SUDDEN CARDIAC DEATH TRIGGERED BY AN EARTHQUAKE

Jonathan Leor, M.D., W. Kenneth Poole, Ph.D., and Robert A. Kloner, M.D., Ph.D.

Abstract *Background.* The earthquake that struck the Los Angeles area at 4:31 a.m. on January 17, 1994, was one of the strongest earthquakes ever recorded in a major city in North America. Once the life-threatening situation was over, the Northridge earthquake, so called because its epicenter was near Northridge, California, just north of Los Angeles, provided investigators an unusual opportunity to examine the relation between emotional stress and sudden cardiac death.

Methods. We reviewed the records of the Department of Coroner of Los Angeles County for the week before the earthquake, the day of the earthquake, the six days after the earthquake, and corresponding control periods in 1991, 1992, and 1993.

Results. On the day of the earthquake, there was a sharp increase in the number of sudden deaths from cardiac causes that were related to atherosclerotic cardiovascular disease, from a daily average ($\pm$SD) of 4.6 ± 2.1 in the preceding week to 24 on the day of the earthquake ($z=4.41$, $P<0.001$). Sixteen victims of sudden death either died or had premonitory symptoms, usually chest pain, within the first hour after the initial tremor. Only three sudden deaths occurred during or immediately after unusual physical exertion. During the six days after the earthquake, the number of sudden deaths declined to below the base-line value, to an average of 2.7 ± 1.2 per day.

Conclusions. The Northridge earthquake was a significant trigger of sudden death due to cardiac causes, independently of physical exertion. This finding, along with the unusually low incidence of such deaths in the week after the earthquake, suggests that emotional stress may precipitate cardiac events in people who are predisposed to such events. (N Engl J Med 1996;334:413-9.)

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O N January 17, 1994, at 4:31 a.m., Los Angeles County was jolted by an earthquake centered near Northridge, California — one of the strongest earthquakes ever recorded in a major city in North America.[1,2] In this unusual situation, millions of people were awakened simultaneously at 4:31 a.m. by a life-threatening situation; the earthquake created a "natural experiment," providing a rare opportunity to investigate features of the relation between emotional stress and sudden death due to cardiac causes.

Sudden death from cardiac causes is the leading cause of death due to cardiovascular disease in this country, resulting in more than 300,000 deaths per year.[3] Because many such deaths are unwitnessed, however, many features of the mechanism and onset of sudden death remain unclear. Muller, Tofler, Willich, and their associates[4-6] have suggested that certain "triggers" are responsible for the onset of sudden death. These investigators found a significantly higher incidence of myocardial infarction, ventricular tachyarrhythmias, and sudden death due to cardiac causes in the morning hours than at other times of day,[6-10] and they have suggested that these events may be triggered by increases in adrenergic activity, heart rate, systemic arterial pressure, and blood coagulability that occur in the morning.[6-8,11]

A few observational studies[12-18] have investigated mortality from cardiac causes after stressful events, with conflicting results. None of these studies, however, specifically investigated the relation between environmental stress and sudden death. The purpose of our study was to investigate the relation between widespread emotional stress experienced simultaneously in a defined population and the occurrence of sudden death from cardiac causes. To address this issue, we reviewed the records of the Department of Coroner of Los Angeles County, which compiles data on the circumstances, onset, and causes of death.

METHODS

Acquisition of Data

The Department of Coroner of Los Angeles County investigates cases of sudden, unexpected death, the deaths of persons who did not visit a physician in the 20-day period before they died, deaths not from natural causes, and cases in which the family doctor refuses to sign a death certificate. Most of the deaths take place outside the hospital.

We reviewed the daily mortality figures and determined the underlying causes of death, the age, and the sex of all persons whose deaths were investigated by the Los Angeles County coroner's office for the seven-day period before the earthquake (January 10 through 16, 1994), the day of the Northridge earthquake (January 17, 1994), and the six days thereafter (January 18 through 23, 1994); we obtained similar data for the corresponding period (January 10 through 23) in 1991, 1992, and 1993.

