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Miscellaneous

Medium- and long-term health effects of earthquakes in high-income countries: a systematic review and meta-analysis

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Abstract

Background: Accurate monitoring of population health is essential to ensure proper recovery after earthquakes. We aimed to summarize the findings and features of post-earthquake epidemiological studies conducted in high-income countries and to prompt the development of future surveillance plans.

Methods: Medline, Scopus and six sources of grey literature were systematically searched. Inclusion criteria were: observational study conducted in high-income countries with at least one comparison group of unexposed participants, and measurement of health outcomes at least 1 month after the earthquake.

Results: A total of 52 articles were included, assessing the effects of 13 earthquakes that occurred in eight countries. Most studies: had a time-series (33%) or cross-sectional (29%) design; included temporal comparison groups (63%); used routine data (58%); and focused on patient subgroups rather than the whole population (65%). Individuals exposed to earthquakes had: 2% higher all-cause mortality rates [95% confidence interval (CI), 1% to 3%]; 36% (95% CI, 19% to 57%) and 37% (95% CI, 29% to 46%) greater mortality rates from myocardial infarction and stroke, respectively; and 0.16 higher mean percent points of glycated haemoglobin (95% CI, 0.07% to 0.25% points). There was no evidence of earthquake effects for blood pressure, body mass index or lipid biomarkers.

Conclusions: A more regular and coordinated use of large and routinely collected datasets would benefit post-earthquake epidemiological surveillance. Whenever possible, a cohort design with geographical and temporal comparison groups should be used, and both communicable and non-communicable diseases should be assessed. Post-earthquake epidemiological surveillance should also capture the impact of seismic events on the access to and use of health care services.

Key words: Earthquake, health, methods, natural disaster, systematic review, meta-analysis

Key Messages

- This systematic review and meta-analysis found increased mortality and morbidity after earthquakes for some health outcomes in the medium- and long term, particularly: (i) increased mortality rates for all causes, myocardial infarction and stroke; and (ii) greater mean levels of glycated haemoglobin.
- However, this review also found no evidence of earthquake effects in terms of blood pressure, body mass index or lipid biomarkers.
- Epidemiological surveillance after all major earthquakes is essential to set up public health priorities and advance research.
- Whenever possible, future studies should use a cohort design, include both temporal and geographical comparison groups and assess both physical and mental health indicators.
- Post-earthquake epidemiological surveillance should also capture the impact of seismic events on the access to and use of health care services.

Introduction

Over recent decades, the frequency of natural disasters has risen sharply, leading to dramatic consequences and huge economic losses. In 2014 alone, 324 natural disasters were reported, resulting in 141 million casualties and damages for nearly $100 billion.[1] Geophysical disasters, including earthquakes, accounted for about 10% of these events.

The Sendai Framework for Disaster Risk Reduction promoted by the United Nations fosters a comprehensive approach to disaster prevention, response and recovery, and therefore represents an important step forward to reducing mortality and morbidity from disasters. As such, the Sendai Framework highlights that accurate monitoring of the health status of populations exposed to disasters is essential to identify priority interventions and restore previous health conditions.[1,2] Given that earthquakes are currently non-predictable, epidemiological surveillance is particularly useful to alleviate the burden of death, disability and disease that often follows these calamities.

It is noteworthy that low-income countries are the most affected by disasters. Regrettably, more pressing political and economic constraints often make long-term epidemiological surveillance impracticable in these settings. In contrast, high-income countries rely on more robust health care networks, which should allow for the conduct of long-term epidemiological research. However, epidemiological follow-up after earthquakes often seems to be scant and poorly planned also in countries with well-established health care systems.[3–5]

Although several approaches for proper epidemiological monitoring after earthquakes have been discussed,[1,6] a comprehensive overview of earthquake-related health effects in the medium- or long term is not yet available because most previous studies focused on the immediate health effects of these calamities (i.e. in terms of hours or days).[7,8] Reviews reporting on medium- and long-term earthquake effects focused on either specific earthquakes[3,9] or specific sets of health outcomes—particularly in the field of mental health.[10,11]

To our knowledge, no comprehensive systematic research has been conducted on all medium- and long-term health effects of earthquakes. This study aimed to fill this gap by providing an insight into the methodological approaches and main findings of epidemiological studies assessing the medium- and long-term effects of earthquakes in high-income countries.

Methods

We carried out this systematic review and meta-analysis in accordance with the Preferred Reporting Items for Systematic review and Meta-Analysis (PRISMA) statement.[12]

Search and selection

We searched two electronic databases—PubMed (MEDLINE) and Scopus—and six sources of grey literature, including the websites of the World Health Organization, Centers for Disease Control and Prevention—USA, European Centre for Disease Control and Prevention—European Union, National Institutes of Health—USA, EpiCentro Istituto Superiore di Sanità—Italy and Centro di documentazione per la promozione della salute—Italy. Supplementary materials 1 (available as Supplementary data at *IJE* online) lists the search strings used. We included all studies relating to humans and written in any of the following six languages: English, Italian, Spanish, French, Portuguese or German. No time restrictions were set. All the reviews found with this search were manually inspected to obtain additional studies.

Four authors (A.R.G., B.P., E.A., M.A.) independently screened the titles and abstracts of all papers to exclude those not relevant to the objective of the review; any disagreement was resolved through discussion among these authors. One author (among A.R.G., D.S., G.I., M.A.) read the full texts of the papers that passed the initial screening to assess compliance with the predefined inclusion and exclusion criteria, and their work was checked independently by another author (either B.P. or E.A.).

Inclusion and exclusion criteria

We included studies that: (i) focused on health indicators[13,14] such as mortality and disease incidence, prevalence of risk factors and access to and use of health care services; (ii) measured indicators that occurred at least 1 month after the main seismic event; (iii) investigated an earthquake that took place in a country classified as a high-income economy by the World Bank;[15] (iv) had an observational design with at least one comparison group, including a measurement either done before the earthquake (hereafter, 'temporal comparison group') or obtained from an area that was not affected by the earthquake ('geographical comparison group').

Studies were excluded if: (i) the health effects of the earthquake could not be distinguished from those due to other natural disasters; (ii) some or all of the participants in the comparison group were exposed to the earthquake; (iii) exposure or outcome was not measured objectively (e.g. measurement of self-reported intensity of earthquake damage or use of self-reported pre-earthquake health status collected during a post-earthquake survey); or (iv) the study did not report on quantitative research, was a literature review or was retracted.

For the specific case of the Great East Japan earthquake of 11 March 2011, which was followed by a tsunami that flooded the area within 10 km from the coast[16] and a nuclear accident that caused a mass evacuation of the area in a radius of 20 km from the Fukushima-Daiichi nuclear power plant,[17] we excluded studies regarding areas located $\leq$ 10 km from the coast and $\leq$ 20 km from the Fukushima-Daiichi power plant.

