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

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Abstract

Background

Psychological stress has been known to affect bone metabolism and increase fracture risk. However, the association between post-traumatic stress disorder (PTSD) and bone fractures remains unclear. The current study aimed to clarify the effects of disaster-induced PTSD symptoms on fracture risk in older adults.

Methods

This study analyzed responses from 17,459 individuals aged ≥65 without a history of fractures at the time of the Great East Japan Earthquake who answered the Mental Health and Lifestyle Survey component of the Fukushima Health Management Survey conducted in 2011. Obtained data were able to determine the presence or absence of fractures until 2016. Age, sex, physical factors, social factors, psychological factors, and lifestyle factors were subsequently analyzed. Survival analysis was then performed to determine the relationship between each factor and fractures. Thereafter, univariate and multivariate Cox proportional hazard models were constructed to identify fracture risk factors.

Results

A total of 2,097 (12.0%) fractures occurred during the follow-up period. Accordingly, univariate and multivariate Cox proportional hazard models showed that PTSD symptoms (total PTSD checklists scoring ≥ 44) [hazard ratio (HR): 1.26; 95% confidence interval (CI): 1.10–1.44; P = 0.001], history of cancer (HR: 1.48; 95% CI: 1.23–1.79; P < 0.001), history of stroke (HR: 1.26; 95% CI: 1.04–1.52; P = 0.021), history of heart disease (HR: 1.30; 95% CI: 1.13–1.49; P < 0.001), history of diabetes (HR: 1.23; 95% CI: 1.09–1.39; P = 0.001), current smoking (HR: 1.27; 95% CI: 1.01–1.61; P = 0.045), and high dissatisfaction with sleep or no sleep at all (HR: 1.36; 95% CI: 1.04–1.77; P = 0.024) promoted a significant increase in fracture risk independent of age and sex.

Conclusions

The present study indicate that disaster-induced PTSD symptoms and insomnia could contribute to increased fracture risk among older adults residing in evacuation areas within Fukushima prefecture.

Background

On March 11, 2011, the magnitude 9.0 Great East Japan Earthquake occurred with its epicenter at the sea floor 130 km off the southeast Oshika Peninsula, Miyagi Prefecture,1 subsequently triggering the Fukushima Daiichi Nuclear Power Station (FDNPS) accident in Fukushima Prefecture. Accordingly, surveys of evacuation zone inhabitants have indicated that the proportion of adults with PTSD checklist (PCL) scores above the cutoff value, reflecting the presence of traumatic symptoms (2011: 21.6%; 2012: 18.3%), was comparable to that of workers affected by the 9/11 World Trade Center attack.2-3 A survey of
240 evacuees in Hirono Town, Fukushima prefecture, one of the evacuation areas, found that 66.8% and 53.5% had reported symptoms of depression and clinically relevant symptoms of PTSD, respectively. Thus, residents of evacuation areas, such as those in Fukushima prefecture, could have presented with PTSD symptoms caused by disaster-related events.

One study had recently reported a possible association between increased fracture risk and PTSD. Therefore, residents in Fukushima evacuation areas who presented with PTSD symptoms could have also been at high risk for fractures. The results of the 2016 Basic Survey on National Life published by the Japanese Ministry of Health, Labor, and Welfare revealed that 12.1% of the 100,000 individuals needing care had been certified as requiring support or nursing care owing to falls or broken bones—major factors equivalent to arthritis or infirmity due to aging. Moreover, Tanji et al. reported that those with higher psychological distress after an earthquake have a higher risk for requiring nursing care than those with lower psychological distress. As such, the associated higher risk for increased fractures among residents in evacuation areas within Fukushima prefecture presenting with PTSD symptoms could affect their healthy life expectancy and quality of life (QOL). In particular, the increased fracture risk among older adults could contribute to an increase in the number of those requiring support or nursing care. However, no study has examined the relationship between earthquake-induced PTSD symptoms and fractures in older adult residents of evacuation areas within Fukushima prefecture. Therefore, investigating the association between PTSD symptoms and fractures among such residents is imperative for maintaining and improving their healthy life expectancy and QOL.

This study used data from the Fukushima Health Management Survey to investigate associations between PTSD symptoms and bone fractures after the Great East Japan Earthquake in older adults.

**Methods**

**Study group**

The Fukushima Health Management Survey had been conducted on January 18, 2012 to evaluate the impact of radiation and determine the health status of Fukushima residents, considering the diffusion of radioactive substances and evacuation due to the FDNPS accident, subsequently helping with illnesses prevention, early illnesses detection, and early treatment provision aimed at maintaining and improving the future health of the residents. Individuals who completed the Fukushima Health Management Survey, including the Mental Health and Lifestyle Survey component, comprised those residing in any of the 13 municipalities (all areas within Hirono-machi, Naraha-machi, Tomioka-machi, Kawauchi-mura, Okuma-machi, Futaba-machi, Namie-machi, Katsurao-mura, and Iitate-mura, as well as parts of Tamura city, Minamisoma city, Kawamata town, and Date city) who had to be evacuated because of the Great East Japan Earthquake (registered residents).

