Seismic Intensity and Risk of Cerebrovascular Stroke: 1995 Hanshin-Awaji Earthquake

Shigeru Sokejima, MD;[1] Yoshimi Nakatani, MNSc;[2] Kazuomi Kario, MD;[3] Kazunori Kayaba, MD;[4] Masumi Minowa, MD;[5] Sadanobu Kagamimori, MD[2]

1. Department of Public Health Administration and Policy, National Institute of Public Health, Wako, Saitama, Japan
2. Department of Welfare Promotion and Epidemiology, Toyama Medical and Pharmaceutical University, Toyama, Japan
3. Department of Cardiology, Jichi Medical School, Minamikawachi-machi, Tochigiken, Japan
4. Department of Community and Family Medicine, Jichi Medical School, Minamikawachi-machi, Tochigiken, Japan
5. Department of Epidemiology, National Institute of Public Health, Wako, Saitama, Japan

Correspondence:
Dr. Shigeru Sokejima
Department of Public Health
Administration and Policy
National Institute of Public Health
2-3-6 Minami
Wako, Saitama, 351-0197 Japan
E-mail: sokejima@niph.go.jp

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Abbreviations:
CI = 95% confidence interval
EQ = 1995 Hanshin-Awaji earthquake
JMAI = Japan Meteorological Agency's intensity
MMI = modified Mercalli intensity
NHI = National Health Insurance
PGA = peak ground acceleration
PGV = peak ground velocity
RR = relative risk

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Abstract

Introduction: No epidemiological data exist concerning the influence of an earthquake on the risk of stroke. Whether the incidence of cerebrovascular stroke increased after the 1995 Hanshin-Awaji earthquake (EQ) in Japan and whether seismic intensity affected stroke risk dose-dependently was examined.

Methods: A retrospective cohort study was conducted among residents, who were living in two towns on the island of Awaji and were participants of the National Health Insurance (NHI) program. The two towns were divided into 11 districts and their respective damage and socioeconomic states were investigated. Reviewing the NHI documents issued before and after the EQ, people who had strokes (9th International Classification of Diseases, codes 430–431 or 433–434.9) were identified. Risk of stroke in relation to the seismic intensities, was assessed with the Cox proportional hazard model.

Results: Among subjects aged 40 to 99 years, 45 of 8,758 (0.514%) had a stroke the year before the EQ, 72 of 8,893 (0.810%) had a stroke in the first year following the EQ, and 49 of 8,710 (0.566%) had a stroke in the second year following the EQ. In districts where the earthquake's intensity was ≤9.5 on the modified Mercalli intensity (MMI), compared with the year prior to the EQ, the relative risk (RR) of stroke was 2.4 (95% confidence interval (CI) = 1.1, 5.0) in the first year following the EQ, after adjusting for age, gender, and income. In that year, compared with MMI of <8.5–9.0, RRs for 9.0–9.5 and ≥9.5 were 1.6 (CI = 0.9, 2.1) and 2.0 (CI = 1.1, 3.7), respectively (p for trend 0.02). No trend for the RR was observed in the year before the EQ or in the second year following the EQ.

Conclusion: The incidence of stroke increased in the first year following the EQ. The increase was associated with seismic intensity in a dose-response manner. Results suggest a potential threshold for RR of >2.0 in areas near 9.5 on the MMI scale.

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Introduction

On 17 January 1995, at 05:46 hours, the Great Hanshin-Awaji earthquake (EQ) jolted the island of Awaji, located in the Inland Sea of Japan.[1] Its epicenter was approximately 14 kilometers from the north end of the island, located 34 degrees latitude, 36 minutes North, and 135 degrees longitude, 2 minutes East. This earthquake was one of the strongest ever recorded in Japan, and its maximum seismic intensity in the northern and central part of the island was estimated to be seven on the Japan Meteorological Agency's intensity (JMAI) scale,[2] and >10 on the modified Mercalli intensity (MMI)

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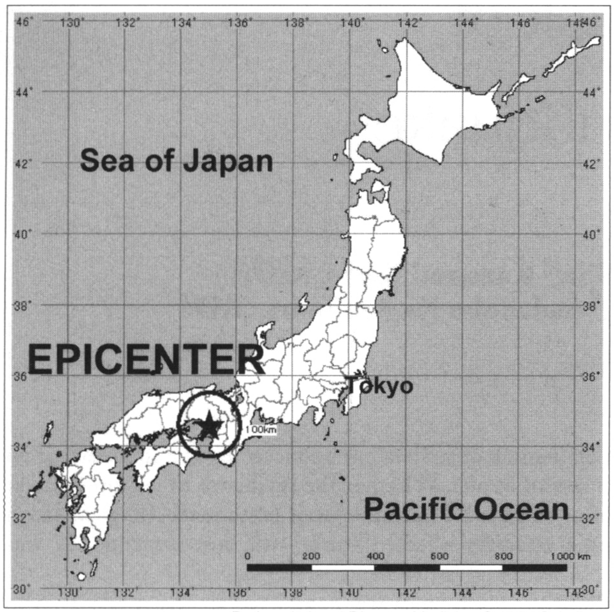