Data extraction

For each study, one author (among A.R.G., M.A., D.S., G.I., B.P., E.A.) extracted data from included papers using a predefined data extraction template, and another author (either B.P. or E.A.) independently checked their work. Any disagreement was resolved by discussion. We extracted the following study-specific characteristics: earthquake investigated; study design (prospective or retrospective cohort, cross-sectional, time-series); study population; sample size; percentage of male participants; mean participant age; and data source (e.g. hospital records, *ad hoc* databases or both). For each outcome and comparison group, we extracted the following variables as appropriate: number of participants; start and end of follow-up; and mean and variance (either standard deviation, standard error or interquartile range; the latter two were converted to standard deviation as appropriate). As most studies reported on more than one outcome, the total number of outcomes is greater than the total number of studies. We calculated person-years by multiplying group-specific number of participants and length of follow-up. We extracted reported units for all continuous outcomes. In case of multiple publications about the same earthquake, we used the most up-to-date and comprehensive information.

Data synthesis

In descriptive analyses, we used frequencies and proportions to describe categorical variables, and medians and interquartile ranges to summarize continuous variables. We conducted meta-analyses for all the outcomes assessed. Before carrying out meta-analyses, we harmonized units for continuous outcomes, collapsed within-study subgroups and dealt with multiple comparison groups as detailed in Supplementary materials 2, available as

Supplementary data at *IJE* online. For each outcome, within-study summary measures, such as incidence rate ratio (IRR), risk ratio (RR) and mean difference (MD), were estimated as appropriate to compare exposed and unexposed participants, using the default settings of the metafor package in R.[18] Outcome-specific summary estimates were then pooled if available for at least two studies having the same type of comparison group (either temporal of geographical) and the same type of summary measure (either IRR, RR or MD). Owing to heterogeneity in study characteristics and earthquakes assessed, we fitted random effects models. We tested evidence of heterogeneity with the Q statistic and quantified the percentage of variability in the effect estimates due to heterogeneity with the I-squared statistic. We plotted both study-specific and pooled effect estimates, including 95% confidence intervals, using Forest plots. For all meta-analyses including at least four studies, we conducted sensitivity analyses to check if the pooled estimates were robust to variations in the following study-level characteristics: maximum duration of follow-up; proportion of male participants; mean age; study design; and study population. All analysis tests were two-sided.

Results

Search and selection of studies

Overall, we found 2976 papers (1549 from PubMed/MEDLINE and Scopus, and 1427 from the grey literature—Figure 1). The initial screening of titles and abstracts led to inclusion of 377 papers. In all, 52 papers met the eligibility criteria and were included. Among the 325 papers excluded: 122 (38%) either focused on a different natural disaster or the earthquake effects could not be disentangled from those of other natural disasters; 84 (26%) lacked a non-overlapping comparison group; and 49 (15%) did not report on quantitative research (e.g. were case reports, commentary articles, letters, news articles or editorials).

Earthquake characteristics

Most studies were conducted in Japan ($n = 27$) and Italy ($n = 13$) (Table 1). The most investigated earthquakes, with 10 studies each, occurred in Kobe (Japan, 17 January 1995), L'Aquila (Italy, 6 April 2009) and Eastern Japan (11 March 2011). The median number of deaths was 143 [interquartile range (IQR), 12 to 2342] and the median

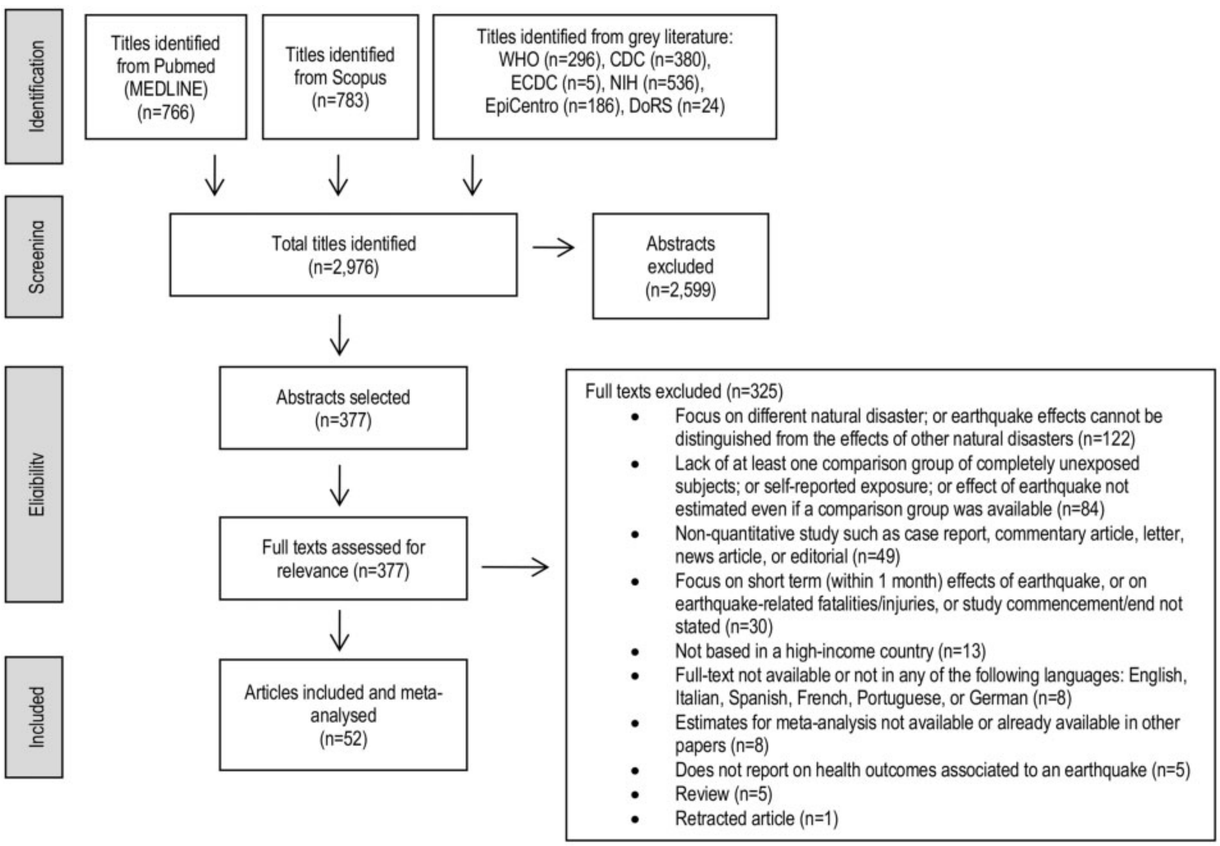


Figure 1. Article selection and reasons for exclusion. WHO, World Health Organization; CDC, Centers for Disease Control and Prevention (USA); ECDC, European Centre for Disease Control and Prevention (EU); NIH, National Institutes of Health (USA); EpiCentro, Istituto Superiore di Sanità (Italy); DoRS, Centro di Documentazione per la Promozione Della Salute (Italy).