A total of 180,604 individuals aged ≥15 years (individuals born before April 1, 1995) had been eligible for the 2011 edition of the registered questionnaire. Valid responses were obtained from 73,431 individuals
(mean age, 56.4 years), with a response rate of 40.7%. After excluding 46,365 individuals under 65 years of age, 1,220 with an unknown fracture history, and 3,933 who already had a history of fractures in 2011, a total of 21,913 individuals aged ≥65 years (10,271 men; 11,642 women; mean age: 75.0 ± 6.9 years) comprised the sample for the present study.

Incidences of fractures were determined using the questionnaire on fractures from 2012 to 2016. Accordingly, 4,454 individuals were further excluded due to missing fracture data from 2012 to 2016 given that they had never responded to a questionnaire after 2011. Ultimately, 17,459 patients (8,331 men; 9,128 women; mean age, 74.3 ± 6.5 years; mean follow-up duration, 3.7 ± 1.5 person-years) were targeted (Figure 1).

Data regarding 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 the earthquake, tsunami, and nuclear power plant accident (heard the explosion); need for assistance; change in employment status; and change in residence], psychological factors (history of mental illness and PCL), and lifestyle factors (history of smoking and drinking, sleep satisfaction levels, and exercise habits) obtained from the self-administered questionnaire items used in the 2011 Mental Health and Lifestyle Survey were herein analyzed.

**Fracture determination**

In the Mental Health and Lifestyle Survey, questions regarding the presence or absence of fractures differ depending on the year. Thus, incidences of fractures were 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, apart from 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 fractures. 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.”

**Definition of estimated fracture occurrence date and calculation of follow-up period**

The questionnaire used herein could not determine the date on which the fracture occurred. As such, this study estimated fracture occurrence dates by identifying the midpoint between the date the questionnaire for the year no fracture occurred was filled out and the date the questionnaire for the year a fracture occurred was filled out or 6 months before the date the questionnaire for the year a fracture occurred was filled out.

On the other hand, individuals who had at least one response to the questionnaire between 2012 and 2016 and had never had a bone fracture until the last questionnaire were censored. In such cases, the follow-up period was calculated from the date the 2011 questionnaire was filled out to the date the last questionnaire was filled out.
A number of participants also had trouble completing the questionnaire, particularly with regard to information on the month and date of completion, making it impossible to calculate the follow-up period. The questionnaire was distributed by mail in February of the survey year (e.g., for 2011, the questionnaire would have been distributed by February 2012). A breakdown of the months in which the questionnaire had been filled out showed that approximately 77% to 87% were filled out in February for each year. Therefore, when information regarding the month in which they responded was missing, we assumed that they responded in February of that year. Moreover, when information regarding the date the questionnaire was answered was missing, we assumed that they responded to the questionnaire on the 15th of that month.

**Evaluation of post-traumatic stress disorder symptoms**

The presence or absence of PTDS symptoms was evaluated using PCL, a self-administered questionnaire that obtained information regarding symptoms of PTSD according to the Diagnostic and Statistical Manual of Mental Disorders-IV diagnostic criteria. The reliability, validity, and diagnostic efficiency of the Japanese version of the PCL reported for the determining PTSD symptoms among residents who experienced the Fukushima nuclear accident had been previously established. The respondents were asked to answer a total of 17 questions using a five-point Likert scale. Accordingly, individuals with higher total scores were strongly suspected to have PTSD. Moreover, a previous study had determined that a total PCL score ≥ 44 was the cutoff point for suspecting the presence of PTSD symptoms. In the present study, the total PCL score could be calculated only for those who answered 16 or more questions. When only 16 questions were answered, the average score for the 16 questions was assigned to the missing items to calculate the total score. Participants with total PCL scores ≥ 44 were defined as "with PTSD symptoms" and examined.

**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 sleep satisfaction 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 exercise habits 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 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 independently. Those who answered that assistance was required for any of the four items were defined as 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 with one of the following answers: residing in a shelter, residing in temporary housing, renting a house or apartment, residing in a relative’s house, residing in their own house, or other (free to comment). Respondents who had lived in temporary or evacuation shelters immediately after the earthquake were defined as having changed their residence.

In addition, residents of Tamura city, Minamisoma city, Date city, and Kawamata towns did not reside in a temporary or evacuation center in 2011 were defined as not having evacuated. Others were defined as having evacuated.

**Statistical analysis methods**

All statistical analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). The Kaplan–Meier method and log-rank test were used to compare difference in the incidence of fractures based on questionnaire answers. Moreover, univariate and multivariate Cox proportional hazards models were used to obtain crude and adjusted hazard ratios (HRs) and 95% confidence intervals (CIs) for the association between each factor and fractures. Furthermore, multivariate Cox proportional hazards models for men and women were established to determine differences according to sex.

Considering the potential for selection bias due to loss of untraceable outcomes, this study conducted sensitivity analysis using Poisson regression to confirm the robustness of the results. Subjects were divided into four groups according to PCL score quartiles while adjusting for age, sex, and follow-up period, with the low PCL score group being used as control.

