

# The Great East Japan Earthquake Disaster and cardiovascular diseases

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## Aims

While previous studies reported a short-term increase in individual cardiovascular disease (CVD) after great earthquakes, mid-term occurrences of all types of CVDs after great earthquakes are unknown. We addressed this important issue in our experience with the Great East Japan Earthquake (11 March 2011).

## Methods and results

We retrospectively examined the impact of the Earthquake on the occurrences of CVDs and pneumonia by comparing the ambulance records made by doctors in our Miyagi Prefecture, the centre of the disaster area, during the periods of 2008–11 ( $n = 124\,152$ ). The weekly occurrences of CVDs, including heart failure (HF), acute coronary syndrome (ACS), stroke, cardiopulmonary arrest (CPA), and pneumonia were all significantly increased after the Earthquake compared with the previous 3 years. The occurrences of ACS and CPA showed the rapid increase followed by a sharp decline, whereas those of HF and pneumonia showed a prolonged increase for more than 6 weeks and those of stroke and CPA showed a second peak after the largest aftershock (7 April 2011). Furthermore, the occurrence of CPA was increased in the first 24 h after the Earthquake, followed by other diseases later on. These increases were independent of age, sex, or residence area (seacoast vs. inland).

## Conclusion

These results indicate that the occurrences of all types of CVDs and pneumonia were increased in somewhat different time courses after the Earthquake, including the first observation of the marked and prolonged increase in HF, emphasizing the importance of intensive medical management of all types of CVDs after great earthquakes.

## Keywords

Earthquake • Cardiovascular disease • Heart failure • Tsunami

## Introduction

On 11 March 2011, the Great East Japan Earthquake hit the north-east part of Japan with a magnitude of 9.0 on the Richter scale, which was one of the largest ocean-trench earthquakes ever recorded in Japan (Table 1).<sup>1</sup> The Earthquake caused huge damage, including 15 861 dead, 3018 missing persons, and 388 783 destroyed houses as of 6 June 2012.<sup>2</sup> It forced many people (~400 000) to be evacuated to temporary accommodation, such as public halls, gymnastic halls, and scholastic institutions in North-east Japan. Since the Earthquake occurred with its epicentre located at 38° latitude, 19 min North, and 142° longitude, 22 min East, our Miyagi Prefecture with a population of 2 348 165 was the closest area to the epicentre (Figure 1A), where there was

the largest amount of damage and number of victims, including 9512 dead, 1581 missing persons, and 232 553 destroyed houses as of 8 May 2012,<sup>2,3</sup> and most of the damage was observed in the seacoast area, including 9506 dead (95.8%), 1578 missing persons (99.8%) and 222 880 destroyed houses (95.8%).

It has been previously reported that the occurrences of acute coronary syndrome (ACS), stroke, pulmonary embolism, and takotsubo cardiomyopathy were increased after the large earthquakes in Japan (Table 1).<sup>4–9</sup> Furthermore, it has been reported that the occurrences of sudden cardiac death and haemodynamically unstable ventricular tachyarrhythmias were increased after the Northridge Earthquake in California, USA, and the Wenchuan Earthquake in China, respectively (Table 1).<sup>10</sup> Thus, the previous reports have revealed that the occurrences of

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**Table 1** Past major earthquakes and cardiovascular diseases

Place of earthquake (country)	Year	Month	Magnitude	Temperature on onset day (°C) (high/low)	No. of deaths	No. of injured	Diseases increased	Periods of increased occurrences after each earthquake
Northridge (USA) <sup>11</sup>	1994	January	6.7	19/9	57	5400	Sudden deaths	On the day of the earthquake
Hanshin-Awaji (Japan) <sup>8,9,13</sup>	1995	January	7.3	8/1.4	6434	43 792	AMI, pneumonia	AMI: from 1st to 4th week Pneumonia: first month
Indian Ocean (Indonesia)	2004	December	9.1	32/25	Over 220 000	130 000	No data available	No data available
Mid-Niigata (Japan) <sup>6,7</sup>	2004	October	6.8	26.4/22	68	4805	Takotsubo cardiomyopathy, PE, sudden deaths	Takotsubo cardiomyopathy: from 1st to 3rd week, PE and sudden deaths: first week
Wenchuan (China) <sup>17</sup>	2008	May	7.9	25.0/17	69 197	18 222	VT/VF	From 1st to 3rd day
East Japan (Japan)	2011	March	9.0	6.2/-2.5	15 845	5894	HF, ACS, stroke, CPA, pneumonia	See text

AMI, acute myocardial infarction; PE, pulmonary artery embolism; ACS, acute coronary syndrome; VT/VF, ventricular tachycardia/ventricular fibrillation; HF, heart failure; CPA, cardiopulmonary arrest.

various cardiovascular diseases (CVDs) were increased after large earthquakes. However, these studies reported only the short-term occurrence of individual CVD and the longer-term occurrences of all types of CVDs after great earthquakes remain to be elucidated.