Table 1. Characteristics of the 13 earthquakes investigated by the 52 studies included in this review

Country	Date	Earthquake	**Magnitude**[a]	***n* deaths**[a]	*n* studies
Australia	28 December 1989	Newcastle	5.4[b]	12[b]	1
Chile	13 June 2005	Tarapacá	7.8	11	1
	27 February 2010	Maule region	8.8	547	1
Greece	7 September 1999	Athens and Ano Liosia	6.0	143	2
Iceland	17 June 2000	Holt	6.6	0	1
Italy	23 November 1980	Irpinia and Naples	6.5[c]	2735[c]	3
	6 April 2009	L'Aquila	6.3	295	10
Japan	17 January 1995	Kobe and Hanshin-Awaji	6.9	5530	10
	23 October 2004	Niigata Prefecture	6.6	40	6
	25 March 2007	Noto Peninsula	6.7	1	1
	11 March 2011	Great East Japan (Higashi-Nihon)	9.0	20 896	10
New Zealand	22 February 2011[d]	Christchurch	6.1	181	5
USA	17 January 1994	Los Angeles/Northridge, California	6.7	60	1

[a]Except where specified otherwise, magnitude and numbers of deaths are obtained from the United States Geological Survey 1990–2012 archive.[19]
[b]Source: National Centers for Environmental Information.[20]
[c]Source: United States Geological Survey archive of the earthquakes with >1000 fatalities 1900–2014.[21]
[d]One study focused on shocks occurring on 4 September 2010; four on shocks occurring in both 2010 and 2011 (22 February, 13 June, 23 December).

earthquake magnitude was 6.6 on the Richter scale (IQR, 6.3 to 6.9). The countries that presented the largest cumulative number of deaths were Japan ($n = 26\,467$) and Italy ($n = 3030$).

Study characteristics

We extracted meta-analysis data from 52 studies including 82 479 subjects from studies that analysed individual-level data and 50 015 914 subjects from studies based on aggregated data, in which individual participant characteristics were not available for the denominator. Table 2 presents the main characteristics and outcomes assessed by the studies included in this review.

Included studies were published between 1981 and 2015, mostly (58%) between 2010 and 2015. Most studies used time-series ($n = 17$) and cross-sectional ($n = 15$) study designs and employed a temporal comparison group (i.e. the outcome of interest was measured at least twice, both before and after the earthquake) ($n = 33$). Most studies ($n = 34$) selected participants based on their age or medical condition and 15 studies focused on the general population. Most studies used routinely collected data ($n = 30$), such as data from hospital databases ($n = 18$). A considerable number of studies ($n = 19$) used *ad hoc* data, mostly obtained from questionnaires ($n = 13$). Only seven of 52 studies evaluated whether the effects of earthquakes varied by the intensity of earthquake exposure (e.g. distance from the earthquake epicentre).

Studies had a median sample size of 1448 subjects (IQR, 175 to 372 253); the largest samples were collected in studies with a time-series design (median, 417 900; IQR, 301 053 to 4 391 035) and having both temporal and geographical comparison groups (median, 163 992; IQR, 742 to 845 617). The median number of measurements was three (IQR, 2 to 10); the highest number of measurements was observed in studies with a time-series design (median number of measurements, 14; IQR, 6 to 39) and in studies with temporal comparison group (median number of measurements, four; IQR, 2 to 12). Overall, the median length of follow-up was 6 months (IQR, 3 to 12); the median length of follow-up was longest for time-series studies (7 months; IRQ, 3 to 12) and for studies with both temporal and geographical comparison groups (20 months; IQR, 10 to 36).

Earthquake effects on outcomes assessed by four or more studies

While accounting for across-study heterogeneity, there was strong evidence ($P < 0.001$) of 36% greater mortality rates from myocardial infarction after earthquakes compared with measurements carried out before the earthquake (95% CI, 19% to 57%) (Figure 2A). In a meta-analysis of four studies, there was weak evidence ($P = 0.0725$) of 11% lower suicide rates after the earthquakes (95% CI, –21% to 1%).

People exposed to earthquakes had higher mean levels of glycated haemoglobin (0.16% points; 95% CI, 0.07 to 0.25) compared with people unexposed to the earthquake (Figure 2B). There was no evidence of earthquake effects in terms of blood pressure, body mass index or lipid biomarkers.

Table 2. Main characteristics and outcomes assessed by the 52 studies included in the review

Study	Earthquake (year)	Study design (comparison)	Mean age (years)	% males	Follow-up (months)	*n* participants	Mortality	Disease							Pharmacology	Vital signs and biomarkers	Lifestyle, prevention, screening, health care	Psychometric scales	Other outcomes
								Circulatory	Nervous system	Mental health	Infections	Digestive	Pregnancy, childbirth and puerperium	Endocrine					
Alexander *et al.* 1982[22]	Irpinia & Naples (1980), Italy	Time-series (T)	–	–	7	6 033 296	–	–	–	✓	✓	–	–	–	–	–	✓	–	–
Aoki *et al.* 2012[23]	Great East Japan (2011)	Time-series (T)	–	–	6	4 391 035	–	–	–	✓	–	–	–	–	–	–	–	–	–
Aoyama *et al.* 1998[24]	Kobe (1995), Japan	Cross-sectional (GT)	–	–	2	26 931	–	–	–	–	–	✓	–	–	–	–	–	–	–
Azuma *et al.* 2010[25]	Niigata (2004), Japan	Cohort (T)	41	71	14	4035	–	✓	–	–	–	–	–	–	–	✓	–	–	–
Bodvarsdottir and Elklit 2004[26]	Iceland (2000)	Cross-sectional (G)	42	47	3	81	–	–	–	✓	–	–	–	–	–	–	–	✓	–
Bourque *et al.* 2002[27]	Los Angeles (1994), USA	Time-series (T)	–	–	12	7 676 512	–	–	–	✓	–	–	–	–	–	–	–	–	–
Chan *et al.* 2013[28]	Christchurch (2010-2011), NZ	Time-series (T)	–	–	1	372 253	–	✓	–	–	–	–	–	–	–	–	–	–	–
D'Argenio *et al.* 2013[29]	L'Aquila (2009), Italy	Cross-sectional (T)	50	50	19	1240	–	–	–	✓	–	–	–	–	–	✓	✓	–	✓
Dobson *et al.* 1991[30]	Newcastle (1989), Australia	Time-series (T)	–	–	4	417 900	✓	✓	–	–	–	–	–	–	–	–	–	–	–
Fergusson *et al.* 2014[31]	Christchurch (2010-2011), New Zealand	Cohort (G)	35	–	24	952	–	–	–	✓	–	–	–	–	–	–	✓	–	–
Fujihara *et al.* 2012[32]	Great East Japan (2011)	Cohort (T)	65	63	3	320	–	✓	–	–	–	–	–	–	–	✓	–	–	–
Fukuda *et al.* 1998[33]	Kobe (1995), Japan	Time-series (T)	–	–	9	5 395 158	–	–	–	–	–	–	✓	–	–	–	–	–	–
Hata *et al.* 2012[34]	Great East Japan (2011)	Cohort (T)	66	100	2	5	–	✓	–	–	–	–	–	–	–	–	–	–	–
Hyodo *et al.* 2010[35]	Niigata (2004), Japan	Time-series (GT)	–	48	36	2 426 359	–	–	–	✓	–	–	–	–	–	–	–	–	–
Inui *et al.* 1998[36]	Kobe (1995), Japan	Cohort (GT)	59	52	2	434	–	–	–	–	–	–	–	–	–	✓	–	✓	–
Ishii *et al.* 2014[37]	Great East Japan (2011)	Cohort (T)	41	6	4	16	–	–	–	✓	–	–	–	–	–	–	–	–	–
ISS 1981[38]	Irpinia & Naples (1980), Italy	Time-series (T)	–	–	3	1 212 387	✓	–	–	–	–	–	–	–	–	–	–	–	–
Kamoi *et al.* 2006a[39]	Niigata (2004), Japan	Cohort (T)	67	75	6	222	–	✓	✓	–	–	–	–	✓	✓	✓	–	–	–
Kamoi *et al.* 2006b[40]	Niigata (2004), Japan	Cohort (T)	59	42	12	65	–	✓	–	–	–	–	–	✓	✓	✓	–	–	–
Kamoi *et al.* 2006c[41]	Niigata (2004), Japan	Cohort (T)	49	16	2	352	–	–	–	–	–	–	–	–	✓	✓	–	–	–
Kannis-Dymand *et al.* 2015[42]	Christchurch (2010), New Zealand	Cross-sectional (G)	46	–	2	345	–	–	–	✓	–	–	–	–	–	–	–	✓	–