To study the details of the deaths listed as due to atherosclerotic cardiovascular disease or sudden death due to cardiac causes, we reviewed the case records of all such deaths from January 10 through 23, 1994. The coroner's records included case reports as well as brief medical histories and information derived from witnesses regarding the cir-
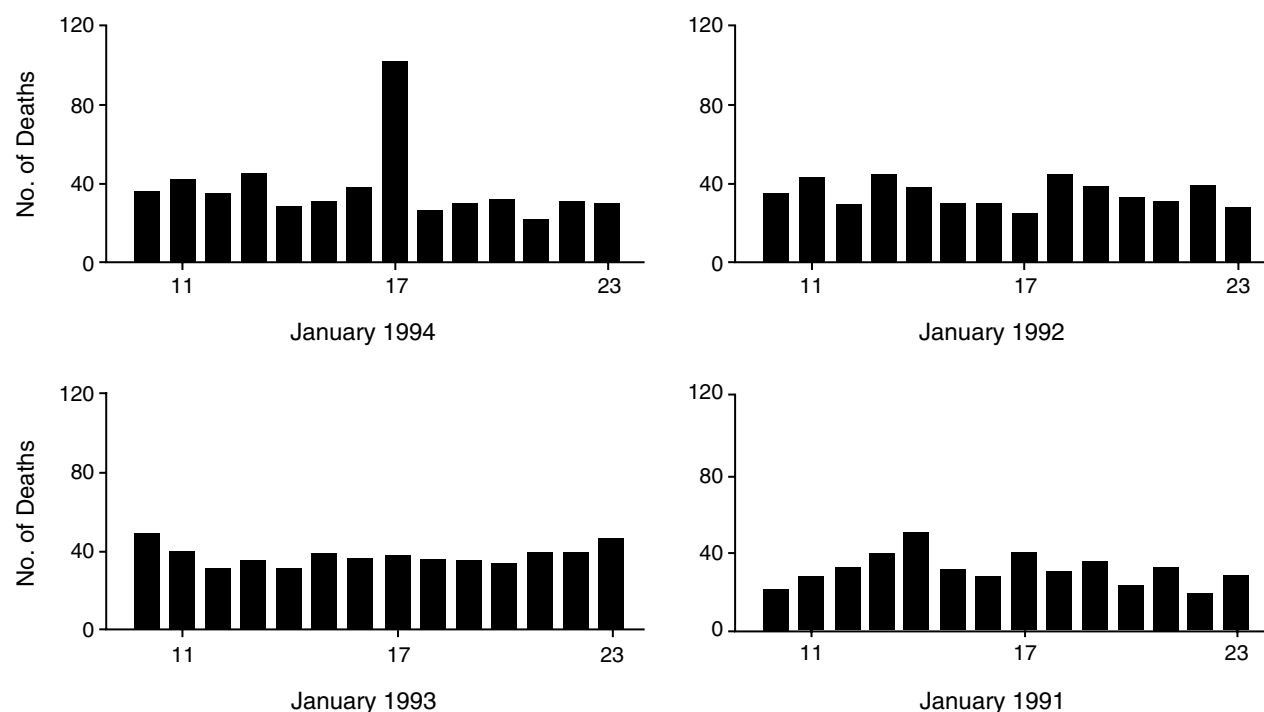
Figure 1. Daily Numbers of Deaths Listed by the Department of Coroner of Los Angeles County from January 10 through 23, 1991, 1992, 1993, and 1994.

There was a sharp rise in the total number of deaths (n = 101) on January 17, 1994, the day of the Northridge earthquake (relative risk of death on the day of the earthquake as compared with other days, 2.4; 95 percent confidence interval, 1.9 to 3.0).

cumstances, time, and mode of death. In addition, they included copies of death-investigation reports from the Los Angeles Police Department, emergency-medical-system records, emergency room records (when applicable), results of autopsies (if performed), and death certificates.

Definitions

We considered the specification of atherosclerotic cardiovascular disease as the underlying cause of death to be confirmed by one or more of the following: acute myocardial infarction or sudden death from cardiac causes (excluding known cardiomyopathy and valvular or congenital heart disease) as the cause of death; a history of myocardial infarction, angina pectoris, or coronary artery disease confirmed by coronary

Table 1. Causes of Deaths on the Day of the Northridge Earthquake (January 17, 1994) That Were Investigated by the Department of Coroner of Los Angeles County.

Cause of Death	Women	Men	Total
	number		
Atherosclerotic cardio-vascular disease (including sudden death)	18	33	51
Other cardiac causes	1	1	2
Rupture of aortic aneurysm	2	0	2
Trauma	12	17	29
Violence	0	3	3
Drugs or alcohol	0	1	1
Infectious disease	4	2	6
Cancer	0	1	1
Stroke	0	1	1
Other	2	3	5
Total	39	62	101

angiography or a noninvasive stress test; the results of an autopsy indicating the presence of coronary artery disease; and the exclusion of other lethal diseases in subjects who had at least one risk factor for atherosclerotic cardiovascular disease. The final criterion (exclusion of other lethal diseases) was required for the determination of death from atherosclerotic cardiovascular disease. Risk factors for atherosclerotic cardiovascular disease were diabetes mellitus, hypertension, smoking, hyperlipidemia, obesity, and an age greater than 50 years.