In the present study, we thus addressed this important issue by comparing the ambulance records made by medical doctors in our Miyagi Prefecture, the centre of the disaster area, during the periods of 2008–11. The present study demonstrates for the first time the marked and prolonged increase in the occurrence of heart failure (HF), in addition to other CVDs, which has not been reported previously.

## Methods

This study was a collaboration study with the Miyagi Medical Association and the Fire Departments of the Miyagi Prefecture. The Ethics Committees of Tohoku University Hospital approved this study protocol.

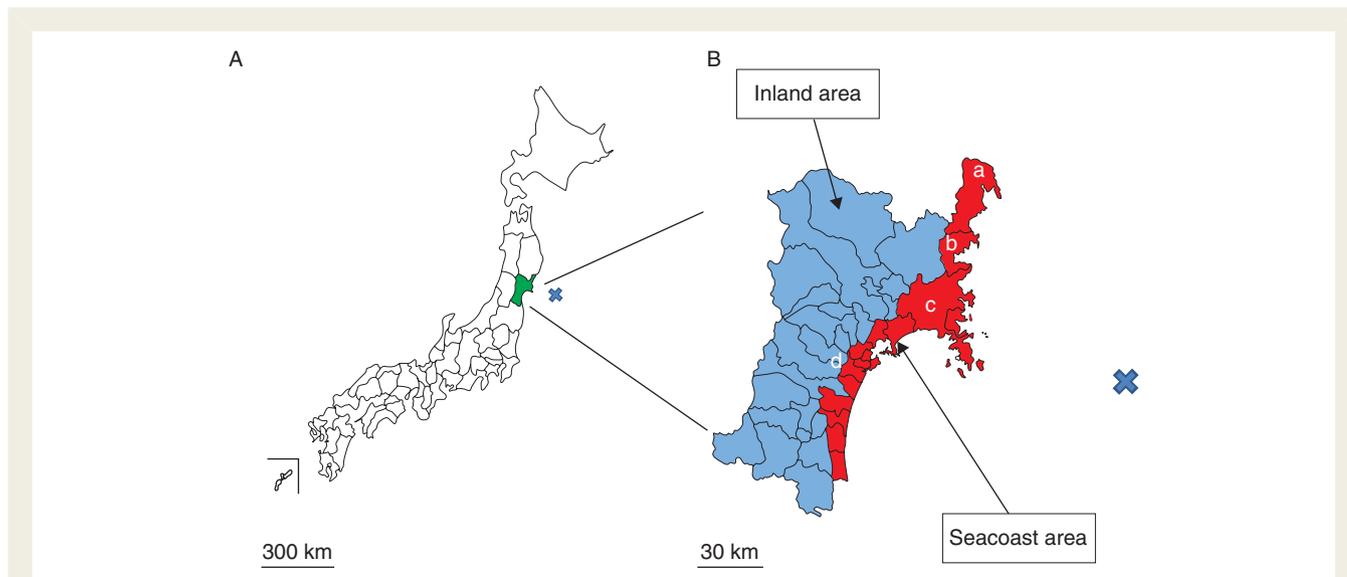
### Study population

We enrolled all ambulance transport records in the Miyagi Prefecture from 11 February to 30 June in each year of 2008–11 ( $n = 124\,152$ ), from 4 weeks before to 16 weeks after 11 March, in order to reveal the effects of the Earthquake on the occurrence of CVDs. In Japan, medical doctors in the emergency rooms routinely make the diagnoses of transported patients at the initial visit. These reports were collected and stored in the fire departments that operate the emergency medical system. We were able to obtain all the medical records from the 12 fire departments in the Miyagi Prefecture. In our prefecture, the 12 fire departments routinely transfer patients to the 57 hospitals with emergency rooms that are registered by the prefecture. Among these 57 hospitals, 56 (98%) have an echocardiography machine, 57 (100%) have full-time physicians, and 38 (67%) have full-time cardiologists. It has been reported that the diagnostic accuracy of ACS in the emergency room is 83.4% in Japan.<sup>10</sup> Based on the records, we examined the weekly occurrences of HF, ACS, stroke, cardiac pulmonary arrest (CPA), and pneumonia and compared them with those in the previous 3 years (2008–10). Furthermore, we examined the daily occurrences of the diseases for a week before and after the Earthquake.