All data are presented as number of individuals (n), mean, standard deviation, median, 25th percentile, 75th percentile, or percentages. P < 0.05 indicated statistical significant.
Results

Participant characteristics

Table 1 summarizes the participants’ characteristics. A total of 2,097 (12.0%) participants experienced a fracture during the follow-up period, with an incidence rate of 0.032 (/year).

Survival analysis results

The relationship between each factor and the incidence of fractures was examined among participants divided into the fracture and nonfracture groups (Table 1). Accordingly, survival analysis results found significant differences in fracture incidence among older adults according to sex (P < 0.001), PTSD symptoms (P < 0.001), experience of earthquake (P = 0.016), 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 = 0.005), smoking habits (P < 0.001), drinking habits (P < 0.001), sleep satisfaction (P < 0.001), and exercise habits (P = 0.003).

Univariate and multivariate Cox proportional hazards models

Univariate and multivariate Cox proportional hazards models were established using factors determined to be significant during survival analysis to identify the association between psychological indicators and fracture frequency among older adults (Table 2). Accordingly, multivariate Cox proportional hazards model using factors determined to be significant during survival analysis and univariate Cox proportional hazards analysis showed that PTSD symptoms (HR: 1.26; 95% CI: 1.10–1.44; P = 0.001), history of cancer (HR: 1.48; 95% CI: 1.23–1.79; P < 0.001), history of stroke (HR: 1.26; 95% CI: 1.04–1.52; P = 0.021), history of heart disease (HR: 1.30; 95% CI: 1.13–1.49; P < 0.001), history of diabetes (HR: 1.23; 95% CI: 1.09–1.39; P = 0.001), current smoking (HR: 1.27; 95% CI: 1.01–1.61; P = 0.045) and high dissatisfaction with sleep or no sleep at all (HR: 1.36; 95% CI: 1.04–1.77; P = 0.024) significantly increased fracture risk, independent of age and sex.

Table 3 presents the results of multivariate Cox proportional hazards analysis according to sex to determine the sex-related differences. Accordingly, PTSD symptoms (HR: 1.39; 95% CI: 1.11–1.74; P = 0.004), history of cancer (HR: 1.50; 95% CI: 1.16–1.94; P = 0.002), history of diabetes (HR: 1.35; 95% CI: 1.12–1.63; P = 0.001), and high dissatisfaction with sleep or no sleep at all (HR: 1.80; 95% CI: 1.19–2.72; P = 0.006) had significantly increased fracture risk among older men, independent of age. By contrast, a history of cancer (HR: 1.45; 95% CI: 1.11–1.90; P = 0.007) and history of heart disease (HR: 1.36; 95% CI: 1.13–1.64; P = 0.001) significantly increased fracture risk among older adult women, independent of age. The main conclusions obtained herein remained largely the same regardless of whether or not entry date supplementation was performed.

Poisson regression models
The robustness of the multivariate Cox proportional hazards models was confirmed using Poisson regression analysis (Table 4). Accordingly, after adjusting for age and sex, those with high middle PCL scores ($31.0 \leq \text{total PCL score} \leq 43.6$) (odds ratio: 1.17; 95% CI: 1.02–1.34; $P = 0.025$) and high PCL scores (total PCL score $\geq 44$) (odds ratio: 1.44; 95% CI: 1.26–1.63; $P < 0.001$) had significantly higher odds ratios than those with low PCL scores ($17.0 \leq \text{total PCL score} \leq 21.3$). After adjusting for age, sex, and follow-up period, those with high PCL scores (odds ratio: 1.28; 95% CI: 1.12–1.46; $P < 0.001$) had significantly higher odds ratios than those with low PCL scores. The aforementioned results confirm the robustness of multivariate Cox regression analysis.

**Discussion**

Our study suggested that PTSD symptoms were significantly associated with the occurrence of fractures among older adults, particularly men, who resided in evacuation areas within Fukushima prefecture. Previous studies have reported an increase in the prevalence of diseases, such as obesity and lifestyle-related diseases, in residents of evacuation areas within Fukushima prefecture. This increase in disease prevalence could be partly attributed to the increase in stress due to environmental changes caused by moving into temporary housing, living in an evacuation site outside the local area, or disturbance in eating habits. Thus, psychological stress has been considered to be associated with adverse health effects among residents of evacuation areas throughout Fukushima prefecture. One study found that those who reported to have experienced high psychological stress were at increased risk for fractures due to osteoporosis. 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 have been known to induce bone loss and increase the risk of osteoporotic fractures. Individuals with PTSD symptoms can be considered to have had high psychological stress immediately after a disaster. Furthermore, studies have reported that older adults and those with severe living conditions were more likely to experience worse symptoms. The psychological effects caused by the Fukushima nuclear accident have been widespread, causing not only trauma symptoms but also chronic and more complex social problems, such as stigma and community and family fragmentation. Therefore, persistent high levels of stress caused by disasters could contribute to increased fracture risk in older adults. To prevent fractures following a disaster, older adults with PTSD symptoms need to be assessed for bone mineral density and receive aggressive interventions to reduce psychosocial stress.

