------------|-------------------|---------|----------------------|---------|
| Age                            | Continuous     | 1.05 (1.04 - 1.06) | <.0001  | 1.04 (1.03 - 1.05)   | <.0001  |
| Sex                            | Men Ref.       |                   |         |                      |         |
|                                | Women          | 1.69 (1.53 - 1.86) | <.0001  | 1.77 (1.45 - 2.16)   | <.0001  |
| PCL Score                      | < 44 Ref.      |                   |         |                      |         |
|                                | ≥ 44           | 1.38 (1.24 - 1.54) | <.0001  | 1.18 (1.01 - 1.38)   | 0.039   |
| Experience of earthquake       | No Ref.        |                   |         |                      |         |
|                                | Yes            | 0.80 (0.67 - 0.95) | 0.013   | 0.83 (0.61 - 1.13)   | 0.242   |
| History of mental illness      | No Ref.        |                   |         |                      |         |
|                                | Yes            | 1.56 (1.29 - 1.88) | <.0001  | 1.00 (0.74 - 1.33)   | 0.974   |
| Need for assistance            | No Ref.        |                   |         |                      |         |
|                                | Yes            | 2.09 (1.82 - 2.41) | <.0001  | 1.19 (0.94 - 1.50)   | 0.147   |
| History of cancer              | No Ref.        |                   |         |                      |         |
|                                | Yes            | 1.41 (1.20 - 1.65) | <.0001  | 1.58 (1.28 - 1.93)   | <.0001  |
| History of stroke              | No Ref.        |                   |         |                      |         |
|                                | Yes            | 1.47 (1.27 - 1.70) | <.0001  | 1.33 (1.08 - 1.65)   | 0.009   |
| History of heart disease       | No Ref.        |                   |         |                      |         |
|                                | Yes            | 1.38 (1.22 - 1.54) | <.0001  | 1.23 (1.05 - 1.45)   | 0.012   |
| History of diabetes mellitus   | No Ref.        |                   |         |                      |         |
|                                | Yes            | 1.14 (1.03 - 1.26) | 0.015   | 1.21 (1.05 - 1.39)   | 0.007   |
| History of hepatic disorder    | No Ref.        |                   |         |                      |         |
|                                | Yes            | 1.29 (1.00 - 1.67) | 0.048   | 0.78 (0.50 - 1.20)   | 0.257   |
| Smoking habit                  | never smoked   | Ref.              |         |                      |         |
|                                | former smoker  | 0.70 (0.62 - 0.79) | <.0001  | 0.95 (0.77 - 1.16)   | 0.590   |
|                                | current smoker | 0.80 (0.67 - 0.96) | 0.017   | 1.17 (0.89 - 1.52)   | 0.267   |
| Drinking habit                 | never drinks or rarely drinks | (less than once a month) | Ref. | Ref. |
| Factors                     | Classification | Crude HR (95% CI) | P value | Adjusted HR (95% CI) \(^a\) | P value |
|-----------------------------|----------------|-------------------|---------|-----------------------------|---------|
|                             | former drinker | 0.95 (0.76 - 1.18) | 0.613   | 1.25 (0.91 - 1.72)          | 0.175   |
|                             | current drinker (more than once a month) | 0.74 (0.67 - 0.82) | <.0001 | 1.10 (0.93 - 1.31)          | 0.261   |

| Level of sleep satisfaction | satisfied with sleep | Ref. | Ref. | slightly unsatisfied with sleep | 1.20 (1.05 - 1.36) | 0.006 | 1.08 (0.93 - 1.25) | 0.335 |
|                            | quite unsatisfied with sleep | 1.36 (1.14 - 1.61) | 0.001 | 1.01 (0.81 - 1.26)          | 0.930   |
|                            | very dissatisfied with sleep or does not sleep at all | 1.78 (1.41 - 2.24) | <.0001 | 1.40 (1.04 - 1.89)          | 0.025   |

| Exercise habit              | almost daily | Ref. | Ref. | 2 to 4 times a week | 1.05 (0.92 - 1.20) | 0.497 | 0.99 (0.83 - 1.18) | 0.882 |
|                            | approximately once a week | 1.09 (0.93 - 1.29) | 0.277 | 1.07 (0.87 - 1.33)          | 0.526   |
|                            | almost never | 1.26 (1.10 - 1.44) | 0.001 | 1.05 (0.88 - 1.27)          | 0.580   |

