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Impact of disasters, including pandemics, on cardiometabolic outcomes across the life-course: a systematic review

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ABSTRACT

Background Disasters are events that disrupt the daily functioning of a community or society, and may increase long-term risk of adverse cardiometabolic outcomes, including cardiovascular disease, obesity and diabetes. The objective of this study was to conduct a systematic review to determine the impact of disasters, including pandemics, on cardiometabolic outcomes across the life-course.

Design A systematic search was conducted in May 2020 using two electronic databases, EMBASE and Medline. All studies were screened in duplicate at title and abstract, and full-text level. Studies were eligible for inclusion if they assessed the association between a population-level or community disaster and cardiometabolic outcomes ≥1 month following the disaster. There were no restrictions on age, year of publication, country or population. Data were extracted on study characteristics, exposure (eg, type of disaster, region, year), cardiometabolic outcomes and measures of effect. Study quality was evaluated using the Joanna Briggs Institute critical appraisal tools.

Results A total of 58 studies were included, with 24 studies reporting the effects of exposure to disaster during pregnancy/childhood and 34 studies reporting the effects of exposure during adulthood. Studies included exposure to natural (n=35; 60%) and human-made (n=23; 40%) disasters, with only three (5%) of these studies evaluating previous pandemics. Most studies reported increased cardiometabolic risk, including increased cardiovascular disease incidence or mortality, diabetes and obesity, but not all. Few studies evaluated the biological mechanisms or high-risk subgroups that may be at a greater risk of negative health outcomes following disasters.

Conclusions The findings from this study suggest that the burden of disasters extend beyond the known direct harm, and attention is needed on the detrimental indirect long-term effects on cardiometabolic health. Given the current COVID-19 pandemic, these findings may inform public health prevention strategies to mitigate the impact of future cardiometabolic risk.

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Strengths and limitations of this study

- This systematic review is one of the first to review the literature on disasters, including pandemics, and subsequent cardiometabolic outcomes throughout the life-course.
- A comprehensive search strategy was used to identify studies that covered a range of disasters (eg, famine, war, terrorism, natural disasters and infectious disease epidemics), periods of exposure from pregnancy, childhood to older adulthood and a wide breadth of cardiometabolic outcomes.
- Only studies published in English were included and a search of the grey literature was not conducted.
- Due to the heterogeneity of studies, a meta-analysis could not be conducted, and results were only synthesised narratively.
- Limited evidence was available on the impact of pandemics specifically, and few studies evaluated proposed mechanisms or risk modification across subgroups of the populations.

BACKGROUND

Disasters, as defined by the WHO, are events that disrupt the daily functioning of a community or society causing material, economic or environmental losses, overwhelming local capacity.[1] Disasters can be categorised into natural disasters, human-made disasters and hybrid disasters.[2] Natural disasters include natural phenomenon above and beneath the earth's surface (eg, tsunamis or landslides), meteorological phenomenon (eg, tornadoes or floods) or biological phenomenon (eg, epidemics and pandemics).[2] Human-made disasters include adverse transportation incidents, technological events (eg, fire or toxic leaks), terrorism, warfare or conflict.[2] A hybrid disaster results from both human

and natural forces, such as the clearing of a jungle that results in a landslide.[2] All types of disasters can result in public health emergencies as they typically impact a significant proportion of people.[3] Epidemics, defined as a greater than expected increase in cases of a disease, and pandemics, which cross countries and continents, are types of natural disasters with far-reaching global disruption.[4] The COVID-19 pandemic is a present-day example of a global disaster that is unlike any disaster in recent history. Understanding the potential long-term health implications of the current COVID-19 pandemic and resulting public health mitigation strategies is urgently needed.

Previous systematic reviews have focused on acute outcomes, specifically on the psychological impact of quarantine during pandemics,[5] the impact on health outcomes after disasters in older adults,[6] medically unexplained physical symptoms following disasters[7] and chronic medical interventions following a natural disaster.[8] It is biologically plausible that exposure to a disaster may lead to long-term or chronic outcomes that could arise many years later and this may be modified by the time of exposure across the life-course. Consistent with established models of life-course epidemiology, there may be critical periods of exposure (eg, during development in childhood), where exposure to a disaster substantially increases later life disease risk, or exposure to a disaster may contribute to a chain of risk or accumulation of risks across the life-course.[9 10] There is currently no review on the long-term impacts of disasters, or more specifically, epidemics and pandemics on cardiometabolic outcomes across the life-course. Noncommunicable diseases (NCDs), including cardiovascular disease (CVD), obesity and diabetes, are the leading cause of morbidity and mortality worldwide.[11 12] NCDs are attributed to 71% of all global deaths annually, with approximately 14 million CVD-related deaths and 1.6 million diabetes-related deaths.[12] Findings from the Global Burden of Diseases Study indicate that CVD and diabetes account for over 20% of the global burden of disability, with diabetes recently emerging as the fourth leading cause of disability globally.[11] Exposure to disasters may cause cardiometabolic outcomes to emerge or worsen through several different mechanistic pathways including stress exposure,[13] lack of access to health services,[14] food security, and behavioural changes such as alterations in physical activity, sleep and diet.[15] It is important to understand the impact of disasters on the incidence of new cardiometabolic diseases and changes in disease status in all populations and age groups. Particular subgroups of a population may be more or less susceptible to cardiometabolic outcomes and understanding this can inform targeted interventions. The primary objective of this review was to determine the impact of disasters, including pandemics on risk of cardiometabolic outcomes across the life-course. The secondary objectives were to determine how to reduce the impact of chronic disease outcomes following a disaster and to identify populations at highest risk of cardiometabolic outcomes following a disaster.

Table 1 Search strategy for EMBASE

1 social isolation.mp. or social isolation/	24 963
2 quarantine.mp. or quarantine/	4752
3 *epidemic/	32 686
4 *pandemic/	4387
5 disease outbreak.mp.	2321
6 disaster/	13 321
7 *natural disaster/	968
8 humanitarian crisis.mp.	257
9 mass casuality.mp. or mass disaster/	3654
10 coronavirus.mp. or coronaviridae/	23 106
11 cardiovascular disease.mp. or *cardiovascular disease/	357 319
12 *diabetes mellitus/	210 248
13 *cerebrovascular accident/	78 444
14 *heart infarction/	99 072
15 *angina pectoris/	22 631
16 *obesity/	178 134
17 public health emergency.mp.	1752
18 *body mass/	31 459
19 *hypertension/	198 593
20 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 17	109 105
21 11 or 12 or 13 or 14 or 15 or 16 or 18 or 19	1 087 681
22 20 and 21	2047
23 limit 22 to human	1832

METHODS

A systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[16]

Search strategy

A systematic search was conducted in May 2020 using the electronic databases EMBASE and MEDLINE. The health research librarians at McMaster University assisted in developing the search strategy. The search broadly captured two concepts: disasters and cardiometabolic outcomes (eg, diabetes, obesity, hypertension). The complete search strategy for EMBASE can be found in table 1. The search strategy for MEDLINE can be found in the online supplemental table A1. Reference lists of eligible studies and relevant systematic reviews were hand searched to identify additional articles.

Eligibility criteria

Studies were eligible for inclusion if they assessed the relationship between a population level or community disaster and the risk of future cardiometabolic outcomes

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including CVD, diabetes or obesity or cardiometabolic risk scores.[17] CVD included myocardial infarction, stroke, hypertension and angina. There were no restrictions on year of publication, country of disaster or population. Only studies evaluating the impact of real-world disasters in humans were included. Due to the research team's capacity, only studies published in English were included. Observational and quasi-experimental study designs, including case–control, cohort and other longitudinal study designs or natural experiments, were included. Outcomes that were not cardiometabolic related or acute cardiometabolic events, such as an immediate complication (defined as <1 month after disaster), were excluded. Studies that assessed the exposure to a chemical as a result of the disaster were excluded, as we were not interested in outcomes resulting from chemical exposure. Earthquake studies were also excluded since a systematic review was published in 2018 that assessed the impact of earthquakes on cardiometabolic outcomes.[18]

Study selection

After running the search, all identified studies were imported into Covidence and duplicates were removed.[19] Studies were screened at title and abstract level, and then at full text by any two of the following independent reviewers: VDR, JL, MSA, YY-M, ATA, ES, SI, JDM, RR, LNA. Conflicts were resolved by a third reviewer who made the final decision regarding eligibility for inclusion.

Data extraction

A data extraction template was created and pilot tested prior to data extraction. Data were then extracted from all studies by any two of the following independent abstractors: VDR, JL, MSA, YY-M, ATA, RR, ES and conflicts were resolved by a third independent abstractor. Study characteristics including year of publication, study design, country of disaster, sample size and length of study were extracted where reported. Specific information on the exposure and outcome in each study was extracted including the type and name of the disaster, country and year of the disaster, the outcome of interest, and how the exposure and outcome were measured. Finally, any information on subgroups including age, population, sex and disaster type was also extracted, if applicable.