Sudden death from cardiac causes was defined according to the classification of the Framingham Heart Study.[8] All four of the following conditions had to be met: the subject had been apparently well and stable; the subject had died within one hour after the onset of acute symptoms; the death had been witnessed; and the death could not be attributed to some potentially lethal disease other than atherosclerotic cardiovascular disease or cardiomyopathy.

Statistical Analysis

All statistical analyses were carried out at Research Triangle Institute, Research Triangle Park, North Carolina. Chi-square tests or two-tailed Fisher's exact tests were used to compare categorical data. Continuous variables, such as age, were compared by means of t-tests.

To calculate the relative risk of death from a specific cause, we constructed two-by-two tables; 95 percent confidence intervals were calculated for relative risks.[19]

To assess the differences between the number of sudden deaths from cardiac causes on the day of the earthquake and the daily averages before and after the earthquake, we assumed that the numbers of sudden deaths due to cardiac causes in these three periods divided by the total number of sudden cardiac deaths in the two-week period were trinomial proportions. Two questions of interest were whether the proportion of deaths occurring on the day of the earthquake was the same as the average daily proportion for the previous week, and whether it was the same as the average for the subsequent six days. Hence, we computed two z statistics for these two tests, taking into consideration that the proportions were correlated and that the two proportions in each comparison were computed for periods of different lengths. We assumed that the sample sizes were large enough to use the normal distribution in calculating the two-tailed P values for these tests.

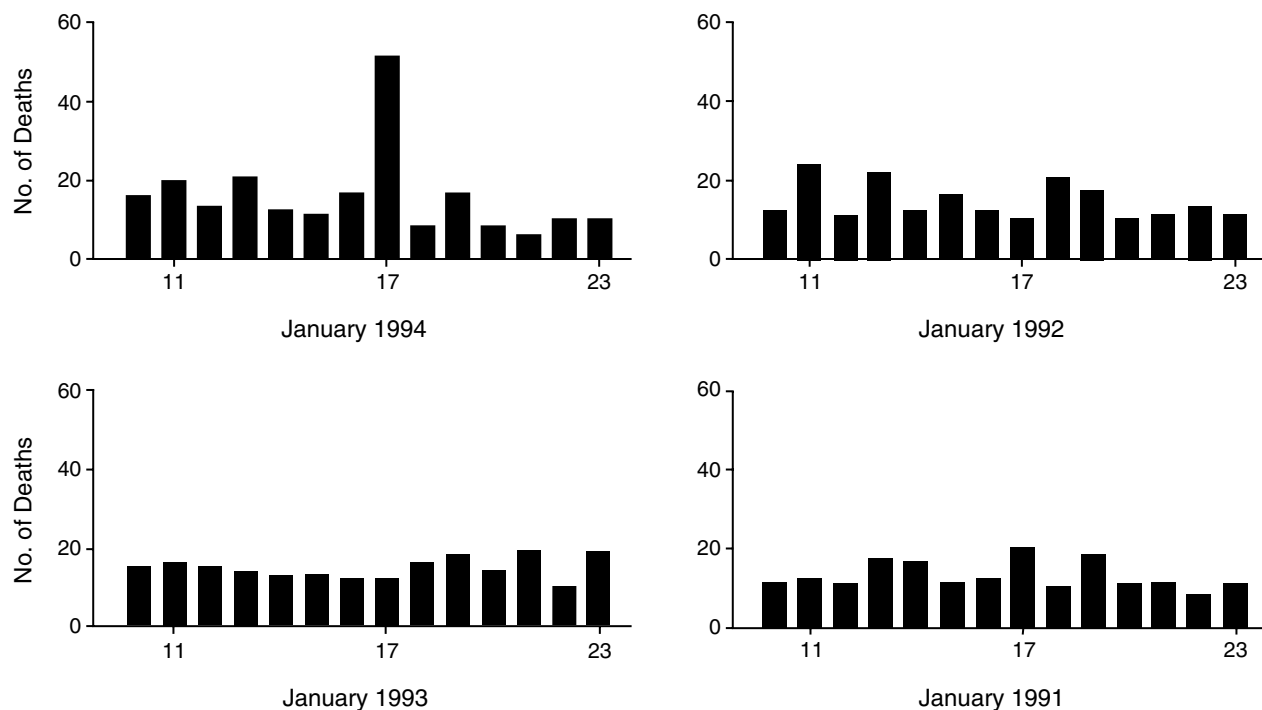A similar strategy was used for other causes of death and for the

Figure 2. Daily Numbers of Deaths Found to Be Related to Atherosclerotic Cardiovascular Disease from January 10 through 23, 1991, 1992, 1993, and 1994.