\(^a\) Adjusted for age, sex, PCL score, experience of earthquake, history of mental illness, need for assistance, history of cancer, history of stroke, history of heart disease, history of diabetes mellitus, history of hepatic disorder, smoking habit, drinking habit, level of sleep satisfaction, and exercise habit.

95% CI: 95% confidence interval, HR: hazard ratio, Ref: reference, PCL: post-traumatic stress disorder checklist.

The univariate Cox proportional hazard model showed age (HR: 1.05; 95% CI: 1.04–1.06; P < 0.001), women (HR: 1.69; 95% CI: 1.53–1.86; P < 0.001), high risk for PTSD (PCL ≥ 44) (HR: 1.38; 95% CI: 1.24–1.54; P < 0.001), experience of earthquake (HR: 0.80; 95% CI: 0.67–0.95; P = 0.013), mental illness (HR: 1.56; 95% CI: 1.29–1.88; P < 0.001), need for assistance (HR: 2.09; 95% CI: 1.82–2.41; P < 0.001), history of cancer (HR: 1.41; 95% CI: 1.20–1.65; P < 0.001), history of stroke (HR: 1.47; 95% CI: 1.27–1.70; P < 0.001), history of heart disease (HR: 1.38; 95% CI: 1.22–1.54; P < 0.001), history of diabetes (HR: 1.14; 95% CI: 1.03–1.26; P = 0.015), history of hepatic disorder (HR: 1.29; 95% CI: 1.00–1.67; P = 0.048), former smokers (HR: 0.70; 95% CI: 0.62–0.79; P < 0.001), current smokers (HR: 0.80; 95% CI: 0.67–0.96; P = 0.017), or current drinkers (HR: 0.74; 95% CI: 0.67–0.82; P < 0.001), a little dissatisfied with sleep (HR: 1.20; 95% CI: 1.05–1.36; P = 0.006), quite dissatisfied with sleep (HR: 1.36; 95% CI: 1.14–1.61; P = 0.001), very dissatisfied with sleep or did not sleep at all (HR: 1.78; 95% CI: 1.41–2.24; P < 0.001), or almost no exercise (HR: 1.26; 95% CI: 1.10–1.44; P = 0.001) showed a significant association with the incidence of fractures in the older adult.

The multivariate Cox proportional hazard model was performed using factors that were significant in the univariate Cox proportional hazard model. As a result, the older adult with high risk of PTSD (HR: 1.18; 95% CI: 1.05–1.38; P = 0.039), history of cancer (HR: 1.58; 95% CI: 1.28–1.93; P < 0.001), stroke history (HR: 1.33; 95% CI: 1.08–1.65; P = 0.009), history of heart disease (HR: 1.38; 95% CI: 1.22–1.55; P < 0.001), and very dissatisfied with sleep or did not sleep at all (HR: 1.78; 95% CI: 1.41–2.24; P < 0.001) showed a significant association with the incidence of fractures in the older adult.
disease (HR: 1.23; 95% CI: 1.05–1.45; P = 0.012), history of diabetes (HR: 1.21; 95% CI: 1.05–1.39; P = 0.007), and those very dissatisfied with sleep or who did not sleep at all (HR: 1.40; 95% CI: 1.04–1.89; P = 0.025) had a significant increase in fracture risk, independent of age and sex.