Critical appraisal

Critical appraisal was conducted using the Joanna Briggs Institute Critical Appraisal Tools.[20] This tool was chosen due to the availability of checklists for a wide range of study designs, including cohort, cross-sectional and quasi-experimental designs.[20] The quasi-experimental study design checklist was used for natural experiments including time-series studies and pre/post-designs, as it was decided this was the most appropriate tool. All studies were critically appraised independently by any two of the following individuals: VDR, JL, MSA, YY-M, ATA, ES, SI, and a third individual was consulted for any discrepancies.

Data analysis

Data from the included studies were narratively synthesised. Results are presented by exposure period (perinatal/childhood vs adulthood) and by cardiometabolic outcome (obesity, CVD and diabetes). Characteristics of studies are presented as frequencies and percentages. Due to the heterogeneity of studies, a meta-analysis was not conducted.

RESULTS

A total of 4830 studies were identified through the electronic database search. An additional 12 studies were identified through manual searching of the reference lists of relevant studies. After removing duplicates (n=439), 4403 studies were screened at title and abstract level. After applying inclusion and exclusion criteria, 4068 studies were excluded, leaving 335 studies screened for full-text eligibility. A total of 58 studies were eligible for inclusion into the review. The complete screening process is described in figure 1.

Description of studies

Table 2 provides a summary of included studies. Of 58 included studies, 24 studies[15 21–43] investigated exposure to disasters during pregnancy or childhood while the remaining 34 studies[14 44–76] investigated exposure to disaster during adulthood. Almost all studies (n=49) assessed cardiometabolic outcomes during adulthood, only two studies assessed outcomes during pregnancy[27 28] and seven studies assessed outcomes during childhood and adolescence.[15 21–26] The length of studies, including prospective follow-up and retrospective assessment, ranged from 1 month to 95 years. Most studies (n=36) focused on disasters that occurred in North America,[14 21–28 38 39 42 45–49 51 52 54 55 57–60 63–65 67–72 75 76] followed by Europe (n=13).[29–33 35 41 43 53 62 73 74] The remaining disasters occurred in Asia (n=7)[15 37 40 44 50 56 61] and Africa (n=2).[36 66] The characteristics of included studies and key findings are provided in table 3 for disaster exposure during the perinatal period and childhood, and table 4 for exposure during adulthood.

Exposure to disaster in the perinatal and childhood period

Of the 24 studies that evaluated perinatal and childhood exposure to disaster, 12 studies evaluated human-made disasters[29–35 40 41 47] and the remaining 12 evaluated natural disasters[15 21–28 38 39 42] of which 2 were pandemics.[38 39] Most studies (n=15) assessed the disaster as the main exposure of interest.[24 28–33 35 36 39–42] The remaining studies evaluated stress (eg, maternal stress, disaster-related post-traumatic stress disorder (PTSD), subjective stress, objective hardship),[21–25 27 47] maternal weight and maternal nutrition status,[15 34] cognitive appraisal[26] and coping strategies[27]

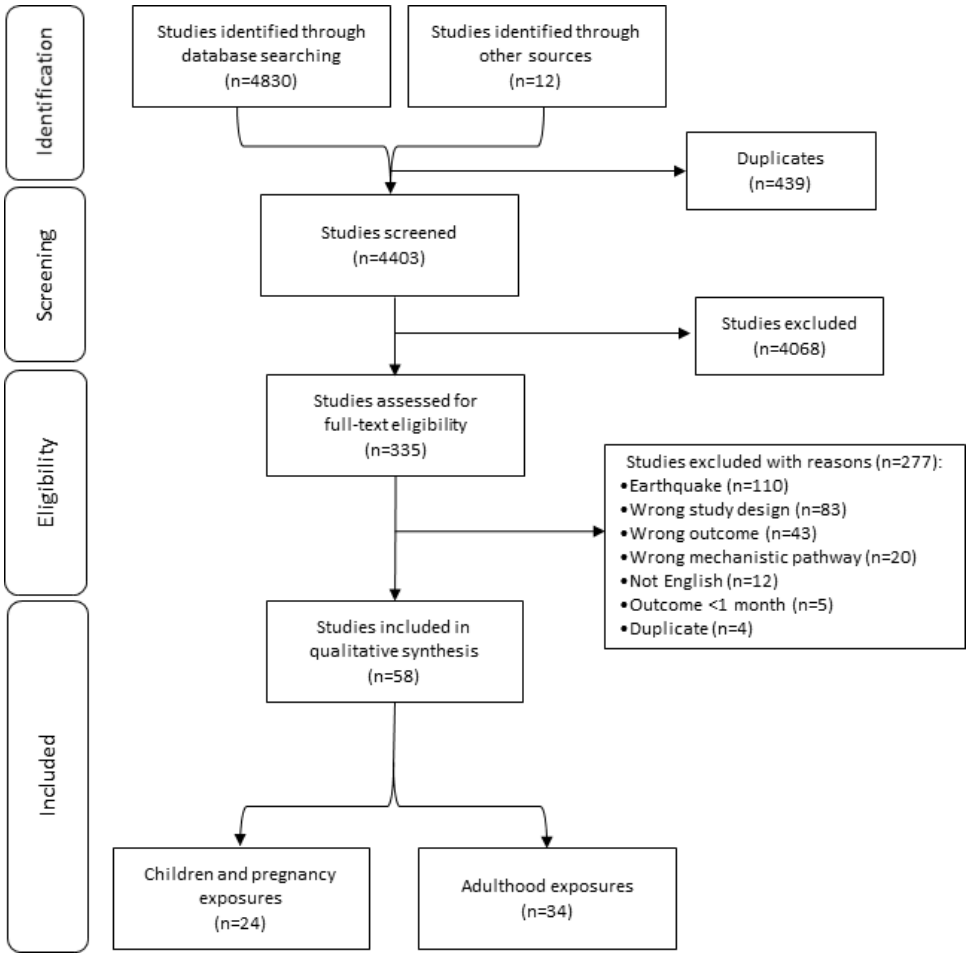

Figure 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram.

that were the result of the disaster as the exposure variable. The age when cardiometabolic outcomes were assessed varied across studies, with 2 studies evaluating pregnancy outcomes,[27 28] 8 studies evaluating outcomes among children and youth,[15 21–26 47] 4 studies assessed outcomes during young to mid-adulthood (>18–40 years of age)[27 29 36 37] and 10 during later adulthood (≥50 years of age).[30 32–35 38–42] One study did not specify the exact age, rather evaluated outcomes throughout adulthood, from 18 to 63 years of age.[31] Detailed characteristics and findings of all studies that assessed perinatal and childhood exposures to disasters can be found in table 3.

Within the 10 studies that evaluated perinatal or childhood disaster exposure in relation to pregnancy, childhood or youth outcomes, 1 study evaluated a human-made disaster (the World Trade Center attacks) and the other 9 studies evaluated natural disasters (including ice storms, floods and hurricanes) and the findings were mixed. The one study that evaluated a human-made disaster found limited evidence of any increased cardiometabolic risk and a small decrease in both body mass index (BMI), and zBMI was observed for children exposed to the World Trade Center attacks compared with those who were not found no differences in triglycerides or lipids.[47] Within the eight studies that evaluated exposure to a natural disaster during the perinatal and childhood period and cardiometabolic outcomes in later childhood, there were six studies that evaluated measures of child growth and four of these studies reported increased BMI or adiposity in later childhood,[21 23 25 26] one study was null,[22] and one study reported increased wasting or malnutrition following exposure to a flood.[15] Importantly, the one study where increased wasting was observed was in Bangladesh, whereas all of the studies that observed increased risk of obesity were in North America. Of the studies that evaluated childhood cardiometabolic outcomes other than growth, one study found increased insulin concentrations at age 13 years.[24] There were two studies that evaluated exposure to a natural disaster (Hurricane Katrina and Hurricane Sandy) during pregnancy and both found increased incidence or hospital visits for gestational hypertension and diabetes.[27 28]

There were 14 studies that evaluated exposure to a disaster in pregnancy or childhood in relation to the subsequent onset of adult cardiometabolic conditions; 11 of these studies evaluated exposure to human-made disasters and 3 evaluated natural disasters. Within the 11 studies that evaluated human-made disasters, 1 study found no association between exposure to the Dutch famine and coronary artery disease in older adulthood.[32]

Table 2 Characteristics of included studies (n=58)

Characteristics	N (%)
Continent	
North America	36 (62)
Europe	13 (22)
Asia	7 (12)
Africa	2 (3)
Year of publication	
2010–2020	44 (76)
2000–2009	12 (21)
1996–1999	2 (3)
Study design	
Cohort/longitudinal	41 (71)
Quasi-experimental*	10 (17)
Cross-sectional	7 (12)
Sample size	
≥10 000	19 (33)
1000–<10 000	10 (17)
≤1000	24 (41)
Not specified	5 (9)
Exposure life stage	
Pregnancy/childhood	24 (41)
Adulthood	34 (57)
Outcome life stage	
Pregnancy	2 (3)
Childhood†	8 (13)
Adult	47 (81)
Disaster	
Human-made	23 (40)
Natural	35 (60)
Cardiometabolic outcome‡	
Cardiovascular disease§	41 (71)
Diabetes¶	11 (19)
Obesity or BMI	12 (21)
Mortality from cardiovascular disease	9 (16)
Cardiometabolic risk during pregnancy**	2 (3)

*Includes pre/post-study design, time-series and natural experiments.
†Children defined as ≤18 years of age.
‡Does not equal to 100% as studies report multiple cardiometabolic outcomes.
§Includes hypertension, coronary artery disease/heart disease, angina, heart attack/myocardial infarction, metabolic syndrome, cardiac disease-related blood markers, stroke.
¶Diabetes, blood glucose, metabolic syndrome.
**Gestational diabetes, gestational hypertension, pre-eclampsia.
BMI, body mass index.