On the day of the earthquake (January 17, 1994), there was a sharp rise in the number of deaths related to atherosclerotic cardiovascular disease (n = 51; relative risk, 2.6; 95 percent confidence interval, 1.8 to 3.7). The daily number of deaths related to atherosclerotic cardiovascular disease declined in the six days after the earthquake (z = 3.15, P = 0.002).

comparison of deaths before and after the earthquake. All tests were two-sided. Results are presented as means ±SD.

RESULTS

A total of 1952 deaths were investigated by the Department of Coroner of Los Angeles County during the week before the earthquake (January 10 through 16, 1994), the week beginning with the earthquake (January 17 through 23, 1994), and the same periods in 1991, 1992, and 1993.

Deaths Investigated by the Coroner on the Day of the Earthquake

Figure 1 shows the number of deaths investigated by the coroner that occurred each day from January 10 through 23, 1994, and during the control periods. There was a sharp increase in the number of deaths, from a daily average of 35.7±5.9 during the seven days before the 1994 Northridge earthquake to 101 deaths on the day of the earthquake (relative risk of death on the day of the earthquake, as compared with previous years, 2.4; 95 percent confidence interval, 1.9 to 3.0).

Table 1 shows the causes of deaths assigned by the coroner's office on the day of the earthquake. Fifty percent of the deaths (n = 51) were found to be related to underlying atherosclerotic cardiovascular disease. Not surprisingly, trauma was the second most frequent cause of death assigned by the coroner (n = 29).

Deaths Related to Atherosclerotic Cardiovascular Disease

There were 109 deaths due to atherosclerotic cardiovascular disease during the week before the earthquake

and 109 during the week of the earthquake. However, analysis of the number of deaths each day that were determined to be related to atherosclerotic cardiovascular disease (Fig. 2) revealed a sharp increase, from an average of 15.6±3.9 deaths per day during the seven days before the earthquake to 51 on the day of the earthquake (relative risk as compared with the same period in previous years, 2.6; 95 percent confidence interval,
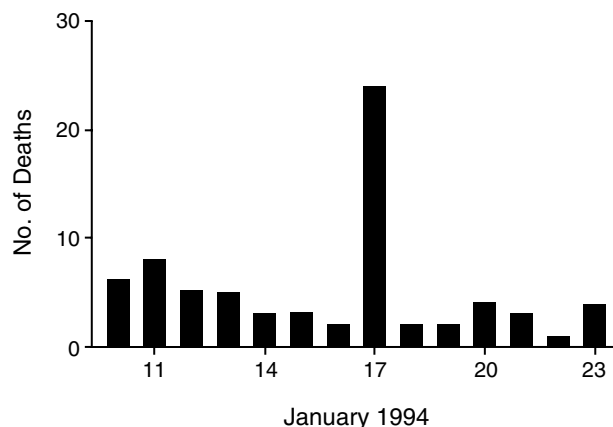

Figure 3. Daily Numbers of Sudden Deaths Related to Atherosclerotic Cardiovascular Disease from January 10 through 23, 1994.

On January 17, the day of the earthquake, there were 24 cases of sudden death related to atherosclerotic cardiovascular disease (z = 4.41, P<0.001). There was a decline in number of sudden deaths on each of the six days after the earthquake (z = 1.73, P = 0.084).

Table 2. Characteristics of 25 People with Witnessed Sudden Death Due to Cardiac Causes on the Day
of the Earthquake.*