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Figure 1a—Location of the 1995 Hanshin-Awaji earthquake, 17 January 1995

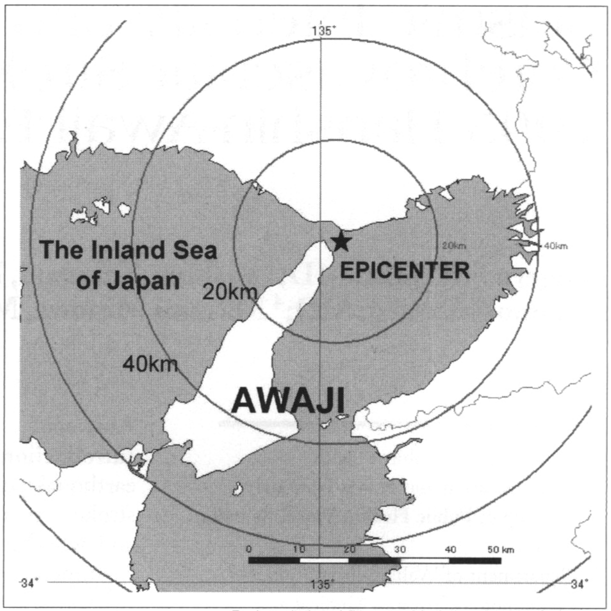

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Figure 1b—Enlarged view of location of the 1995 Hanshin-Awaji earthquake, 17 January 1995

scale.[3] The earthquake caused extensive destruction of housing in this area,[2,4] and a huge number of inhabitants were housed in refugee camps for up to several years.

A previous study observed increases in blood pressure, blood viscosity, and fibrin turnover among hypertensive patients following the EQ, compared with these indices in the same patients preceding the EQ.[5] These changes in values could represent risk factors not only for ischemic heart disease but also for stroke.[6–11] In addition, sustained societal disruption following the EQ might have presented barriers that made it difficult for some hypertensive patients to consult physicians on blood pressure management necessary to prevent stroke.[12,13] Although there have been reports of increased cases of acute myocardial infarction following an earthquake,[14–16] no study has detected an increase in the incidence of stroke or deaths from stroke after an earthquake.[16]

Determination of whether the risk of stroke might increase after a major earthquake may form the basis for public health and housing decisions after such an event. Although Kloner and colleagues did address the issue of stroke in association with earthquakes, their study focused on the risk of death due to stroke rather than on the incidence of stroke *per se*.[16] Armenian *et al* investigated the contribution of intensity of earthquake on heart diseases in a case-control study,[17] but the threshold of intensity of earthquake with regard to the risk of stroke is unstudied. It could be that the intensity of the earthquake was not so strong as to increase the risk of stroke in those previous studies. In examination of the relationship between the earthquake and the incidence of stroke, it would be useful to clarify the degree to which the intensity of the earthquake might contribute to an increase in the risk for stroke.

The general aim of this study was to examine the relationship between the earthquake and the subsequent increase in risk of stroke. A limitation of previous studies on the impact of an earthquake on health was that the studies did not investigate a dose-response relationship between the intensity of the earthquake and its health impact. Thus, whether there truly is no relationship between an earthquake and stroke risk has not been proven nor has it been clarified whether there is an intensity of earthquake at which stroke risk is increased. The hypothesis that stroke risk increased after earthquake and that the risk was higher in areas with higher seismic intensity of earthquake was examined.

Methods

Study Design and Population

A retrospective cohort study concerning the influence of strong ground motion caused by the EQ on the risk for stroke was performed. Subjects were recruited from residents who were: (1) ≥40 years old at the time of the EQ; (2) living in the town of Hokudan or Goshiki on the island of Awaji; and (3) enrolled in the National Health Insurance Program. The centre of Hokudan was located 14 km (8.5 miles, range 5–20 km) from the epicenter, and Goshiki was 33 km (20 miles, range 28–39 km) from the epicenter. Hokudan and Goshiki were divided into six and five administrative community districts, respectively, in order to investigate the relationship between the gradient of seismic intensity by district and the incidence of stroke.

