asthma attacks were more common after the disaster. The mean age of patients hospitalised for respiratory disease was significantly higher than that in the corresponding periods in the previous 2 years. The majority of patients had poor ADL status and many experienced deterioration in ADL status after the disaster.

Effect on respiratory disease

Previous reports on the Hanshin-Awaji earthquake showed an initial increase in patients with injury and a subsequent increase in patients with respiratory disease, especially pneumonia.[11–13] Similarly, our observation showed a marked increase in pneumonia patients, although there was no initial increase in patients with serious injury as the majority of victims drowned and heavily injured patients were rarely transferred to hospital.

The epidemiology of respiratory disease varies depending on the situation. For instance, after the 2004 Sumatra-Andaman earthquake and subsequent tsunami, the number of lower respiratory infections in Ache rapidly increased and then sharply declined during the second week.[14] However, after the 1995 Hanshin-Awaji earthquake, the number of patients hospitalised for pneumonia increased gradually and remained high for over 2 months[9 10] as pneumonia developed more slowly. In the Sumatra-Andaman earthquake, many cases of pneumonia resulted from aspiration of tsunami-water in near-drowning events ('tsunami lung').[15 16] On the other hand, in the Hanshin-Awaji earthquake, numerous, mostly elderly patients staying in the unhealthy conditions of shelters developed pneumonia ('shelter pneumonia').[17] In this earthquake and tsunami, we experienced few cases of pneumonia directly caused by aspiration of tsunami-water. A few patients came from the field, but most were from shelters, their own or relative's homes, other hospitals or nursing homes. Their mean age was significantly higher than in 2009 or 2010. Therefore, we regarded and treated most of the pneumonia as 'shelter pneumonia'. We were unable to carry out bacteriological tests for 14 days after the earthquake due to a shortage of water, fuel and manpower. Most pneumonias were considered 'aspiration pneumonia acquired in a nursing home' because of the patients' ADL status.

Cases of AE-COPD were also significantly increased. COPD was one of the most common chronic respiratory diseases, especially in the elderly. It is well known that interruption of treatment for chronic disease frequently exacerbates the patient's condition, as after a natural disaster.[14 18–20] Many patients lost their drugs in the tsunami, and therefore disruption of regular medication may partly account for the increase in AE-COPD admissions. Also, the weather was sunny and windy from the end of March and dust from the tsunami sludge was an important component of particulate air pollution and may have contributed to the significant rise in the number of admissions for AE-COPD.

Although asthma was also a common chronic respiratory disease and had the same precipitating cause as COPD, asthma attacks did not increase as much as AE-COPD, perhaps because of two important differences between the two conditions. First, COPD patients were generally older than those with asthma and so the baseline health status of COPD patients was poorer than that of those with asthma.[21] As a result, COPD patients required more frequent hospitalisation. In our study, the mean age of AE-COPD patients was higher than that of those experiencing asthma attacks. Second, bacterial respiratory infection affects patients with COPD more than those with asthma.[22] In the aftermath of the disaster, poorer hygiene and overcrowding in shelters would have increased the risk of respiratory bacterial infection resulting in AE-COPD.

Hospitalisation for lung cancer related symptoms increased only slightly and actually declined as a proportion of total admissions for respiratory diseases. The mean age of lung cancer patients was similar to that in the previous 2 years. Maeda *et al*[23] also reported that no increase in lung cancer related hospitalisation was observed after the Hanshin-Awaji earthquake. As lung cancer progression may be influenced less by the environment than by growth of the cancer, the disaster would not impact on lung cancer immediately. Although the interruption of chemotherapy and/or radiotherapy would have worsened prognosis, this cannot be confirmed during our study period.

Effect on ADL status

In the acute phase following the disaster, patients with poor ADL status, especially those 'originally dependent', were hospitalised for pulmonary diseases, typically pneumonia, although substantial numbers of patients with good ADL status were also hospitalised. After 3 weeks, there was a sharp increase in 'newly dependent' patients whose ADL status had deteriorated. It was reported that physical disability was an independent risk factor for death in the Hanshin-Awaji earthquake and the 1999 Taiwan earthquake.[9 10] However, those reports investigated mortality in the acute phase, not hospitalisation in the subacute or chronic phases. After the earthquake and tsunami, one in four Ishinomaki residents moved into shelters, many of which were also flooded by the tsunami. They lacked water and food and lived in unheated and overcrowded conditions, with many sleeping on the floor. As a result, the elderly had restricted consumption of food and water, and kept still in a small space, resulting in deterioration in their ADL status. In addition, scarcity of water worsened oral hygiene. Poor functional status and loss of oral hygiene were the major risk factor for pneumonia,[24–27] especially in the elderly, many of whom were subsequently hospitalised for 'shelter pneumonia'. Also, poor oral hygiene induces swallowing dysfunction[28] which could be a risk factor for COPD exacerbation[29] and may explain why AE-COPD increased especially in the elderly.

Effect on an aging society

According to the report of the Japanese government, in the Great East Japan earthquake 93% of deaths occurred as a result of drowning and over 60% of these victims were over 60 years of age. Many previous studies have noted that the elderly are at greater risk of death after earthquakes; however, the proportion of elderly people killed in this earthquake and tsunami was extremely high compared to other similar disasters.[4–8] Comparable findings were reported only for 1995 Hanshin-Awaji earthquake and the 2004 mid-Niigata earthquake, both in Japan.[12 17] Moreover, 90.8% of patients hospitalised for respiratory disease after the earthquake in our study were over 60 years of age. These results suggest that the elderly are vulnerable immediately and also for a while after earthquakes.

In the 1999 Taiwan earthquake, the 2003 heat waves in the Czech Republic, and the 2004 Sumatra-Andaman earthquake, subsequent decreased mortality in the affected areas was the result of the large number of direct deaths caused by the disasters among vulnerable populations such as the elderly or children,[5 30 31] the so-called 'harvesting effect'. However, our observation suggests that, in an aging society, a disaster not only directly kills the vulnerable but also produces a new vulnerable population. Previous reports demonstrated that a prolonged harmful effect on mental health and slow psychological recovery were seen more frequently in the elderly than in young people.[32–35] Therefore, we should provide long-term care to the elderly after a disaster.

Implications for policy and practice

Our observations suggest two important targets for reducing hospitalisation for respiratory disease after a major disaster in an aging society: interrupted chronic respiratory disease treatment and deterioration in ADL status. Interruption of treatment for chronic respiratory disease could be prevented if a few days' stored drug supply were available. This would necessitate a storage system containing regional prescription data for each drug and personal medication data. Telemedicine systems or web-based patient data storage systems might be useful. Prevention of deterioration in ADL status is also important. Elderly people are potentially vulnerable and their ADL status can easily deteriorate. In our study, living in shelters for more than 3 weeks resulted in deterioration in ADL status and hospitalisation for respiratory diseases. Therefore, we propose that the elderly should be evacuated from disaster areas as quickly as possible.

Strengths and weaknesses of this study

Our study has two important strengths. First, the Great East Japan Earthquake affected one of the most rapidly aging societies in the world.[3] As the proportion of elderly people continues to increase in both developed and developing countries, there is an urgent need for information on and analysis of aging societies. The findings of our study are applicable to natural disasters worldwide. Secondly, we were able to obtain detailed information on patient demographics, diagnosis and ADL status in a catastrophic situation. This was because our hospital continued to function and maintained its electronic medical record systems and laboratory systems, despite a devastating earthquake and tsunami which severely affected most other medical facilities, and because staff in our hospital had received earthquake training and had recorded our experiences as memos or on digital recorders for analysis for disaster medicine.