To access the impact of the Earthquake and the aftershocks on the occurrence of the diseases, we counted the number of earthquakes with a seismic intensity of 1 or greater on the Japanese scale, which were observed in the Miyagi Prefecture during the study period (Japan Meteorological Agency: <http://www.jma.go.jp/jma/index.html>). We defined the municipalities facing the Pacific Ocean as the seacoast area where the Tsunami directly attacked and the remaining inner area as the inland area (Figure 1B).

### Definition of the diseases

We obtained all diagnoses from the ambulance records, which were made by attending doctors in emergency rooms based on physical examination, ECG, chest X-ray, echocardiography, and laboratory findings including the blood gas test. When definitive diagnoses are made by doctors in the emergency rooms, they write the diagnoses on the ambulance records; however, when definitive diagnoses are not confirmed in the emergency rooms, they write tentative diagnoses or only symptoms, which are defined as undiagnosed cases in the present study. We have excluded such undiagnosed cases from the analyses in the present study.



**Figure 1** Locations of the epicentre of the Great East Japan Earthquake and the Miyagi Prefecture. (A) The epicentre of the East Japan Earthquake (cross) was under the Pacific Ocean about 150 km east of the Miyagi Prefecture. (B) The municipalities in the Miyagi Prefecture facing the Pacific Ocean were defined as the seacoast area (shown in red) and the other area as the inland area (shown in blue). Many cities in the coast area, including Kesennuma (a), Minami-sanriku (b), Ishinomaki (c), and Sendai (d) were seriously damaged by the Tsunami.

Acute coronary syndrome was defined as acute myocardial infarction or unstable angina, stroke as intracranial haemorrhage, cerebral infarction or subarachnoid haemorrhage, and CPA as cardiopulmonary resuscitation performance regardless of the causes. In each year, we calculated 'the rate of definitive diagnosis at admission in the emergency rooms (%)', which means the percentage of cases with definitive diagnosis made by doctors among all transported cases.

### Statistical analysis

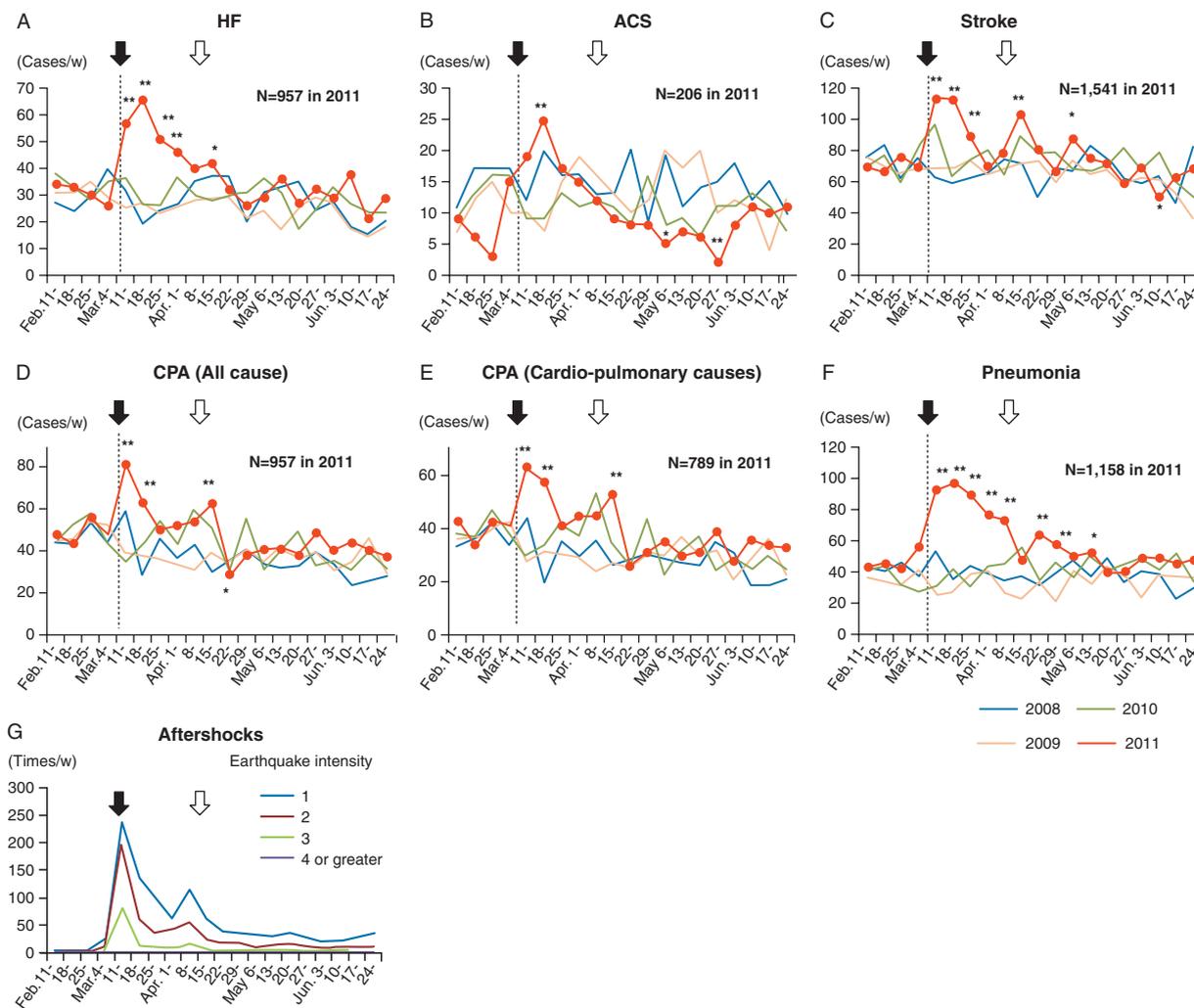
To assess the differences in the occurrences of CVDs and pneumonia before and after the Earthquake between 2011 and the previous 3 years, we applied the Poisson regression model to the daily occurrences in 2008–11 with the 'dummy' variables which indicate the individual weeks in 2011.<sup>11</sup> First, we defined the dummy variable of each week after 11 March 2011 that takes a value of 1 or 0, indicating whether or not the sample was observed in the corresponding week. Then, we fitted the Poisson regression model with all dummy variables to explain the daily occurrences of the CVDs. Finally, we selected effective dummies of significant weeks by the backward elimination stepwise regression method. Furthermore, we calculated odds ratio with the 4-week occurrence of the disease in 2011 before and after the Earthquake in the following subgroups; young (<75 years old) and old ( $\geq 75$  years old) patients, male and female, and the inland and seacoast residence areas. We used Fisher's exact test for the subgroup analyses. Continuous variables are expressed as mean  $\pm$  SD. All statistical analyses were performed using R 2.15.0 ([www.r-project.org/](http://www.r-project.org/)). All *P*-values were two-sided, and *P*-values of <0.05 were considered to be statistically significant.