By reviewing inhabitant ledgers and documents of the National Health Insurance program, the number of residents and also the number of residents enrolled in the National Health Insurance program by age and gender for

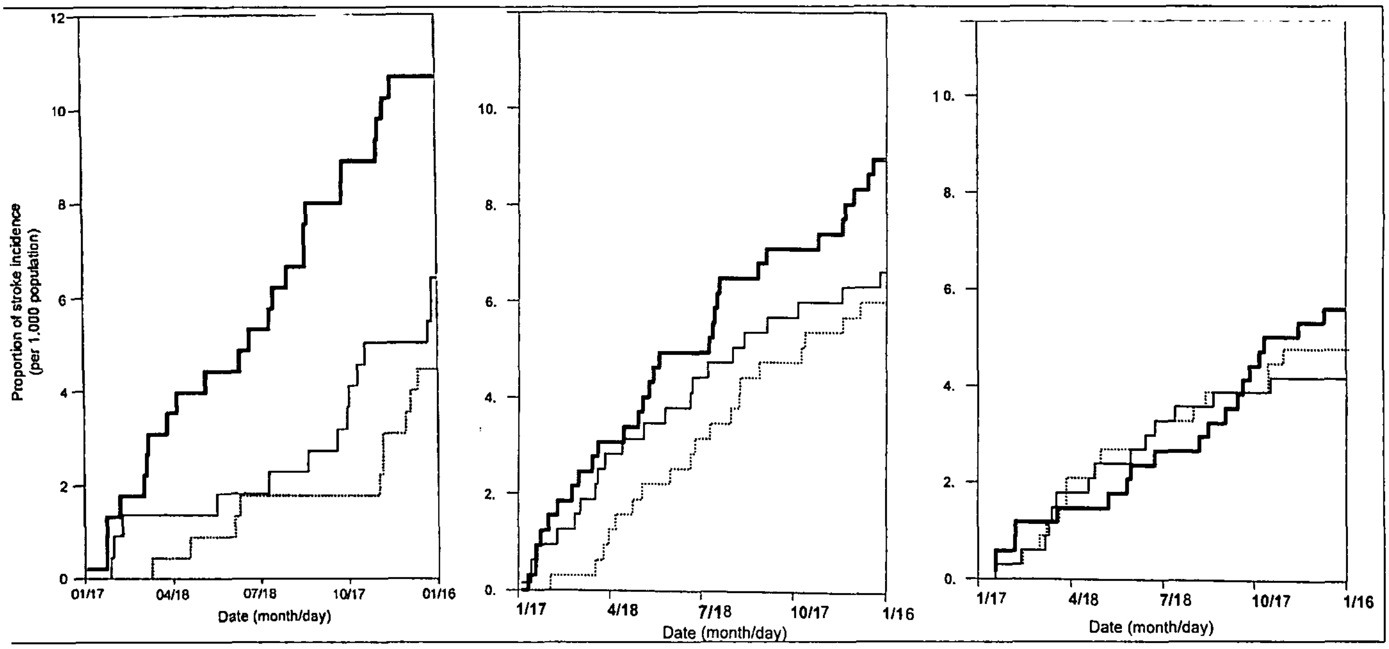

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Figure 2—Kaplan-Meier estimates of stroke incidence over time before and after the Hanshin-Awaji earthquake, which occurred on 17 January 1995. Curves are stratified by categories of seismic intensity in the modified Mercalli intensity (MMI) scale: (a) MMI <9.5 (strongest intensity); (b) MMI 9.0-9.4 (second strongest intensity); and (c) MMI <9.0 (third strongest intensity). Analysis of data shown was carried out without adjustment. Only in the category of (a), curves by year group were significantly unequal (log-rank test for the equality of curves by year; *p* = 0.03). ···Year immediately before earthquake (17 January 1994-16 January 1995); — 1st year after earthquake (17 January 1995-16 January 1996); — 2nd year after earthquake (17 January 1996-16 January 1997)

each district was determined. All citizens in Japan are required by law to subscribe to one of the medical care insurance programs. Among those programs, the largest is National Health Insurance, which mainly serves self-employed people, farmers, and the elderly.