Our study was conducted in a single centre. This might be a weakness of our study, but our hospital was the only functional hospital after the disaster in the Ishinomaki medical zone which experienced over 30% of the total fatalities in this earthquake. Also, it was the only hospital in the medical zone with a department of respiratory medicine and pulmonary specialists, and previously had accepted most seriously ill patients with pulmonary disease who needed hospitalisation. Therefore, we think our study accurately describes the impact of the earthquake on pulmonary diseases and explains what happened in a hospital directly affected by the earthquake.[2] However, it is also weakness of our study that we only analysed hospitalised patients as there were also numerous outpatients, many of whom died. These events will be analysed in a future report. Another weakness is that a cross-sectional study cannot elucidate a causal relationship. Finally, we did not clearly define conditions for hospitalisation. Because of the destruction of the normal healthcare system and poor hygiene outside the hospital, we admitted some patients who normally would have been treated in an outpatient setting. However, this was a real situation after a devastating disaster.

CONCLUSION

The Great East Japan earthquake and subsequent tsunami affected one of the most rapidly aging societies in the world. After the disaster, pneumonia, COPD exacerbation and asthma attacks associated with low ADL status in the elderly significantly contributed to the increase in hospitalisation for pulmonary diseases. These observations should be used when planning emergency medical management for disasters in a progressive but rapidly aging society.

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Contributors SY was responsible for study design and interpretation of the data, and drafted the manuscript. MH, SK, HS, ST and MY were responsible for the collection and interpretation of the data. KN drafted the statistical analysis section of the manuscript, and provided suggestions on public health and epidemiology. MH, SK and MY were responsible for study design and revised the draft manuscript. SY, MH, SK, HS, ST and MY treated the patients. All authors approved the final version of the manuscript.

Competing interests None.

Ethics approval The ethics review committee of Japanese Red Cross Ishinomaki Hospital approved this study.

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ORIGINAL ARTICLE

Impact of the Tohoku earthquake and tsunami on pneumonia hospitalisations and mortality among adults in northern Miyagi, Japan: a multicentre observational study

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ABSTRACT

Background On 11 March 2011, the Tohoku earthquake and tsunami struck off the coast of northeastern Japan. Within 3 weeks, an increased number of pneumonia admissions and deaths occurred in local hospitals.

Methods A multicentre survey was conducted at three hospitals in Kesennuma City (population 74 000), northern Miyagi Prefecture. All adults aged ≥18 years hospitalised between March 2010 and June 2011 with community-acquired pneumonia were identified using hospital databases and medical records. Segmented regression analyses were used to quantify changes in the incidence of pneumonia.

Results A total of 550 pneumonia hospitalisations were identified, including 325 during the pre-disaster period and 225 cases during the post-disaster period. The majority (90%) of the post-disaster pneumonia patients were aged ≥65 years, and only eight cases (3.6%) were associated with near-drowning in the tsunami waters. The clinical pattern and causative pathogens were almost identical among the pre-disaster and post-disaster pneumonia patients. A marked increase in the incidence of pneumonia was observed during the 3-month period following the disaster; the weekly incidence rates of pneumonia hospitalisations and pneumonia-associated deaths increased by 5.7 times (95% CI 3.9 to 8.4) and 8.9 times (95% CI 4.4 to 17.8), respectively. The increases were largest among residents in nursing homes followed by those in evacuation shelters.

Conclusions A substantial increase in the pneumonia burden was observed among adults after the Tohoku earthquake and tsunami. Although the exact cause remains unresolved, multiple factors including population aging and stressful living conditions likely contributed to this pneumonia outbreak.

Key messages

What is the key question?

- ▸ Did the pneumonia incidence increase among the adult population after the Tohoku earthquake/tsunami, what were the characteristics of the disaster-associated pneumonia?

What is the bottom line?

- ▸ Our survey in a well defined population of northern Miyagi Prefecture revealed that a marked increase in the incidence of pneumonia hospitalisations and pneumonia-associated deaths was observed during the 3-month period following the disaster, the vast majority of the victims were older people, only 3.6% were associated with near-drowning in the tsunami waters, and the clinical and microbiological characteristics of the post-disaster patients were similar to those of the pre-disaster patients.

Why read on?

- ▸ Because this disaster affected a notably aging population with the highest baseline pneumonia incidence rate, the disaster caused a drastic increase in the number of admissions and placed a heavy burden on local hospitals. In addition to using the pneumococcal vaccine for disaster-affected populations, the provision of optimal living conditions, medical check-ups and oral hygiene care must be a priority for older people after natural disasters.

INTRODUCTION

On 11 March 2011, a magnitude 9.0 earthquake struck off the northeastern coast of Japan. Within an hour of the earthquake, devastating tsunamis swept over the east coast of the Tohoku Region, resulting in approximately 20 000 deaths and catastrophic damage to the local infrastructure and environment.[1 2] As a result of the extensive destruction of homes, more than 400 000 displaced people were moved to emergency evacuation shelters that were not supplied with electricity, gas, water or food, despite sub-freezing winter temperatures.[3 4]

Previous studies showed that acute respiratory infections were frequently observed among people displaced by the 2001 earthquake in El Salvador,[5] among those affected by the 2003 Bam earthquake in Iran[6] and among people in Aceh Province affected by the 2004 Indian Ocean earthquake and tsunami.[7] Furthermore, severe pneumonia associated with the aspiration of seawater, known as 'tsunami lung', was reported in areas affected by the Indian Ocean tsunami.[8–10] However, these studies were conducted in resource-limited settings without reliable baseline data and lacked a standardised case definition. The impact of natural disasters, including tsunamis, on the risk of pneumonia remains largely unknown.

Within 3 weeks of the earthquake and tsunami on 11 March, a rapid increase in pneumonia hospitalisations and related deaths in northern Miyagi Prefecture was reported by mass media outlets.[11] We undertook an investigation to elucidate the impact of the Tohoku earthquake/tsunami on the incidence of pneumonia-related hospitalisations and mortality among adults aged ≥18 years in Kesennuma. We also sought to describe the clinical characteristics of disaster-related pneumonia and investigate the potential causes of increased rates of pneumonia in the affected population.

METHODS

Setting

Kesennuma is located on the northeastern coast of Miyagi Prefecture (figure 1). The city has a long, saw-toothed coastline with narrow, flat land facing the Pacific Ocean. The total population in February 2011 was 74 257 (source: Department of