While the remaining 10 studies all found some evidence of increased cardiometabolic outcomes in adulthood following perinatal or childhood exposure, the results were mixed with many null results depending on outcome or exposure. For example, prenatal exposure to famine was associated with higher low-density lipoprotein (LDL) and coronary heart disease approximately 28 years later, however no difference was found for glucose, insulin, BMI or other lipids.[29] The results were not consistent across outcomes, for example, increased risk of hypertension was found in three studies[29 36 40] but not in two studies.[35 37] Within the three studies that evaluated adult cardiometabolic outcomes following exposure to a natural disaster, all three studies found increased risk of CVDs or mortality following prenatal exposure to famine or the 1918 influenza pandemic.[38 39 42]

Studies on adult exposure to disaster and subsequent cardiometabolic outcomes

Thirty-four studies investigated the effects of exposure to disasters during adulthood on cardiometabolic outcomes. The length of follow-up ranged from 1 month to 13 years. There were 23 studies that examined natural disasters,[14 44–46 48 51 52 54–56 58–61 64–67 72–76] and 11 studies that examined human-made disasters.[43 49 50 53 57 62 63 68–71] Of these studies, only one evaluated the impact of an infectious disease epidemic.[66] Most studies (n=27) considered the disaster as the main exposure of interest.[14 43–46 48 50 52 54–56 58–66 68 71–76] The remaining seven studies assessed disaster-related stress,[53 57 67 69] including PTSD and psychological strain, unemployment rates as a result of the disaster[51] and exposure to damaged or collapsed buildings during the World Trade Center disaster.[70] Detailed characteristics and findings of all studies that assessed adult exposures to disasters are included in table 4.

The studies that assessed exposure to human-made disasters (n=11) during adulthood reported mixed results in terms of associations with outcomes and statistical significance. Three studies assessed PTSD related to disasters and found an increased association with stoke,[69] heart disease[57] and cardiovascular/vascular problems,[53] two of which were exposure to the World Trade Centre disaster and the third was a fireworks depot explosion. Two studies assessing exposure to the World Trade Center disaster and Amsterdam Air disaster found an increased association with cardiovascular hospitalisations[49] and cardiovascular symptom complaints[62] in rescue workers compared with non-rescue workers. Of the remaining six studies, three studies reported an increased association with hypertension,[43] systolic blood pressure[71] and CVD mortality,[63] however, the exact exposure varied across studies. For instance, one study explored the level of exposure, defined as low, intermediate or high to the World Trade Center disaster,[63] whereas another study evaluated exposure to the Volendam Pub fire among parents who had children who were injured or died.[43] The final three studies assessing exposure to human-made disasters (World Trade Center disaster and Sewol Ferry disaster) reported mixed results with some showing a decreased association or null findings.[53 68 70]

Table 3 Characteristics of included studies investigating the association between exposure to a disaster during the perinatal and childhood periods and cardiometabolic outcomes across the life-course, by disaster type (n=24)

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Human-made disaster with child/youth outcomes									
Trasande *et al*[47]	Prospective cohort	USA	World Trade Center attacks (9/11)	2001	402	New York children and youth enrolled in the World Trade Center Health Registry (WTCHR) (birthdates: 11 Sept 1993–10 September 2001) compared with individuals born during the same time period who were ineligible for enrolment in the WTCHR	2 years	Youth outcomes: 1. BMI (kg/m^2) 2. zBMI 3. Trig (mg/dL) 4. Chol (mg/dL) 5. LDL (mg/dL) 6. HDL (mg/dL)	Regression coefficient and 95% CI: 1. BMI: –1.12 (–2.11 to –0.12) 2. zBMI: –0.24 (–0.49 to 0.002) 3. logTrig: 0.02 (–0.07 to 0.12) 4. logChol: 0.02 (–0.02 to 0.06) 5. log LDL: 0.06 (–0.001 to 0.12) 6. logHDL: –0.04 (–0.10 to 0.03)
Human-made disaster with adult outcomes									
Bercovich *et al*[40]	Cross-sectional	Israel	Holocaust	1941–1945	300	European Jews born in 1940–1945 with exposure to the holocaust compared with European Jews during the same time period born	N/A	Adult outcomes: 1. Hypertension 2. Diabetes 3. Dyslipidaemia 4. Any CVD	1. Adjusted OR: 2.2, 95% CI: 1.2 to 3.8 2. Adjusted OR: 2.2, 95% CI: 1.2 to 4.2 3. Adjusted OR: 3.1, 95% CI: 1.7 to 5.7 4. Adjusted OR: 2.6, 95% CI: 1.4 to 4.7
de Rooij *et al*[30]	Cohort	Netherlands	Dutch famine	1944–1945	783	Prenatal exposure to Dutch famine defined as people born between 7 January 1945 and 8 December 1945 compared with people born before 7 January 1945 or conceived after 8 December 1945	58 years	Metabolic syndrome at age 58	Metabolic syndrome OR: 1.2; 95% CI: 0.9 to 1.7
Ekamper *et al*[31]	Cohort	Netherlands	Dutch famine	1944–1945	41 096	Male military conscripts born between Jan 1944 and 1946 and compared with military conscripts born before 1944 or after 1946	63 years	Adult outcomes: (1) Heart disease mortality, (2) cerebrovascular disease mortality, (3) diabetes mellitus mortality	HR: 1. HR: 0.94; 95% CI: 0.77 to 1.15 2. HR: 1.55; 95% CI: 0.95 to 2.51 3. HR: 1.61; 95% CI: 0.91 to 2.86

Continued

Table 3 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Huang *et al*[37]	Cohort	China	1959–1961 Chinese famine	1959–1961	35 025	County-level famine intensity for women born during 1957–1962 compared with women born post-famine in 1963	32 years	Adult outcomes at age 32: (1) BMI among rural sample, (2) BMI among urban sample, (3) hypertension among rural sample, (4) hypertension among urban sample	1. Average effect=0.92, 95% CI: 0.32 to 1.51 2. Average effect=0.03, 95% CI: −2.82 to 2.87 3. Log odds=1.23, 95% CI: −0.38 to 2.84 4. Log odds=0.37, 95% CI: −2.07 to 2.80
Hult *et al*[36]	Cohort	Nigeria	Biafran famine	1967–1970	1339	Individuals exposed to famine during early childhood (born 1965–1967) or exposed to famine in fetal life and infancy (born 1968–Jan 1970) compared with people born between 1971 and 1973	~40 years	Adult outcomes at age ~40 years: 1. Hypertension 2. Diabetes 3. Overweight (BMI >25 kg/m^2) 4. Obesity (BMI >30 kg/m^2)	Adjusted OR (95% CI) 1. Childhood exposure: 1.42 (0.63 to 3.13); fetal–infant exposure: 2.50 (1.19 to 5.26) 2. Childhood exposure: 1.81 (0.64 to 5.15); fetal–infant exposure: 2.56 (0.92 to 7.17) 3. Childhood exposure: 1.02 (0.77 to 1.34); fetal–infant exposure: 1.41 (1.03 to 1.93) 4. Childhood exposure: 1.20 (0.87 to 1.67); fetal–infant exposure: 1.30 (0.92 to 1.85)
Lumey *et al*[32]*	Cohort	Netherlands	Dutch famine	1944–1945	1075	Infants whose mothers were exposed to famine during or immediately preceding pregnancy (born 1 Feb 1945–31 March 1946) compared with individuals born in the same hospital before or after famine	~56–62 years	Adult outcomes at 56–62 years: coronary artery disease	Early gestation HR: 1.26, 95% CI: 0.59 to 2.70 Late gestation HR: 1.31, 95% CI: 0.67 to 2.57