All reports on patients in the National Health Insurance program were examined for documentation of a first cerebrovascular stroke for one year prior to the EQ and for two years after the EQ. The reports were compiled by the hospitals on the basis of medical records compiled by qualified medical doctors for the program. Each report included: (1) the name and address of the hospital; (2) gender; (3) birthdate; (4) district address; (5) National Health Insurance program identification number; (6) list of diagnoses; (7) dates on which diagnoses and subsequent treatments were begun; (8) details of diagnostic and treatment procedures; (9) number of days involved in both diagnosis and treatment; and (10) outcome.

From these records, the date of diagnosis of cerebrovascular stroke (9th International Classification of Diseases, 430–431 or 433–434.9), gender, and age at the time of diagnosis were abstracted. Stroke events were identified based on all of the following criteria: (1) diagnosis of cerebrovascular stroke; (2) patient admitted to a hospital; and (3) typical therapy prescribed for stroke.

Residents <40 years old were excluded from this study because of the rarity of stroke morbidity in this age group, and excluded residents ≥100 years old because of their rarity. All of the residents enrolled in the National Health Insurance Program participated in this study, and the proportions of participating residents relative to the entire population of the region were 67.6% for the year before the EQ, 68.5% for the first year after the EQ, and 68.8% for the second year after the EQ.

Exposure Assessment

Since the ground motion records were not sufficient in the affected areas studied, it was necessary to estimate the distribution of seismic intensity using other data sources. For this purpose, the prevalence of collapsed buildings in a given area was utilized. The local governments of Hokudan and Goshiki, using consistent criteria, had recorded the number and proportion of collapsed buildings for each community district. A completely collapsed building was defined in terms of one of two conditions: (1) whether the proportion of damaged to undamaged floors reached or exceeded 70%; or (2) whether damage to the main structure reached or exceeded 50%.[18] According to these definitions, the prevalence of collapsed buildings ranged from 2.9–45.0 percent for each community district (Table 1).

Fragility curve models between the prevalence of collapsed buildings and indices of ground motion had been developed and estimated by Yamaguchi and Yamazaki (Appendix).[2,19] By using these curves, instrumental seismic intensities on the JMAI scale, peak ground velocity (PGV) [cm/second], and peak ground acceleration (PGA) [cm/second^2] by community district were estimated (Table 1).

The equation of Shabestari was used to convert the seismic intensity on the JMAI scale to that on the MMI

Community District		No. of Buildings	Proportion of Collapsed Buildings (%)	Seismic Intensity*		PGV*	PGA*
No	Town			(JMAI scale)	(MMI scale)	(cm/s)	(cm/s^2)
1	Goshiki	903	2.9	5.9	8.6	55.3	452
2	Goshiki	296	3.7	5.9	8.7	57.7	476
3	Goshiki	722	5.7	6.0	8.8	62.4	521
4	Goshiki	351	7.1	6.0	8.9	65.1	549
5	Hokudan	265	7.9	6.0	9.0	66.5	563
6	Goshiki	872	9.5	6.1	9.0	69.0	588
7	Hokudan	570	18.2	6.2	9.3	79.7	698
8	Hokudan	798	23.9	6.3	9.4	85.2	757
9	Hokudan	678	26.1	6.3	9.5	87.2	777
10	Hokudan	382	37.4	6.4	9.6	96.4	877
11	Hokudan	917	45.0	6.4	9.7	102.1	939
Total		6,754	18.3				

Table 1—Distribution of collapsed buildings and seismic indicators in 11 community districts, the 1995 Hanshin-Awaji earthquake, Hokudan, and Goshiki. (JMAI = Japan Meteorological Agency's intensity; MMI = modified Mercalli intensity; PGV = peak ground velocity; PGA = peak ground acceleration; s = second; *JMAI, PGV, and PGA were estimated using the fragility curves between proportion of collapsed buildings and instrumental intensity indicators of earthquake that were developed by Yamaguchi[2] (Appendix A). MMI was derived from JMAI using newly proposed method by Shabestari.[3])

scale, which commonly is used in the United States and other countries (Table 1).[3] These estimated MMI values were consistent with those estimated from PGV and PGA by using the equation of Wald.[20] Then, the MMI values were divided into three categories: (1) strongest (≥ 9.5); (2) second strongest (9.0 to 9.5); and (3) third strongest (<8.5 to 9.0). These categories correspond approximately to (1) ≤ 6.3 JMAI, ≤ 85 PGV, ≤ 760 PGA; (2) 6.1–6.3 JMAI, 69–85 PGV, 590–760 PGA; and (3) ≤ 5.9–6.1 JMAI, ≤ 55–69 PGV, ≤ 450–590 PGA. The MMI scale subsequently was used to describe the results of the relation between ground motion and stroke risk.

