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Balancing the risk of the evacuation and sheltering-in-place options: a survival study following Japan's 2011 Fukushima nuclear incident

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ABSTRACT

Objective The decision to evacuate or shelter-in-place is fundamental to emergency response, especially for a vulnerable population. While an elevated risk of mortality due to a hasty, unplanned evacuation has been well documented, there is little research on and knowledge about the health consequences of sheltering-in-place in disaster contexts. We compared hospital mortality in patients who sheltered-in-place (non-evacuees) after the incident with the baseline preincident mortality and articulated postincident circumstances of the hospital while sheltering-in-place.
Participants We considered all 484 patients admitted to Takano Hospital (located 22 km South of the Fukushima Daiichi nuclear power plant) from 1 January 2008 to 31 December 2016.
Methods Significant differences in mortality rates between preincident baseline and three postincident groups (evacuees, non-evacuees (our major interest) and new admittees) were tested using the Bayesian survival analysis with Weibull multivariate regression and survival probability using the Kaplan-Meier product limit method. All the analyses were separately performed by the internal and psychiatry department.
Results After adjusting for covariates, non-evacuees in the internal department had a significantly higher mortality risk with an HR of 1.57 (95% credible intervals 1.11 to 2.18) than the baseline preincident. Of them, most deaths occurred within the first 100 days of the incident. No significant increase in mortality risk was identified in evacuees and new admittees postincident in the department, which were adjusted for covariates. In contrast, for the psychiatry department, statistical difference in mortality risk was not identified in any groups.
Conclusions The mortality risk of sheltering-in-place in a harsh environment might be comparable to those in an unplanned evacuation. If sheltering-in-place with sufficient resources is not guaranteed, evacuation could be a reasonable option, which might save more lives of vulnerable people if performed in a well-planned manner with satisfactory arrangements for appropriate transportation and places to safely evacuate.

Strengths and limitations of this study

- ► This is the first study to assess the mortality in hospital patients who sheltered-in-place following Japan's 2011 Fukushima nuclear power plant incident.
- ► Medical records from 2008 to 2016 from the most affected hospital, 22 km from the Fukushima Daiichi nuclear power plant, were evaluated.
- ► We considered proxy measures of patients' health conditions as an adjustment variable.
- ► Data were obtained from a single hospital and may not be simply generalisable.

INTRODUCTION

Elderly, disabled and/or ill persons are more vulnerable and less resilient to hazardous events, such as natural and man-made disasters, than the general population because of decreased sensory awareness, physical and cognitive impairment, chronic health factors, and socioeconomic limitations (eg, high reliance on social support and fewer transportation options and opportunities).[1 2] As for institutionalised patients (in hospitals and nursing and retirement homes), disasters often pose significant safety challenges to healthcare providers and disaster relief responders: whether they should be evacuated in response to the threat of disasters themselves; a widespread lack of basic healthcare resources as a result of, for example, overwhelming demand, infrastructure collapse or power failures following disasters or a government proclamation concerning evacuation.[3–5] The latest systematic review on the health risk of immediate postdisaster evacuation claimed that the chaos of a hasty, unplanned evacuation seems to have a negative effect on the survival of vulnerable people.[5]

Implementation of immediate evacuation of vulnerable people should be determined based on an appropriate balance between potential health risks (and benefits) of evacuation and sheltering-in-place.[3 4 6 7] The

decision to evacuate or shelter-in-place should arise from a judicious, evidence-based perspective. However, while an elevated risk of mortality due to unplanned evacuations has been well documented, there is little research on and knowledge about the health consequences of sheltering-in-place in disaster contexts as well as information on the capacity of health institutions to deliver healthcare and other essential services while sheltering-in-place. In particular, most evidence in this regard relates only to nursing homes[5] rather than hospitals to which those who need more acute and specialised healthcare (namely, unhealthy patients) are admitted.

In this paper, in the context of Japan's Fukushima nuclear power plant incident (triggered by the earthquake and massive tsunami that occurred on 11 March 2011), using the data from Takano Hospital (located 22 km to the South of the Fukushima Daiichi nuclear power plant (FDNPP), Fukushima prefecture, Japan), we compared hospital mortality in patients who sheltered-in-place (non-evacuees) after the incident with the baseline preincident mortality and articulated postincident circumstances of the hospital while sheltering-in-place.