(Continued)

Table 2. Continued

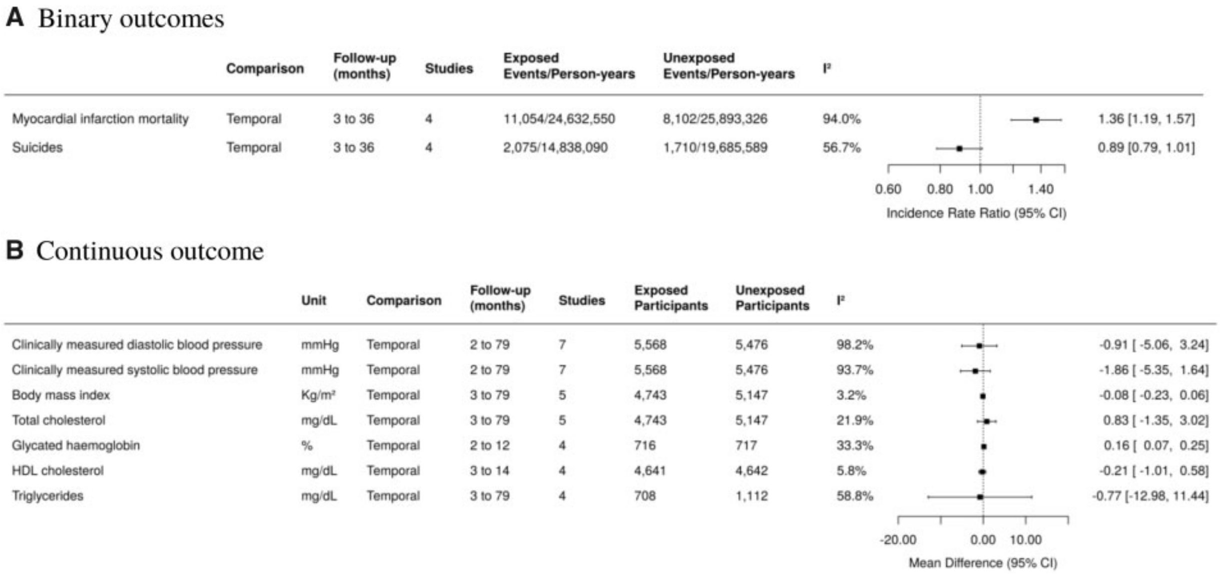
Study	Earthquake (year)	Study design (comparison)	Mean age (years)	% males	Follow-up (months)	*n* participants	Mortality	Disease							Pharmacology	Vital signs and biomarkers	Lifestyle, prevention, screening, health care	Psychometric scales	Other outcomes
								Circulatory	Nervous system	Mental health	Infections	Digestive	Pregnancy, childbirth and puerperium	Endocrine					
Kario *et al.* 2001[43]	Kobe (1995), Japan	Cohort (T)	69	34	2	124	–	✓	–	–	–	–	–	–	–	–	–	–	–
Kario and Ohashi 1997[44]	Kobe (1995), Japan	Time-series (T)	–	–	3	64 082	✓	✓	–	–	–	–	–	–	–	–	–	–	–
Kato *et al.* 2014[45]	Great East Japan (2011)	Cross-sectional (T)	41	33	6	600 000	–	–	–	✓	–	–	–	–	–	–	–	–	–
Kolaitis *et al.* 2003[46]	Athens (1999), Greece	Cross-sectional (G)	11	47	6	163	–	–	–	✓	–	–	–	–	–	–	–	✓	–
Kotozaki and Kawashima 2012[47]	Great East Japan (2011)	Cohort (T)	21	50	3	30	–	–	–	–	–	–	–	–	–	✓	–	✓	✓
Nakagawa *et al.* 2009[48]	Niigata (2004), Japan	Cross-sectional (GT)	–	–	36	2 426 359	✓	–	–	–	–	–	–	–	–	–	–	–	–
Nakano *et al.*2012[49]	Great East Japan (2011)	Cohort (T)	56	71	6	170	–	✓	–	–	–	–	–	–	–	–	–	–	–
Nishio *et al.* 2009[50]	Kobe (1995), Japan	Time-series (T)	–	–	36	1 273 333	–	–	–	✓	–	–	–	–	–	–	–	–	–
Pearson *et al.* 2013[51]	Christchurch (2010-2011), New Zealand	Time-series (T)	–	–	16	372 253	–	–	–	–	✓	–	–	–	–	–	–	–	–
Pollice *et al.* 2012[52]	L'Aquila (2009), Italy	Cohort (T)	32	62	3	117	–	–	–	–	–	–	–	–	–	–	–	✓	–
Rossi *et al.* 2012[53]	L'Aquila (2009), Italy	Cross-sectional (T)	18	42	10	1476	–	–	–	–	–	–	–	–	–	–	–	✓	–
Roussos *et al.* 2005[54]	Athens (1999), Greece	Cross-sectional (G)	–	44	3	1937	–	–	–	–	–	–	–	–	–	–	–	✓	–
Sofia *et al.* 2012[55]	L'Aquila (2009), Italy	Cross-sectional (T)	75	52	4	102 669	–	✓	–	–	–	–	–	–	–	–	–	–	–
Sokejima *et al.* 2004[56]	Kobe (1995), Japan	Time-series (T)	–	45	24	17 651	–	–	✓	–	–	–	–	–	–	–	–	–	–
Stratta *et al.* 2012[57]	L'Aquila (2009), Italy	Cross-sectional (G)	33	44	12	948	–	–	–	✓	–	–	–	–	–	–	–	✓	–
Sugiura *et al.* 2013[58]	Great East Japan (2011)	Time-series (T)	–	50	2	10 106	–	–	–	✓	–	–	–	–	–	–	–	–	–
Takegami *et al.* 2015[59]	Great East Japan (2011); Kobe (1995), Japan	Time-series (T)	–	–	12	16 545 012	✓	–	–	–	–	–	–	–	–	–	–	–	–
Tanaka *et al.* 2014[60]	Great East Japan (2011)	Cohort (T)	66	80	2	25	–	✓	–	–	–	–	–	–	✓	✓	–	–	–
Tani *et al.* 2014[61]	Great East Japan (2011)	Cohort (T)	67	52	2	205	–	✓	–	–	–	–	–	–	–	✓	–	–	–
Tempesta *et al.* 2013[62]	L'Aquila (2009), Italy	Cross-sectional (GT)	–	50	24	1419	–	–	–	–	–	–	–	–	–	–	–	✓	–