Continued

Table 3 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Painter *et al*[33]	Cohort	Netherlands	The Dutch famine	1944–1945	975	Infants who were born between January 1945 and December 1945 who were exposed to famine in utero compared with infants born before the famine (November 1943 and January 1945) and after the famine (December 1945 and February 1947)	~50–58 years	Adult outcomes at 50–58 years: coronary artery disease	HR: 1.9, 95% CI: 1.0 to 3.8
Ravelli *et al*[34]†	Cohort	Netherlands	The Dutch famine	1944–1945	741	Infants exposed to famine during different periods of gestation (late, mid and early) whose maternal daily ration was <1000 kcal (born between January 1945 and December 1945) compared with those born not during the famine	50 years	Obesity adult outcomes at 50 years stratified by sex: 1. Weight (kg) 2. BMI (kg/m^2) 3. Waist circumference (cm)	Mean difference (95% CI) between exposure during late or early gestation versus non-exposed: Men: 1. Late: 0.8 (–3.1 to 4.7); early: 1.5 (–3.5 to 6.6) 2. Late: 0.4 (–3.5 to 4.5); early: 0.5 (–4.6 to 6.0) 3. Late: 1.8 (–1.4 to 4.9); early: 1.8 (–2.4 to 6.0) Women: 1. Late: –1.8 (–6.1 to 2.5); early: 7.9 (2.5 to 13.2) 2. Late: –2.1 (–7.0 to 3.1); early 7.4 (0.7 to 14.5) 3. Late: –0.7 (–4.4 to 3.0); early: 5.7 (1.1 to 10.3)

Continued

Table 3 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Roseboom *et al*[29]†	Cohort	Netherlands	The Dutch famine	1944–1945	2414	Infants who were exposed to famine in utero whose mother had a daily ration <1000 calories during any 13-week period of gestation compared with infants who were born before or conceived after the famine period (before November 1943 or after February 1947)	~28 years	Adult outcomes at 28 years; 1. Plasma glucose (mmol/L) 2. Plasma insulin (pmol/L) 3. Total cholesterol (mmol/L) 4. HDL (mmol/L) 5. LDL (mmol/L) 6. LDL/HDL cholesterol 7. BMI (kg/m^2) 8. CHD 9. Systolic BP (mm Hg) 10. Diastolic BP (mm Hg)	Mean values of outcomes for late gestation and early gestation: 1. Late: 6.3; early: 6.1 2. Late: 200; early: 207 3. Late: 5.83; early: 6.13 4. Late: 5.83; early: 6.13 5. Late: 1.32; early: 1.26* 6. Late: 3.87; early: 3.26* 7. Late: 26.7; early: 28.1 8. Late: 2.5; early: 8.8* 9. Late: 127.4; early: 123.4 10. Late: 86.4; early: 84.8 *p<0.05
Schreier *et al*[41]	Cohort	Finland	Winter War and Continuation War	1939–1940 (Winter War), 1941–1944 (Continuation War)	13 039	Individuals in utero who were exposed to bombings that occurred for 48 days between 1934 and 1944 compared with those who were not exposed in utero	~60–70	Adult outcomes: 1. CHD 2. Cerebrovascular disease	Results are shown graphically Higher CHD survival rates among women 64+ years and among men aged 50–54 years exposed while in utero

Continued

Table 3 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Stein *et al*[35]	Cohort	Netherlands	The Dutch famine	1944–1945	971	Prenatal exposure to famine defined as the weeks post-last menstrual period that mother was exposed to an official ration of <900 kcal/week (gestation weeks: 1–10, 11–20, 21–30, or 31–delivery)	59	Adult outcomes: 1. Systolic BP (mm Hg) 2. Diastolic BP (mm Hg) 3. Hypertension	Adjusted regression coefficients 1. 1–10 weeks: 1.20 (95% CI: −3.28 to 5.69); 11–20 weeks: −1.19 (95% CI: −4.92 to 2,55); 21–30 weeks: 1.33 (95% CI: −2.24 to 4.90); 31–delivery: 2.02 (95% CI: −1.53 to 5.57) 2. 1–10 weeks: 1.10 (95% CI: −1.36 to 3.57); 11–20 weeks: −1.26 (95% CI: −3.32 to 0.80); 21–30 weeks: 1.19 (95% CI: −0.78 to 3.15); 31–delivery: 0.71 (95% CI: −1.24 to 2.66) 3. 1–10 weeks: 1.14 (95% CI: 0.62 to 2.11); 11–20 weeks: 0.98 (95% CI: 0.59 to 1.65); 21–30 weeks: 1.23 (95% CI: 0.74 to 1.05); 31–delivery: 1.42 (95% CI: 0.86 to 2.35)
Natural disaster with pregnancy outcomes									
Oni *et al*[27]	Cross-sectional	USA	Hurricane Katrina	2005	146	Women who were pregnant during Hurricane Katrina or became pregnant immediately after hurricane compared with those who were not exposed to the hurricane; women who experienced prenatal stress caused by Hurricane Katrina compared with those who did not experience stress	9 months	Pregnancy-related outcomes: 1. Pregnancy-induced hypertension 2. Gestational diabetes	1. Hurricane exposure: adjusted OR: 1.22 (95% CI: 0.81 to 1.84); perceived stress: adjusted OR: 1.16 (95% CI: 1.05 to 1.30) 2. Hurricane exposure: adjusted OR: 1.04 (95% CI: 0.69 to 1.57); perceived stress: adjusted OR: 1.13 (95% CI: 1.02 to 1.25)

Continued

Table 3 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Xiao *et al*[28]	Time-series/quasi-experimental	USA	Hurricane Sandy	2012	Not reported	Exposure to Hurricane Sandy lasting impacts defined as the following 12 months after Sandy (November 2012–October 2013) compared with the November–October in other years during November 2005–October 2014 among women who were pregnant	12 months	Outcomes in adults: 1. Emergency department visits for gestational hypertension 2. Emergency department visits for diabetes or abnormal glucose	1. Increased at 7 months: 7.3% (95% CI: 1.0% to 13.9%) 2. Increased at 8 months: 26.3% (95% CI: 3.9% to 53.6%) *Results for 12 months reported graphically
Natural disaster with child/youth outcomes									
Cao-Lei *et al*[26]	Cohort	Canada	Quebec ice storm	1998	31	Negative cognitive appraisal of the impact of the ice storm among pregnant women compared with neutral or positive appraisal	13 years	Outcomes among children at age 13 years: 1. Central adiposity (waist to height ratio) 2. BMI (kg/m^2)	Mean (SD) 1. Exposed: 20.86 (3.73); unexposed: 22.84 (5.19) 2. Exposed: 0.43 (0.04); unexposed: 0.45 (0.06)
Dancause *et al*[23]	Cohort	Canada	Quebec ice storm	1998	111	Higher objective PNMS scores compared with lower scores among women who were pregnant or conceived within 3 months of the storm	5.5 years	Childhood obesity at 5.5 years of age	OR: 1.37, 95% CI: 1.06 to 1.77
Dancause *et al*[24]	Cohort	Canada	Quebec ice storm	1998	32	Higher objective hardship compared with lower hardship scores reported among pregnant women exposed to the storm	13.4 years	Childhood insulin secretion at 13 years of age	Insulin secretion: adjusted linear regression standardised coefficient=0.52, p<0.01

Continued

Table 3 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Dancause *et al*[22]	Cohort	USA	Iowa flood	2008	106	Higher reported measures of objective hardship and subjective distress compared with lower scores among pregnant women during the floods	2.5–4 years	Childhood outcomes: 1. Child BMI z-scores at age 2.5 2. Child BMI z-scores at age 4 3. Difference in BMI from age 2.5 to 4 years 4. Child adiposity (skinfolds) at age 2.5 years 5. Child adiposity (skinfolds) at age 4 years 6. Difference in adiposity from age 2.5 to 4 years	Beta coefficient (p value) 1. –0.07 (0.56) 2. –0.22 (0.07) 3. 0.11 (0.41) 4. 0.00 (0.97) 5. –0.06 (0.72) 6. 0.03 (0.82)
Goudet *et al*[15]	Cohort	Bangladesh	1998 Bangladesh flood	1998	220	Maternal malnutrition among mothers of infants and young children following flood exposure defined as underweight (BMI <18.5 kg/m^2) compared with normal (BMI ≥18.5)	12 months	Child outcomes at 12–36 months of age: 1. Underweight (weight for age z-score <–2) 2. Stunted (height for age z-score <–2) 3. Wasted (weight for height z-score <–2)	1. Adjusted OR=3.509, 95% CI: 1.022 to 12.048) 2. Adjusted OR: 4.447, 95% CI: 1.044 to 18.943 3. Adjusted OR: 2.097, 95% CI: 0.507 to 8.671
Kroska *et al*[21]	Longitudinal study	USA	Iowa flood	2008	103	Levels of maternal stress among those exposed to Iowa floods	2.5 years	Children outcomes at 2.5 years: BMI (kg/m^2)	Standardised coefficient: 0.2071 (p=0.0322)
Liu *et al*[25]	Longitudinal study	Canada	Quebec ice storm	1998	52–111 at different time points	Levels of maternal stress (objective hardship and subjective stress) among those exposed to Iowa floods	5.5–15.5 years	Children outcomes at 5.5–15.5 years: 1. BMI (kg/m^2) 2. Waist to height ratio	Correlation r (p value) Age 8.5 years 1. Objective hardship: 0.21 (0.05) 2. Objective hardship: 0.23 (0.03) Age 15.5 years 1. Objective hardship: 0.34 (0.02) 2. Objective hardship: 0.44 (<0.01)
Natural disaster with adult outcomes									