## Results

The total number of ambulance transports in the period of 11 February to 30 June in 2008, 2009, 2010, and 2011 was 28 709,

28 069, 30 645, and 36 729, respectively. When compared with the previous 3 years (2008–10), the number of ambulance transports in 2011 peaked on Day 2 (12 March) followed by a gradual decline (see Supplementary material online, *Figure S1*). The rate of definitive diagnosis at admission in the emergency rooms made by attending doctors was 56.7% (16 265/28 709 cases), 56.6% (15 873/28 069 cases), 56.2% (17 217/30 645 cases), and 55.5% (20 400/36 729 cases), respectively. Thus, the rate of definitive diagnosis at admission in the emergency rooms was comparable among the 4 years studied. The prevalence of male sex was also comparable among the 4 years (51.9, 51.3, 51.4, and 51.8%, respectively). The age of all transported patients in 2011 ( $61.2 \pm 25.3$  years old) was significantly higher than those in the previous 3 years ( $57.6 \pm 26.5$  years old in 2008;  $58.3 \pm 26.2$  years old in 2009;  $59.3 \pm 26.4$  years old in 2010, all  $P < 0.001$ ); however, the age of patients with each disease in 2011 was comparable with that in the previous 3 years (2008–10) (data not shown).

Importantly, the weekly occurrences of the five diseases examined, including HF, ACS, stroke, CPA, and pneumonia, were all significantly increased soon after the Earthquake (*Figure 2A–F*; see Supplementary material online, *Table S1*). The occurrence of CPA was significantly increased after the Earthquake even after excluding the non-cardiopulmonary cases (*Figure 2D* and *E*). Furthermore, in the time-course analyses of daily occurrences, we were able to demonstrate the significant increase in the occurrence of CPA on the day of the Earthquake even after excluding the non-cardiopulmonary cases, while the increased occurrences of other diseases were noted a few days after the Earthquake (*Figure 3A* and *C–F*). Also, the occurrence of ACS did not peak during the first 7 days (*Figure 3B*). In the subanalysis of the patients with stroke, a significant increase in the occurrence was noted only



**Figure 2** Time course of weekly occurrences of the diseases. (A–F) Weekly occurrences of heart failure (HF), stroke, cardiopulmonary arrest (CPA), and pneumonia were significantly increased after the Earthquake. \* $P < 0.05$  and \*\* $P < 0.01$ . (G) The weekly counts of aftershocks observed in the Miyagi Prefecture with a seismic intensity of 1.0 or greater on the Japanese scale. The seismic intensity of the major Earthquake of 11 March 2011 was 7 in the Miyagi Prefecture. The number in the panels indicates the total number of the patients in 2011. Black arrows indicate the occurrence of the Great East Japan Earthquake (magnitude of 9.0, 11 March 2011) and white arrows indicate the largest aftershock (magnitude of 7.0, 11 April 2011).