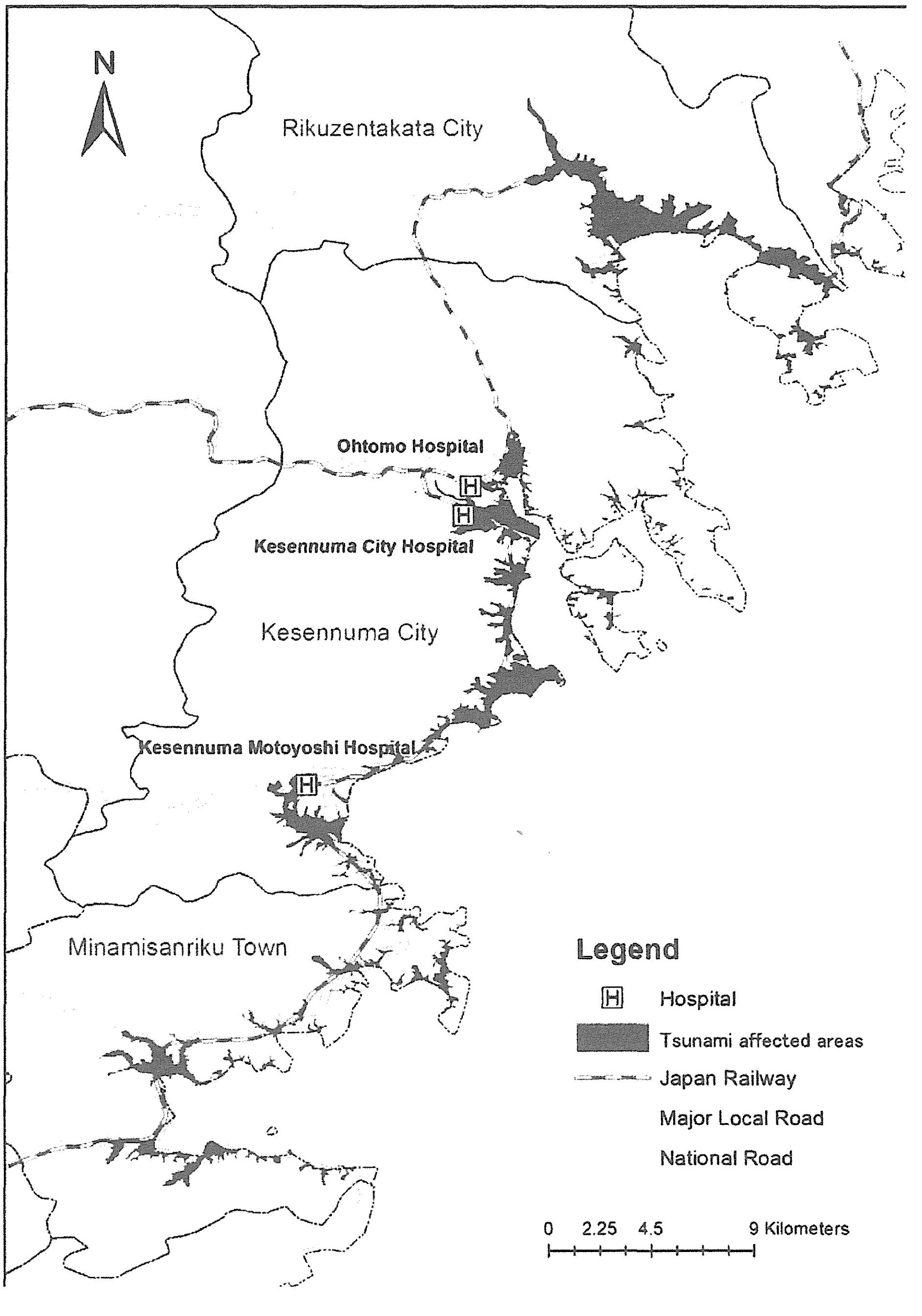

Figure 1 Area affected by the Tohoku earthquake and tsunami, Kesennuma City, Miyagi Prefecture. The disaster area data were obtained from the overview map of tsunami-affected areas released by the Geospatial Information Authority of Japan (http://www.gsi.go.jp/BOUSAI/h23_tohoku.html).

Vital Statistics, Kesennuma City). The city inhabitants included a substantial number of older adults: 30.2% (n=22 421) were aged ≥65 years and 8.9% (n=6618) were aged ≥80 years. These percentages were higher than the national averages (23% and 6.4%, respectively). At the time of the disaster, no national programme for the administration of the 23 valent polysaccharide pneumococcal vaccine (PPV23) existed in Japan, and its coverage among Kesennuma residents aged ≥65 years was <5%.

At 14 : 46 local time on 11 March 2011, the earthquake shook Kesennuma. The first large tsunami wave hit Kesennuma within a half hour of the earthquake, resulting in the deaths of 1032 residents; an additional 324 residents were listed as missing. The majority (>90%) of the victims died from drowning.[2]

The tsunamis devastated buildings, cars, ships and all other structures. Major oil tanks in the port were damaged and leaked petroleum, leading to massive conflagrations in the city. The main road was demolished to the north and the south, and the city was isolated (figure 1). In the aftermath, residents fled to evacuation shelters, including schools and public halls, to relatives' houses located on higher ground. The number of evacuees reached a peak on 17 March 2011 (20 105 individuals at 99 sites), while many other residents remained in their partially damaged houses.

In early April 2011, a considerable increase in pneumonia hospitalisations was reported from hospitals in northern Miyagi Prefecture. Media outlets reported that the outbreak may have been related to exposure to dried oil mist (ie, oil leaked from damaged storage tanks) or contaminated tsunami water.

Study design

In response to this outbreak, the Kesennuma City Hospital (KCH), the Kesennuma City Medical Association and Nagasaki University established an investigation team and initiated a multicentre survey on 12 May. The team identified three hospitals in Kesennuma that were providing inpatient care for patients with pneumonia before the disaster (KCH, 451 beds; Kesennuma Motoyoshi Hospital (KMH), 38 beds; and Ohtomo Hospital (OH), 78 beds). The team also identified an orthopaedic hospital and some clinics that had a small number of pneumonia admissions before the disaster (approximately 10 cases per year in total); however, their buildings were completely demolished, and their patients' records were unavailable. Therefore, we did not include those cases.

Case ascertainment

For the study period (defined as 1 March 2010 to 30 June 2011), all patients who were hospitalised with a diagnosis of pneumonia were enumerated from existing hospitalisation databases. Working as a panel, three qualified pulmonologists reviewed medical charts and chest radiographs (CXRs) in September 2011 using a standardised case definition based on the British Thoracic Society guidelines.[12] After reviewing the medical charts and CXRs, the panel's consensus CXR interpretations were recorded. Patients were classified as having any pneumonia if they showed pulmonary consolidation on CXR and any respiratory symptoms consistent with pneumonia. If a patient developed the disease 48 h after admission, the patient was classified as having hospital-acquired pneumonia and was excluded from further analysis. Repeated episodes of pneumonia in the same patient within a 2-week period were regarded as a single episode.

While inspecting hospitalisation records and CXRs, we realised that a considerable proportion of paper-based medical charts and CXRs in KMH were lost or damaged by the tsunami, and only discharge summaries were available. Therefore for analysis, the patients were classified into one of two pneumonia case categories: (1) *confirmed pneumonia* (full medical records were available and the presence of consolidation was confirmed by pulmonologists) and (2) *probable pneumonia* (detailed data and CXRs were not available, but the history described in the summary records was compatible with pneumonia). We defined pneumonia episodes as near-drowning related if patients were engulfed by the tsunami water on 11 March 2011, and their disease onset occurred within 4 weeks of the disaster.

Data collection

Demographic, clinical, radiographic, microbiological and evacuation site information was collected from the medical charts using a standardised abstraction form. The patients' addresses before the disaster were extracted from the hospital database and converted to geographical coordinates. Patients with pneumonia who died in any of the three study hospitals were categorised as fatal cases. The severity of pneumonia was assessed using the CURB65 scoring system.[13] Microbiological tests were routinely performed for clinically suspected cases throughout the study period at KCH, but they were not available at the other hospitals.

Data analysis

The demographic and clinical characteristics of the study patients were compared between the pre-disaster and post-disaster periods using χ^2 and Fisher's exact tests. The near-drowning-related cases were excluded from this comparison because the cause of disease was clear. The factors associated with death were assessed using Poisson regression models with robust SEs.[14] Pneumonia incidence and mortality rate calculations were limited to patients living in Kesennuma. The effects of the disaster, defined as a change in the weekly incidence of hospitalisations and associated deaths after the disaster (ie, the incidence rate ratios), were separately assessed using segmented generalised linear Poisson regression models allowing for overdispersion.[15] The regression models included terms for the disaster and time trends before and after the disaster. The change in the population size due to the disaster was taken into account using the offset function. Partial correlograms were used to assess serial autocorrelation of the residuals and, since there was no detectable autocorrelation, the data were modelled assuming independence.