Postdisaster contexts are region specific and may vary from location to location depending on local conditions and healthcare systems. In this context, a unique, independent study in Fukushima could provide new insights into the strategy to prevent the disaster-related death of vulnerable people, particularly in light of the increasing severity and frequency of disasters worldwide.[8 9] Empirical evidence from Takano Hospital would be immensely helpful in revealing the characteristics of sheltering-in-place under certain circumstances. We believe this study will help enhance the understanding of how and in what environment sheltering-in-place could be a life-threatening risk for patients for healthcare providers and others who are responsible for emergency response, including evacuation plans, and better inform the design of future disaster preparedness policies.

METHODS

Settings

Takano Hospital is a private hospital in the town of Hirono, Futaba District, Fukushima prefecture, 22 km South of the FDNPP (figure 1). It was established in 1980 as a hospital that provides long-term internal and psychiatric care to those whose nursing and medical care needs cannot be met in nursing homes. The internal department of the hospital admits patients on a voluntary basis and accepts those on referral from other hospitals with a focus on acute care outside Futaba District. The psychiatric department of the hospital admits patients on a voluntary basis, while for some cases in which patients may pose a danger to themselves or others the department commits patients involuntarily. As such, Takano Hospital has played a central role in maintaining the welfare of residents in town and across

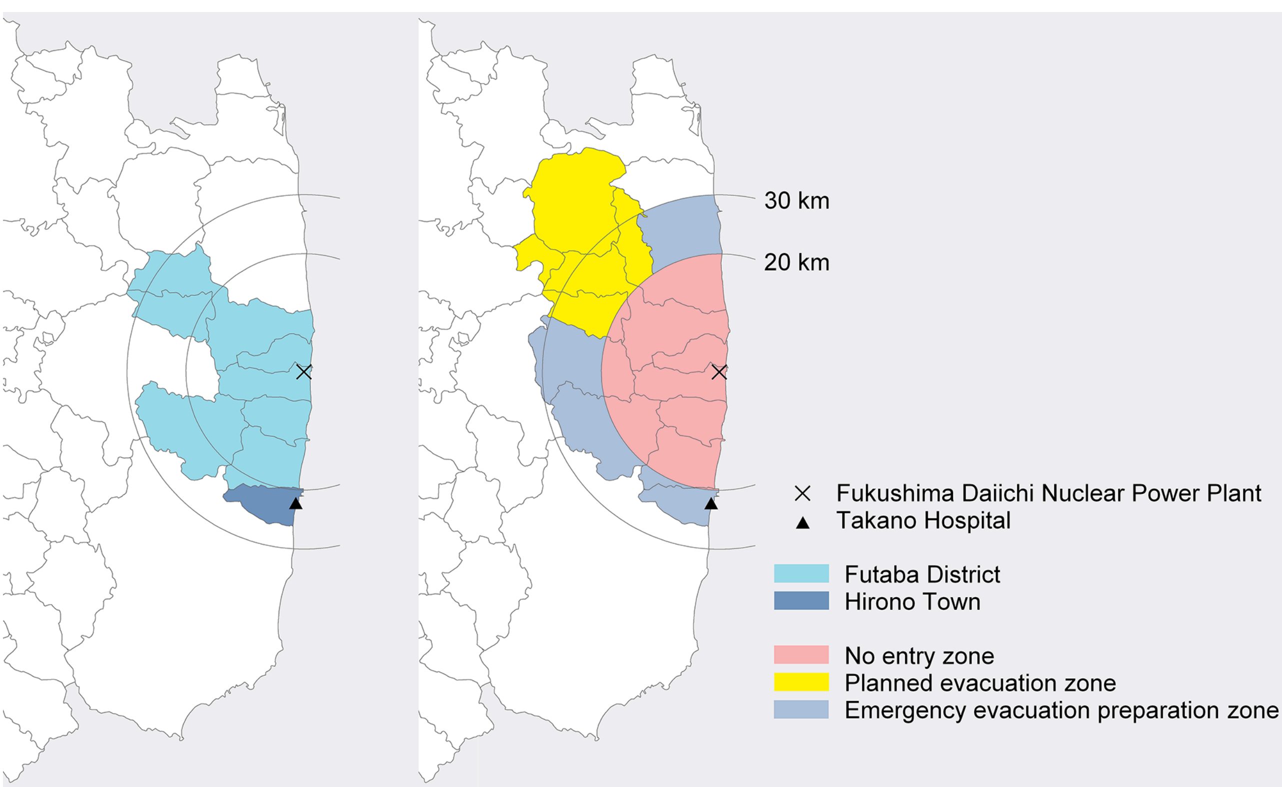

Figure 1 Geographical scope of the locations of Takano Hospital and evacuation instructions issued in April 2011. The no entry zone is within a 20 km radius of the Fukushima Daiichi nuclear power plant, while the planned evacuation zone is an area that could see more than 20 mSv of accumulated radiation a year after the Fukushima nuclear incident. Residents in emergency evacuation preparation zones must always be prepared to flee in case of emergency.