(Continued)

Table 2. Continued

Study	Earthquake (year)	Study design (comparison)	Mean age (years)	% males	Follow-up (months)	*n* participants	Mortality	Disease							Pharmacology	Vital signs and biomarkers	Lifestyle, prevention, screening, health care	Psychometric scales	Other outcomes
								Circulatory	Nervous system	Mental health	Infections	Digestive	Pregnancy, childbirth and puerperium	Endocrine					
Torche and Kleinhaus 2012[63]	Chile (2005), Chile	Cohort (GT)	–	0	9	7035	–	–	–	–	–	–	✓	–	–	–	–	–	–
Trevisan *et al.* 1992[64]	Irpinia & Naples (1980), Italy	Cohort (T)	41	100	79	505	–	✓	–	–	–	–	–	–	–	✓	–	–	–
Trifirò *et al.* 2013[65]	L'Aquila (2009), Italy	Time-series (T)	–	–	11	301 053	–	–	–	–	–	–	–	–	✓	–	–	–	–
Tsuchida *et al.* 2009[66]	Japan Noto Peninsula (2007), Japan	Time-series (T)	–	–	1	34 000	–	✓	✓	–	–	–	–	–	–	–	–	–	–
Valenti *et al.* 2012a[67]	L'Aquila (2009), Italy	Cohort (GT)	–	–	12	36	–	–	–	–	–	–	–	–	–	–	–	✓	–
Valenti *et al.* 2012b[68]	L'Aquila (2009), Italy	Cohort (T)	–	49	11	179	–	–	–	–	–	–	–	–	–	–	–	✓	–
Valenti *et al.* 2014[69]	L'Aquila (2009), Italy	Cohort (GT)	–	11	24	64	–	–	–	–	–	–	–	–	–	–	–	✓	–
Wu *et al.* 2014[70]	Christchurch (2010-2011), New Zealand	Time-series (T)	–	–	1	372 253	–	✓	✓	–	–	–	–	–	–	–	–	–	–
Yamamoto *et al.* 1997[71]	Kobe (1995), Japan	Cross-sectional (T)	–	53	6	221	–	–	–	–	–	–	–	–	–	–	–	–	✓
Yashiro *et al.* 2000[72]	Kobe (1995), Japan	Cross-sectional (G)	67	63	36	30	✓	–	–	–	–	–	–	–	✓	✓	–	–	✓
Zubizarreta *et al.* 2013[73]	Chile (2010), Chile	Cross-sectional (T)	48	33	4	5040	–	–	–	–	–	–	–	–	–	–	–	✓	–

Comparison groups: T, temporal; G, geographical; GT, geographical and temporal.
ISS is the Italian National Institute of Health (Istituto Superiore di Sanità).



A Binary outcomes

	Comparison	Follow-up (months)	Studies	Exposed Events/Person-years	Unexposed Events/Person-years	I²	
Myocardial infarction mortality	Temporal	3 to 36	4	11,054/24,632,550	8,102/25,893,326	94.0%	1.36 [1.19, 1.57]
Suicides	Temporal	3 to 36	4	2,075/14,838,090	1,710/19,685,589	56.7%	0.89 [0.79, 1.01]

B Continuous outcome

	Unit	Comparison	Follow-up (months)	Studies	Exposed Participants	Unexposed Participants	I²	
Clinically measured diastolic blood pressure	mmHg	Temporal	2 to 79	7	5,568	5,476	98.2%	-0.91 [-5.06, 3.24]
Clinically measured systolic blood pressure	mmHg	Temporal	2 to 79	7	5,568	5,476	93.7%	-1.86 [-5.35, 1.64]
Body mass index	Kg/m²	Temporal	3 to 79	5	4,743	5,147	3.2%	-0.08 [-0.23, 0.06]
Total cholesterol	mg/dL	Temporal	3 to 79	5	4,743	5,147	21.9%	0.83 [-1.35, 3.02]
Glycated haemoglobin	%	Temporal	2 to 12	4	716	717	33.3%	0.16 [0.07, 0.25]
HDL cholesterol	mg/dL	Temporal	3 to 14	4	4,641	4,642	5.8%	-0.21 [-1.01, 0.58]
Triglycerides	mg/dL	Temporal	3 to 79	4	708	1,112	58.8%	-0.77 [-12.98, 11.44]

Figure 2. Earthquake effects for all outcomes assessed by four or more independent studies. HDL, high-density lipoprotein. I^2 is percentage of variation across studies due to heterogeneity. Follow-up refers to the latest post-earthquake measurement.

These findings were generally robust to a number of sensitivity analyses (Supplementary materials 3, available as Supplementary data at *IJE* online), with the exception of suicide rates that were higher among people exposed to the earthquake in one study using a geographical comparison—an apparent contradiction with the four studies using temporal controls.

Earthquake effects on outcomes assessed by one to three studies

The full results of earthquake effects for all outcomes from all studies, including effects on several psychometric scales, are available in Supplementary materials 4, available as Supplementary data at *IJE* online. In the interests of conciseness, Figure 3 presents only findings based on a sample size of at least 1000 participants and with an effect *P*-value lower than 0.001.