Ethics

This study was approved by the Institutional Review Board of KCH.

RESULTS

Patients

Over the course of the study period (1 March 2010 to 30 June 2011), a total of 550 pneumonia cases were identified from hospital and facility records. According to the patients' disease onset, 225 confirmed cases and 100 probable cases occurred before 11 March and 225 confirmed cases occurred after 11 March (see online supplementary appendix figure 1). There was a sharp rise in the weekly number of pneumonia hospitalisations shortly after the disaster (figure 2A). A majority of the patients (95%) were city residents and their geographical distribution was similar across the study periods (see online supplementary appendix figure 2). When only city residents were included in the analysis, the highest incidence rate occurred during the first 2 weeks after the disaster, and the

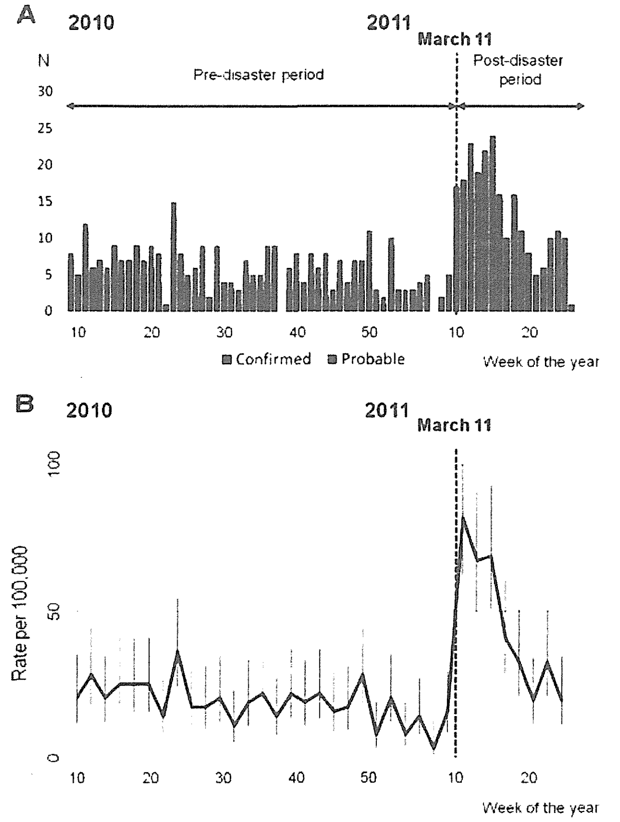

Figure 2 Trend of pneumonia hospitalisations in Kesennuma City, March 2010 to June 2011. (A) Weekly number of confirmed and probable cases according to the date of onset. (B) Biweekly incidence rates (per 100 000 people) calculated according to the date of onset. Cases were limited to the residents of Kesennuma City. The vertical lines indicate 95% CI.

incidence declined to the baseline level by mid-June 2011 (figure 2B).

To understand changes in the incidence of pneumonia, we compared the periods before (1 March 2010–10 March 2011) and after (11 March–30 June 2011) the disaster (table 1). The demographic and clinical pictures of disaster-related pneumonia were similar to those of pre-disaster cases, except that a substantial proportion (27.7%) of post-disaster patients were living in evacuation shelters. Nearly 90% of patients were older adults aged ≥65 years. The patients who were identified from evacuation shelters were younger (average age 76.7 years vs 80 years, p=0.047), less likely to have underlying medical conditions (45% vs 59.9%, p=0.049) and less likely to have fatal pneumonia (10% vs 29.3%, p=0.003) than patients with pneumonia identified from residences and nursing homes.

The patients identified from nursing homes were predominantly women, older and more likely to have had underlying conditions than were patients from homes and evacuation shelters. The proportion of patients with severe pneumonia with CURB65 ≥3 was high among patients from nursing homes, and those patients were more likely to die in the post-disaster period than in the pre-disaster period.

Incidence rates

During the three and a half months following 11 March, the weekly incidence of pneumonia hospitalisations increased by 5.7 times (95% CI 3.9 to 8.4) from the baseline level (table 2). The age group specific ratios were similar across all generations, whereas the absolute increase in the incidence was substantially greater among older people, especially those aged ≥80 years (the rate difference, 156.3 (95% CI 90.8 to 221.9) per 100 000 per population-week). The admission rate ratio was highest among nursing home residents followed by the residents of evacuation shelters. For pneumonia-related deaths, the rate increased by 8.9 times (95% CI 4.4 to 17.8) from the baseline level, and the mortality rate ratio was highest among nursing home residents.

Pneumonia aetiologies

Streptococcus pneumoniae, *Haemophilus influenzae* and *Klebsiella pneumoniae* were the leading causative pathogens identified in pre-disaster and post-disaster pneumonia cases. The positivity of *H influenzae* increased by fourfold after 11 March, especially among patients from evacuation shelters. *Staphylococcus aureus* was also found in patients throughout the study period, but its causative role was unclear (see online supplementary appendix table 1). None of the patients in this study were reported to have had positive rapid tests for influenza (the percentages tested before and after the disaster were 11.4% and 17.9%, respectively) or *Legionella pneumophila* serogroup 1 (28.4% and 35.5%, respectively).

Risk factors for death

Both before and after 11 March, a higher CURB65 score was significantly associated with an increased risk of death; the mortality also increased by age group, but the statistical evidence of this increase was weak. After the disaster, male gender and prehospital antibiotics use were associated with a higher risk of death after adjusting for other factors, and staying at an evacuation shelter was associated with a lower risk of death, although the significance was only marginal after adjustment. However, their effects on death were similar to the baseline figures (see online supplementary appendix table 2).

Near-drowning-related pneumonia

A history of exposure to tsunami water on 11 March was recorded in 10 patients. Among them, eight (3.6% of the disaster-related cases) were near-drowning-related pneumonia; seven were women, three were inside a car when engulfed by the tsunami, and one died from the disease. The median age was younger than that of other disaster-related pneumonia patients (62 years vs 79 years, p<0.001).

DISCUSSION

In this report, we documented a substantial increase in the rate of pneumonia-related hospital admissions and deaths in Kesennuma among adults of all age groups soon after the Tohoku earthquake and tsunami. The clinical and microbiological characteristics of the post-disaster patients were similar to those of the pre-disaster patients. The vast majority of the victims were older people. Because this disaster affected a notably aging population with the highest baseline pneumonia incidence rate, the disaster caused a drastic increase in the number of admissions and placed a heavy burden on local hospitals.