Futaba District, as the only hospital in operation since the Fukushima nuclear incident on 11 March 2011. In Futaba, there were 6 hospitals and 48 clinics before the incident,[10] but now (March 2018) it has only 1 hospital (Takano Hospital) and 13 clinics.

Many of the town's residents were subject to a series of postincident government evacuation instructions; Hirono, as a whole, was eventually designated as an emergency evacuation preparation zone on 22 April 2011. This instruction was lifted on 30 September 2011, and residents have been slowly making their way back. The town's current population is about 3000, fewer than 60% of preincident levels.[11] Similarly, Futaba District, most parts of which were placed under a compulsory evacuation order issued on 12 March 2011, has decreased in population from 72 000 preincident to 11 000 postincident (as of mid-2017).[12] The geographical scope of the evacuation instructions and the location of Takano Hospital, relative to the FDNPP, are shown in figure 1.

DESIGN

All hospital patients who were admitted to Takano Hospital between 1 January 2008 and 31 December 2016 were included in this study. Data on patients' demographic and clinical characteristics as well as entry records were obtained from their medical records, including sex, age at endpoint with death/discharge or at the end of study period (25 June 2017), and admitting department at the hospital (internal or psychiatry). For patients in the internal department, the data included their primary diseases and activities of daily living (ADL), which were measured at admission. ADL refers to a patient's ability to perform daily activities, including personal self-care, mobility and eating (on a scale from 0 to 24, with higher scores reflecting greater ability).[13] In addition, it included the Japanese medical condition category, iryo-kubun (Japanese), as a proxy measure of patients' health conditions that were assessed at admission. It refers to the necessity of medical treatment based on the type and severity of the disease on a scale from 1 to 3, with 3 being of the highest necessity,[14] such as patients who need total parenteral nutrition, ventilator support or 24 hours care. Data on causes of death were not available because such data are located at several different hospitals, due to patients dying in different locations.

For patients who evacuated after the incident, their survival was tracked until 25 June 2017 (study end) by hospital staff on the basis of our request, and we collected these data along with the date of evacuation and site of evacuation. Evacuation distances were calculated on the basis of geographical location of the evacuation sites as the shortest distance on a public road.

Mortality for the preincident baseline and three postincident groups

The mortality rate before and after the incident was calculated as the number of deaths divided by the sum of person-days at risk, which were measured from the date of admission or the beginning of the study periods (for those admitted before it) until the end of the study period, death or discharge. Person-years at risk were divided into preincident and postincident periods. Postincident periods were separately measured for those who evacuated after the incident, those who did not evacuate but sheltered-in-place (ie, stayed on-site at the hospital), and those newly admitted to the hospital after the incident. Therefore, our study considered the mortality rates per person-days for the baseline preincident and three groups postincident: evacuees, non-evacuees (our major interest) and new admittees. All the analyses below were separately performed by the internal and psychiatry department.

Significant differences in mortality rates between the baseline and three groups were tested using the Bayesian survival analysis with Weibull multivariate regression.[15] The estimates were computed using Markov chain Monte Carlo, and uninformative priors were assumed for all parameters. Only statistically significant interactions (posterior 95% credible interval (CrI) excluding 0) were retained in the final models. Since some patients had multiple admissions, the regression models included a random effect at an individual level to control the fact that the same individual's data were correlated. The candidate variables in the models were sex and age at endpoint. For patients in the internal department, we also considered their primary diseases, ADL and medical conditions at the time of admission.

Survival probability curve

The Kaplan-Meier product limit method was used to assess survival probability curves. The probability of survival of the baseline and postincident groups was plotted against the time of follow-up.

All statistical analyses were conducted using STATA/IC V.15.