Furthermore, those with PTSD are presumed to have an increase likelihood of having other mental disorders, such as depression. In previous studies, the percentage of residents with PCL scores above the cut-off in residents with Kessler Psychological Distress Scale (K6) scores above the cut-off was significantly higher than among those with K6 score below the cut-off. In addition, prefectural health surveys have reported that the coexistence of PTSD and previous mental illness or mental disorders was a poor predictor of mid-term mental health. Thus, the mental health deterioration caused by a disaster can promote even more confined and sedentary lifestyles among older adults who already tend to have low physical function in a depressed state, leading to a decrease in physical function and
thus increased risk of fractures. Therefore, social participation should be encouraged in older adults with PTSD symptoms and low physical function in order to maintain and improve their physical function and mental health.

Depression itself has also been reported to be associated with an increased risk of fractures,\(^3\) which may be mediated by the use of antidepressants.\(^3\) For instance, taking one class of antidepressants, selective serotonin reuptake inhibitors (SSRIs), has been shown to increase the risk of fractures regardless of depression or bone density.\(^4\) Moreover, SSRIs have been reported to contribute to fracture-induced falls and increased fracture risk.\(^5\) Considering that SSRIs have occasionally been considered for the treatment of PTSD, older adults receiving medication for PTSD symptoms need to be aware of the risk for fractures brought by antidepressants.

The present study found that those who were very dissatisfied with their sleep, particularly older men, were at increased risk of fractures. The prevalence of insomnia and use of sleeping pills among Japanese individuals have been reported to increase with age.\(^6\) Benzodiazepines or benzodiazepine receptor agonists, a nonbenzodiazepine alternative, have been among the commonly prescribed sleeping pills in Japan. Accordingly, studies have shown that prolonged and high-dose usage of benzodiazepines was associated with increased risk for falls and fractures,\(^7\) suggesting that insomnia pharmacotherapy could have also contributed toward increasing fracture risk among older adult residents, such as those residing in evacuation areas within Fukushima prefecture. Understanding the sleep environment and providing sleep hygiene guidance should be the initial management for insomnia. Our study suggests that securing sleep time and improving sleep quality are imperative for preventing fractures among older adults, particularly men, residing in evacuation areas within Fukushima prefecture.

Our study found that women have a higher risk for fractures than men. Conversely, although PTSD symptoms tended to be associated with the occurrence of fractures in women, such an association was not statistically significant. Moreover, sleep satisfaction was not significantly associated with the occurrence of fractures in women. Primary osteoporosis among women is often caused by heredity, aging, and postmenopausal decline in female hormones.\(^8\) Patients with osteoporosis have also been found to be more likely to experience fractures after a fall.\(^9\) Osteoporosis-related fractures can also have a significant impact on health-related quality of life (HRQOL).\(^10\) Thus, the aforementioned results suggest that health problems specific to women, which could not be investigated herein, could have had 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 among patients with low bone mineral density.\(^11\) Therefore, regular bone density measurements and exercise habit formation for individuals with PTSD symptoms are recommended, especially for women, to prevent fractures from falling and a decline in HRQOL.

The current study found that current smokers and those with a history of diabetes, heart disease, and cancer were at an increased risk for fractures. Indeed, previous studies have reported that the presence of
smoking habits, type 2 diabetes, cardiovascular disease, stroke, and cancer increased the risk for fractures, suggesting that a comprehensive strategy, including smoking cessation to prevent lifestyle-related diseases, cardiovascular events, and cancer, is necessary for preventing fractures among older adult residents of evacuation areas.

The present study has some limitations worth noting. First, the age-adjusted prevalence of post-traumatic stress has been known to decrease yearly, while studies have shown that the mental health of residents in evacuation areas within Fukushima prefecture has improved compared to that at the time of the earthquake. However, whether such an improvement is present among residents of the 13 municipalities remains unclear given that our participants comprised only a small percentage of those who participated in the Fukushima Health Management Survey. Horikoshi et al. had also reported that those who did not respond to the mental survey had significantly higher rate of psychological distress than respondents. Therefore, the results of this study could have underestimated the impact of increased PTSD symptoms caused by the Great East Japan Earthquake and the FDNPS accident on fractures. As such, expanding the scope of psychological research to include a survey on the mental health of non-respondents might be necessary.

Second, this survey did not include details regarding medication conditions, bone density tests, fracture sites, circumstances at which fractures were sustained, presence of osteoporosis, or use of antidepressants. Hence, factors that could contribute to fracture risk, such as osteoporosis and the use of antidepressants and steroids, could not be investigated. Moreover, the effects of sex differences on fractures could not be completely clarified given that information regarding menopause or hormone levels among women were not surveyed. Therefore, future studies should include examinations and questions addressing these factors.