Demographic Factors

To control for the influence of age and gender, the residents were categorized according to both age group and gender. Subjects were grouped into three age categories: (1) 40–64 years; (2) 65–74 years; and (3) 75–99 years. Subjects were divided according to gender without regard to age. To control for the influence of socioeconomic status, each community district was categorized into one of three groups according to yearly income: (1) low income community district of less than 1.08 million yen (US$9.39 thousand) per person; (2) "medium" income district of 1.08–1.14 million yen (US$9.39–9.91 thousand) per person; and (3) "high" income community district of greater than or equal to 1.15 million yen (US$10.00 thousand) per person. These income categories were selected in order to equalize the number of residents in each category as much as possible.

Statistical Analysis

Linear regression analyses of seismic intensity to the proportion of stroke patients were performed among the 11 community districts for three one-year periods: (1) year before the EQ (17 January 1994 to 16 January 1995); (2) first year after the EQ (17 January 1995 to 16 January 1996); (3) and second year after the EQ (17 January 1996 to 16 January 1997). Incidences of stroke patients were calculated according to categories of exposure to seismic

	Year before 1995 Hanshin-Awaji Earthquake		First year after 1995 Hanshin-Awaji Earthquake		Second year after 1995 Hanshin-Awaji Earthquake		Total	
Type of stroke	number of stroke patients	(%)	number of stroke patients	(%)	number of stroke patients	(%)	number of stroke patients	(%)
Cerebral infarction	31	(69)	62	(86)	34	(69)	127	(77)
Cerebral hemorrhage	12	(27)	6	(8)	12	(24)	30	(18)
Subarachnoid hemorrhage	1	(2)	3	(4)	3	(6)	7	(4)
Unknown type	1	(2)	1	(1)	0	(0)	2	(1)
Total	45	(100)	72	(100)	49	(100)	166	(100)

Table 2—Identification of stroke patients among residents aged 40 to 99 years, living near the epicenter of the 1995 Hanshin-Awaji earthquake, Hokudan and Goshiki, during a 3-year period (earthquake occurred on 17 January 1995)

Community District	Year before the EQ		Frst year after the EQ		Second year after the EQ	
	n	Incidence of stroke[a]	n	Incidence of stroke[a]	n	Incidence of stroke[a]
Number	17 January 1994	17 January 1994 -16 January 1994	17 January 1995	17 January 1995 -16 January 1996	17 January 1996	17 January 1996 -16 January 1997
1	1,094	0.9	1,084	3.7	1,091	1.8
2	364	2.8	405	2.5	367	5.5
3	1,042	6.7	1,046	9.6	1,041	7.7
4	463	8.6	459	2.2	456	4.4
5	393	7.6	397	7.6	400	0.0
6	1,085	4.6	1,148	10.5	1,073	8.4
7	929	12.9	929	10.8	923	8.7
8	1,149	1.7	1,167	6.0	1,173	3.4
9	815	3.7	815	9.8	800	5.0
10	441	4.5	447	9.0	434	2.3
11	983	5.1	996	12.1	952	9.5
Total	**8,758**	**5.1**	**8,893**	**8.1**	**8,710**	**5.6**
	Incidence = 0.7 MM[b] - 1.2 R^2 = 1%, p = 0.8[c]		Incidence = 5.9 MM[b] - 46.9 R^2 = 42%, p = 0.03[c]		Incidence = 1.9 MM[b] - 12.2 R^2 = 4%, p = 0.6[c]	

Table 3—Incidence of stroke patients among residents in 11 community districts one year before and two years after the 1995 Hanshin-Awaji earthquake, Hokudan and Goshiki. (EQ = 1995 Hanshin-Awaji earthquake, which occured on 17 January 1995; n = number; [a]Proportion of newly diagnosed stroke patients per year per 1,000 subjects;[b]Seismic intensity by means of modified Mercalli intensity scale in community district; [c]*p*-values are according to *F*-test)