CASE NO.	AGE (YR)	SEX	TIME OF DEATH	TIME TO ONSET OF SYMPTOMS AFTER THE EARTHQUAKE (HR)	RISK FACTORS FOR ATHEROSCLEROTIC CARDIOVASCULAR DISEASE	HISTORY OF ATHEROSCLEROTIC CARDIOVASCULAR DISEASE	PHYSICAL EXERTION BEFORE ONSET	PREMONITORY SYMPTOMS
1	66	Female	5:00 a.m.	0–1	Yes	No	No	No
2	66	Male	6:56 a.m.	1–2	Yes	No	No	Chest pain
3	62	Male	5:00 a.m.	0–1	Yes	No	Yes	No
4	68	Male	7:00 a.m.	0–1	Yes	Yes	Yes	Chest pain
5	45	Male	5:12 a.m.	0–1	No	Yes	No	No
6	47	Male	12:15 p.m.	0–1	Yes	No	No	Chest pain
7	59	Male	5:30 a.m.	0–1	Yes	No	No	No
8	83	Female	5:50 a.m.	0–1	Yes	Yes	No	No
9	56	Male	7:55 p.m.	14–15	Yes	No	No	Chest pain
10	79	Male	10:45 a.m.	4–6	Yes	Yes	Yes	No
11	92	Female	6:00 a.m.	0–1	Yes	No	No	Chest pain, dyspnea
12	67	Male	6:35 a.m.	1–2	Yes	Yes	No	No
13	71	Male	11:05 p.m.	18–19	Yes	No	No	No
14	64	Male	4:31 a.m.	0–1	Yes	Yes	No	Chest pain
15	80	Female	10:36 p.m.	17–18	Yes	Yes	No	Chest pain, dyspnea
16	75	Male	5:23 a.m.	0–1	Yes	No	No	Dyspnea
17	84	Female	6:30 a.m.	0–1	Yes	Yes	No	Chest pain
18	55	Male	5:30 a.m.	0–1	Yes	No	No	Dyspnea
19	79	Male	4:25 a.m.	Not relevant†	Yes	Yes	No	Chest pain
20	90	Male	5:20 a.m.	0–1	Yes	No	No	No
21	51	Male	5:45 a.m.	0–1	Yes	No	No	Chest pain
22	75	Female	5:24 p.m.	11–12	Yes	No	No	Dizziness
23	56	Male	7:00 a.m.	0–1	Yes	Yes	No	No
24	62	Male	5:32 a.m.	0–1	Yes	No	No	No
25	38	Male	11:10 a.m.	5–6	No	No	No	Dyspnea

*All deaths were related to atherosclerotic cardiovascular disease, except that in Case 25, in which an autopsy disclosed hypertrophic cardiomyopathy. The time of death shown in the table is that recorded on the death certificate or the patient's records. "Onset of symptoms" refers to premonitory symptoms or sudden death. In some cases the time of death recorded on the death certificate was later than the time of the victim's collapse (Cases 4, 6, 8, and 23).

†This death occurred before the earthquake.

1.8 to 3.7). The average age of those who died from atherosclerotic cardiovascular disease was 70.2±13.5 years, and 33 (65 percent) were men. These age and sex characteristics were similar to those of the people who died during the week before the earthquake and during the control periods (age, 69.8±13.6 years; 62 percent male). This similarity suggests that the increase in the number of deaths on the day of the earthquake occurred among people already at risk of death from atherosclerotic cardiovascular disease.

The average daily number of deaths determined by the coroner's office to be due to atherosclerotic cardiovascular disease declined from the seven days before the earthquake to the six days after it (from 15.6±3.9 to 9.7±3.4, z=3.15, P=0.002). This pattern — a sharp increase in the number of deaths, followed by a decrease — suggests that the earthquake precipitated death among people who were at risk of dying during the week of the earthquake. Because of this trigger, they died a few days earlier.

Sudden Death Due to Cardiac Causes

Figure 3 shows the number of sudden deaths related to atherosclerotic cardiovascular disease each day from January 10 through January 23, 1994. Of the 51 deaths from atherosclerotic cardiovascular disease on the day of the earthquake, 24 (47 percent) were witnessed sudden deaths. This number was unusually high as compared with the coroner's office average of 4.6±2.1 sudden deaths per day in the week before the earthquake (z=4.41, P<0.001). Another case of sudden death on the day of the earthquake was related to hypertrophic cardiomyopathy.

Table 2 shows the characteristics of the 25 persons who died suddenly. Twenty-four of the 25 subjects had either risk factors for or a history of atherosclerotic cardiovascular disease. The average age of the victims of sudden death who had atherosclerotic heart disease was 68.0±13.1 years. There were 18 men (75 percent; age, 64.0±11.8 years) and 6 women (25 percent; age, 80.0±8.8 years; P=0.006 for the comparison between the sexes).

The age and sex distribution of these persons who died suddenly on the day of the earthquake were similar to that of those who died during the seven days before the earthquake (age, 62.9±13.6 years; 69 percent male).