Third, studies on postmenopausal women have reported that obesity and underweight were both risk factors for fractures. However, given that the present survey contained no items on height and weight in FY2011, body mass index could not be calculated. Therefore, we plan to examine the relationship between weight and fractures by evaluating health checkup data in our next study.

Fourth, the results of a systematic review and meta-analysis showed that frailty and pre-frailty were significant predictors of fractures among community-dwelling older adults. Frailty can be assessed using the frailty index, which combines several variables (functioning, cognition, comorbidities, health attitudes and habits, and physical performance). However, the Mental Health and Lifestyle Survey does not include many questions on physical functioning, while the present survey items did not allow us to examine the association between frailty and fractures. Future investigations may need to include a questionnaire on health examination results in order to screen for frailty.

Fifth, certain nutrients and foods have been reported to be associated with fracture risk. Previous studies on the Fukushima Health Management Survey also reported an association between psychological distress and food intake. However, the Fukushima Health Management Survey contained
very limited questionnaires on food intake. Moreover, a clear bias was noted when evaluating each food group. As such, we determined that data obtained from this study did not allow for a comprehensive examination of the association between fractures and food intake and were unfortunately excluded from consideration.

Conclusions

The present study indicated that disaster-induced PTSD symptoms and insomnia could contribute to increased fracture risk among older adults residing in evacuation areas within Fukushima prefecture. The 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.

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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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; SD: Standard Deviation; Ref: Reference.

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Tables

Table 1. The association between fracture and Mental Health and Lifestyle Survey items
| Factor                              | Classification | All participants (n = 17,459) | Nonfracture group (n = 15,362) | Fracture group (n = 2,097) | P value |
|------------------------------------|----------------|--------------------------------|--------------------------------|---------------------------|---------|
|                                    |                | Mean | SD   | Mean | SD   | Mean | SD   |                   |
| Age                                |                | 74.3 | 6.5  | 74.2 | 6.5  | 75.5 | 6.7  | <0.001            |
| Follow-up period                   |                | 3.7  | 1.5  | 3.9  | 1.4  | 2.0  | 1.4  |                   |
|Sex                                 | Men            | 8,331 | 74.7 | 7,545 | 49.1 | 786  | 37.5 | <0.001            |
|                                    | Women          | 9,128 | 52.3 | 7,817 | 50.9 | 1,311 | 62.5 |                   |
| PTSD symptoms                      | No             | 11,677 | 74.5 | 10,440 | 75.3 | 1,237 | 67.9 | <0.001            |
|                                    | Yes            | 4,006 | 25.5 | 3,420 | 24.7 | 586  | 32.1 |                   |
| Experience of evacuation           | No             | 13,441 | 77.0 | 11,810 | 76.9 | 1,631 | 77.8 | 0.310            |
|                                    | Yes            | 4,018 | 23.0 | 3,552 | 23.1 | 466  | 22.2 |                   |
| Experience of earthquake           | No             | 6,933 | 39.7 | 6,080 | 39.6 | 853  | 40.7 | 0.163            |
|                                    | Yes            | 10,526 | 60.3 | 9,282 | 60.4 | 1,441 | 59.3 |                   |
| Experience of tsunami              | No             | 16,051 | 94.8 | 14,155 | 95.0 | 1,896 | 93.4 | <0.001            |
|                                    | Yes            | 875 | 5.2  | 741  | 5.0  | 134  | 6.6  |                   |
| Need for assistance                | No             | 15,751 | 91.4 | 13,923 | 91.8 | 1,828 | 88.4 | <0.001            |
|                                    | Yes            | 1,488 | 8.6  | 1,248 | 8.2  | 240  | 11.6 |                   |
| History of cancer                  | No             | 15,232 | 91.8 | 14,349 | 92.1 | 1,793 | 90.0 | <0.001            |
|                                    | Yes            | 1,355 | 8.2  | 1,155 | 7.9  | 200  | 10.0 |                   |
| History of stroke                  | No             | 15,044 | 89.9 | 13,276 | 90.3 | 1,768 | 87.4 | <0.001            |
|                                    | Yes            | 1,686 | 10.1 | 1,432 | 9.7  | 254  | 12.6 |                   |
| History of heart disease           | No             | 13,603 | 81.0 | 12,658 | 81.7 | 1,545 | 76.6 | <0.001            |
|                                    | Yes            | 3,181 | 19.0 | 2,708 | 18.3 | 473  | 23.4 |                   |
| History of diabetes mellitus       | No             | 10,959 | 65.9 | 9,685 | 66.2 | 1,274 | 63.4 | 0.005            |
|                                    | Yes            | 5,674 | 34.1 | 4,940 | 33.8 | 734  | 36.6 |                   |
| History of dyslipidemia            | No             | 8,309 | 49.6 | 7,329 | 49.7 | 980  | 48.6 | 0.729            |
|                                    | Yes            | 8,454 | 50.4 | 7,416 | 50.3 | 1,038 | 51.4 |                   |
| History of hepatic disorder        | No             | 16,116 | 96.7 | 14,186 | 96.8 | 1,930 | 96.2 | 0.070            |
|                                    | Yes            | 545 | 3.3  | 469  | 3.2  | 76  | 3.8  |                   |
| History of hypertension            | No             | 4,984 | 29.2 | 4,403 | 29.3 | 581  | 28.2 | 0.177            |
|                                    | Yes            | 12,111 | 70.8 | 10,632 | 70.7 | 1,479 | 71.8 |                   |
| History of thyroid disease         | No             | 16,597 | 97.1 | 14,618 | 97.1 | 1,979 | 96.8 | 0.327            |
|                                    | Yes            | 496 | 2.9  | 430  | 2.9  | 66  | 3.2  |                   |
| Smoking habit                      | never smoked   | 10,174 | 61.3 | 8,853 | 60.5 | 1,321 | 67.3 | <0.001            |
|                                    | former smoker  | 4,781 | 28.8 | 4,316 | 29.5 | 465  | 23.7 |                   |
|                                    | current smoker | 1,644 | 9.9  | 1,468 | 10.0 | 176  | 9.0  |                   |
| Drinking habit                     | never drinks or rarely drinks (less than once a month) | 9,296 | 55.2 | 8,110 | 54.6 | 1,186 | 59.3 | <0.001            |
|                                    | former drinker  | 958 | 5.7  | 847  | 5.7  | 111  | 5.6  |                   |
|                                    | current drinker (more than once a month) | 6,592 | 39.1 | 5,889 | 39.7 | 703  | 35.2 |                   |
| Level of sleep satisfaction        | satisfied with sleep | 5,304 | 41.9 | 4,733 | 42.6 | 571  | 36.9 | <0.001            |
|                                    | slightly unsatisfied with sleep | 5,119 | 40.5 | 4,485 | 40.4 | 634  | 41.0 |                   |
|                                    | quite unsatisfied with sleep | 1,648 | 13.0 | 1,406 | 12.7 | 242  | 15.6 |                   |
|                                    | very dissatisfied with | 582 | 4.6  | 482  | 4.3  | 100  | 6.5  |                   |
**Table 2. The results of univariate and multivariate Cox proportional hazard models.**