Although only two studies were available for each meta-analysis, all-cause mortality rates were 2% higher (95% CI, 1% to 3%) and stroke mortality rates were 37% higher (95% CI, 29% to 46%) among individuals exposed to earthquakes compared with unexposed participants (Figure 3A). In four individual studies that could not be pooled together owing to incompatible outcome and comparison group definitions, individuals exposed to earthquakes had generally higher mortality rates from cardiovascular disease (Supplementary materials 4, available as Supplementary data at *IJE* online).

Among people exposed to the Kobe earthquake (Japan, 1995), there was evidence of a general increase in incidence rates of both total and bleeding gastric ulcers. People exposed to the Irpinia and Naples earthquake (Italy, 1980) had: (i) lower incidence rates of German measles and whooping cough; (ii) higher incidence rates of typhoid/paratyphoid and viral hepatitis infections; and (iii) 3% lower hospital discharge rates (95% CI, –3% to –2%). After the L'Aquila earthquake (2009, Italy), there was evidence of a 6% increase in overall antipsychotics consumption (95% CI, 4% to 8%), particularly promazine and amilsulpride. Earthquake effects for antidepressants were in different directions. There was evidence of a 2% increase in serotonin reuptake inhibitor consumption rates (95% CI, 1% to 2%), but also evidence of a 5% reduction in tricyclics (95% CI, –6% to –4%) and a 1% reduction in other antidepressants (95% CI, –2% to –1%). People exposed to the L'Aquila earthquake also had a 2-fold greater risk of sedentary behaviour (95% CI, 1.56 to 2.60) (Figure 3B). After the Great East Japan 2011 earthquake, there was evidence of a 0.95% point greater average daily prevalence of insomnia compared with daily measurements recorded before the earthquake (95% CI, 0.93 to 0.98% points) (Figure 3C).

Discussion

The steep rise in the world population over recent decades and the urbanization of zones with high seismic risk have played a key role in amplifying the impact of earthquakes on human health.[74] Unfortunately, this has not triggered a simultaneous improvement of epidemiological surveillance plans in the aftermath of earthquakes. For this reason, a review of the epidemiological studies investigating the chronic health effects of earthquakes can be helpful

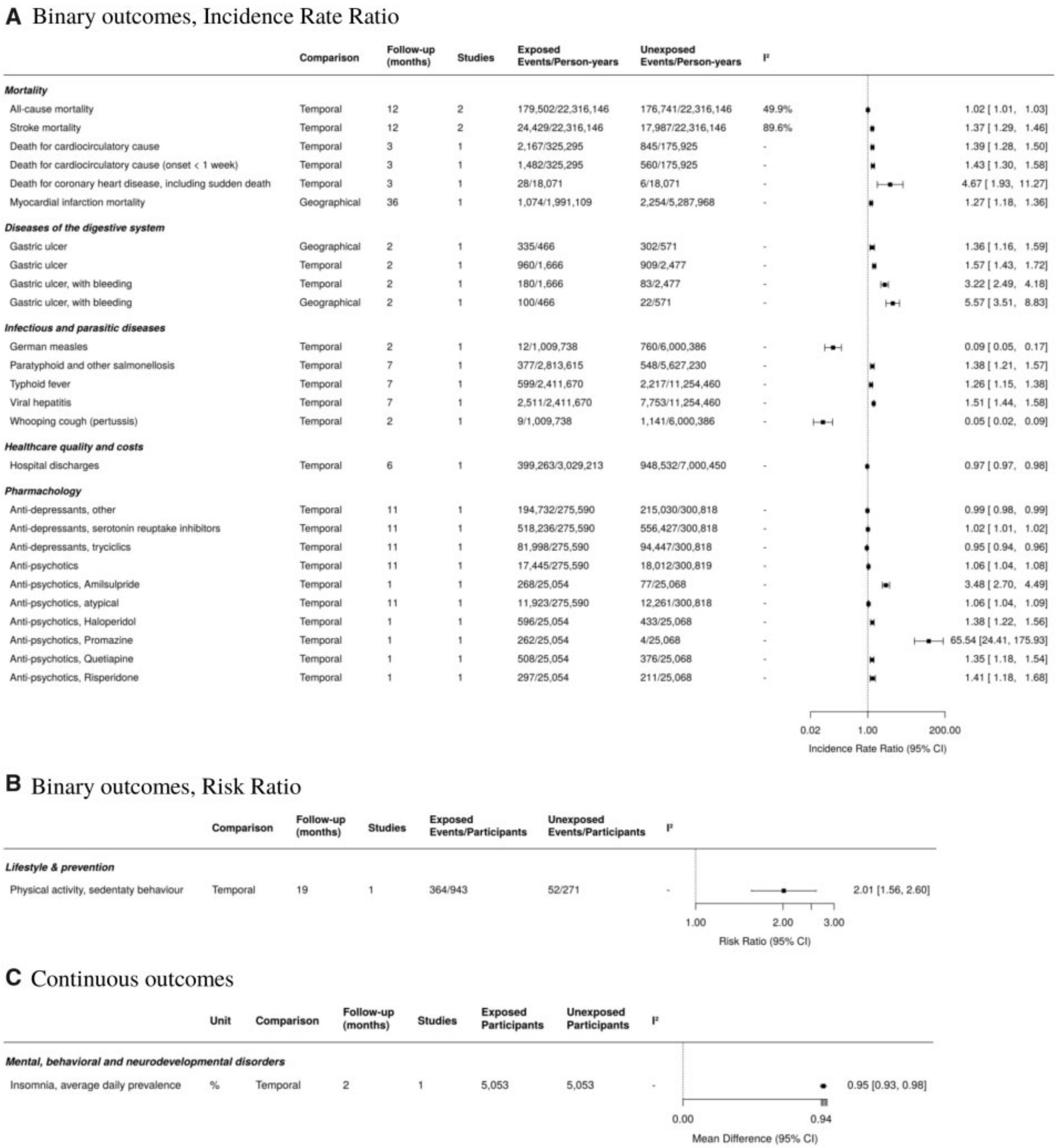


Figure 3. Earthquake effects for outcomes assessed by one to three studies based on at least 1000 participants and with effect *P*-value <0.001.[a]
[a]Sample size and *P*-value thresholds were set in the interest of conciseness. The full results are available in Supplementary materials 4, available as Supplementary data at *IJE* online. I^2 is percentage of variation across studies due to heterogeneity. Follow-up refers to the latest postearthquake measurement

to guide the development and implementation of future surveillance.