Although the causal mechanism was not fully established, our findings suggested that multiple factors have contributed to this outbreak. The largest increase in the pneumonia burden was observed in nursing home residents, the majority of which were older people with physical and mental limitations and needed assistance with daily activities. A sudden change in their living

Table 1 Characteristics of confirmed pneumonia cases by residence, before and after the 2011 Tohoku earthquake and tsunami, Kesennuma City, Miyagi, Japan

	Pre-disaster period (1 March 2010–10 March 2011)†			Post-disaster period (11 March–30 June 2011)†				
	Residential category*			Residential category**				Pre-disaster vs post-disaster period
Characteristics	Total (n=225)	Home (n=193)	Nursing home (n=32)	Total (n=217)	Home (n=117)	Nursing home (n=40)	Evacuation shelter (n=60)	p Value‡
Female sex (%)	98 (43.6)	77 (39.9)	21 (65.6)	93 (42.9)	46 (39.3)	26 (65)	21 (35)	0.882
Age category (%)								
18–49 years	13 (5.8)	12 (6.2)	1 (3.1)	4 (1.8)	3 (2.6)	0 (0)	1 (1.7)	0.161§
50–64 years	21 (9.3)	20 (10.4)	1 (3.1)	18 (8.3)	10 (8.6)	3 (7.5)	5 (8.3)	
65–79 years	61 (27.1)	56 (29)	5 (15.6)	67 (30.9)	32 (27.4)	6 (15)	29 (48.3)	
≥80 years	130 (57.8)	105 (54.4)	25 (78.1)	128 (59)	72 (61.5)	31 (77.5)	25 (41.7)	
Duration of symptoms before admission (%)								
≤2 days	109 (48.4)	91 (47.2)	18 (56.3)	114 (52.5)	59 (50.4)	25 (62.5)	30 (50)	0.434
3 days or more	109 (48.4)	96 (49.7)	13 (40.6)	98 (45.2)	54 (46.2)	14 (35)	30 (50)	
Antibiotics prescribed before admission (%)	32 (14.2)	23 (11.9)	9 (28.1)	29 (13.4)	7 (6)	10 (25)	12 (20)	0.794
With underlying conditions (%)	129 (57.3)	107 (55.4)	22 (68.7)	121 (55.8)	64 (54.7)	30 (75)	27 (45)	0.739
CURB65 score (%)								
3–5 (severe)	26 (11.6)	23 (11.9)	3 (9.4)	27 (12.4)	10 (8.6)	13 (32.5)	4 (6.7)	0.916
0–2 (less severe)	186 (82.7)	159 (82.4)	27 (84.4)	179 (82.5)	97 (82.9)	26 (65)	56 (93.3)	
Deceased (%)	39 (17.3)	31 (16.1)	8 (25)	52 (24)	28 (23.9)	18 (45)	6 (10)	0.085
Microbiological tests performed	145 (64.4)	129 (66.8)	16 (50)	139 (64.1)	74 (63.3)	22 (55)	43 (71.7)	0.932
Positive for *Streptococcus pneumoniae*¶	15 (6.7)	13 (6.7)	2 (6.3)	22 (10.1)	9 (7.7)	4 (10)	9 (15)	0.402
Positive for *Haemophilus influenzae*	3 (1.3)	3 (1.5)	0 (0)	14 (6.5)	7 (6)	0 (0)	7 (11.7)	0.013§
Positive for *Klebsiella pneumoniae*	8 (3.6)	6 (3.1)	2 (6.2)	11 (5.1)	5 (4.3)	4 (10)	2 (3.3)	0.698

*The characteristics differed by residential categories for gender (p=0.007) and pre-hospital antibiotic treatment (p=0.015).
†The pre-disaster and pos-disaster cases were categorised according to the date of onset. The near-drowning-related cases were excluded.
‡Characteristics were compared between the pre-disaster and post-disaster cases. χ^2 tests were performed unless otherwise indicated.
§Fisher's exact test.
¶Either a bacterial culture was isolated or a rapid urinary antigen test was positive.
**The characteristics differed by residential categories for gender (p=0.006), age group (p=0.012), pre-hospital antibiotic treatment (p=0.002), presence of underlying conditions (p=0.012), clinical severity (p<0.001) and fatality (p<0.001).

environment after the disaster, such as a lack of appropriate nutrition, the loss of regular medicines and a shortage of caregivers, must have worsened their conditions.[16] It should be noted that many caregivers were also victims who lost their families, friends and homes. This may have been reflected by the fact that the highest mortality rate among patients from nursing homes occurred in the early post-disaster period (results not shown). A high incidence was also observed in the residents of evacuation shelters. Crowding is a risk factor for *S pneumoniae* and *H influenzae* infection,[17 18] and we found that these pathogens, particularly *H influenzae*, were isolated more frequently in patients from evacuation shelters.

The increased incidence observed in all residential places suggests that other factors which were shared by all survivors have also played an important role. First, hypothermia is known to increase the risk of subsequent infections, including pneumonia.[19 20] On 11 March, it was snowing in northern Miyagi. All survivors were suddenly left without running water, gas, electricity or oil in freezing weather (−3 to −5°C at night; see online supplementary appendix figure 3). The majority of the evacuation shelters were not sufficiently equipped with heating and blankets immediately after the disaster. Second, people experience stress reactions after the disaster. Psychological stress weakens the immune system and may increase the risk of respiratory infections.[21 22] Third, the medical supply systems have drastically changed. Soon after the disaster, more than a hundred relief teams arrived in Kesennuma and initiated care for survivors; this change may have increased the chance of identifying patients with pneumonia.

The abovementioned reasons also explain the decline in pneumonia cases after May; the temperature increase, improvements in living conditions (water, gas and electricity had been fully restored by the end of May), recovery of medical supplies, and the decline in the number of evacuees reduced the risks of pneumonia. However, in our study, it was impossible to know what factors have truly contributed to this outbreak.

Pneumonia outbreaks after natural disasters have never been documented in the past. In 2005, Nishikiori and colleagues conducted a cross-sectional survey (n=3533 individuals) in Sri Lanka after the Indian Ocean tsunami,[23] and no deaths were reported between one week and two and a half months after the tsunami. The different findings in Sri Lanka may be explained by the difference in population structures. If we projected our age group-specific estimates onto a population in Sri Lanka, where the proportions of people aged ≥65 years and ≥80 years in 2004 were 7% and <0.5%, respectively, the overall impact on pneumonia admission and mortality would decrease by almost 80%. Therefore, it is plausible that the impact of

Table 2 Incidence of pneumonia hospitalisations and pneumonia-associated mortality among people aged ≥18 years before and after the 2011 Tohoku earthquake and tsunami, Kesennuma City, Miyagi, Japan

	Pre-disaster period (1 March 2010–10 March 2011)*			Post-disaster period (11 March 2011–30 June 2011)*			
	Pop.†	N‡	Weekly incidence rate§ (95% CI)	Pop.†	N‡	Weekly incidence rate§ (95% CI)	Rate ratio (95% CI)¶
Pneumonia hospitalisations							
Total	63365	305	9.2 (8 to 10.4)	61104	208	38.3 (28.6 to 48)	5.7 (3.9 to 8.4)
Age category (years)							
18–49	23354	14	1 (0.4 to 1.5)	22291	6	3.6 (-0.4 to 7.7)	10 (1.9 to 54.3)
50–64	17590	24	2.5 (1.3 to 3.6)	17245	18	7.3 (0.6 to 14)	6.1 (1.5 to 24.7)
65–79	15803	85	10.6 (8.2 to 13.1)	15241	62	62.6 (37.5 to 87.7)	6.2 (3.3 to 11.5)
80+	6618	182	52.3 (43.8 to 60.8)	6327	122	193.3 (129.1 to 257.5)	5.2 (3.2 to 8.5)
Residence location							
Home	62239	262	8.1 (7 to 9.2)	54460	111	21 (12.9 to 29)	2.7 (1.7 to 4.4)
Nursing home	1126	43	57 (38.6 to 75.5)	796	38	882.8 (481.3 to 1284.3)	28.2 (11.7 to 68)
Evacuation shelter	–	–	–	5848	59	328.7 (190.8 to 466.7)	10.2 (6.2 to 16.9)
Pneumonia-associated deaths							
Total	63365	55	1.6 (1.2 to 2.1)	61104	49	12.8 (7.5 to 18.1)	8.9 (4.4 to 17.8)
Age category (years)							
18–79	56747	13	0.4 (0.2 to 0.7)	54777	12	8.7 (3 to 14.4)	18.6 (5.3 to 64.9)
80-	6618	42	12 (8.5 to 15.5)	6327	37	66.3 (32.8 to 99.8)	6.7 (3 to 14.8)
Residence location							
Home	62239	46	1.4 (1 to 1.8)	54460	27	7.1 (2.7 to 11.5)	4.8 (2 to 11.2)
Nursing home	1126	9	12.4 (4.5 to 20.3)	796	17	555.2 (216.6 to 893.7)	40.6 (9.1 to 180.8)
Evacuation shelter	–	–	–	5848	5	80.6 (0.2 to 160.9)	11.6 (3.7 to 36.2)