| Exercise habit         | sleep or does not sleep at all |
|------------------------|--------------------------------|
|                        | almost daily | 4,301 | 25.9 | 3,827 | 26.2 | 474 | 23.9 | 0.003 |
|                        | 2 to 4 times a week | 5,222 | 31.4 | 4,611 | 31.5 | 611 | 30.8 |
|                        | approximately once a week | 2,503 | 15.1 | 2,191 | 15.0 | 312 | 15.7 |
|                        | almost never | 4,584 | 27.6 | 3,998 | 27.3 | 586 | 29.6 |

| Job change            | No | 8,233 | 54.5 | 7,288 | 54.6 | 945 | 53.7 | 0.888 |
|                       | Yes | 6,869 | 45.5 | 6,053 | 45.4 | 816 | 46.3 |

| Loss of job           | No | 15,119 | 86.6 | 13,294 | 86.5 | 1,825 | 87.0 | 0.145 |
|                       | Yes | 2,340 | 13.4 | 2,068 | 13.5 | 272 | 13.0 |

| Residential changes   | No | 10,345 | 62.1 | 9,125 | 62.2 | 1,220 | 61.4 | 0.742 |
|                       | Yes | 6,320 | 37.9 | 5,553 | 37.8 | 767 | 38.6 |

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, PTSD: post-traumatic stress disorder. p < 0.05 was considered statistically significant.
Table 3. The results of multivariate Cox proportional hazard models by sex.