	Year before the EQ			First year after the EQ			Second year after the EQ			p-value^{b}
	% of subjects (n = 8,758)	Incidence of stroke^{a}	95%CI	% of subjects (n = 8,893)	Incidence of stroke^{a}	95%CI	% of subjects (n = 8,710)	Incidence of stroke^{a}	95%CI	
Seismic intensity, modified Mercallii intensity										
8.5–9.0	38	4.8	2.4–7.1	38	5.6	3.1–8.1	39	4.2	2.0–6.4	0.7
9.0–9.5	36	6.0	3.3–8.7	37	8.9	5.7–12.2	36	6.6	3.8–9.5	0.3
≥9.5	26	4.5	1.7–7.2	25	10.6	6.4–14.9	25	6.4	3.1 ±9.8	0.04
Age (years)										
40–64	42	0.8	-0.1–1.7	41	2.7	1.0–4.4	40	1.4	0.2–2.7	0.1
65–74	29	4.7	2.0–7.3	31	7.0	3.9–10.1	32	6.2	3.3–9.1	0.6
≥75	29	11.8	0.6–16.0	28	17.0	12.0–22.1	29	10.9	6.8–15.0	0.1
Gender										
Female	55	6.2	4.0–8.4	55	8.0	5.5–10.5	55	6.0	3.9–8.2	0.4
Male	45	3.8	1.9–5.8	45	8.3	5.5–11.1	45	5.1	2.9–7.3	0.03
Average income of community^{c}										
Low	40	4.6	2.4–6.9	39	7.5	4.6–10.3	40	5.2	2.8–7.6	0.3
Middle	26	4.8	2.0–7.7	27	8.3	4.7–12.0	26	5.3	2.3–8.3	0.2
High	34	6.0	3.2–8.7	34	8.6	5.3–11.9	34	6.4	3.5–9.3	0.4
Total	**100**	**5.1**	**3.6–6.6**	**100**	**8.1**	**6.2–10.0**	**100**	**5.6**	**4.1–7.2**	**0.03**

Table 4—Incidence of stroke patients among residents, according to seismic intensity and demographic factors before and after the 1995 Hanshin-Awaji earthquake (EQ), Hokudan and Goshiki (CI = confidence interval; n = number; ^{a}Proportion of newly diagnosed stroke patients per year per 1,000 subjects; ^{b}p-value, according to Pearson's Chi-square test for equality of incidence rates of stroke between years; ^{c}Average income of community was divided into three categories: Low = <1.08 million yen (US$9.39 thousand) per person per year, Middle = 1.08–1.14 million yen (US$9.39–9.91 thousand) per person per year, High = ≥1.15 million yen (US$10.00 thousand) per person per year)

intensity, age, gender, and average income for each of the one-year periods. The Chi-square test was used to determine significant differences between the three years. The Kaplan-Meier method was used to compare cumulative incidence curves between year groups,[21] and statistical significance was determined using the log-rank test.[22] Subjects were followed from entry into the study (17 January) until occurrence of a stroke, or 16 January of the next year, whichever came first. The Cox proportional hazard model was used to examine the association of seismic intensity with subsequent morbidity risk, adjusted for age group, gender, and average income, and used the Wald test to determine the significance of the coefficient.[23] Seismic intensity was evaluated as both a continuous variable (with increase in risk calculated per increment of 0.1 on the MMI scale) and a categorical variable. Trend models were constructed to determine whether there was a continuous gradient of stroke risk across categories of seismic intensity. All reported p-values were two-sided. A p-value of >0.05 was considered to indicate statistical significance. All analyses were performed using the SPSS software (version 11.0J for Windows, SPSS, Inc., Chicago).[24]

Results

Of the 6,754 buildings in the study area, 1,235 were collapsed by the EQ. Seismic intensities in the 11 districts ranged from 8.6–9.7 (Table 1). During the three-year study period, 166 cases of newly diagnosed stroke (6.30/1,000 persons per study year) were documented (Table 2). Of the 166 cases of stroke, 127 (4.82/1,000/year) had cerebral infarction, 30 (1.14/1,000/year) had cerebral hemorrhage, seven (0.27/1,000/year) had subarachnoid hemorrhage, and the type of stroke was unknown in two patients. The number of cerebral infarction patients increased from 31 in the year before the EQ, to 62 in the year following the EQ, while the number of patients with cerebral bleeding decreased from 12 to six. Only one case of subarachnoid hemorrhage was noted in the year before the EQ, while

Time period and seismic intensities in relation to the EQ	Crude		Adjusted[a]	
	Relative risk	95% Confidence interval	Relative risk	95% Confidence interval
Area of greatest ground motion[b]				
Year before the EQ	1.00		1.00	
First year after the EQ	2.39	1.14–5.00	2.39	1.14–4.99
Second year after the EQ	1.44	0.64–3.23	1.48	0.66–3.33
Remaining area studied[c]				
Year before the EQ	1.00		1.00	
First year after the EQ	1.35	0.87–2.09	1.35	0.88–2.09
Second year after the EQ	1.00	0.63–1.60	0.99	0.62–1.58
First year after the earthquake, modified Mercalli intensity				
8.5–8.9	1.00		1.00	
9.0–9.4	1.60	0.90–2.86	1.61	0.90–2.88
≥9.5	1.90	1.04–3.47	2.01	1.10–3.68
p-value for trend	0.03		0.02	
Remaining years studied,[d] modified Mercalli intensity				
8.5–8.9	1.00		1.00	
9.0–9.4	1.42	0.88–2.27	1.44	0.89–2.32
≥9.5	1.21	0.71–2.07	1.30	0.76–2.23
p-value for trend	0.41		0.28	