Continued

Table 3 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Mazumder *et al*[38]	Cohort	USA	1918 influenza pandemic	1918–1919	101 068	Infants who were born during the influenza pandemic (third and fourth quarter of 1918, and the first, second and third quarter of 1919) compared with those born in the last quarter of 1919	~60–82 years	Adult outcomes at 60–82 years: 1. Diabetes 2. Heart disease	Excess cases of diabetes/heart disease: 1. 1918 Q4: 7.7% excess (95% CI: −10.6% to 25.9%); 1919 Q1: −5.2 (95% CI: −22.9 to 12.5); 1919 Q2: 36.7% excess (95% CI: 18.9% to 54.4%); 2. 1918 Q4: 4.6% excess (95% CI: −4.3% to 13.5%); 1919 Q1: 10.9% excess (95% CI: 2.3% to 19.6%); 1919 Q2: 6.4% excess (95% CI: −2.2% to 15.1%)
Myrskyla *et al*[39] ‡	Cohort	USA	1918 influenza pandemic	1918–1919	81 571	Infants who were born during the influenza pandemic (born during different quarters of 1917, 1918 and 1919) compared with those born in 1920–1924	~63–95 years	Adult outcomes at 63–95 years: cardiovascular mortality	1918 Q1 HR: 1.05 (95% CI: 0.94 to 1.17); 1918 Q2 HR: 1.02 (95% CI: 0.91 to 1.14); 1918 Q3 HR: 0.99 (95% CI: 0.89 to 1.10); 1918 Q4 HR: 0.97 (95% CI: 0.87 to 1.09); 1919 Q1 HR 1.07 (95% CI: 0.96 to 1.19); 1919 Q2 HR: 1.06 (95% CI: 0.95 to 1.19)

Continued

Table 3 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Sotomayor[42]	Cohort/ natural experiment	Puerto Rico	Hurricanes San Felipe and San Cipiran	1928 and 1932	11 990	Those born during 1929 and 1933 were defined as exposed to the hurricanes compared with individuals born outside of these years between 1920 and 1940	Not reported (average age=70 years)	Outcomes at ~70 years of age: 1. Diabetes 2. Hypertension 3. High cholesterol 4. CVD 5. AMI 6. Coronary/angina 7. Stroke	Linear regression estimates (p value) 1. San Felipe: 5.94 (<0.01); San Ciprian: 5.43 (<0.01) 2. San Felipe: 4.73 (<0.01); San Ciprian: 6.39 (<0.01) 3. San Felipe: 8.85 (<0.01); San Ciprian: 5.28 (<0.01) 4. San Felipe: −1.48; San Ciprian: 1.33 5. San Felipe: 0.81; San Ciprian: 3.26 (<0.01) 6. San Felipe: 0.40; San Ciprian: −0.60 7. San Felipe: −0.25; San Ciprian: 0.58

*Results are numbered to correspond with the numbered outcomes in the outcomes column.
†Only presenting results for early and late gestation; results for mid-gestation are not included in summary table but can be found in studies.
‡Not all results presented for different exposure groups.
AMI, acute myocardial infarction; BMI, body mass index; BP, blood pressure; CHD, coronary heart disease; Chol, cholesterol; CVD, cardiovascular disease; HDL, high-density lipoprotein; LDL, low-density lipoprotein; N/A, not available; PNMS, prenatal maternal stress; Q1–Q4, quarter; Trig, triglycerides.

Table 4 Description of studies investigating the association between exposure to a disaster during adulthood and cardiometabolic outcomes across the life-course, by disaster type (n=34)

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Human-made disaster									
Brackbill *et al*[70]	Cohort	USA	World Trade Center attacks (9/11)	2001	8418	Adult survivors of 9/11 present at time of first aeroplane impact in a structure that was damaged compared with those that collapsed; time of evacuation before compared with after damage	1 year	1. Hypertension 2. Coronary heart disease 3. Angina 4. Heart attack 5. Diabetes 6. Stroke	1. Building type: aOR: 1.2 (p<0.05); time of evacuation: aOR: 0.9 (0.6 to 1.3) 2. Building type: aOR: 0.8 (0.4 to 1.6); time of evacuation: aOR: 0.5 (0.1 to 2.2) 3. Building type: aOR: 0.8 (0.4 to 1.6); time of evacuation: aOR: 0.7 (0.2 to 3.1) 4. Building type: aOR: 2.1 (0.9 to 4.9); 5. Time of evacuation: aOR: 0.7 (0.3 to 1.7) 6. Building type: aOR: 1.5 (0.6 to 4.0)
Dirkzwager *et al*[53]	Cohort	Netherlands	Fireworks depot explosion	2000	896	PTSD among those exposed to the fireworks disaster 19 months following the disaster compared with those with no PTSD exposed to the fireworks explosion	18 months	1. Cardiovascular 2. Vascular problems	1. Physical health problems OR: 1.23; 95% CI: 0.78 to 1.94; new health problems (not present pre-disaster): 1.11; 0.65 to 1.89 2. Physical health problems OR: 2.12, 95% CI: 1.23 to 3.68; 1.92; new health problems (not present pre-disaster) OR: 1.92, 95% CI: 1.04 to 3.55
Dorn *et al*[43]	Cohort	Netherlands	Volendam Pub fire	2001	2255	Parents of children with burns from fire, parents of children without burns, bereaved parents compared with community controls who were not trapped in fire	4 years	Incidence of hypertension	Bereaved parents: OR: 2.42, 95% CI: 0.90 to 6.55; parents of victims with burns: OR: 1.43, 95% CI: 0.97 to 2.11; parents of victims without burns: OR: 1.44, 95% CI: 0.92 to 2.26
Gerin *et al*[71]	Pre/post-design/quasi-experimental	USA	World Trade Center attacks (9/11)	2001	528	Adults 2 months before 9/11 compared with 2 months after 9/11 across 4 cities (Chicago, Washington DC, New York and Mississippi)	4 months	Systolic BP	Difference (SE) New York: 1.58 (0.82) p<0.05 Chicago: 2.15 (0.32) p<0.001 Mississippi: 2.92 (0.67) p<0.001 Washington DC: 8.67 (1.16) p<0.001

Continued

Table 4 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Huizink *et al*[62]	Cohort	Netherlands	Amsterdam Air disaster	1992	1996	Police officers and firefighters who performed at least one disaster-related task compared with professional colleagues who did not perform any disaster-related tasks	8.5 years	Cardiovascular complaints	Adulthood outcomes Police officers: OR: 1.76 (95% CI: 1.35 to 2.29) Firefighters: OR: 3.3 (95% CI: 1.70 to 6.41)
Jordan *et al*[57]	Prospective cohort	USA	World Trade Center attacks (9/11)	2001	39 324	9/11-related PTSD compared with no PTSD	2.9 years	Heart disease	Women aOR: 1.68 (95% CI: 1.33 to 2.12) Men aOR: 1.62 (95% CI: 1.34 to 1.96)
Jordan *et al*[63]	Prospective cohort study	USA	World Trade Center attacks (9/11)	2001	39 324	Low, intermediate and high exposure to 9/11	2.9 years	Heart disease mortality	Intermediate exposure: HR: 1.21 (95% CI: 80 to 1.83) High exposure: HR: 2.06 (95% CI: 1.10 to 3.86)
Jordan *et al*[49]†	Cohort	USA	World Trade Center attacks (9/11)	2001	46 346	Low, intermediate and high exposure to 9/11	7 years	CVD hospitalisations	Rescue/recovery workers: women: high: adjusted HR: 3.29 (95% CI: 0.85 to 12.69); men: high: 1.82 (95% CI: 1.06 to 3.13) Non-rescue/recovery workers: women: high: adjusted HR: 0.88 (95% CI: 0.54 to 1.43); men: high: adjusted HR: 0.94 (95% CI: 0.60 to 1.47)
Kong *et al*[50]	Pre/post-design/quasi-experimental	South Korea	Sewol Ferry disaster	2014	73 632	Exposure to the Sewol Ferry disaster in 1-week periods from 21 May through 17 June 2014 compared with the reference period (March 2015–April 2015)	8 weeks	Adulthood outcomes 1. Acute MI 2. Angina	1. 8 weeks after Sewol: IRR: 0.91 (95% CI: 0.81 to 1.02) 2. 8 weeks after Sewol: IRR: 0.93 (95% CI: 0.85 to 1.01)