| Factors                         | Classification | Crude HR (95% CI) | P value | Adjusted HR (95% CI) | P value |
|---------------------------------|----------------|-------------------|---------|-----------------------|---------|
| Age                             | Continuous     | 1.04 (1.04 - 1.05) | <0.001  | 1.04 (1.03 - 1.05)    | <0.001  |
| Sex                             | Men            | Ref.              |         |                       |         |
|                                 | Women          | 1.59 (1.45 - 1.73) | <0.001  | 1.85 (1.55 - 2.20)    | <0.001  |
| PTSD symptoms                   | No             | Ref.              |         |                       |         |
|                                 | Yes            | 1.43 (1.30 - 1.58) | <0.001  | 1.26 (1.10 - 1.44)    | 0.001   |
| Experience of earthquake        | No             | Ref.              |         |                       |         |
|                                 | Yes            | 0.82 (0.70 - 0.97) | 0.017   | 0.91 (0.69 - 1.20)    | 0.507   |
| History of mental illness       | No             | Ref.              |         |                       |         |
|                                 | Yes            | 1.44 (1.21 - 1.72) | <0.001  | 0.96 (0.75 - 1.25)    | 0.783   |
| Need for assistance             | No             | Ref.              |         |                       |         |
|                                 | Yes            | 1.84 (1.61 - 2.11) | <0.001  | 1.15 (0.93 - 1.42)    | 0.209   |
| History of cancer               | No             | Ref.              |         |                       |         |
|                                 | Yes            | 1.31 (1.13 - 1.51) | <0.001  | 1.48 (1.23 - 1.79)    | <0.001  |
| History of stroke               | No             | Ref.              |         |                       |         |
|                                 | Yes            | 1.41 (1.24 - 1.61) | <0.001  | 1.26 (1.04 - 1.52)    | 0.021   |
| History of heart disease        | No             | Ref.              |         |                       |         |
|                                 | Yes            | 1.37 (1.23 - 1.51) | <0.001  | 1.30 (1.13 - 1.49)    | <0.001  |
| History of diabetes mellitus    | No             | Ref.              |         |                       |         |
|                                 | Yes            | 1.14 (1.04 - 1.25) | 0.005   | 1.23 (1.09 - 1.39)    | 0.001   |
| Smoking habit                   | never smoked   | Ref.              |         |                       |         |
|                                 | former smoker  | 0.73 (0.66 - 0.81) | <0.001  | 1.03 (0.86 - 1.24)    | 0.737   |
|                                 | current smoker | 0.83 (0.71 - 0.97) | 0.021   | 1.27 (1.01 - 1.61)    | 0.045   |
| Drinking habit                  | never drinks or rarely drinks (less than once a month) | Ref. |         |                       |         |
|                                 | former drinker | 0.95 (0.78 - 1.15) | 0.584   | 1.22 (0.92 - 1.62)    | 0.173   |
|                                 | current drinker| 0.79 (0.72 - 0.87) | <0.001  | 1.15 (0.99 - 1.33)    | 0.067   |
| Level of sleep satisfaction     | satisfied with sleep | Ref. |         |                       |         |
|                                 | slightly unsatisfied with sleep | 1.15 (1.02 - 1.28) | 0.018   | 1.04 (0.92 - 1.19)    | 0.523   |
|                                 | quite unsatisfied with sleep | 1.40 (1.20 - 1.62) | <0.001  | 1.03 (0.85 - 1.24)    | 0.773   |
|                                 | very dissatisfied with sleep or does not sleep at all | 1.69 (1.37 - 2.10) | <0.001  | 1.36 (1.04 - 1.77)    | 0.024   |
| Exercise habit                  | almost daily   | Ref.              |         |                       |         |
|                                 | 2 to 4 times a week | 1.06 (0.94 - 1.20) | 0.328   | 1.01 (0.86 - 1.18)    | 0.911   |
|                                 | approximately once a week | 1.16 (1.00 - 1.33) | 0.046   | 1.08 (0.89 - 1.31)    | 0.423   |
|                                 | almost never   | 1.24 (1.10 - 1.40) | <0.001  | 1.07 (0.91 - 1.26)    | 0.434   |

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, smoking habit, drinking habit, level of sleep satisfaction, and exercise habit.

95% CI: 95% confidence interval, HR: hazard ratio, Ref: reference, PTSD: post–traumatic stress disorder.