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Table 5—Relative risks of stroke in relation to earthquake-related years and seismic intensity by the Cox proportional hazards regression model, the 1995 Hanshin-Awaji earthquake (EQ), Hokudan and Goshiki ([a]Adjusted for age, gender, and average income of community; [b]Seismic intensity ≥9.5 on the modified Mercalli intensity scale; [c]Seismic intensity 8.5–8.9 on the modified Mercalli intensity scale; [d]Year immediately before the earthquake and second year after the earthquake)

three were identified in the year following the EQ. In the following analysis, these stroke subgroups were combined into one group to investigate the association of all strokes with the EQ.

Annual incidence of stroke in the area studied was 5.1 per 1,000 population in the year before the EQ, 8.1 in the first year after the EQ, and 5.6 in the second year (Table 3). According to the linear regression analyses, seismic intensity explained 42% of the variation in the incidence of stroke by districts in the first year after the EQ, while no such contribution was observed in the other two years.

Table 4 and Figure 2 show the risk of stroke in each of the three years, according to three categories of seismic intensity. Residents living in the districts of strongest seismic intensity showed a significant change in the incidence of stroke during the three-year study period, while those living in other areas showed no significant change. The incidence in males, but not in females, increased after the EQ. Neither age nor average regional income of the community was associated with a significant change in incidence of stroke between the year before the EQ and the years after the EQ.

For the residents living in the area of the strongest seismic intensity, relative to the year before the EQ, the relative risk (RR) was 2.39 (95 % confidence interval (CI) = 1.14–5.02) in the first year after the EQ, and 1.48 (CI = 0.66–3.33) in the second year after the EQ (Table 5). Even after controlling for age, gender, and the district's average income, the RR stayed essentially the same. For residents living in the area of the second or the third strongest area of seismic intensity, no significant RR of stroke was observed in the years after the EQ.

During the first year after the EQ, the RR of stroke for residents in the area of the second strongest seismic intensity, after controlling for age, gender, and district's average income, was 1.61 (CI = 0.90–2.88) relative to the area of the third strongest seismic intensity. For the residents of the area of the strongest seismic intensity, the RR was 2.01 (range 1.10–3.68; p-value for trend = 0.02) (Table 5). No significant trend for the RR of stroke combined with increasing seismic intensity was recorded in either the year before the EQ or the second year after the EQ. When the variable of the seismic intensity in each community district is used as a continuous one, the RR according to a 0.1 of MMI scale was 1.55 (range 1.10–2.17; p-value = 0.01).

Discussion

The results of this study suggest that earthquake-induced risks of stroke in a given district are correlated with the intensity of earthquake, which was estimated by the prevalence of buildings collapsed in that district. Approximately half of the strokes in the year following the EQ could be attributed to earthquakes, in which seismic intensity was >9.5 on the MMI scale, which corresponded to areas where >25% of all houses collapsed. In summary, the results suggest a potential threshold for RR of greater than two, near

9.5 on the MMI scale. This is the first report to show a positive relationship between the seismic intensity of an earthquake and the risk of stroke.

Kloner *et al* showed no subsequent increase in the number of stroke deaths following the 1994 Northridge earthquake.[16] However, their study did not incorporate a gradation of seismic intensity into the analyses. Therefore, it is possible that the intensity of the earthquake did not exceed the threshold for an increase in stroke risk in certain areas examined. Therefore, the effects of the earthquake on health outcomes may not have been apparent through the dilution effect. This study did suggest a dose-response type of relationship between seismic intensity and stroke risk.

In addition, Kloner *et al's* study covered only the duration immediately after the earthquake.[16] This study, which covered a two-year period after the EQ, suggested that the tendency toward increased stroke risk continued for a year. Similar phenomena for mortality from all causes and from heart disease were observed following the 1988 earthquake in Armenia.[17] Therefore, if other studies had investigated a long-term change in stroke incidence after an earthquake, results may have differed. Of course, this is speculation, but perhaps future studies may consider long-term effects of earthquakes on stroke.