Table 4 presents the results of the multivariate Cox proportional hazard model by sex to examine the effects of sex differences. For older adult men, those who were at high risk of PTSD (HR: 1.35; 95% CI: 1.05–1.73; P = 0.021), a history of cancer (HR: 1.64; 95% CI: 1.23–2.18; P = 0.001), history of stroke (HR: 1.37; 95% CI: 1.01–1.84; P = 0.042), history of diabetes (HR: 1.32; 95% CI: 1.07–1.62; P = 0.010), and who were very dissatisfied with sleep or did not sleep at all (HR: 1.85; 95% CI: 1.18–2.92; P = 0.008) had a significant increase in fracture risk, independent of age. By contrast, older adult women who had a history of cancer (HR: 1.48; 95% CI: 1.10–1.99; P = 0.010) or heart disease (HR: 1.32; 95% CI: 1.07–1.64; P = 0.010) had a significant increase in fracture risk, independent of age.
Table 4  
The results of multivariate Cox proportional hazard models by sex.

| Factors                          | Classification | Men                          | Women                         |   |
|----------------------------------|----------------|------------------------------|-------------------------------|---|
|                                  |                | **Adjusted HR** | **P value** | **Adjusted HR** | **P value** |
|                                  |                | (95% CI) a              |                      | (95% CI) b              |                      |
| Age                              | Continuous     | 1.03 ( 1.01 - 1.05 ) | 0.001 | 1.05 ( 1.03 - 1.06 ) | <.0001 |
| PCL Score                        | < 44 Ref.      |                             |                  |                          |                      |
|                                  | ≥ 44           | 1.35 ( 1.05 - 1.73 ) | 0.021 | 1.10 ( 0.90 - 1.34 ) | 0.375 |
| Experience of earthquake         | No Ref.        |                             |                  |                          |                      |
|                                  | Yes            | 0.82 ( 0.53 - 1.28 ) | 0.383 | 0.82 ( 0.53 - 1.26 ) | 0.357 |
| History of mental illness        | No Ref.        |                             |                  |                          |                      |
|                                  | Yes            | 0.99 ( 0.61 - 1.61 ) | 0.980 | 1.01 ( 0.70 - 1.46 ) | 0.955 |
| Need for assistance              | No Ref.        |                             |                  |                          |                      |
|                                  | Yes            | 1.15 ( 0.73 - 1.80 ) | 0.547 | 1.18 ( 0.89 - 1.57 ) | 0.242 |
| History of cancer                | No Ref.        |                             |                  |                          |                      |
|                                  | Yes            | 1.64 ( 1.23 - 2.18 ) | 0.001 | 1.48 ( 1.10 - 1.99 ) | 0.010 |
| History of stroke                | No Ref.        |                             |                  |                          |                      |
|                                  | Yes            | 1.37 ( 1.01 - 1.84 ) | 0.042 | 1.26 ( 0.92 - 1.72 ) | 0.149 |
| History of heart disease         | No Ref.        |                             |                  |                          |                      |
|                                  | Yes            | 1.11 ( 0.87 - 1.43 ) | 0.402 | 1.32 ( 1.07 - 1.64 ) | 0.010 |
| History of diabetes mellitus     | No Ref.        |                             |                  |                          |                      |
|                                  | Yes            | 1.32 ( 1.07 - 1.62 ) | 0.010 | 1.13 ( 0.93 - 1.36 ) | 0.221 |
| History of hepatic disorder      | No Ref.        |                             |                  |                          |                      |
|                                  | Yes            | 0.67 ( 0.36 - 1.26 ) | 0.214 | 0.88 ( 0.48 - 1.61 ) | 0.681 |
| Smoking habit                    | never smoked   | Ref.                        |                  | Ref.                     |                      |
|                                  | former smoker  | 0.97 ( 0.76 - 1.24 ) | 0.808 | 0.98 ( 0.62 - 1.54 ) | 0.921 |
|                                  | current smoker | 1.17 ( 0.85 - 1.61 ) | 0.325 | 1.16 ( 0.66 - 2.02 ) | 0.607 |
| Drinking habit                   | never drinks or rarely drinks | Ref. |                  | Ref.                     |                      |
|                                  | (less than once a month) |              |                  |                          |                      |
|                                  | former drinker | 1.25 ( 0.87 - 1.79 ) | 0.236 | 0.90 ( 0.33 - 2.43 ) | 0.832 |
|                                  | current drinker | 1.06 ( 0.83 - 1.36 ) | 0.635 | 1.16 ( 0.92 - 1.47 ) | 0.206 |
| Level of sleep satisfaction      | satisfied with sleep | Ref. |                  | Ref.                     |                      |
| Factors | Classification                                      | Men          | Women         |          |          |
|--------|----------------------------------------------------|--------------|---------------|----------|----------|
|        |                                                    | Adjusted HR  | Adjusted HR   | P value  | P value  |
|        |                                                    | (95% CI)     | (95% CI)      |          |          |
|        | slightly unsatisfied with sleep                    | 1.06 (0.83 - 1.34) | 1.06 (0.88 - 1.29) | 0.652 | 0.540 |
|        | quite unsatisfied with sleep                       | 1.36 (0.98 - 1.90) | 0.83 (0.62 - 1.11) | 0.070 | 0.209 |
|        | very dissatisfied with sleep or does not sleep at all | 1.85 (1.18 - 2.92) | 1.12 (0.76 - 1.67) | 0.008 | 0.570 |
|        | Exercise habit                                     |              |               |          |          |
|        | almost daily                                       | Ref.         | Ref.          |          |          |
|        | 2 to 4 times a week                                | 0.88 (0.67 - 1.14) | 1.09 (0.85 - 1.39) | 0.336 | 0.507 |
|        | about once a week                                  | 0.97 (0.70 - 1.34) | 1.17 (0.88 - 1.57) | 0.861 | 0.283 |
|        | almost never                                       | 0.98 (0.74 - 1.29) | 1.13 (0.88 - 1.45) | 0.876 | 0.346 |