Cox proportional hazard model; p < 0.05 was considered statistically significant.
| Factors                      | Classification | Men                        | Women                       |
|------------------------------|----------------|----------------------------|-----------------------------|
|                              |                | Adjusted HR (95% CI)a      | P value                     | Adjusted HR (95% CI) b      | P value |
| Age                          | Continuous     | 1.03 ( 1.02 - 1.05 )       | <0.001                      | 1.04 ( 1.03 - 1.06 )        | <0.001  |
| PTSD symptoms                | No             | Ref.                       | Ref.                        | Ref.                       |         |
|                              | Yes            | 1.39 ( 1.11 - 1.74 )       | 0.004                       | 1.18 ( 0.99 - 1.41 )        | 0.065   |
| Experience of earthquake     | No             | Ref.                       | Ref.                        | Ref.                       |         |
|                              | Yes            | 0.88 ( 0.60 - 1.28 )       | 0.508                       | 0.93 ( 0.62 - 1.38 )        | 0.703   |
| History of mental illness    | No             | Ref.                       | Ref.                        | Ref.                       |         |
|                              | Yes            | 0.88 ( 0.57 - 1.38 )       | 0.587                       | 1.02 ( 0.74 - 1.40 )        | 0.915   |
| Need for assistance          | No             | Ref.                       | Ref.                        | Ref.                       |         |
|                              | Yes            | 0.94 ( 0.61 - 1.43 )       | 0.762                       | 1.21 ( 0.94 - 1.57 )        | 0.136   |
| History of cancer            | No             | Ref.                       | Ref.                        | Ref.                       |         |
|                              | Yes            | 1.50 ( 1.16 - 1.94 )       | 0.002                       | 1.45 ( 1.11 - 1.90 )        | 0.007   |
| History of stroke            | No             | Ref.                       | Ref.                        | Ref.                       |         |
|                              | Yes            | 1.30 ( 1.00 - 1.70 )       | 0.050                       | 1.19 ( 0.89 - 1.58 )        | 0.241   |
| History of heart disease     | No             | Ref.                       | Ref.                        | Ref.                       |         |
|                              | Yes            | 1.21 ( 0.97 - 1.50 )       | 0.087                       | 1.36 ( 1.13 - 1.64 )        | 0.001   |
| History of diabetes mellitus | No             | Ref.                       | Ref.                        | Ref.                       |         |
|                              | Yes            | 1.35 ( 1.12 - 1.63 )       | 0.001                       | 1.13 ( 0.96 - 1.34 )        | 0.134   |
| Smoking habit                | never smoked   | Ref.                       | Ref.                        | Ref.                       |         |
|                              | former smoker  | 1.02 ( 0.82 - 1.26 )       | 0.862                       | 1.10 ( 0.75 - 1.61 )        | 0.636   |
|                              | current smoker | 1.21 ( 0.91 - 1.60 )       | 0.195                       | 1.46 ( 0.94 - 2.27 )        | 0.091   |
| Drinking habit               | never drinks or rarely drinks (less than once a month) | Ref.                       | Ref.                        | Ref.                       |         |
|                              | former drinker | 1.27 ( 0.92 - 1.76 )       | 0.153                       | 0.88 ( 0.39 - 1.99 )        | 0.763   |
|                              | current drinker| 1.14 ( 0.91 - 1.42 )       | 0.252                       | 1.17 ( 0.96 - 1.44 )        | 0.129   |
| Level of sleep satisfaction  | satisfied with sleep | Ref. | Ref. | | | |
|                              | slightly unsatisfied with sleep | 0.99 ( 0.81 - 1.22 ) | 0.931 | 1.06 ( 0.90 - 1.26 ) | 0.486 |
|                              | quite unsatisfied with sleep | 1.26 ( 0.94 - 1.69 ) | 0.124 | 0.90 ( 0.70 - 1.16 ) | 0.423 |
|                              | very dissatisfied with sleep or does not sleep at all | 1.80 ( 1.19 - 2.72 ) | 0.006 | 1.14 ( 0.80 - 1.61 ) | 0.469 |
| Exercise habit               | almost daily   | Ref.                       | Ref.                        | Ref.                       |         |
|                              | 2 to 4 times a week | 0.93 ( 0.74 - 1.18 ) | 0.557 | 1.09 ( 0.87 - 1.35 ) | 0.457 |
|                              | about once a week | 1.01 ( 0.76 - 1.35 ) | 0.945 | 1.16 ( 0.90 - 1.50 ) | 0.258 |
|                              | almost never   | 1.01 ( 0.79 - 1.30 )       | 0.913                       | 1.12 ( 0.90 - 1.40 )        | 0.301   |

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, smoking habit, drinking habit, level of sleep satisfaction, and exercise habit.

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

Cox proportional hazard model; p < 0.05 was considered statistically significant.
### Table 4. The results of Poisson regression models.

| Range of PCL score [median (minimum–maximum)] | Low            | Middle         | High (Middle) | High          | Total |
|----------------------------------------------|----------------|----------------|--------------|---------------|-------|
| The number of participants                   | 3,923          | 3,923          | 3,831        | 4,006         | 15,683|
| Women (%)                                    | 41.2           | 50.7           | 53.2         | 58.4          | 50.9  |
| Age (years) (mean [SD])                      | 74.3 (6.8)     | 73.8 (6.5)     | 73.9 (6.4)   | 74.2 (6.1)    | 74.0 (6.5) |
| Follow–up period (person–years) (mean [SD])  | 3.8 (1.5)      | 3.8 (1.5)      | 3.7 (1.5)    | 3.6 (1.6)     | 3.7 (1.5) |
| The number of fracture                        | 389            | 401            | 447          | 586           | 1,823 |
| Age and sex adjusted odds ratios              | Ref.           | 1.00           | 1.17*        | 1.44**        |       |
| (95% CI)                                     | (0.87–1.15)    | (1.02–1.34)    | (1.26–1.63)  |               |       |
| Age, sex, and follow–up period adjusted odds ratios | Ref. | 1.02 | 1.08 | 1.28** | (trend p < 0.001) |
| (95% CI)                                     | (0.89–1.17)    | (0.94–1.23)    | (1.12–1.46)  |               |       |

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

Poisson regression model: p < 0.05 was considered statistically significant. * p = 0.025, ** p < 0.001.

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**Figures**
2011 Mental Health and Lifestyle Survey respondents: 73,431

Exclusion of 46,365 individuals aged <65 years at 2011 and 1,220 individuals with unknown history of fracture and 3,933 individuals existing history of fracture.

21,913 individuals aged >= 65 at 2011 with no history of fracture.
(1,0271 men, 11,642 women; mean age 75.0 ± 6.9 years)

Exclusion of 4,454 individuals who could not track fractures from 2012 to 2016.

A total of 1,7459 individuals (8,331 men and 9,128 women) were targeted.
(mean age 74.3 ± 6.5, mean follow-up period 3.7 ± 1.5 person-years)

Figure 1
Selection of study participants.

Supplementary Files
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- renamed89cb4.docx
- renamed0e167.docx