Continued

Table 4 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Lin *et al*[68]	Pre/post-design/quasi-experimental	USA	World Trade Center attacks (9/11)	2001	Not reported	Areas affected by 9/11 compared with areas not affected by 9/11	10 years	Adulthood outcomes for CVD hospitalisations	Prevalence ratio (95% CI): 14 Aug–10 Sep: 0.51 (95% CI: 0.26 to 1.00) 11 Sep–17 Sep: 0.56 (95% CI: 0.28 to 1.11); 18 Sep–24 Sep: 0.77 (95% CI: 0.44 to 1.32); 25 Sep–01 Oct: 0.49 (95% CI: 0.24 to 1.00); 02 Oct–08 Oct: 0.98 (95% CI: 0.53 to 1.87); 09 Oct–15 Oct: 1.09 (95% CI: 0.60 to 1.98); 16 Oct–22 Oct: 0.50 (95% CI: 0.26 to 0.95); 23 Oct–29 Oct: : 0.45 (95% CI: 0.20 to 0.98); 30 Oct–05 Nov: 0.48 (95% CI: 0.23 to 0.97)
Yu *et al*[69]	Cohort Study	USA	World Trade Center attacks (9/11)	2001	42 527	9/11-related PTSD compared with no PTSD	13 years	Stroke	Adjusted HR: 1.69 (95% CI: 1.42 to 2.02)
Natural disaster									
An *et al*[67]	Cross-sectional	USA	Hurricane Ike	2008	19	Psychological strains among Hurricane Ike survivors	3 months	1. Blood glucose (mg/dL) 2. Obesity (BMI; kg/m^2)	Mean (high vs low) and SD: PTSD symptom: 22.44 (4.93) vs 12.86 (10.48); p=0.014; perceived stress: 23.00 (5.03) vs 28.11 (5.07) p=0.048 28.43 kg/m^2 (3.92) vs 20.83 kg/m^2 (3.92) p=0.018

Continued

Table 4 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Baum *et al*[14]	Cohort study	USA	Hurricane Sandy	2012	81 544	Veterans who used Manhattan VA Medical Center before Hurricane Sandy and experienced decreased access to healthcare services compared with veterans who used the VA Bronx, Brooklyn or West Haven medical centres	2 years	1. Uncontrolled hypertension 2. Systolic BP (mm Hg) 3. Diastolic BP (mm Hg) 4. Uncontrolled diabetes 5. Uncontrolled cholesterol (mg/dL) 6. Weight (lbs)	% differential change (95% CI): 1. 6 months: 19.3 (4.5 to 8.7); 12 months: 4.5 (3.1 to 5.9); 18 months: 5.0 (3.5 to 6.5); 24 months: 2.1 (0.5 to 3.6) 2. 6 months: 3.8 (3.1 to 4.5); 12 months: 2.3 (1.7 to 2.9); 18 months: 3.1 (2.5 to 3.7); 1.5 (0.9 to 2.1) 3. 6 months: 2.7 (2.3 to 3.1); 12 months: 2.2 (1.9 to 2.6); 18 months 2.9 (2.5 to 3.3), 24 months: 2.0 (1.7 to 2.4) 4. 6 months: 1.9 (–0.1 to 4.0); 12 months: 1.7 (–0.3 to 3.6); 18 months: 0.8 (–1.2 to 2.8); 24 months: –0.2 (–2.2 to 1.8) 5. 6 months: 1.3 (–0.1 to 2.6); 12 months: 0.6 (–0.6 to 1.8); 18 months: –0.7 (–2.0 to 0.6); 24 months: –0.2 (–1.4 to 1.0) 6. 6 months: –0.1 (–0.5 to 0.2); 12 months: 0.2 (–0.2 to 0.5); 18 months: –0.2 (–0.5 to 0.2); 24 months: 0.5 (0.1 to 0.9)
Becquart *et al*[48]	Time-series/quasi-experimental	USA	Hurricane Katrina	2005	383 552	Exposure to hurricane before, during and after among older adults in Louisiana in the affected counties	1 year	Hospitalisations due to CVD	Mean (SD) Orleans: T1: 7.25 (2.44); T2: 3.91 (1.45)*; T3; 18.47 (17.3)*; T4:13.76 (6.51)*; T5: 9.54 (2.78); T6: 4.69 (2.08) Jefferson: T1: 5.90 (1.90); T2: 5.01 (1.52); T3: 8.118 (3.70)*; T4: 7.25 (2.15)*; T5: 5.26 (1.53); T6: 4.65 (1.57)* East BR: T1: 8.69 (2.74); T2: 9.11 (2.69); T3: 6.52 (2.58); T4: 6.55 (1.70)*; T5: 6.69 (2.42)*; T6: 7.39 (2.37)* *p<0.05
Bich *et al*[61]	Cross-sectional	Vietnam	Historic flood in 2008	2008	781	Individuals who resided in households affected by flood in Hanoi in 2005 compared with non-affected households	1 month	Worsening hypertension after rain/flood	Rural: non-flooded 33.3%; flooded: 51.2%; Urban: non-flooded 20.3% flooded: 42.9%* *p<0.05

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Table 4 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Fonseca *et al*[59]	Cohort	USA	Hurricane Katrina	2005	1795	Adults with diabetes who were in the databases from 3 healthcare systems 6 months before the hurricane (28 Feb 2005–27 Aug 2005) compared with 6–16 months after the hurricane (1 March 2006–31 December 2006)	22 months	1. Glycaemic control/A1c 2. Systolic BP (mm Hg) 3. Diastolic BP (mm Hg) 4. HDL (mg/dL) 5. LDL (mg/dL) 6. Triglycerides (mg/dL)	Difference in mean (SD) 1. 0.1 (1.6) (p<0.01) 2. 10.5 (20.4) (p<0.01) 3. 3.9 (13.1) (p<0.01) 4. 6.0 (35.5) (p<0.01) 5. –2.4 (9.2) (p<0.01) 6. –2.1 (137.5) (p=0.60)
Gautam *et al*[55]	Retrospective cohort	USA	Hurricane Katrina	2005	396	Exposure to Hurricane Katrina compared with period before hurricane	4 years	Incidence of AMI admission	Pre-Katrina group: 150 admissions for AMI (0.71%) Post-Katrina group: 246 admission for AMI (2.18%) p<0.0001
Hendrickson and Vogt[64]	Pre/post-design/quasi-experimental	USA	Hurricane Iniki	1992	Not reported	Mortality data for residents of Kauai for 5-year period 1987–1991 prior to disaster compared with the year immediately following the hurricane (1 Oct 1992–30 Sept 1993)	6 years total	Mortality by: 1. Heart disease 2. Stroke 3. Diabetes mellitus	1. RR: 0.96 (95% CI: 0.79 to 1.17) 2. RR: 1.20 (95% CI: 0.81 to 1.78) 3. RR: 2.61 (95% CI: 1.44 to 4.74)
Husarewycz *et al*[72]	Cross-sectional	USA	Natural disaster/ terrorism	Lifetime disaster experience	34 653	Number of times directly experienced natural disaster/ terrorism compared with no experiences	1 year	1. CVD 2. Hypertension/ arteriosclerosis 3. Diabetes 4. Obesity	1. OR: 1.28 (95% CI: 1.10 to 1.49) 2. OR: 1.08 (95% CI: 0.95 to 1.24) 3. OR: 1.10 (95% CI: 0.94 to 1,29) 4. OR: 1.01 (95% CI: 0.90 to 1.14)
Jiao *et al*[54]	Retrospective cohort observational study	USA	Hurricane Katrina	2005	Not reported	2 years prior to the hurricane (29 August 2003–28 August 2005) compared with the 3-year period post-Hurricane Katrina (14 February 2006–13 February 2009)	5 years	Incidence of AMI	Pre-Katrina: 0.7% compared with post-Katrina: 2% (p<0.001)
Joseph *et al*[51]	Cohort/longitudinal	USA	Hurricane Katrina	2005	215	African Americans who experienced acute unemployment due to hurricane compared with those who remained employed	4 years	Cardiometabolic event	aOR=5.65, p<0.05
Karatzias *et al*[44]	Cross-sectional	Hong Kong	Natural disaster	Not specified	1147	Experience of natural disaster across life-course compared with less or no experiences	Survey done from August to December 2012	1. Hypertension 2. Heart disease 3. Diabetes	X^2 (p value) 1. 3.3 (0.047) 2. 3.6 (0.056) 3. 2.5 (0.088)