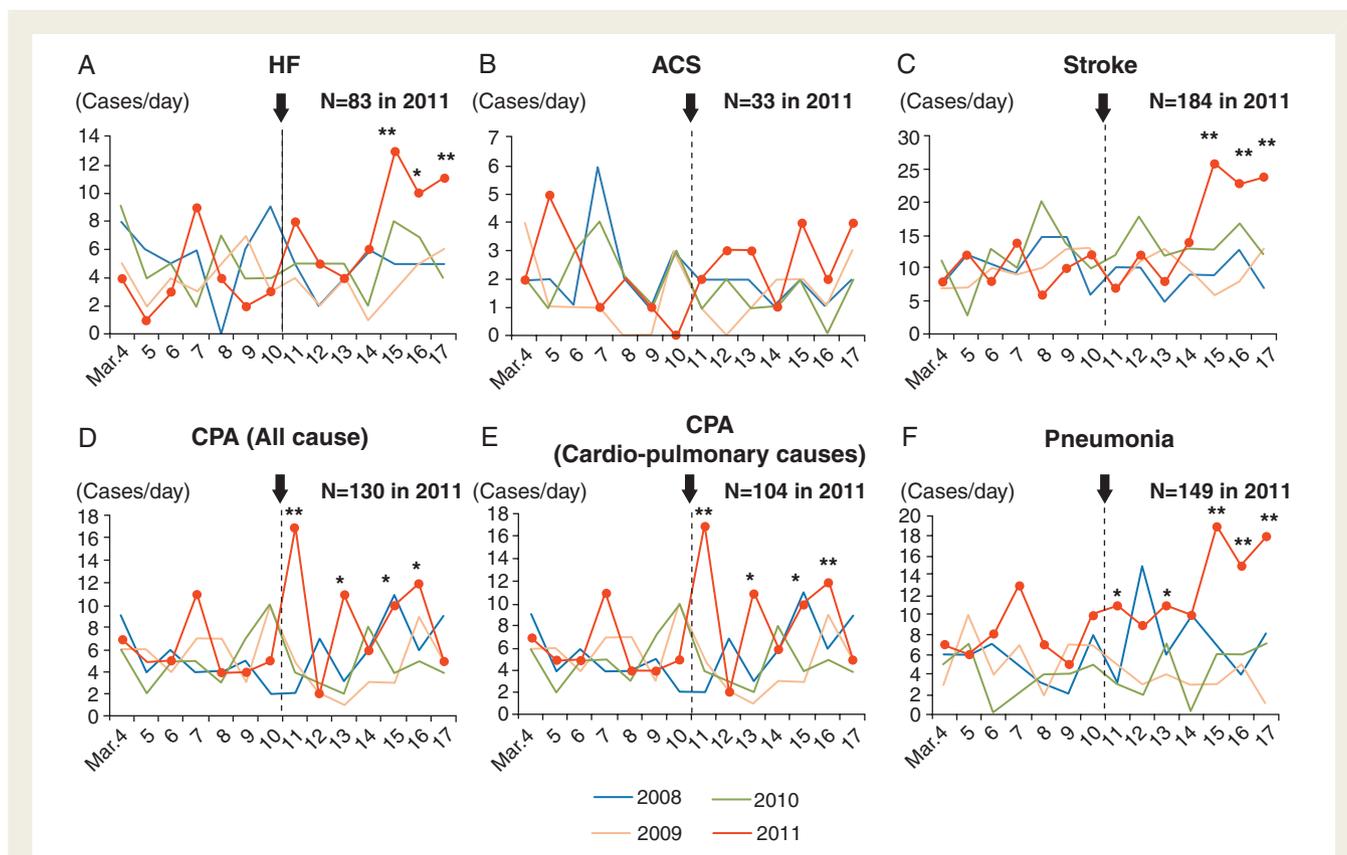
for cerebral infarction but not for intracranial haemorrhage (see Supplementary material online, Figure S2). The number of aftershocks in the Miyagi Prefecture was frequent during the 6 weeks after the Earthquake, and the second peak was noted at the large aftershock on 7 April 2011 (magnitude of 7.0) (Figure 2G). When compared with the previous 3 years, the significant increases in the occurrence of HF and pneumonia were prolonged for more than 6 weeks after the Earthquake in 2011 (Figure 2A and F). On the other hand, the time course of the occurrences of stroke and CPA was shown by the second peak, corresponding to the distribution of the aftershocks (Figure 2C–E). We also observed that the rapid increase in the occurrence of ACS was followed by a significant decline (Figure 2B). Similarly, the occurrence of CPA showed a significant increase after the large aftershock followed by a rapid decline (Figure 2D and E). Those results

by the Poisson regression stepwise analysis were comparable with those by the full Poisson regression analysis without stepwise methods (data not shown).