*The pre-disaster and post-disaster cases were categorised according to the date of onset. The near-drowning-related cases were excluded.
†Population in 28 February 2011 for the pre-disaster period and in 31 May 2011 for the post-disaster period. The population in each residential category reflects the period average. Data provided by Kesennuma City Hall.
‡Number of patients living in Kesennuma.
§Per 100 000 people. Weekly incidence rates were estimated using segmented generalised linear Poisson regression models allowing for time trends and the change in the population size.
¶Rate ratios were estimated using segmented generalised linear Poisson regression models. Rate ratios for evacuation shelter residents were estimated using the overall pre-disaster incidence as a reference.

disasters on pneumonia incidence was overlooked in developing countries with relatively young populations.

A comparable event may have been observed in Japan after the Hanshin-Awaji earthquake that occurred in Hyogo Prefecture (where 15% of the population were aged ≥65 years) in January 1995. Among 1948 patients admitted for illness during the first 15 days after the earthquake, 418 (21%) had pneumonia. Their average age was 66 years,[24] although population-based impact estimates were unavailable. In contrast, no pneumonia outbreak was documented after Hurricane Katrina, which occurred during the summer.[25 26] Freezing temperatures may be a critical factor in pneumonia outbreaks after a disaster.

In our study, eight cases of near-drowning-related pneumonia were identified. Pneumonia associated with the aspiration of tsunami water drew global attention after a series of melioidosis cases among the Indian Ocean tsunami survivors was reported.[8–10] This condition has been sometimes referred to as 'tsunami lung', which is defined as pneumonia caused by the aspiration of tsunami water containing soil, oil and sewage.[27 28] However, there is no evidence that this condition is distinct from seawater drownings unrelated to tsunami disasters. Furthermore, the clinical characteristics of victims of the Indian Ocean tsunami may not be comparable to those of patients in settings where *Burkholderia pseudomallei* is not endemic, as in our case. Natural disasters do not cause new diseases that are not endemic to the affected area.[29–31] The term 'tsunami lung' must be used with caution to avoid media sensationalism.

The limitations of our study arise from the nature of hospital-based data collection. In Japan, 70% of the medical costs for people aged <70 years and 80–90% of the medical costs for people aged ≥70 years are covered by insurance,[32] and all medical fees for the disaster-affected people were waived after 11 March.[33] The cost was not a barrier to hospitalisation throughout the study period. Non-pneumonia diseases, such as heart failure, might have been misdiagnosed as pneumonia during the post-disaster period especially among older patients. However, the cases in this study were confirmed by experts using a standardised case definition, and the microbiological confirmation rate was similar between the pre-disaster and post-disaster period. Thus, the impact of misclassification and potential changes in admission criteria on our incidence estimates must be minimal. However, due to the limited microbiological data, the aetiology of our cases was not fully established.

Pneumonia and pneumonia-related deaths among older people have been overlooked in emergency preparedness and humanitarian responses, most likely because both are common events in this population. The key findings of our study are: disaster-affected people, especially those exposed to stressful living conditions, are at high risk of developing pneumonia and pneumonia-related death during the emergency phase of a disaster; and the pneumonia burden becomes substantial in areas with an aging population. This situation may arise in low-income and middle-income countries, as their populations are rapidly aging.[34] In addition to using the PPV23 or pneumococcal conjugate vaccine for disaster-affected populations, the provision of optimal living conditions, medical check-ups and oral hygiene care must be a priority for older people after natural disasters.[35]

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Supplementary Appendix

Appendix Table 1.
Microbiological profile of pneumonia hospitalisation cases before and after the 2011 Tohoku earthquake and tsunami, Kesennuma City.

Appendix Table 2. Comparisons of factors associated with death among patients hospitalised for pneumonia before and after the 2011 Tohoku earthquake and tsunami, Kesennuma City.

Appendix Figure 1.
Flow chart of study patients.

Appendix Figure 2.
Geographical distributions of patients hospitalised for pneumonia during the study period, Kesennuma City, Miyagi.

Appendix Figure 3.
Number of evacuees and daily cases by date of onset.

Appendix Table 1. Microbiological profile of patients hospitalised for pneumonia before and after the 2011 Tohoku earthquake and tsunami, Kesennuma City.

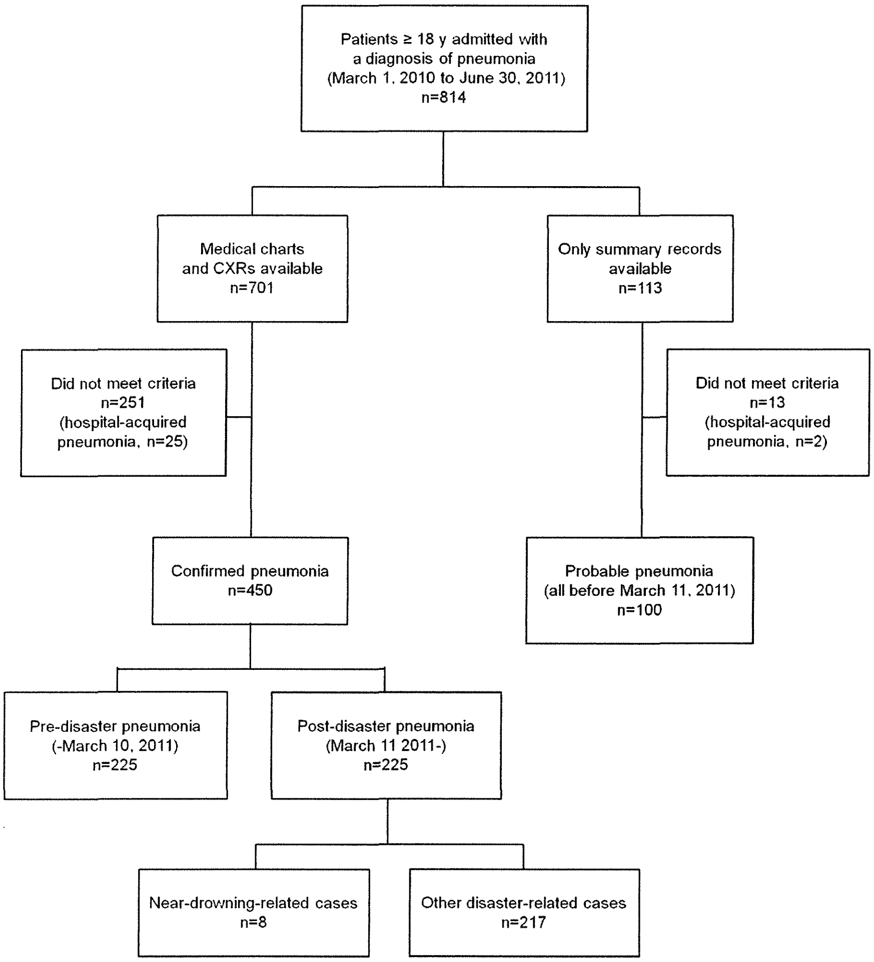
	Pre-disaster period (March 1, 2010-March 10, 2011) n=225			**Post-disaster period (March 11, 2011-June 30, 2011) n=217**		
Microbiological test	**No. positive/tested**	**% positive among those tested**	**% positive among total cases**	**No. positive/tested**	**% positive among those tested**	**% positive among all cases**
Sputum culture						
Staphylococcus aureus	16/93	17.2%	7.1%	14/91	15.4%	6.2%
Klebsiella pneumoniae	8/93	8.6%	3.6%	11/91	12.1%	4.9%
Streptococcus pneumoniae	7/93	7.5%	3.1%	14/91	15.4%	6.2%
Pseudomonas aeruginosa	6/93	6.5%	2.7%	3/91	3.3%	1.3%
Haemophilus influenzae	3/93	3.2%	1.3%	14/91	15.4%	6.2%
Enterobacter spp.	3/93	3.2%	1.3%	2/91	2.2%	0.9%
Acinetobacter spp.	3/93	3.2%	1.3%	2/91	2.2%	0.9%
E. coli	2/93	2.2%	0.9%	2/91	2.2%	0.9%
Other bacteria	13/93	14%	5.8%	10/91	11%	4.4%
Blood culture						
E. coli	1/22	4.5%	0.4%	0/8	0%	0%
Group G *Streptococcus*	0/22	0%	0%	1/8	12.5%	0.4%
Urinary antigen test for *S. pneumoniae*	12/67	17.9%	5.3%	17/84	20.2%	7.6%
Urinary antigen test for *Legionella pneumophila* serogroup 1	0/64	0%	0%	0/77	0%	0%
IgM antibodies to *Mycoplasma pneumoniae* (ImmunoCard *Mycoplasma* test)	12/69	17.4%	5.3%	2/29	6.9%	0.9%
Rapid influenza diagnostic test	0/24	0%	0%	0/38	0%	0%