Patient and public involvement

Because this study is a retrospective study using patients' medical records, no patients were involved in setting the research questions or the outcome measures, nor were they involved in developing plans for design or implementation of the study. No patients were asked to advise on interpretation or writing up of results.

RESULTS

Basic characteristics of patients

From 1 January 2008 to 31 December 2016, medical records were collected for all 484 patients (female: 269 (55.6%) and male: 215 (44.4%)) admitted to either department (internal: 356 (73.3%) and psychiatry: 128 (26.3%)) of Takano Hospital. Their characteristics are shown in table 1 by department. Age distributions at the endpoint were substantially different between the departments, with the psychiatry department admitting

Table 1 Demographic characteristics of residents admitted between 1 January 2008 and 31 December 2016

	Internal department (n=356)	Psychiatry department (n=128)	Total (n=484)
Sex, no (%)			
Male	127 (35.7)	88 (68.8)	215 (44.4)
Female	229 (64.3)	40 (31.3)	269 (55.6)
No of deaths (%)	261 (73.3)	32 (25.0)	293 (60.5)
Age at endpoint*, median (IQR)	86.0 (8.5)	61.0 (27.5)	83.0 (18.5)
Primary disease†			
Cardiovascular disease‡	87 (24.4)	–	–
Lifestyle disease§	34 (9.6)	–	–
Nervous disease¶	92 (25.8)	–	–
Mental illness	32 (9.0)	–	–
Other**	111 (31.2)	–	–
ADL†, median (IQR)			
Bed morbidity	6 (2)	–	–
Toileting	6 (1)	–	–
Transfers	6 (2)	–	–
Eating	5 (4)	–	–
Total	23 (11)	–	–
Medical condition†, no (%)			
1	11 (3.1)	–	–
2	239 (67.1)	–	–
3	102 (28.7)	–	–
Missing	4 (1.1)	–	–

For those who had multiple admission records, the latest records were used in this table.
*Endpoint with death/discharge or at the end of the study period (25 June 2017).
†Evaluated at admission; ADL: activities of daily living (on a scale from 0 to 24, with higher scores reflecting greater ability).
‡Stroke, coronary heart disease, etc.
§Hypertension, diabetes, kidney disease, etc.
¶Parkinson's disease, dementia, etc.
**Digestive and respiratory diseases, cancer, etc.

younger patients (median: 86.0 years (IQR: 8.5) for the internal department and 61.0 (27.5) for the psychiatry department). The median ADL score at admission for internal patients was 23 (out of 24) with an IQR of 11. The percentage of those with a medical condition at 3 was 28.7%. Note that these distributions of the ADL and medical conditions within the group of study patients were similar to those of patients nationwide.[16]

Evacuation history

A total of 108 patients (internal: 63 (58.3%) and psychiatry: 45 (41.7%)) experienced the Fukushima incident (female: 62 (57.4%) and male: 46 (42.6%)) while admitted in the hospital. Among them, 61 patients (internal: 22 (37.7%) and psychiatry: 38 (62.3%)) evacuated; they were then monitored for survival until 25 June 2017. The date of evacuation was available for 57 patients as follows: 15, 17, 18, 19 and 21 March 2011 (4, 1, 1, 28 and 21 patients, respectively). Information on evacuation sites was collected for 51 patients, with a median evacuation distance of 195.5 km (IQR: 54.7).

Mortality rate

During the study period, 293 (60.5%) of the 484 patients died. Before the incident, much higher mortality was observed in the internal department than the psychiatry department, with 1.90 and 0.22 deaths per 1000 person-days, respectively. While small gaps in mortality were identified in the psychiatry department in the baseline preincident and three groups postincident, the gap was substantial in the internal department, with non-evacuees being associated with a higher mortality rate than the preincident baseline as well as the other postincident groups (2.27 vs 0.74 for evacuees and 1.19 for new admittees). Details of the department-specific number of deaths and mortality rate are shown in table 2. Demographic characteristics of patients by these groups can be found in online supplementary table. It should be noted

Table 2 Death records by study period and population

	Internal department		Psychiatry department		Total	
	No of deaths	Mortality rate*	No of deaths	Mortality rate*	No of deaths	Mortality rate*
Preincident	104	1.90	10	0.22	114	1.14
Postincident						
Non-evacuees	35	2.27	1	0.43	36	2.03
Evacuees	16	0.74	8	0.27	24	0.47
New admittees	106	1.19	13	0.42	117	0.99

*Per 1000 person-days.

that it was unlikely that the high cost significantly affected the mortality rate after the incident because most hospital costs are covered by Japan's national health insurance system.