a, b Adjusted for age, PCL score, experience of earthquake, history of mental illness, need for assistance, history of cancer, history of stroke, history of heart disease, history of diabetes mellitus, history of hepatic disorder, smoking habit, drinking habit, level of sleep satisfaction, and exercise habit.

95% CI: 95% confidence interval, HR: hazard ratio, Ref: reference, PCL: post-traumatic stress disorder checklist.

Cox proportional hazard model; p < 0.05 was considered statistically significant.

Discussion

Previous studies have reported an increase in the prevalence of diseases such as obesity and lifestyle-related diseases in residents of evacuation areas in Fukushima Prefecture\textsuperscript{13–16}. This increase could be due in part to an increase in stress from changes in the environment caused by moving into temporary housing or living in an evacuation site other than the local area or disturbance in eating habits\textsuperscript{17–20}. Thus, psychological stress is considered to be related to adverse effects on the health of residents, such as those in evacuation areas in Fukushima Prefecture. Those who reported feeling high psychological stress were found to be at increased risk of fracture due to osteoporosis\textsuperscript{21}. One possible mechanism for the association between stress and fracture risk is that psychological stress increases cortisol secretion through the hypothalamus–pituitary–adrenal system. Glucocorticoids induce bone loss and increase the risk of osteoporotic fractures\textsuperscript{22, 23}. Those at high risk of developing PTSD were considered to have high psychological stress immediately after a disaster. Furthermore, older adult people and those with severe living conditions are reportedly more likely to experience worsening symptoms\textsuperscript{24}. The psychological effects from the Fukushima nuclear accident have been widespread, causing not only trauma symptoms but also chronic and more complex social problems, such as fragmentation of community and family, and stigma\textsuperscript{25}. Therefore, chronic sustained high stress caused by a disaster could contribute to increased fracture risk in the older adult. Thus, to prevent fractures after a disaster, older adult people at increased risk of developing PTSD might need to be assessed for bone mineral density and receive aggressive interventions to reduce psychosocial stress.