Discussion of the methodological approaches of the studies included

Out of the 50 seismic events with magnitude ≥6.0 which occurred in high-income countries between 1990 and 2012,[19] only 11 were investigated by the studies included in this review (Supplementary materials 5, available as Supplementary data at *IJE* online). These 11 events caused a median of 143 deaths (IQR, 26 to 421), and the 39 events that were not investigated resulted in a median of two deaths (IQR, 1 to 7) despite having similar magnitudes (6.7 vs 6.6). This suggests that the studies meeting the inclusion criteria for this review focused mostly on the earthquakes that caused the highest number of casualties. The fact that the earthquakes of Great East Japan (20 896 deaths), Kobe/Hanshin-Awaji (5530) and L'Aquila (295) were the most frequently investigated, supports this hypothesis. However, other deadly seismic events were apparently not investigated, such as the earthquakes of Hokkaido (Japan 1993, 243 deaths) and Georgia (29 April 1991, 114 deaths). As most of the studies included in this review were published after the year 2000 and the number of studies increased over time, it is possible that some earthquakes were not investigated either because, at that time, the monitoring of the chronic effects of earthquakes was not deemed a public health priority or because the epidemiological studies conducted were never published or made available in the institutional websites that we inspected.

The principal reason for exclusion from this review was the difficulty in disentangling the effects of earthquakes from those of other natural disasters that occurred simultaneously or as a consequence of the main seismic event (e.g. the Great East Japan earthquake in March 2011, which was followed by a tsunami and a nuclear accident). These studies were excluded based on the assumption that different types of disasters may result in different types of health effects.[75] For example, an isolated nuclear accident can cause immediate mental stress on an anticipatory basis alone (fear of cancer, congenital anomalies etc.), with a greater impact on adult-age subgroups (those who are capable of recognizing the risk). By contrast, people exposed to earthquakes appear more likely to suffer from post-traumatic stress disorder rather than from anticipatory mental stress.[76] Therefore, we excluded a considerable number of studies so as to be able to specifically assess the epidemiological effects of earthquakes.

Most studies used a cross-sectional or time-series design (33% each) and included temporal comparison groups (63%); prospective cohorts were used in only 14 studies (27%). It is well-known that longitudinal studies have a more robust design than cross-sectional studies, enabling the investigation of causal hypotheses when using appropriate methods. However, cohort studies can be resource-consuming, whereas cross-sectional studies with a temporal or geographical comparison group are generally cheaper and can provide timely estimates if a quick response is needed.[77] As timeliness is usually not a priority for studies assessing medium- and long-term health effects, it is possible that the availability of resources may have influenced the choice of the cross-sectional design over the cohort design for some studies.

Furthermore, data sources and their accessibility play an important role in influencing the choice of many study characteristics, such as the outcome under study, study design and timeliness of the investigation. The majority of the studies (58%) used routinely collected data, especially hospital databases (37%). Interestingly, in several studies regarding the L'Aquila earthquake (Italy, 2009), there was less use of routine data, compared with studies of other earthquakes in high-income countries.[78] The type of outcomes investigated and the study design applied might have been influenced by context-specific factors; namely, availability of appropriate resources, human capital and data sources. A nationally coordinated and interdisciplinary approach could overcome these limitations by involving epidemiologists and health professionals from both the area hit by the earthquake and from other centres specialized in disaster epidemiology.

In the case of unpredictable exposures, such as some natural disasters, routine data with proper temporal and geographical coverage can provide a good compromise between methodological rigour and economic sustainability. As high-quality routine data are available in many affluent countries, more widespread linkage between routinely collected data sources (e.g. primary care records, specialist registries, hospital admission records, mortality registries) would enable systematic assessment of the effects of earthquakes on the most relevant health outcomes while accounting for the most common sources of bias and confounding.

Discussion of the main earthquake effects captured by the studies included

The studies included in this review measured several outcomes: mortality, cardiovascular diseases, mental health and problems related to lifestyle (Figures 2 and 3; Supplementary materials 3 and 4, available as Supplementary data at *IJE* online). Some evidence of a post-earthquake increase was observed for many of these outcomes, suggesting that the long-term assessment of the population's health status is essential to set priorities in resource allocation. Interestingly, in their review on the public health effects of mass traumatic events, Johnson and Galea[75] mentioned motor disability and musculoskeletal sequelae as chief chronic earthquake-related health problems. On the contrary, our findings suggest that a wide range of physical and mental health endpoints should be monitored several months or years after an earthquake.

This systematic review and meta-analysis found an increased mortality rate for all causes, myocardial infarction and stroke from the first month to up to 3 years after an earthquake. While these findings have been consistently reproduced in the literature, the reasons for them are still unclear. Previous research has underscored the importance of psychological stress as a predictor of coronary heart disease;[79,80] therefore, it is possible that psychological stress and the subsequent sympathetic activation may have played a role in explaining this association. However, a meta-analysis of seven studies included in this paper showed that earthquakes do not seem to affect clinically measured blood pressure. Additional factors explaining these findings include: the destruction of medical records, which can lead to one or more consultations or treatments missed; the occurrence of circumstances that can delay self-care, such as relocation and unemployment; and reporting bias, as some outcomes may have been considered less interesting by researchers and journals.

Regarding the metabolic effects of earthquakes, previous reviews pointed to higher rates of diabetes among disaster-exposed individuals.[75,81] Our meta-analysis confirms that a modest increase in glycated haemoglobin level occurs from 2 to 12 months after earthquakes. Previous literature suggests that a combination of various factors may cause this phenomenon, such as the disruption of normal routines, emotional stress, change in dietary intake and difficult access to supplies due to damage of health facilities and pharmacies or interruption in the mobilization of stockpiles to long-term established shelters.

Studies reporting on the rates of bleeding and non-bleeding gastric ulcers highlighted an increased probability of these events in the long term among individuals exposed to earthquakes. Interestingly, this was true regardless of the temporal or geographical nature of the comparison group. This could be attributed to the loss of function of hospitals located in the hardest-hit areas and to the failure to follow up patients with mild symptoms and mental stress. Of note, the negative impact of the earthquake on the functioning of health facilities located near the epicentre determined, such as in the study by Aoyama *et al.*,[24] a lower number of diagnostic procedures performed; this may have masked an even greater incidence of gastrointestinal ulcer in the areas most affected by earthquakes.

Limited evidence for infectious epidemics after geophysical disasters is available;[82] our results suggest that gastrointestinal infectious agents could be more easily spread in the aftermath of earthquakes, while conversely, airborne infections might decrease. These data are in contradiction with current literature[75] and might be due to the fact that this meta-analysis included only one paper focusing on infectious diseases, which was restricted to a single country (Italy). Further studies would be useful to elucidate long-term earthquake-related patterns of infectious diseases in high-income countries.

In light of our findings, the role that earthquakes may play in mental health also deserves special attention. Earthquakes seemed to protect from suicide when temporal comparison groups were used, but the opposite was found when the comparison group was geographical and when assessing both suicidal ideation and suicide attempts (Supplementary materials 3 and 4, available as Supplementary data at *IJE* online). This highlights the complexity of this phenomenon, which might be heavily influenced by both individual and socio-contextual factors, such as gender, earthquake-related experience (e.g. injury, clean-up work activity, loss of family members), sociocultural factors and pre-earthquake mental health. Some studies reported an increase in a vast array of psychiatric and mood disorders, especially in the case of repeated or high-intensity exposure to earthquakes.[56,62] This suggests that earthquakes may be a serious risk factor for mental health disease due to, first, the traumatic environmental experience and, second, the life changes that follow the initial event (e.g. loss of family and friends, unemployment and/or relocation). Unfortunately, differences in terms of outcome definitions and comparison groups prevented further analysis. Altogether, our findings make the case for additional and larger studies including both geographical and temporal comparison groups.