Table 3 reports the Bayesian estimate, which is expressed as a multiplicative change (ie, HR) in the adjusted mortality rate, which was obtained using the Weibull regression. After adjusting for covariates, non-evacuees in the internal department had a significantly higher mortality risk with an HR of 1.57 (95% CrI 1.11 to 2.18) than the baseline preincident. Statistically, significant increase in mortality risk was not observed in evacuees and new admittees in the department, which were adjusted for covariates. In contrast, for the psychiatry department, statistical increases were not identified in any groups, although CrIs were wide.

In addition to the preincident and postincident comparisons, we identified several other covariates associated with mortality (table 3). For example, the HR for a 1-year increase in age was 1.04 for the internal department (95% CrI 1.04 to 1.04) and 1.04 (95% CrI 1.01 to 1.06) for the psychiatry department. Female patients in

Table 3 Bayesian estimates of HRs with 95% credible intervals by department

	Internal department	Psychiatry department
Study population		
Preincident	1.00	1.00
Postincident		
Non-evacuees	1.57 (1.11 to 2.18)	3.83 (0.08 to 15.75)
Evacuees	0.53 (0.42 to 0.66)	1.36 (0.45 to 3.29)
New admittees	0.64 (0.49 to 0.82)	1.39 (0.53 to 2.99)
Sex		
Male	1.00	1.00
Female	0.91 (0.77 to 1.06)	0.32 (0.10 to 0.66)
Age at endpoint*	1.04 (1.04 to 1.04)	1.04 (1.01 to 1.06)
Primary disease†		
Cardiovascular disease‡	1.00	–
Lifestyle disease§	0.83 (0.57 to 1.21)	–
Nervous disease¶	0.67 (0.53 to 0.86)	–
Mental illness	0.42 (0.31 to 0.55)	–
Other**	1.22 (0.94 to 1.58)	–
Medical condition†		
1	1.00	–
2	1.91 (1.55 to 2.28)	–
3	4.51 (3.37 to 5.80)	–

*Endpoint with death/discharge or at the end of study period (25 June 2017).
†Evaluated at admission; ADL: activities of daily living (on a scale from 0 to 24, with higher scores reflecting greater ability).
‡Stroke, coronary heart disease, etc.
§Hypertension, diabetes, kidney disease, etc.
¶Parkinson's disease, dementia, other dementia, etc.
**Digestive and respiratory diseases, cancer, etc.