Furthermore, it is presumed that those who are at high risk of developing PTSD are more likely to also have other mental disorders, such as depression\textsuperscript{26, 27}. In fact, residents of Kawauchi Village, one of the 13 municipalities in the evacuation area that exceeded the reference value of Kessler Psychological Distress Scale (K6) scores\textsuperscript{28–30} were found to have a significantly
higher percentage of those with PCLs of 44 or higher. In addition, prefectural health surveys have reported that coexistence of PTSD and past mental illness or mental disorders was a poor predictor of mid-term mental health. Thus, the deterioration of mental health caused by a disaster can lead older adult people who already had a tendency to have low physical function in a depressed state to have an even more confined and sedentary lifestyle, leading to a decrease in physical function and thus increased risk of fractures. Therefore, it is important for older adult people with high PTSD risk and low physical function to maintain and improve their physical function and mental health by encouraging social participation.

Depression itself has also been reported to be associated with an increased risk of fractures. This increase might be mediated by antidepressants. For example, taking one class of antidepressants, selective serotonin reuptake inhibitors (SSRIs), can increase the risk of fractures regardless of depression or bone density. In addition, SSRIs have been reported to contribute to fracture-induced falls and increases in fracture risk. The use of SSRIs is sometimes considered when treating PTSD. Thus, older adult people who are receiving medication for PTSD need to be aware of the risk of fractures due to antidepressants.

We found that those who were very dissatisfied with their sleep were at increased risk of fractures. The prevalence of insomnia and the use of sleeping pills in the Japanese have been reported to increase with age. One of the commonly prescribed sleeping pills in Japan is benzodiazepine or the similar nonbenzodiazepine benzodiazepine receptor agonist. Long-term and high-dose uses of benzodiazepines have been reported to be associated with an increased risk of falls and fractures. These findings suggest that pharmacotherapy for insomnia could also be a factor in increasing the risk of fractures in older adult residents, such as those in the evacuation areas in Fukushima Prefecture. The first choice of treatment for insomnia is to understand the sleep environment and provide sleep hygiene guidance. Our study suggests that securing sleep time and improving the quality of sleep is important to preventing fractures in older adult residents of the evacuation area in Fukushima Prefecture.

Our study found that those with a history of diabetes, heart disease, or stroke were at an increased risk of fractures. Previous studies have reported that the presence of type 2 diabetes is associated with increased fracture risk and paradoxically increases bone mineral density. The incidence of cardiovascular disease has also been reported to be significantly associated with the risk of subsequent hip fracture. In addition, stroke has been reported to increase the risk of fractures, including hip fractures, by more than seven-fold within 1 year of hospitalization. Therefore, we anticipate that older adult residents in Fukushima evacuation areas who experienced lifestyle-related diseases and cardiovascular events after the earthquake will likely fall and require nursing care due to the increase in the number of fractures. These findings suggest that a comprehensive strategy to prevent lifestyle-related diseases and cardiovascular events is necessary to preventing fractures among older adult residents in evacuation areas.

Our study found that women have a higher risk of fractures than men. Contrarily, we found that the risk of developing PTSD was not significantly associated with the occurrence of fractures in women. Women often have primary osteoporosis caused by heredity, aging, and postmenopausal decline in female hormones. Patients with osteoporosis have also been found to be more likely to experience a fracture after a fall. Osteoporosis-related fractures can also have a significant impact on health-related quality of life (HRQOL). These results suggest that problems characteristic of women, which could not be investigated in this study, could have a greater effect on fracture risk than increased psychological stress. However, exercise can be effective in reducing falls and risk factors associated with fractures from falls in patients with low bone mineral density. Therefore, regular bone density measurements and exercise habit formation for people at high risk of developing PTSD are recommended, especially for women, to prevent fractures from falling and to prevent a decline in HRQOL.

The results of our study revealed that a history of cancer could influence risk of fracture. Hormonal therapies used in breast and prostate cancer can reduce bone mass and bone density, thus increasing fracture risk. Also, individuals with metastatic bone tumors are known to be susceptible to fractures. Thus, older adult patients with cancer are prone to
fractures and are very likely to be bedridden if they fall. Therefore, those who have a history of cancer need assistance with creating an environment to prevent falls and to be given guidance on living.