The subgroup analyses of the 2011 data showed that age, sex, or residence area did not significantly influence the occurrences of CVDs after the Earthquake (Figure 4). In contrast, a significant influence of residence area was noted only for pneumonia with a high occurrence in the seacoast (tsunami) area, although sex and age again had no effect (Figure 4).

## Discussion

The novel findings of the present study are as follows: (i) the occurrences of CVDs and pneumonia were all significantly increased after the Great East Japan Earthquake in 2011 when



**Figure 3** Daily occurrences of the diseases before and after the Earthquake. (A–F) Daily occurrences of heart failure (HF), stroke, cardio-pulmonary arrest (CPA), and pneumonia were significantly increased after the Earthquake. \* $P < 0.05$  and \*\* $P < 0.01$ . The number in the panels indicates that for 4 weeks before and after the Earthquake. Black arrows indicate the occurrence of the Great East Japan Earthquake (magnitude of 9.0, 11 March 2011).

compared with the previous 3 years (2008–10), (ii) the occurrences of HF and pneumonia were then gradually decreased, whereas the occurrences of ACS, stroke, and CPA were rapidly decreased when compared with those of HF and pneumonia, (iii) the occurrences of CVDs were increased independent of age, sex, or residence area, and (iv) the increase in the occurrence of pneumonia was higher in the seacoast (tsunami) area than in the inland area. To the best of our knowledge, this is the first report that demonstrates the mid-term courses of the occurrences of major CVDs and pneumonia after a great earthquake in the large-scale population. Especially, it provides the first evidence that the occurrence of HF was markedly increased for a long period after the Earthquake.

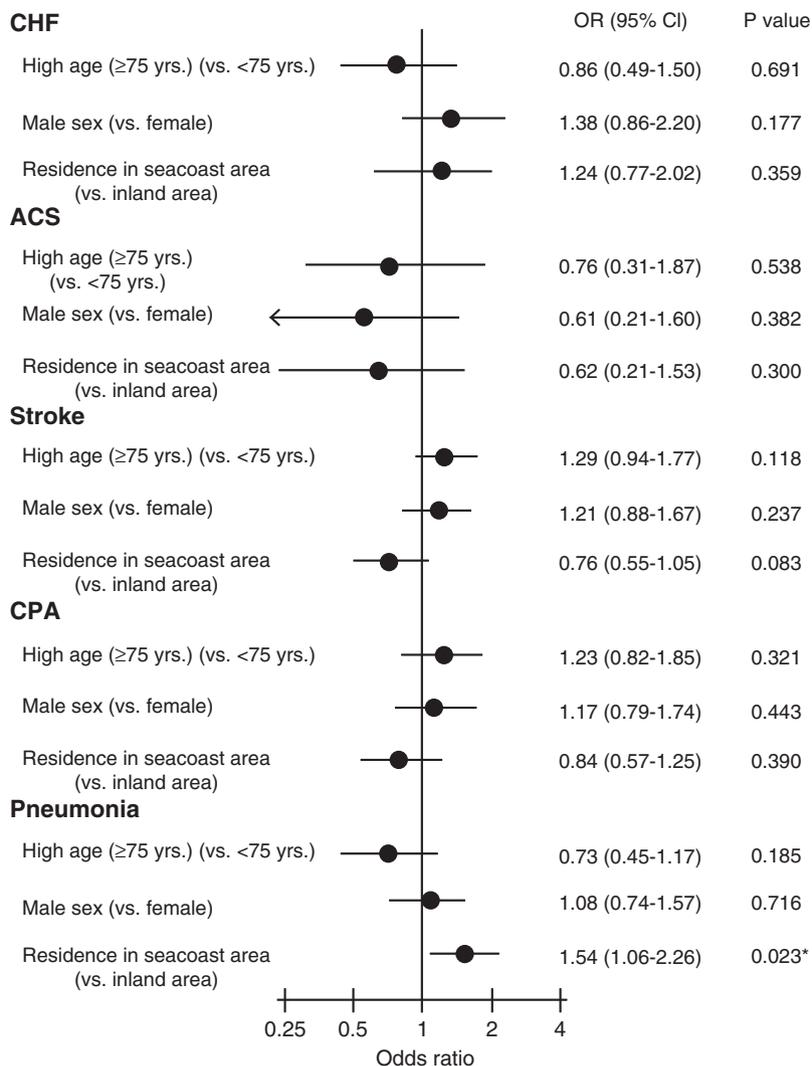
### Increased occurrences of cardiovascular diseases and pneumonia