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Table 4 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Kim *et al*[58]	Pre/post-design/quasi-experimental	USA	Hurricane Sandy	2012	Not reported	The month of Hurricane Sandy (28 October 2012–27 November 2012) compared with the same month in 2009–2011; Sandy quarter (28 October 2012–27 January 2013) compared with the same period in 2009–2011 among elderly people	Sandy month: 28 Oct 2012–27 Nov 2012 Sandy quarter: 28 Oct 2012–27 Jan 2013	CVD-related death	Sandy quarter: adjusted RR: 1.06; 95% CI: 1.02 to 1.10 Sandy month: adjusted RR: 1.10; 95% CI: 1.02 to 1.18
Koroma *et al*[66]	Cross-sectional	Sierra-Leone	Ebola	2014–2015	10011	District facilities for 6-month periods before Ebola (June–December 2012), during Ebola (June–December 2014) and post-Ebola (June–December 2015)	June–December 2012, 2013, 2014	1. CVD 2. Hypertension 3. Diabetes	Number of people with non-communicable diseases 1. Pre-Ebola: 355, Ebola: 300, post-Ebola: 196 2. Pre-Ebola: 282, Ebola: 230, post-Ebola: 457 3. Pre-Ebola: 3716, Ebola: 1851, post-Ebola: 2463
Lawrence *et al*[45]	Prospective cohort study	USA	Superstorm Sandy	2012	651858	Residing in counties affected by Superstorm Sandy compared with non-affected counties; superstorm period compared with reference periods (short-term and long-term (4 and 12 months))	1 year	Emergency department visits, outpatient visits and hospital admissions for CVD	4 months: Superstorm Sandy period: RR: 2.10 (95% CI: 2.10 to 2,10); affected counties RR: 2.62 (95% CI: 2.62 to 2.63) 12 months: Superstorm Sandy period: RR: 2.01 (95% CI: 2.00 to 2.01); affected counties RR: 2.64 (95% CI: 2.64 to 2.65)
McKinney *et al*[52]	Time-series/quasi-experimental	USA	Hurricanes Charley, Frances, Ivan and Jeanne, and Tropical Storm Bonnie	2004	Not reported	Counties in 2004 directly impacted by the hurricanes, ordered evacuated regardless of the level of damage that occurred and adjacent to the impact zone where direct deaths were reported compared with the same areas in 2001–2006	5 years	Heart-related mortality	Results shown graphically Significantly elevated heart-related deaths

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Table 4 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Moscona *et al*[75]	Retrospective cohort study	USA	Hurricane Katrina	2005	2-year pre-Katrina—21 079 10-year post-Katrina—84 751	Individuals who lived in New Orleans who went to the Tulane University Health Sciences Center compared with the 2 months prior to the hurricane	12 years	1. Hospital admission for incidence of AMI 2. Changes in CAD 3. Changes in diabetes mellitus 4. Changes in hypertension 5. Changes in hyperlipidaemia	Pre-Katrina versus post-Katrina 1. 0.7% vs 2.8% (p<0.001) 2. 36.4% vs 47.9%, (p=0.01) 3. 31.3% vs 39.9% (p=0.04) 4. 71.1% vs 80.6% (p=0.12) 5. 45.4% vs 59.3% (p=0.005)
Nagayoshi *et al*[56]	Pre/post-design/quasi-experimental	Japan	12 July 2012 heavy rain and mudslides 'mountain tsunamis'	2012	583	Individuals who were admitted at Aso Central Hospital from 12 July to 31 August 2012 compared with the 3-year period before flooding	3 years	1. Hospital admission for cardiovascular outcomes 2. CVE	1. 4.5 months before compared with 16.8 months after; p<0.01 2. 5.1 months before compared with 16.8 months after; p<0.01)
Ng *et al*[73]	Cohort	UK	Flood	June 2007	1743	Diabetics affected by floods compared with diabetics not affected by floods	2 years	Glycaemic control/ HbA1c levels	Mean HbA1c before 7.6% (7.5–7.7) vs after 7.9% (7.7–8.0); p=0.002
Peters *et al*[65]	Retrospective cohort	USA	Hurricane Katrina	2005	698	Admission to Tulane University Health Sciences Centre in the 3-year period post-Katrina compared with the 6-year period pre-Katrina	9 years	Chronobiology of AMI onset	Pre-Katrina: 45% vs post-Katrina: 30.9%, p=0.002
Rey *et al*[74]	Longitudinal	France	6 heat waves	1971–2003	Not reported	Time of heat wave compared with the expected mortality during the 3 years prior to the heat wave	N/A	Excess CVD death	41% in 1975 to 23% in 2003
Silva-Palacios *et al*[60]	Pre/post-design/quasi-experimental	USA	Oklahoma tornado	2013	22 607	Victims of the Oklahoma tornado outbreaks compared with the same people pre-tornado and same period 1 year prior	6 months	Hospital admissions for CVE	1 year prior: PR=1.05 95% CI: 0.91 to 1.21, p=0.50; 3 months pre-tornado: PR=0.96, 95% CI: 0.83 to 1.21, p=0.63
Thethi *et al*[76]	Cohort	USA	Hurricane Katrina	2005	1523	Individuals exposed to Hurricane Katrina compared with 6–16 months pre-Hurricane Katrina (28 February 2005–27 August 2005)	6 months before Katrina and 6–16 months after Katrina and follow-up 1 year after the first post-Katrina visit	1. LDL (mg/dL) 2. HDL (mg/dL) 3. Triglycerides (mg/dL) 4. Cholesterol (mg/dL) 5. Diastolic BP (mm Hg) 6. Systolic BP (mm Hg)	Mean pre-Katrina versus post-Katrina: 1. 101.34 vs 107.44 2. 43.53 vs 41.08 3. 160.8 vs 158.65 4. 181.9 vs 181.39 5. 70.99 vs 74.88 6. 130.73 vs 141.27

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Table 4 Continued

Study	Study design	Country	Name of disaster	Year	Sample size	Primary exposure and comparator	Average follow-up	Outcomes	Primary results*
Vanasse *et al*[46]	Population-based retrospective cohort study with a time-series design	Canada	Flood of Saint-Jean-sur-Richelieu	2011	111 317	Exposure to flood in spring 2011 and exposure to flooded area (area 1) compared with same period in spring 2010 and 2012 and non-flooded areas in the same town (areas 2, 3 and 4)	4 months	Acute CVE	Spring 2010: aOR 1.25 (95% CI: 0.81 to 1.92); spring 2012 aOR: 1.27 (95% CI: 0.82 to 1.92); non-flooded area 2: aOR: 1.11 (95% CI: 0.79 to 1.59), non-flooded area 3: aOR: 0.94 (95% CI: 0.68 to 1.32); non-flooded area 4: aOR 1.08 (95% CI: 0.78 to 1.47)

*Results are numbered to correspond with the numbered outcomes in the outcomes column.
†Only results for extreme outcomes are reported in table, remaining results can be found in the study.
AMI, acute MI; aOR, adjusted OR; BP, blood pressure; CAD, coronary artery disease; CVD, cardiovascular disease; CVE, cardiovascular events; HbA1c, haemoglobin A1c; HDL, high-density lipoprotein; IRR, incidence rate ratio; LDL, low-density lipoprotein; MI, myocardial infarction; N/A, not available; PR, prevalence ratio; PTSD, post-traumatic stress disorder; RR, relative risk; VA, Veterans Affairs.

Among studies that evaluated the impact of exposure to natural disasters (n=23), six studies that evaluated exposure to Hurricanes Sandy, Katrina, Iniki, and the flood of Saint-Jean-sur-Richelieu reported an increased association with cardiometabolic outcomes.[45 46 51 58 64 72] One of these studies specifically investigated unemployment as a result of Hurricane Katrina and found those who were unemployed, compared with those who remained employed, were 5.65 times more likely to have a cardiometabolic event ($p<0.05$).[51] Nine studies reported a statistically significant increase in outcomes following exposure to a disaster.[52 54–56 61 67 73–75] For instance, one study found those who reported higher levels of psychological strain after surviving Hurricane Ike, compared with those with lower levels of psychological strain, had higher mean blood glucose and obesity 4 months after the disaster.[67] Whereas, another study found a higher proportion of people experiencing worse hypertension who were living in households affected by the 2008 Hanoi flood compared with those who lived in an unaffected households in both rural and urban areas.[61] Two of these studies reported an increase in incidence of acute myocardial infarction (AMI) and AMI hospital admission pre-Hurricane Katrina, compared with post-Hurricane Katrina.[54 55] Three studies found varying associations across outcomes reported within their study. For example, Fonseca *et al*[59] found an increased mean difference pre/post-Hurricane Katrina for glycaemic control, systolic blood pressure, diastolic blood pressure and high-density lipoprotein, but not for LDL and triglycerides. Nine studies reported mixed findings across outcomes within the study. Four of these studies found both an increase and decrease in outcomes when comparing mean difference or proportion pre/post-disaster.[14 48 66 76] One study found those with higher reports of exposure to natural disaster throughout the life-course were significantly different from those with lower reports.[44] The final two studies found a decreased proportion of AMI following Hurricane Katrina[65] and no significant association between exposure to the Oklahoma tornado and hospital admission for cardiovascular events.[60]

Mediation and modification of cardiometabolic outcomes

Across all studies, few evaluated effect modification or subgroups of a population that may be at a greater risk of negative health outcomes following disasters. Eight studies stratified by sex,[30 34 36 41 45 50 57 64] gestational timing of exposure,[22 29 31–33 35 38] year of birth or age at outcome,[42 64 69] urban or rural area,[37] race[45 48] and socioeconomic status,[67] however, results varied greatly due to the differences in exposure period, disaster type, cardiometabolic outcome and age at outcome. One study explored the possible mediators between cognitive appraisal following the Quebec ice storm and obesity. It was noted that negative cognitive appraisal was found to predict obesity via DNA methylation of diabetes-related genes.[26] No studies evaluated or discussed possible

interventions to mitigate risk of cardiometabolic disease following a disaster.