Only one case of sudden death due to cardiac causes on January 17, 1994, occurred before 4:31 a.m., the time the earthquake began (Table 2, Case 19). In two thirds of the cases related to atherosclerosis (16 of 24), symptoms developed or the victim died immediately or within the first hour after the earthquake. In two other cases,

symptoms started during the second hour. Chest pain was the most frequent premonitory symptom. Of the 13 people with atherosclerotic heart disease who had premonitory symptoms before dying suddenly, 10 (77 percent) were reported to have had chest pain (Table 2). Three sudden deaths occurred during unusual physical exertion, such as running out of a shaking house or cleaning up earthquake debris, but the remaining deaths were not associated with unusual physical effort and may have been related to emotional stress.

Figure 4 shows the distribution of the times of day when sudden death occurred (as noted on the death certificates or in the victims' medical records) on the day of the earthquake and during the seven days before the earthquake. Over half the deaths related to atherosclerosis on the day of the earthquake (13 of 24) occurred between midnight and 6 a.m., whereas only 3 of 32 deaths (9 percent) during the seven days before the earthquake occurred during this period (P=0.002).

We also analyzed the locations of sudden deaths. Whereas on the day of the earthquake 13 of the 23 deaths with known locations (57 percent) occurred within 15 miles of the epicenter of the earthquake, only 1 of 31 deaths during the seven days before the earthquake (3 percent) occurred within this radius (P<0.001).

There were 17 additional cases of possible (unwitnessed) sudden death due to cardiac causes on the day of the earthquake. The circumstances in these cases suggested strongly that sudden death was associated with the earthquake; most of the victims were found dead within the first four hours after the earthquake.

Role of Daily Triggers in Causing Sudden Death Related to Atherosclerotic Cardiovascular Disease

There was a "compensatory deficit" in the number of sudden deaths due to atherosclerotic cardiovascular disease that were recorded by the coroner's office in the six days after the earthquake (Fig. 3). The number of such sudden deaths declined from 32 in the week before the earthquake (average, 4.6±2.1 per day) to 16 in the six days after the earthquake (average, 2.7±1.2 per day) (z=1.73, P=0.084). This decrease suggests, once again, that people who were at risk for sudden death due to cardiac causes during that week died several days earlier as a result of the earthquake.

On the basis of these findings, we hypothesized that under ordinary circumstances a certain fraction of sudden deaths are initiated by a triggering mechanism. To quantify that fraction, we used the average number of sudden deaths per day in the seven days before the earthquake (4.6) to estimate the average number of deaths that would have occurred each day from January 18 through January 23, 1994, if the earthquake had not occurred. From this number we subtracted the average number of sudden deaths that did occur per day in the six days after the earthquake (2.7). Thus, we estimate that there were 1.9 fewer deaths per day during the six days after the earthquake than there would otherwise have been. In the absence of a major stressor, such as an earthquake, therefore, 41 percent (1.9÷4.6) of sudden deaths may be related to triggers. Similarly, we estimate that approximately five deaths would have oc-
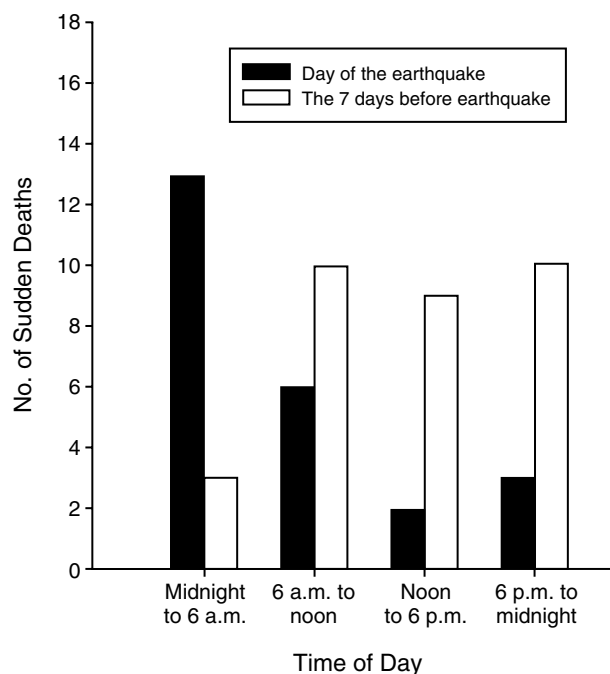

Figure 4. Times of Sudden Deaths Related to Atherosclerotic Cardiovascular Disease on the Day of the Earthquake and the Seven Days before the Earthquake.