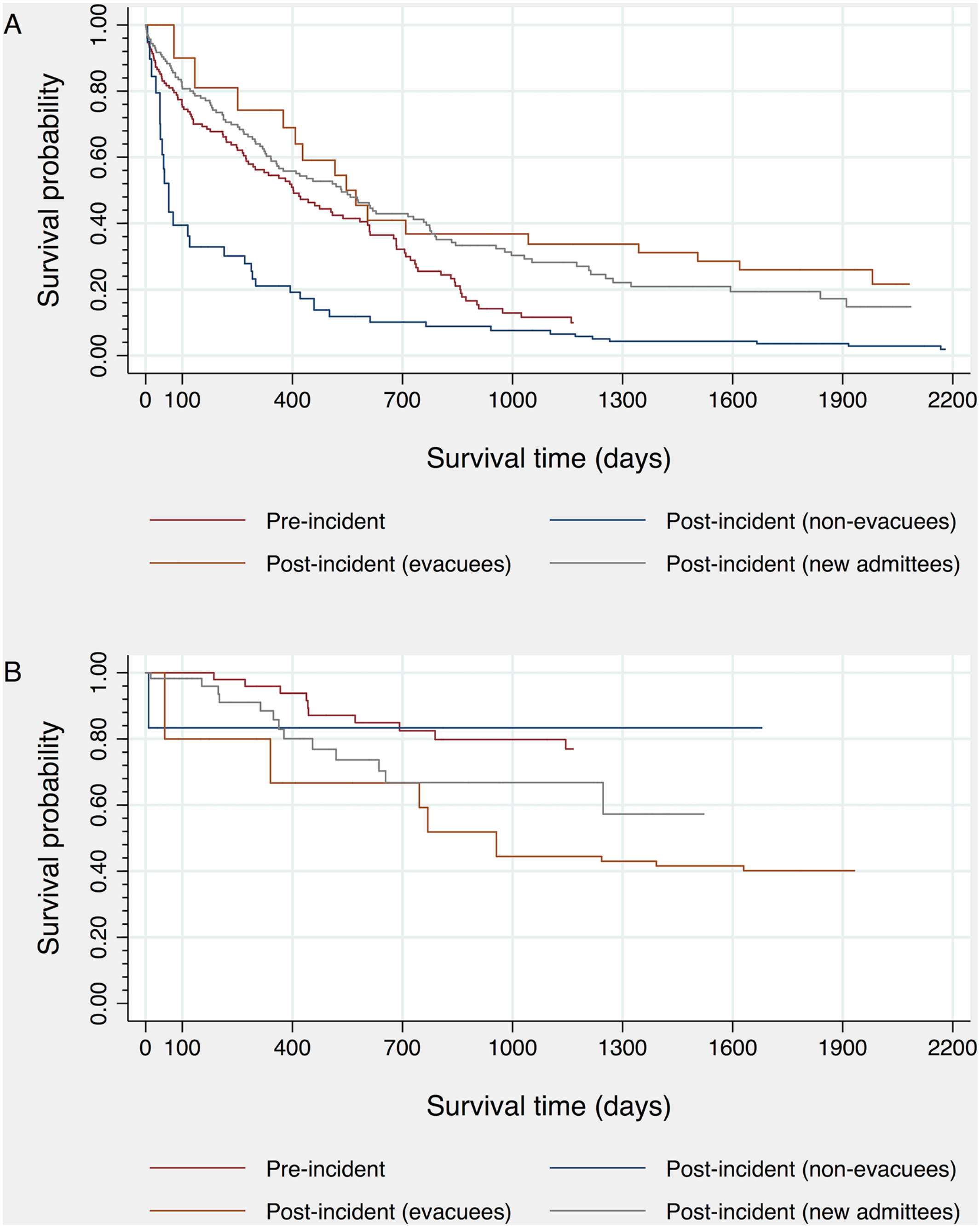

Figure 2 Kaplan-Meier estimate of survival probability for the internal department (A) and psychiatry department (B) in the baseline preincident and three groups postincident (evacuees, non-evacuees and new admittees).

the psychiatry department had a lower mortality risk than males, with an HR of 0.32 (0.10 to 0.66), while there was no significant difference in sexes in the internal department. The medical conditions at admission were positively associated with mortality risk.

Probability of survival

Time-dependent survival probability for the baseline preincident and three groups postincident are shown with Kaplan-Meier curves (figure 2). Analysis time for before/after the incident starts from the date of admission to the hospital (within the study period) and the date of the incident (11 March 2011), respectively. The survival functions in non-evacuees in the internal department significantly differ from the baseline preincident, with the survival time of non-evacuees being lower than in the baseline (Wilcoxon-Breslow test: $p<0.001$, figure 2A). In particular, a sharp decline in the survival of non-evacuees was observed in the first 100 days of the incident.

For the psychiatry department, because of the small number of death cases, it was not possible to obtain smooth probability curves (figure 2B). Although the group differences in the survival functions were observed in greater or lesser degree, they may be mostly explained

by age and/or sex differences in the groups as demonstrated in the Bayesian multivariate regression (table 3).

DISCUSSION

This is the first study to assess the mortality in hospital patients who sheltered-in-place (non-evacuees) following Japan's 2011 Fukushima nuclear power plant incident. Non-evacuees in the internal department had a significantly higher mortality risk, with an HR of 1.57 (95% CrI 1.11 to 2.18), than the baseline preincident, which was adjusted for covariates, including medical conditions of patients (table 3). Of them, most deaths occurred within the first 100 days of the incident (figure 2A). No significant increase in mortality risk was observed in evacuees and new admittees postincident in the department (table 3). Our work, therefore, addresses the critical issue of whether to evacuate or shelter-in-place during disasters.