Our study had some limitations. First, the age-adjusted prevalence of post-traumatic stress is known to decrease year by year, and the mental health of residents in evacuation areas in Fukushima Prefecture has improved compared with that at the time of the earthquake\textsuperscript{51}. However, it is unclear whether this improvement is reflected in the 13 municipalities’ residents, because the ratio of the participants in our study to the total number of participants in the Fukushima residents’ health survey is low. Horikoshi et al. had also reported that those who did not respond to the mental survey had a significantly higher rate of psychological distress than respondents\textsuperscript{52}. Therefore, the results of this study could have underestimated the impact on fractures due to the increased risk of PTSD from the Great East Japan Earthquake and the nuclear accident. Therefore, it might be necessary to survey the mental health of non-respondents by expanding the scope of psychological research and to make efforts to improve it.

Second, in this survey, there were no detailed medication conditions, bone density tests, fracture sites, or questionnaires to survey the situation when a fracture occurs, presence of osteoporosis, or use of antidepressant drugs. As a result, factors that could contribute to fracture risk, such as osteoporosis and the use of antidepressants and steroids\textsuperscript{53}, could not be investigated. In addition, the effects of sex differences on fractures could not be completely clarified because women were not surveyed for menopause or hormone levels. Future studies should include examinations and interviews for these factors.

Finally, studies in postmenopausal women have reported that obesity and underweight are both risk factors for fractures\textsuperscript{54}. In this survey, however, there were no survey items on height and weight in FY2011, and Body Mass Index (BMI) could not be calculated. Therefore, in the next study, we plan to examine the relationship between weight and fractures by evaluating health checkup data.

**Conclusions**

Taken together, the results of our study suggest that chronic psychological stress and reduced sleep time and quality due to disaster could contribute to increased fracture risk. Therefore, understanding bone mineral density, offering active psychological care to reduce psychosocial stress, and providing guidance on sleep are important for preventing fractures in older adult residents, such as those in evacuation areas.

**Abbreviations**

PTSD: Post-traumatic stress disorder; PCL: Post-traumatic stress disorder checklist; HR: Hazard ratio; 95% CI: 95% confidence interval; FDNPS: Fukushima Daiichi Nuclear Power Station; QOL: Quality of life; K6: Kessler Psychological Distress Scale; SSRIs: Selective serotonin reuptake inhibitors; HRQOL: Health-related quality of life; FY: Fiscal Year; BMI: Body Mass Index; SD: Standard Deviation; Ref: Reference.

**Declarations**

**Ethics approval and consent to participate**

The mental health survey participants were told in writing that the survey results would be totaled and reported after analysis, and only those who returned the self-recorded questionnaire were considered to have provided consent to participate in the study. Furthermore, the study was approved by the ethical review board of Fukushima Medical University (approval numbers 1316 and 2148).

**Consent for publication**

Not applicable.
Availability of data and materials

The datasets analyzed during the present study are not publicly available because the data of the Fukushima Health Management Survey belongs to the government of Fukushima prefecture and can only be used within that organization.

Competing interests

The authors declare that there are no competing interests.

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Authors' contributions

Conception and design: FH, TO, SY, MM, HY, YS and KK.

Acquisition of data: MH, MM, HY and SY.

Analysis and interpretation of data: FH.

Drafting the article: FH.

Revising it for intellectual content: TO, HN, MN, KO, MH, SY, MM, AT, HY, YS, and KK.

Final approval of the completed article: All authors.

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Figures
2011 Mental health survey respondents: 73,431

Exclusion of 46,365 individuals aged <65 years at 2011 or 7,222 individuals with history of fracture.

19,844 individuals aged >= 65 at 2011 with no history of fracture. (9,297 men, 10,547 women; mean age 75.2 ± 7.0 years)

Exclusion of 6,076 individuals who could not track fractures from 2012 to 2016.

A total of 13,768 individuals (6,632 men and 7,136 women) were targeted. (mean age 74.5 ± 6.6, mean follow-up period 3.75 ± 1.48 person-years)

Figure 1

Selection of study participants