Appendix Table 2. Comparisons of factors associated with death among patients hospitalised for pneumonia before and after the 2011 Tohoku earthquake and tsunami, Kesennuma City.

	Pre-disaster period (March 1, 2010-March 10, 2011), n=225			Post-disaster period (March 11, 2011-June 30, 2011), n=217			
	Deceased n (CFR*, %)	RR† (95%CI)	ARR‡ (95%CI)	Deceased n (CFR, %)	RR (95%CI)	ARR (95%CI)	Test for interaction
Gender							
Female	16 (16.3)	Ref.	Ref.	20 (21.5)	Ref.	Ref.	0.377
Male	23 (18.1)	1.11 (0.62 to 1.99)	1.16 (0.65 to 2.08)	32 (25.8)	1.2 (0.73 to 2)	1.62 (1 to 2.63)	
Age category							
15-64 years	1 (2.9)	Ref.	Ref.	2 (9)	Ref.	Ref.	0.742
65-79 years	9 (14.8)			11 (16.4)			
≥80 years	29 (22.3)	2.12 (1.08 to 4.14)	1.92 (0.93 to 3.97)	39 (30.5)	2.09 (1.18 to 3.68)	1.53 (0.86 to 2.74)	
Duration of symptoms before admission							
≤2 days	24 (22)	Ref.	Ref.	30 (26.3)	Ref.	Ref.	0.299
3 days or more	15 (13.8)	0.62 (0.35 to 1.13)	0.67 (0.36 to 1.22)	20 (20.4)	0.78 (0.47 to 1.28)	0.85 (0.52 to 1.39)	
Unknown	0 (0)	-	-	2 (40)	-	-	
Antibiotics prescribed before admission							
Yes	5 (15.6)	0.89 (0.37 to 2.1)	1.06 (0.43 to 2.6)	11 (37.9)	1.74 (1.01 to 2.98)	1.81 (1.04 to 3.15)	0.184
No	34 (17.6)	Ref.	Ref.	41 (21.8)	Ref.	Ref.	
Presence of underlying condition							
Yes	28 (21.7)	1.89 (0.99 to 3.62)	1.46 (0.79 to 2.72)	32 (26.5)	1.27 (0.78 to 2.07)	0.96 (0.6 to 1.54)	0.377
No	11 (11.5)	Ref.	Ref.	20 (20.8)	Ref.	Ref.	
CURB65 score							
3-5 (severe)	10 (38.5)	2.55 (1.41 to 4.63)	2.38 (1.34 to 4.23)	16 (59.3)	3.12 (2.02 to 4.83)	2.26 (1.4 to 3.64)	0.497
0-2 (less severe)	28 (15.1)	Ref.	Ref.	35 (19.4)	Ref.	Ref.	
Unknown	1 (7.7)	-	-	2 (18.2)	-	-	
Residence location							
Home	31 (16.1)	Ref.	Ref.	28 (23.9)	Ref.	Ref.	0.253
Nursing home	8 (25)	1.56 (0.79 to 3.08)	1.43 (0.74 to 2.75)	18 (45)	1.88 (1.17 to 3.01)	1.38 (0.79 to 2.42)	
Evacuation site	-	-	-	6 (10)	0.42 (0.18 to 0.96)	0.43 (0.18 to 1.01)	

* Case fatality ratio
† Risk ratio
‡ Adjusted risk ratio

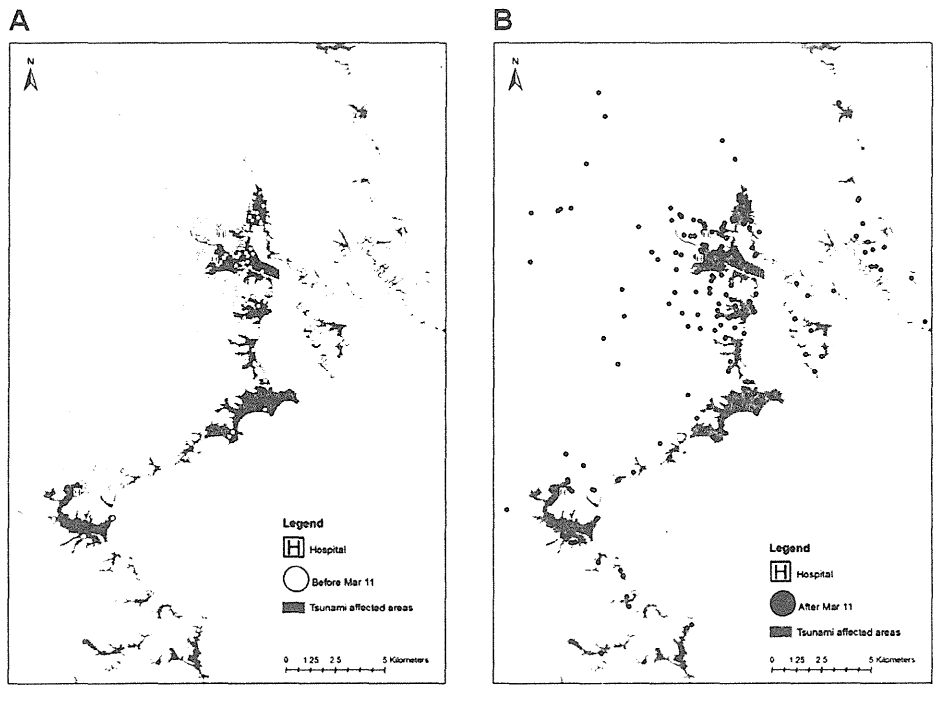
Appendix Figure 1. Flow chart of study patients.



Appendix Figure 2. Geographical distributions of patients hospitalised for pneumonia according to study period, Kesennuma City, Miyagi.