This study also added new insights into the postdisaster mortality risk of psychiatric patients. Individuals with mental illness are at an increased risk of exposure to trauma and stressful experiences in disasters because they may not be adequately responsive to predisaster public health interventions that can reduce risk.[17 18] However, past empirical studies primarily relate to non-fatal outcomes or mental disabilities after disasters, such as post-traumatic stress disorder,[17 19 20] rather than fatal outcome (mortality). Here, we observed no statistically significant difference in the mortality risk of the psychiatry department at Takano Hospital among the baseline preincident and non-evacuees or evacuees and new admittees (table 3), although CrIs were wide. It should be noted that age is an important factor that affects survival in disasters; younger patients are more likely to survive hazardous events than older ones.[21] In the present study, survival time was entirely different between the internal and psychiatry department both preincident and postincident (figure 2), which may be partially explained by the different age distributions between the departments with a median age of 86.0 years for the internal department and 61.0 years for the psychiatry department (table 1). Therefore, caution must be taken because our findings could not be applied to older psychiatric patients.

Our analyses are subject to other limitations. First, for the internal department, we considered patient's medical conditions that were measured at hospital admission in the final Bayesian survival regression model, but they may have changed (generally in a negative way) by the study's endpoint. We did not consider those at the endpoint in the present analysis, as they were not available for evacuees. However, sensitivity analysis without evacuees using medical conditions measured at the endpoint (or near the endpoint) demonstrated similar results in terms of effect size of each covariate. Second, although there were six hospitals in Futaba District before the incident, we were only able obtain data from Takano Hospital. Three of the other five hospitals were located within a radius of 5 km around the Fukushima nuclear power plant, which was within the difficult-to-return zone (one of the re-designated evacuation zones after April 2011), in which lodging is prohibited as of March 2018; thus, they were forced to close. Although the other two hospitals were located outside the difficult-to-return zone, they were also closed because of the incident. For these reasons, we were not able to collect data from these five hospitals in the district. Thus, our results may simply not be generalisable. However, the statistical methods we used increase the generalisability of the study. We employed a Bayesian approach to analyse survival in this study, which includes adjustment for the patient-specific elements in the study (such as age, primary disease and condition); therefore, it is likely that the potential mechanism which explains the significant differences in mortality risk between the study groups is generalisable beyond the specific hospital study.

Previous studies showing elevated mortality due to unplanned postincident evacuation

Our findings in the context of the Fukushima incident should be contrasted by the previous studies on mortality in nursing homes after the Fukushima incident. Nomura *et al* reported a 2.68 (95% confidence interval (CI) 2.04 to 3.49) times increase in mortality on average among five facilities that evacuated all their residents up to once a year following the incident, compared with the preincident mortality levels.[6] Importantly, a statistically significant increase in mortality was only observed in three facilities that performed hasty, unplanned (but unavoidable) evacuation as a group, with relative risk (RR) ranging from 3.01 to 3.93, compared with the preincident levels. The remaining two facilities that evacuated in a planned manner in several groups did not show a mortality increase postevacuation.[6]

Considering the same facilities, Murakami *et al* evaluated the loss of life expectancy (LLE) of residents due to immediate/unplanned evacuation, compared with simulated LLE due to deliberate/planned evacuation as well as those due to cancer mortality attributed to radiation at some realistic levels of exposure in the Fukushima contexts.[22] Their findings indicated 10–100 times higher LLE in unplanned evacuations than in planned evacuations and radiation exposure postincident.[22]

In addition, Nomura *et al* included two additional nursing homes that did not evacuate residents but sheltered-in-place (non-evacuees), demonstrating that there was a small increase in mortality in non-evacuees within a year of the Fukushima incident (RR 1.68, (95% CI 1.12 to 2.29)) and no significant increase when assessed over the 2 years postincident (1.29 (95% CI 0.98 to 1.68)).[23]

For the nursing homes addressed in Nomura *et al*, evacuations were inevitable because of staffing deficiencies due to their lack of daily necessities and nursing care equipment, such as medicines and medical gas (oxygen).[6 24] Regardless of the tremendous efforts, most evacuations were performed in an unplanned and congested manner (eg, inadequate transportation infrastructure, long transfer distance and poor preparations

for care provision at evacuation sites), which eventually resulted in a significant mortality increase postevacuation in three of the five facilities considered. In contrast, for nursing homes that did not perform evacuation (Nomura *et al*), although they also faced staff and other resource shortages after the incident, these facilities were fortunate to receive voluntary, external support and resources, which meant that they could shelter-in-place with sufficient resources at preincident levels. These facilities did not evacuate, and as a result, likely saved the lives of their residents.

These three studies had clear, common implications that evacuation may not be the best life-saving strategy for elderly, vulnerable people if it is to be performed in a hasty, unplanned manner.[6 22 23] It is preferable to seek alternatives, such as sheltering-in-place.