Critical appraisal

The critical appraisal assessment for all study designs can be found in the online supplemental tables A2–A4. Among the cohort studies, most studies met all criteria included in the checklist indicating high study quality. For instance, almost all cohort studies had comparable populations that were recruited in a similar way and exposures that were assessed in the same way across populations. However, across almost all cohort studies, information on follow-up or strategies to address incomplete follow-up were unclear or not addressed. The critical appraisal results for cross-sectional studies were inconsistent with a small number of studies meeting only some checklist requirements. For quasi-experimental studies, the checklist requirements for within-person comparisons were not applicable for all studies, however, all studies clearly defined the cause and effect within the study.

DISCUSSION

Principal findings

A total of 58 studies were identified and they covered a wide breadth of exposures to both natural and human-made disasters, including famine, war, terrorism, natural disasters and infectious disease epidemics. Exposures were investigated in pregnancy and childhood exposure through to adulthood with outcomes measured 1 month to 95 years later. The reviewed studies reflect a true life-course body of literature with exposures at multiple ages and long-term exposures. A range of cardiometabolic outcomes including obesity, hypertension, myocardial infarction, diabetes and cardiac mortality were investigated. Given the varied nature of the studies, it was difficult to draw overall conclusions, but the vast majority of studies provided some evidence of increased cardiometabolic risk following disaster exposure. There were only 11 studies that reported no increased risk or had unclear findings. Across these studies, there was a variety of disaster exposure, outcomes and follow-up periods, however, seven of these studies did not report adjustment or consideration of any confounders.

Relation to other studies

To the best of our knowledge, this is the first review to systematically review the literature on a broad range of disasters and cardiometabolic health outcomes across the life-course. Other reviews have focused on a specific population, such as older adults, specific disaster types (eg, natural disasters only) or other health conditions (eg, mental health) or acute outcomes.[5 6 8] However, across most reviews it was apparent the heterogeneous nature of included studies makes it difficult to summarise findings and make overall conclusions and recommendations. For instance, Chan and Sondorp[8] found exposure to natural disasters negatively affected those with chronic conditions, although authors noted limitations due to limited literature. Another systematic review found very heterogeneous results when reviewing the literature on health outcomes after disasters for older adults with chronic disease.[5] The studies included here were from multiple disciplines, used a variety of study designs, assessed several different outcomes and applied different statistical approaches. Overall, the results suggested increased risk of adverse cardiometabolic outcomes following disasters, although this was not apparent across all included studies.[6] The unexpected nature of disasters, uniqueness of population or region affected, and scale of damage lead to research studies that vary greatly. Although previous reviews and the current review have identified quite heterogeneous studies, overall conclusions suggest risk of disease increases after exposure to disasters.

Biological mechanisms

Several potential mechanisms were discussed in the included studies that may contribute to the observed associations between disaster exposure and increased cardiometabolic outcomes, include the role of both objective and subjective stress, nutritional changes, and reduced access to healthcare. One study that explored mediators in the association between stress and obesity measures identified the role of DNA methylation in this association.[26] It is well postulated that the activation of a stress response following a stressful event leads to changes in the nervous, cardiovascular, endocrine and immune systems.[77] Exposure to disasters including famine, war, terrorism, natural disasters and infectious disease epidemics may activate a stress response, altering the progression of disease development.[77] The repeated or prolonged exposure to various disasters, such as a pandemic spanning over months, may lead to worse health outcomes. Reduction in health services is another possible mechanism leading to worse health outcomes. Healthcare services may be directed toward the immediate response to health-related consequences caused by the disaster (eg, illness from a pandemic, injuries associated with a terrorist attack or natural disaster), limiting access to primary care.[78] This interruption to services may decrease screening or early treatment ultimately leading to the rise in chronic diseases. Lastly, social determinants of health are known to be important risk factors for cardiometabolic conditions.[79] At least one study investigated whether the observed associations were due to changes in educational attainment[42] and unemployment.[51] More investigation of the role of social determinants as modifiers or mediators of the associations between disasters and long-term cardiometabolic outcomes may be warranted. Despite numerous proposed biological mechanisms and well-established life-course frameworks, relatively few studies actually evaluated potential causal pathways using a life-course framework, and this may contribute to some of the observed heterogeneity in results.

Strengths and limitations

This review had several strengths including the comprehensive evaluation of the impact of a wide range of disaster exposures on various cardiometabolic outcomes at different periods throughout the life-course. The search strategy was developed in consultation with health science librarians at McMaster University to ensure the most comprehensive search was developed and relevant literature was identified. The timely findings of this synthesis are a strength of this review, given the current COVID-19 pandemic, which is affecting millions of people worldwide. While only a small proportion of the identified studies focused on pandemics and epidemics, the findings may serve to guide our understanding of expected outcomes, and to develop future research to study the effects of COVID-19 on cardiometabolic outcomes.

Although this review had several strengths, interpretation of findings should be done with caution due to limitations. First, the heterogeneity across studies restricted the ability to conduct a meta-analysis. Studies varied in terms of study design, reported measures of effect, the comparison group (eg, some studies did not include a comparator group), length of follow-up, timing and measurement of exposure, and primary outcomes and how they were measured. Given the multidisciplinary nature of the identified studies, a wide range of analytical approaches were used, and measures of effect varied. These differences in addition to the lack of statistical significance across studies make it difficult to draw overall conclusions. Many of the studies used a retrospective cohort study design and relied on administrative data sources as such many studies were unable to comprehensively adjust for confounders, including social determinants of health. Measurement error and misclassification of exposure status are also possible since many studies did not objectively measure disaster exposure or degree of impact, and instead used proxy measures of disaster exposure based on time and geography.

Very few studies have evaluated the long-term impacts of pandemics and epidemics on cardiometabolic outcomes, identifying a current gap in the literature. This made it difficult to truly assess if exposure to disasters at sensitive periods of development had lasting effects much later in life. Studies also reported insufficient data on subgroups that were at increased risk of worse cardiometabolic health outcomes and interventions that were implemented to mitigate risk of cardiometabolic outcomes. In addition, results were not often explored by sex and gender, or did not apply an equity lens. It has been noted that those of different levels of socioeconomic status experience differential cardiometabolic outcomes.[80 81] This signifies the importance of exploring associations between exposure to disasters and cardiometabolic outcomes stratified by these factors. Understanding how these associations differ will also help to identify groups of people who will experience worse outcomes following a disaster.

Study implications

To the best of our knowledge, this is the first study to comprehensively explore the impact of several different types of disasters on cardiometabolic outcomes at different periods throughout the life-course. The results suggest that increased risk is observed for disaster exposure at any period over the life-course from the perinatal child and adult periods. These findings emphasise that the burden of disasters extends beyond the known direct harms they cause, and attention is needed on the detrimental indirect long-term effects on cardiometabolic health and chronic disease. Given the current COVID-19 pandemic, this review may be helpful in raising awareness of the potential increase in cardiometabolic health outcomes post-pandemic, to ensure appropriate public health mitigation measures are developed and implemented to prevent long-term cardiometabolic outcomes at the population level.

Unanswered questions and future research

Future research should evaluate the impact of pandemics, such as COVID-19, on future cardiometabolic health throughout the life-course. It may also be of interest for future research to explore the impact of implementing public health measures, such as physical distancing to reduce transmission of a virus, and the implications following a disaster with access to healthcare on health outcomes. This information would be helpful in planning public health responses to different disasters. In addition, further investigation of possible mechanisms, such as disruptions to healthcare or medication access, and changes in dietary intake or physical activity, is needed. This would help to develop preventative strategies targeted at these mechanisms to help reduce the possible cardiometabolic consequences after experiencing a disaster. This review found insufficient evidence identifying subgroups of the population who are at the greatest risk or specific disaster-related risk factors that increase cardiometabolic disease development following a pandemic. This is an important gap that needs to be addressed by future research.

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