Last, it is worth noting that four studies included in our review focused on health outcomes after the sequence of four earthquakes that occurred in Christchurch (New Zealand, September 2010 to mid-2012)[28,31,51,70] Owing to the small numbers of studies available, it is difficult to compare the health effects of repeated events with those of a single earthquake. However, taken together, the effects reported by these studies seem to be broadly in line with those found by investigations concerning a single event (e.g. greater prevalence of mental health disorders among people exposed to multiple seismic events compared with unexposed individuals).

Limitations of this review

Papers written in Japanese were excluded from this review; therefore, some relevant studies may have been missed. However, this looks unlikely, as the most relevant Japanese studies were probably published in English, and our search of six sources of grey literature seems sufficiently broad to capture the most influential epidemiological studies carried out in Japan. Only two electronic databases (Medline and Scopus) were used in this review. Considering the number and combination of keywords used in this search, it would have been unfeasible, with the resources available, to extend the search to other databases. However, these two databases are among the most comprehensive for epidemiological literature. Additionally, the grey literature search is likely to have detected articles not initially retrieved.

Some heterogeneity was noted in the meta-analyses we carried out. This is understandable owing to the breadth of our review. Although we attempted to combine studies that were as comparable as possible, this review includes studies conducted at different times and places, and with varying methodology. Between-study heterogeneity was therefore explicitly accounted for, and random-effects meta-analyses were used for all outcomes reported by at least two comparable studies. It is worth noting that the present review focuses on the studies assessing the independent effects of an earthquake or a series of seismic events. Therefore, the findings of this review should not be generalized to other natural disasters occurring simultaneously with earthquakes or caused by them.

Last, this meta-analysis was restricted to earthquakes that occurred in high-income countries, due to the political and economic barriers that render long-term epidemiological surveillance often impracticable in low-income countries. Whereas this limitation may be overcome in future updates of this review, it is worth noting that caution should be used when generalizing the findings of this review to low-income countries.

Suggestions for the epidemiological surveillance of future earthquakes

From the evidence accrued in the epidemiological studies carried out in the past 30 years, some suggestions emerge that could inform future studies aiming to assess the medium- and long-term health effects of earthquakes:

i. Aim: every major earthquake should be investigated for its medium- and long-term health effects. In the past, these effects have not been assessed as extensively as for other types of environmental exposure. The numerous health effects reported in the present review suggest that the health needs arising from earthquakes may have been underestimated in many cases, even in high-income countries. Future epidemiological surveillance should be set up to enable timely and in-depth measurement of the medium- and long-term health effects of every earthquake.

ii. Study design: (a) an intensive and coordinated use of routine data can benefit both epidemiological surveillance and aetiological studies in the aftermath of earthquakes; (b) both geographical and temporal comparison groups should be included, and both the general population and vulnerable groups (e.g. children and the elderly, patients with chronic disease, health care workers involved in the earthquake response) should be considered; (c) a cohort study design should be preferred whenever possible.

iii. Indicators: the complexity in the results obtained in this meta-analysis should prompt epidemiological surveillance studies to capture and report the changes of as many health indicators as possible (e.g. mortality, mental health, vital signs, biomarkers, behavioural risk factors and health service use). This amount of information will be instrumental to guiding practice, by improving efficiency and efficacy of evidence-based public health interventions, and to research, by helping to uncover long-term earthquake effects that have not yet been detected.

iv. Contributors: a multidisciplinary approach should be preferred, starting from the identification of priority indicators. Contributors should encompass professionals from different and complementary disciplines, including epidemiologists, statisticians and public health professionals capable of devising and processing standardized protocols for data collection and analysis. The involvement of professionals from various disciplines would also ensure effective communication of key messages to the population at risk, which is also a priority in both recovery and preparedness phases.[83]

Conclusion

Despite the efforts and resources involved to prevent and mitigate the effects of earthquakes, these disasters continue to have a tremendous health impact, even in high-income countries. The Sendai Framework for Disaster Risk Reduction, adopted at the Third United Nations World Conference (Sendai, Japan, March 2015), aims to achieve a 'substantial reduction of disaster risk and losses in lives, livelihoods and health'.[2] In order to meet this goal, appropriate preparedness, response and damage mitigation are essential when facing unpredictable events, as in the case of earthquakes.[84]

Epidemiology can play a major role in fostering recovery and preparedness. Considering the numerous earthquake-related health effects reported in this review, all future earthquakes should be investigated to capture their medium- and long-term health effects. As earthquakes have been associated with a broad range of health outcomes, rigorous monitoring of their chronic health effects is pivotal to prioritize local and national public health interventions. Allocation of resources matching the health needs of the population affected by the earthquake can alleviate the chronic health effects of these disastrous events. Additionally, regular updates on the health status of the populations would improve future preparedness plans. As far back as 1985, De Bruycker and colleagues[85] pointed out 'the need to establish, in each disaster-prone area, a health evaluation system [...] through which data could be collected in view of improving the preparedness and self-reliance of the stricken community itself'.

Over the past 30 years, epidemiology has benefited from great technological advances in many countries, including improvement in computation capabilities and availability of large and integrated electronic datasets. These advances now render feasible planning of epidemiological surveillance capable of providing regular updates on a population's health status in the medium- and long term. We trust that the experience accrued in the past three decades in the epidemiology of earthquakes, and summarized in this paper, may serve to inform further steps to ensure promotion of the population's health in the aftermath of earthquakes.

Supplementary data

Supplementary data are available at *IJE* online.

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Author Contributions

A.R.G., B.P., F.F. and E.A. contributed to the study concepts. E.A., A.R.G., F.F., F.D.C. identified the search string; A.R.G., B.P., E.A., M.A. screened the titles and abstracts of all papers to select the studies according to predefined the eligibility criteria, and discussed potential disagreement. A.R.G., D.S., G.I., M.A. assessed the full text of the papers that passed the initial screening; B.P. and E.A. reassessed them for compliance with the predefined eligibility criteria. A.R.G., M.A., D.S., G.I., B.P, and E.A. extracted data for meta-analysis. E.A. analysed the data. A.R.G., B.P., M.A., F.D.C., F.F. and E.A. contributed to the interpretation of data. A.R.G., B.P., M.A. and E.A. drafted the manuscript. All authors revised critically and edited the manuscript. All authors have seen and approved the final version of the manuscript. A.R.G., B.P. and E.A. are the guarantors.

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