Over half the deaths related to atherosclerosis (13 of 24) on the day of the earthquake occurred between midnight and 6 a.m., whereas only 3 of 32 (9 percent) of the deaths during the seven days before the earthquake occurred at that time of day (P=0.002).

curred on January 17, 1994, if the earthquake had not occurred. Subtracting 5 from the number of sudden deaths that did occur (24), we estimate that 19 of the sudden deaths due to atherosclerotic cardiovascular disease that took place on January 17, 1994, could be attributed to the earthquake.

Deaths Due to Other Causes

Figure 5 shows the number of deaths due to trauma for each day from January 10 through January 23 in 1991, 1992, 1993, and 1994. As expected, there was a significant increase in the number of deaths due to trauma (n=29) on the day of the earthquake (relative risk, 6.1; 95 percent confidence interval, 2.7 to 13.5). In contrast, there was no significant difference in the number of deaths due to other causes, such as violence, alcohol or drugs, and cancer, between the day of the earthquake and the average for the days during the control periods (data not shown).

DISCUSSION

The Northridge earthquake provided an unusual opportunity to study features of the relation between emotional stress and the triggering of sudden death due to cardiac causes. The information we obtained from the Department of Coroner of Los Angeles County indicated that there was a sharp increase — to five times the previous average — in the number of sudden deaths due to cardiac causes on the day of the earthquake. The length of time between the trigger (the earthquake) and sudden death was, in most of the cases, less than an
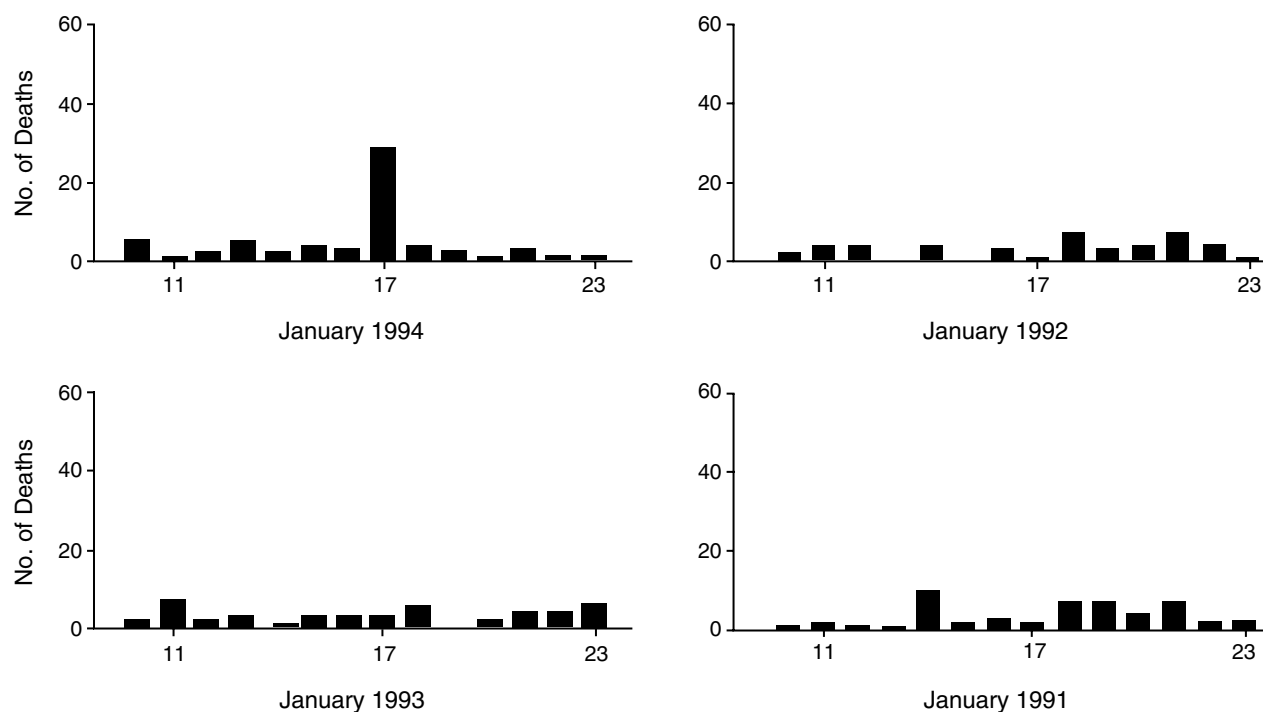
Figure 5. Daily Numbers of Deaths Due to Trauma from January 10 through 23, 1991, 1992, 1993, and 1994.
There was a significant increase in the number of deaths due to trauma (n=29) on January 17, 1994, the day of the earthquake (relative risk, 6.1; 95 percent confidence interval, 2.7 to 13.5).

hour. Unusual physical exertion was an uncommon trigger. On the basis of the unusual pattern of mortality in the weeks surrounding the earthquake, we estimated that such triggering is likely to play a part in a substantial proportion (>40 percent) of cases of sudden death due to cardiac causes under ordinary circumstances. The pattern of mortality and the characteristics of the victims suggest that the earthquake precipitated death primarily in people already at risk for sudden death.