Present study demonstrating elevated mortality due to sheltering-in-place in a harsh postincident environment

In contrast, the present study adds evidence on elevated mortality due to sheltering-in-place in a harsh environment after the Fukushima incident. Here, we elaborate on the challenges regarding hospital operations and patient care that Takano Hospital faced after the incident. On 11 March 2011, coupled with the magnitude 9.0 earthquake and subsequent tsunami, the nuclear incident damaged and disrupted water supply and electricity systems in all of the areas around the hospital. The heating system in the hospital could no longer operate because of a power outage, which might have invoked serious physical burdens on patients in early-mid March (just after winter in Japan) with an average temperature of fewer than 3.4°C that month in the town of Hirono.[6 25] The power generator could not sufficiently supply the power needs of the entire hospital. Underground communication cables were also destroyed in the area. This resulted in the disruption of communication infrastructure (eg, landline, phone and fax services) as well as the information technology infrastructure (email services, web services, etc). Although electricity was restored within a week, the town's water system was not fixed until April; the hospital had to rely on the irregular water supply support of Japan Self-Defense Forces. Fax services and landline phones were finally restored on 12 and 17 April 2011, respectively.

The incident also produced food shortages in the affected area, including Futaba District, which were so severe that they had a critical impact on the nutritional status of the patients.[26] Many suppliers suspended food deliveries in evacuation zones because of concerns about radiation exposure to the delivery staff.

Takano Hospital employed 86 full-time and part-time staff before the incident, including two full-time physicians (including the hospital director) and nurses and care workers. However, after the incident on 11 March 2011, as of 15 March, most staff had evacuated; the only remaining staff consisted of four nurses and two care workers in the internal department and five nurses and two care workers (and the hospital director) in the psychiatry department. One day later, two more internal nurses evacuated. Lack of trained staff might hamper basic (mostly nursing) care delivery, including perineal care, postural change, oral care, meal feeding assistance and suctioning of secretions. At that point, because of poor resources and high workloads among the remaining staff, the hospital director decided to evacuate some patients who were likely to survive rather than radiation concerns.[26] As presented in online supplementary table, patients with the highest score (three) of medical conditions were more likely to sheltered-in-place than those with lower score (28.6% in non-evacuees and 8.7% in evacuees). On 19 March, patients in the psychiatry department evacuated in a planned manner, followed by those in the internal department on 21 March. Given the findings of our study, these evacuations went well, resulting in no mortality increase postevacuation,[26] as with other planned evacuation cases in the previous study.[23] The hospital has 86 staff as of June 2017, similar to the preincident levels.

Added implications for emergency response

We agree that, as emphasised in many relevant studies,[5 27] except for a case where there is a possible direct threat to safety (eg, lethal or harmful levels of radiation exposure), it is preferable to seek alternatives for vulnerable people other than evacuation, such as sheltering-in-place. However, given our findings, we would like to stress that the mortality risk of sheltering-in-place in a harsh environment (as articulated above) might be comparable to those in an unplanned evacuation. It is imperative that potential risks of sheltering-in-place, which are unique to the vulnerable population, are recognised in disaster preparedness policies.

Preferred responses may not always be available or feasible postdisaster. Lack of basic healthcare resources (including equipment, supplies and manpower) as a result of disasters is known to last for weeks to months.[8] It should be noted that most deaths in non-evacuees in the internal department at Takano Hospital occurred within the first 100 days of the incident (figure 2A), which corresponds to the time of severe staffing deficiencies in the hospital. Therefore, if sheltering-in-place and sufficient resources are not guaranteed, evacuation could be a reasonable option and might save more lives of vulnerable people if it is executed in a well-planned manner for appropriate transportation and safe evacuation locations; ideally, this can happen at least at the level expected during ordinary (non-emergency) times. The decision-making for evacuation or sheltering-in-place can be reiterated for each patient depending on their conditions through the iterative gathering and comparison of information, reframing the situation.

Our findings highlighted a gap in knowledge on safe sheltering-in-place. We offer important lessons regarding safe emergency response for vulnerable people, such as the elderly, disabled and/or ill persons. Although these points

are based on our analysis of mortality in a single hospital following Japan's Fukushima nuclear accident, they may apply to nuclear incidents and any major disaster worldwide.

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