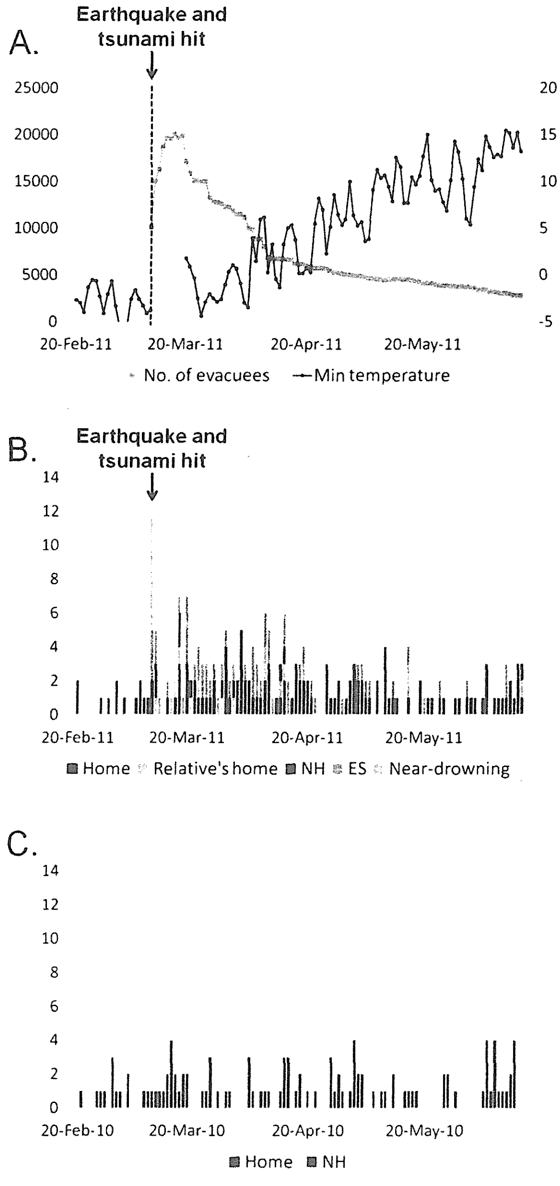
Cases were plotted according to the patients' addresses before the disaster. The disaster area data were obtained from the overview map of tsunami-affected areas released by the Geospatial Information Authority of Japan (http://www.gsi.go.jp/BOUSAI/h23_tohoku.html).

A: Pneumonia hospitalisations during the pre-disaster period (March 1, 2010, to March 10, 2011); B: Pneumonia hospitalisations during the post-disaster period (March 11, 2011, to June 30, 2011).



Appendix Figure 3. Number of evacuees and daily cases according to the date of onset.

A: Number of officially counted evacuees and daily minimum temperature. Climate data were obtained from the Japan Meteorological Agency. Temperature data were not available for the first week after March 11, 2011. B: Cases from February 20, 2011, to June 14, 2011. C: Cases from February 20, 2010, to June 14, 2010.
NH, nursing home; ES, evacuation shelter.



Home oxygen therapy during natural disasters: lessons from the great East Japan earthquake

To the Editors:

Oxygen therapy is given to patients with hypoxaemia caused by diseases such as chronic obstructive pulmonary disease, interstitial lung disease and cystic fibrosis [1]. In cases of natural disasters, patients receiving oxygen therapy in their homes can lose their stable oxygen supply for long periods of time due to power failure or equipment damage. Little has been established for the management of these patients during disasters. On March 11, 2011, a 9.0-magnitude earthquake and subsequent tsunami struck large parts of the east coast of Japan. Over 20,000 people died or were listed as missing following this disaster [2]. Here, we discuss the problems, based on our experience, in the management of patients receiving home oxygen therapy during disasters.

Avoiding treatment interruption during a disaster is essential in maintaining disease stabilisation for patients receiving oxygen therapy. In Japan, home oxygen therapy is widely used for patients with chronic respiratory failure and covered by the national healthcare insurance system [3]. Patients undergoing oxygen therapy are recommended to arrange for spare oxygen cylinders in case of electricity blackouts, and healthcare professionals, who manage respiratory care, can make such provisions in these cases. Since the Great Hanshin Earthquake of 1995, medical personnel and home oxygen service providers have recognised the importance of the management of oxygen-dependent patients during a disaster and have established emergency operation measures. The wide-scale disaster of March 2011, however, exceeded the presumed scenario.

In Ishinomaki, a port town in northeast Japan, more than 4,000 disaster victims visited the Japanese Red Cross Ishinomaki Hospital, a regional disaster medical centre, within a week of the earthquake. 70 patients receiving home oxygen therapy sought refuge at the hospital from March 11–14. Many offices of family physicians in Ishinomaki were destroyed by the tsunami. The interruption of traffic, causing isolation into divided regions, and the destruction of buildings prevented home oxygen providers from obtaining immediate access to sufficient oxygen cylinders for use during emergencies. The oxygen-dependent patients were, therefore, forced to seek refuge in the hospital.

All oxygen-dependent patients were triaged using the START (simple triage and rapid treatment) protocol [4] at the entrance hall of the hospital and brought into the outpatient ward. These patients received continuous oxygen supply *via* the medical gas central piping system. In the outpatient ward, the medical gas central piping system, the stocks of oxygen flow meters and room availability were insufficient for the unexpectedly high number of patients. Therefore, we contacted home oxygen providers *via* satellite phone and asked them to provide oxygen concentrators. On March 14, a temporary shelter was established inside the hospital using oxygen concentrators, and oxygen-dependent patients were transferred to the evacuation centre to receive oxygen therapy (fig. 1).

It is critical to prevent exacerbations in oxygen-dependent patients in order to avoid unnecessary critical care. Trained nurses were assigned to the evacuation centre to provide medical care and chest physicians took rounds in the area regularly. Appropriate infection prevention measures were applied to all patients and their families [5, 6]. Patients were evaluated for their drug adherence because many of them lost their prescribed drugs during the tsunami. Patient medication notebooks, which are provided by the registered Japanese health insurance pharmacies [7], recorded all prescriptions and proved to be useful for identifying regular medications.

Despite these procedures, there was a high incidence of symptom exacerbation in oxygen-dependent patients. In total, 83 chronic pulmonary disease patients who were dependent on oxygen support, including eight patients who underwent combined noninvasive positive pressure ventilation with long-term oxygen therapy, visited the hospital during the 15-day follow-up period. Of these, ~20% (17 out of 83 patients) experienced worsening of symptoms such as increased breathlessness, coughing, sputum production and high fever, thereby requiring additional treatments. None of these patients was found to have influenza. The most common causes of exacerbation were presumed to be tracheobronchial infection and treatment interruption. When the regional electrical power was restored, patients without symptom exacerbation returned home, and the evacuation centre for oxygen-dependent patients was closed on March 26. Patients who had been left homeless were transferred to nearby hospitals. Two patients in the terminal stage of chronic respiratory failure requiring ventilatory support at home underwent in-hospital care but died within 30 days of the disaster due to their exacerbations.

FIGURE 1. A temporary shelter for patients with oxygen therapy was established at the rehabilitation clinic of our hospital (Japanese Red Cross Ishinomaki Hospital, Ishinomaki, Japan).

In summary, we emphasise that patients requiring home oxygen therapy need significant healthcare resources and should come to a hospital to seek medical care in the case of a natural disaster. Community-based plans for patients receiving home oxygen therapy are required. We conclude that emergency physicians, as well as experts from various fields, should develop strategies together for the management of patients receiving oxygen therapy during natural disasters.

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