In the present study, we observed that the occurrences of HF, ACS, stroke, CPA, and pneumonia were all significantly increased after the Great East Japan Earthquake. Although previous studies demonstrated that the occurrences of acute myocardial infarction, stroke, and CPA were increased after earthquakes,<sup>5,8,9,12–14</sup> no study has ever demonstrated the increase in the occurrence of HF. The Earthquake forced many people in the Miyagi Prefecture

to take shelter and/or to live without distribution of daily necessities, lifelines (e.g. water and electric supplies), and medicines. To make the situation worse, they were afflicted by the frequent aftershocks (the aftershocks with a seismic intensity of 1.0 or greater occurred 1025 times from 11 March to 7 April) and the freezing temperature (the average temperature in Sendai City was 3.8°C in March 2011) (Table 1). In these situations, where people are forced to extreme physical/mental stresses, CVDs may be caused by the activated sympathetic nervous system.<sup>15,16</sup> A transient increase in blood viscosity after an earthquake was observed only in those with high stress (e.g. move to shelter and loss of family member), which may increase the occurrences of ACS, stroke, and CPA.<sup>17</sup>

### Increased occurrence of heart failure

When compared with the previous reports (Table 1),<sup>5–9,12,14,18</sup> one of the novel findings of the present study is the significant increase in the occurrence of HF, for which several factors may be involved. The activated sympathetic nervous system in the Great East Japan Earthquake should have elevated blood pressure and heart rate, as previously reported after large earthquakes.<sup>15,19</sup> Furthermore, the discontinued logistics distribution caused by the Earthquake resulted in insufficient delivery of regular medications,



**Figure 4** Subgroup analyses regarding age, sex, and residence area. We first counted the occurrence of each variable in the 4 weeks before and after the Earthquake and subsequently calculated the odds ratio. No significant influences of age, sex, or residence area were noted for the occurrences of cardiovascular diseases and pneumonia, except for the influence of the seacoast residence on the occurrence of pneumonia. HF, heart failure; ACS, acute coronary syndrome; CPA, cardiopulmonary arrest; OR, odds ratio; 95%CI, 95% confidential interval.

such as antihypertensive drugs and antithrombotic drugs, which can increase cardiovascular events as reported previously.<sup>20</sup> Moreover, these situations forced people to use preserved foods with high salt, and not fresh food, which also can elevate blood pressure and worsen HF.<sup>21–23</sup> It has been reported that high-salt intake under mental stress elevates blood pressure to a greater extent than normal conditions, thus easily worsening HF.<sup>24,25</sup> Additionally, the recent study has demonstrated that antecedent hypertension is associated with the increased occurrence of HF.<sup>26</sup> Furthermore, the recent report from our institute demonstrated that self-monitoring blood pressure was significantly elevated after the Earthquake.<sup>27</sup> Recently, we also have reported that the Earthquake increases the occurrence of ventricular tachyarrhythmia and hospitalization from worsening of HF among the patients with implantable cardiac defibrillators.<sup>28</sup> One of the well-known factors that

worsen HF is infection including pneumonia, which was significantly increased after the Earthquake as shown in the present study. Taken together, we consider that discontinuation of drugs, increased salt intake, activated sympathetic nervous system, blood pressure elevation, and increased occurrences of tachyarrhythmia and infections were likely involved in the increased occurrence of HF after the Great East Japan Earthquake.

### Time course of occurrences of the diseases

Unlike HF and pneumonia that showed a gradual decline for more than 6 weeks after the Earthquake, the weekly occurrence of ACS and CPA showed significant increases followed by decreases within 2–3 weeks after the Earthquake. Furthermore, the immediate

increase in the occurrence of the disease on the day of the Earthquake was noted only for CPA. The similar tendency was reported for sudden cardiac deaths related to atherosclerotic CVD after the Northridge Earthquake, although the observational period was very short (7 days)<sup>12</sup> when compared with the present study (16 weeks). These results suggest that the physical and/or mental stress induced by the Earthquake first facilitated CPA events, while other CVDs were due to the catastrophe occurring later on (tsunami, break down of lifelines, low temperatures, etc.). However, in the present catastrophic situation, the emergency care system itself was severely damaged for both ambulance transport and ambulance personnel availability, where the patients with CPA had a priority for ambulance transport. Thus, such a logistic factor may also have been involved in the present results. Furthermore, the onset patterns of CPA and stroke showed the second peak after the largest aftershock, suggesting that unstabilization of atherosclerotic plaques<sup>29</sup> and an increase in blood pressure were accelerated by the Earthquake<sup>27</sup> with a resultant increase followed by a decrease in the occurrence, an interesting and important difference when compared with other diseases.