There may be a difference in the mechanisms by which an earthquake increases the risk of stroke between the acute and chronic period that follows such an event. While increases in blood pressure due to direct stress caused by ground motion may play important roles in the acute phase,[5,26–28] lack of blood pressure control in hypertensive patients also may play important roles in the chronic phase.[13] Accumulated psychosocial stress brought on by the process of rebuilding one's life after an earthquake might increase stroke risk, and this increase could be protracted, not only by the psychological stress induced by the earthquake itself, but by lingering socioeconomic upheaval.[29]

In the chronic phase following an earthquake, residential damage or life in a refugee camp might increase the risk of stroke in relation to weather and climate; for example, an earthquake could disable the cooling system in a house, which at the height of summer, might be hazardous.[30] It has been shown that meteorological conditions act as a trigger for events associated with circulatory disease.[31–34] Increased risk of acute myocardial infarction was shown in relation to the number of working hours and increases in working hours in a year.[35] Similar stresses caused by an earthquake also might influence the risk of stroke in the chronic phase. Further study is necessary to clarify the mechanism of these associations and to determine their relevance to the prevention of stroke.

The present study suggests gender-related differences in the risk of stroke after an earthquake. This point would be of interest in further investigations of the mechanism of association between stress caused by an earthquake and the risk of stroke. A number of studies have focused on gender differences in stress reaction both in humans and animals,[36–41] and recently, results indicates a role of housing conditions in gender differences in behavioral and neurochemical profiles after chronic stress in rats.[39] Collapsed houses rather than ground motion itself might play an important role in stress reactions in the chronic phase.

Accessible records contained both diagnostic and therapeutic procedures in detail, allowing the exclusion of cases that only were suspected to be stroke. Both stroke incidence and percentage, according to type of stroke in the year immediately before the EQ and in the second year after the EQ, when the influence of the earthquake was none or weaker than in the first year after the EQ, were consistent with those observed in a 15.5-year, follow-up study from 1977 to 1992 conducted in Japan.[42]

The subjects of the present study were limited to residents enrolled in the National Health Insurance program. This limitation might have resulted in a selection bias in this study, although the proportion of residents participating in this study was rather high (near 70 percent). Since this study was a retrospective cohort study, it was not possible to randomize subjects for exposure. It also was not possible to control possible confounding factors other than demographic factors on the results in the first year after the EQ. Therefore, the results might have been polluted by confounders. Control groups were formed both for spatial and for temporal comparisons concerning the influence of the EQ. This should increase the reliability of the results, although this study was restricted by the quasi-experimental design. Further investigation is needed to determine the relevance of the association found in this study to the prevention of stroke after an earthquake.

Conclusion

The incidence of stroke increased after the EQ and the increase was associated with seismic intensity in a dose-response manner. Results suggest a potential threshold for RR of greater than two near 9.5 on the MMI scale. Earthquake-induced risk of cerebrovascular stroke was observed for a year following the EQ, and the findings suggest that this risk might have been predicted in terms of the seismic intensity that was estimated from the prevalence of houses collapsed by the EQ. The positive association between seismic intensity and the increased risk of stroke after the EQ was assessed in the present study. Further study is necessary to clarify the mechanism of these associations and to determine their relevance to the prevention of stroke in such situations.

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Appendix

Yamaguchi and Yamazaki constructed fragility curves using the relationship between the ratio of collapsed buildings and the indices of ground motion in the earthquake.[2] For a value of ground motion index, *x*, the cumulative probability PR(x) of the incidence of damage equal to or higher than R, rate of collapsed buildings, was assumed to be normal for the JMAI and lognormal for the PGV and PGA as follows:

$$PR(JMAI) = \Phi((JMAI - \lambda_1)/ \zeta_1) \quad (1)$$

$$PR(PGA) = \Phi((\ln PGA - \lambda_2)/ \zeta_2) \quad (2)$$

$$PR(PGV) = \Phi((\ln PGV - \lambda_3)/ \zeta_3) \quad (3)$$

R: Rate of collapsed buildings

$\lambda_1 = 6.74$, $\zeta_1 = 0.403$, $R^2 = 0.821$

$\lambda_2 = 7.23$, $\zeta_2 = 0.511$, $R^2 = 0.659$

$\lambda_3 = 4.95$, $\zeta_3 = 0.429$, $R^2 = 0.912$

Where Φ is the cumulative probability of the standard normal distribution, and λ and ζ were the mean and the standard deviation of JMAI, PGA, or PGV. The two parameters of the distributions, i.e., λ and ζ, were determined by the least-squares method. The regression analysis for the rate of collapsed buildings was performed on the ground motion indices.