The direct association between the earthquake and the onset of sudden death due to cardiac causes was further supported by other findings. These included the obliteration of the "normal" circadian variation in the incidence of sudden death, with a significant increase in number of deaths that occurred during the first quarter of the day, and the relative increase in the number of sudden deaths occurring within a 15-mile radius of the epicenter near Northridge.

Stress as a Trigger for Sudden Death

Muller, Tofler, Willich, and their associates[4-6] have suggested that both the act of waking and emotional or physical stress can trigger the onset of cardiac events, perhaps by stimulating the release of catecholamines and hypercoagulability factors that may contribute to the rupture of a vulnerable atherosclerotic plaque and subsequent coronary-artery thrombosis.[11,20] Such a triggering mechanism is likely to have played a part in the increased number of sudden deaths and deaths associated with atherosclerotic cardiovascular disease on the day of the Northridge earthquake. The hypothesis that such triggering occurred is supported by our observation of a 35 percent increase in the number of hospital admis-

sions for acute myocardial infarction in 72 coronary care units in southern California in the week after the earthquake.[21] In another study, we detected an increase in the number of episodes of ventricular tachycardia or fibrillation among patients with implantable cardioverter–defibrillators during the two weeks after the earthquake.[22] The precipitation of myocardial ischemia and serious arrhythmias by emotional stress is the most likely underlying mechanism for these observations.

Comparison with Previous Observations

Although anecdotal case reports have suggested that mental or emotional stress can trigger sudden death, the few observational studies of mortality from cardiac causes after extremely stressful events such as earthquakes or wars have yielded conflicting conclusions.[12-18] Whereas some investigators[14,16,17] have failed to find a significant association between the event and an increased risk of mortality due to cardiac causes, others[12,13,15,18] have suggested that such an association does exist. These investigators, however, studied total mortality due to cardiac causes. Our study, on the other hand, focused on sudden death due to cardiac causes.

Limitations of the Study

The Department of Coroner of Los Angeles County did not investigate all deaths in Los Angeles County but, rather, cases in several defined categories. The increase in the number of deaths related to trauma during the earthquake that were investigated by the coroner's office suggests that its records reflect actual changes in daily mortality.

One might speculate that the Department of Coroner

was more active because of the earthquake and that this factor accounts for the increase in deaths in its records. If such were the case, however, we would anticipate a similar increase in deaths due to other causes, such as violence, drugs or alcohol, and cancer. No such rise was observed.

Preliminary results of other studies we are conducting provide further support for our conclusions in the present study. These observations suggest that the occurrence of sudden death due to cardiac causes after the earthquake was related to an increase in incidence of ischemic episodes[21] and serious arrhythmias.[22]

Another important limitation is the fact that most of the people who died suddenly on the day of the earthquake were not examined by autopsy. The finding that 10 of 24 (42 percent) of the patients who died suddenly from atherosclerotic cardiac causes had chest pain before death suggests that myocardial ischemia was involved. This finding is compatible with the association observed by others between myocardial ischemia and sudden death.[23,24]

Practical Considerations and Future Implications

Our findings suggest that a substantial fraction (41 percent) of sudden deaths in persons with atherosclerotic cardiovascular disease that occur under ordinary circumstances are related to a triggering mechanism. Thus, a reasonable strategy for the prevention of sudden death would be to interrupt the linkage between a trigger and the event. The administration of drugs, such as beta-adrenergic–blocking agents and aspirin, to patients who are at high risk because of atherosclerotic cardiovascular disease might be beneficial. These drugs have been shown to prevent the onset of myocardial ischemia[25,26] and may protect high-risk patients from the adverse effects of stress. Another implication is that the emergency services in an area where a disaster has occurred should be prepared for an increase in the number of patients with acute myocardial infarction or aborted sudden death.

Further research is warranted to determine which patients with coronary artery disease are most susceptible to sudden death from cardiac causes after a stressful event and what other kinds of triggers may be involved. Identifying these high-risk patients and defining potential triggers will help in the development of strategies to prevent sudden death due to cardiac causes.

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