### Predictors for increased occurrences of cardiovascular diseases and pneumonia

Little information is available about the impacts of age and sex on the occurrences of CVDs and pneumonia after an earthquake. Although the age of all transported patients in 2011 was significantly higher than that in the previous 3 years, the age of the patients with CVDs and pneumonia was comparable with the previous 3 years, suggesting less impact of age and sex on the increased occurrences of CVDs and pneumonia (Figure 3).

Importantly, although the Earthquake-induced tsunami directly and seriously affected the people in the seacoast area, but not those in the inland area, the increased occurrences of CVDs after the Earthquake were comparable between the two areas. Similar indirect effects of a disaster on CVDs in a remote area have been reported in the World Trade Center Disaster in 2001, where the blood pressure of people living in Mississippi was equally elevated as that of those living in New York City.<sup>30</sup> These results indicate that the impact of life-threatening events, such as the Great Earthquake, could trigger CVDs even in areas distant from the disaster area. However, a certain number of people who suffered damage from the tsunami migrated from the seacoast area to the inland area after the Earthquake, which might have attenuated the influence of the tsunami on the occurrence of the diseases examined. In contrast, the increased occurrence of pneumonia was higher in the seacoast area than in the inland area, which can be explained by aspiration pneumonia in drowned people and/or the large amount of sludge carried by the tsunami.

### Study limitations

Several limitations should be mentioned for the present study. First, in the present study, we analysed the occurrences of the diseases based on the initial diagnoses on the ambulance transport records that were made by attending doctors. Although the diagnoses were made based on physical examination, ECG, chest

X-ray, echocardiography, and laboratory test, the process of the diagnoses were not standardized in the present study. Although this method might reduce the accuracy of diagnoses, the rate of definitive diagnosis at admission in the emergency rooms was comparable among the 4 years studied, and the process of diagnosis was the same throughout the study period. However, in our emergency medical system, we were unable to examine the accuracy of diagnoses in emergency rooms, especially in the catastrophic situations after the Earthquake. Secondly, some people were forced to move from the seacoast area to the inland area after the Earthquake. However, we have no data on how many people moved from the seacoast area to the inland area. This could have affected the increased occurrences of CVDs in the inland area. Thirdly, we do not have background data on the patients who were diagnosed as having HF, including clinical characteristics and underlying heart disease.<sup>31,32</sup> We are now prospectively following the patients with HF in our cohort study in the Tohoku area<sup>33</sup> and we will report the clinical outcomes of those patients in the future. Fourthly, we have no data regarding the number of patients who visited hospitals by themselves without the use of ambulance. We also were unable to exclude the effects of traffic disruption by the Earthquake that might have affected the use of ambulance. Fifthly, the Miyagi Prefecture is located next to the Fukushima Prefecture where the nuclear power plant accident occurred; however, the influence of the nuclear accident was minimal in our Miyagi Prefecture. Sixthly, although ACS and stroke are similarly and strongly associated with atherosclerosis, we were unable to elucidate the mechanism for the different time courses between them. This issue remains to be examined in future studies. Seventhly, we have no data regarding prior medications in each patient, which might have affected the occurrence of CVDs. Eighthly, because the diagnosis of ACS was not based on coronary angiograms, but on ECG, echocardiography, and blood test, which made it difficult to diagnose Takotsubo cardiomyopathy. Finally, we have no data that can differentiate CPA of cardiac causes from CPA of pulmonary causes.

### Clinical implications

We consider that the increased occurrences of CVDs in the Great East Japan Earthquake may have been caused by the following multiple factors: (i) the activated sympathetic nervous system by physical and mental stresses, (ii) insufficient medications, (iii) increased salt intake from preserved foods, and (iv) elevated blood pressure and viscosity; however, further studies are required to elucidate the mechanisms of disaster-related CVDs.

### Conclusions

The present study demonstrates that the East Japan Earthquake Disaster has significantly increased the occurrences of CVDs, including the first observation of the increased occurrence of HF, independent of age, sex, area of residence.

### Supplementary material

Supplementary material is available at *European Heart Journal* online.

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**Conflict of interest:** none declared.

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