Methodological Challenges and Contributions in Disaster Epidemiology

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Abbreviations: MUPS, medically unexplained physical symptoms; PTSD, post-traumatic stress disorder.

INTRODUCTION

Considering the very unusual and extreme situations under which a disaster and the corresponding adverse health responses occur, it is challenging to provide a unified methodological framework for disaster epidemiology. In this commentary, we identify targets of estimation and common challenges in estimating the quantities of interest. In some cases, we discuss methodological contributions and future work regarding the design and analysis of epidemiologic studies of disasters. To ground our points, we refer to some of the papers published in this issue.

Although disasters occur in a wide variety of settings and circumstances, it is possible to identify several methodological challenges and commonalities in the epidemiologic studies of disasters published in this issue. These provide a platform for developing statistical methods to assess short- and long-term adverse health effects of disasters and to predict consequences of future disasters.

Disasters have been defined as acute, collectively experienced traumatic events, with a sudden onset. They can be natural (e.g., hurricanes, floods, earthquakes) or man-made (e.g., plane crashes, industrial accidents, terrorist attacks, suicide bombings). By definition, disasters are rare events that, with respect to timing and form, are somewhat unpredictable. This uncertainty poses obvious methodological challenges, because it is exceedingly difficult to have systems in place to adequately track either exposures or health outcomes before, during, and after significant disasters. Therefore, study design and statistical methods to estimate the health impact of a disaster can deviate substantially from those commonly used in more traditional epidemiologic studies.

ESTIMATION TARGETS

To determine methodological contributions that can potentially advance the analyses of epidemiologic studies of disasters, it is helpful to enumerate scientific targets. Many epidemiologic studies of disasters are aimed at estimating the prevalence or incidence of an adverse health outcome associated with a disaster to quantify the public health burden of the disaster; or estimating the short- and long-term, direct and indirect health effects caused by a disaster to properly treat those who have been affected; or predicting the occurrence of disasters to develop appropriate surveillance and prevention strategies.

In addition to specifying estimation targets, many important characteristics of an epidemiologic study of a disaster need to be properly defined and taken into account. These include 1) characterization of the population at risk and/or exposed to the disaster (e.g., size, location, susceptibility, and age distribution); 2) estimation of the exposure to the disaster (e.g., being in an area affected by an earthquake, flood, heat wave, war; being exposed to physical or psychological stressors); 3) short-term adverse health outcomes (e.g., death, injuries) and long-term adverse health outcomes (e.g., cancer, chronic obstructive pulmonary disease, post-traumatic stress disorders (PTSDs)); and 4) effect modifiers (e.g., building infrastructure, living conditions, communication systems including the media and the Internet). Each of these aspects presents daunting methodological challenges.

ESTIMATING PREVALENCE

To address the foregoing, it is necessary to estimate validly the population at risk (the denominator); otherwise,

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estimates of the prevalence will be biased. Unfortunately, identifying the at-risk population is one of the biggest challenges faced by disaster researchers. Given the sudden onset of many disasters, without a strong surveillance system in place, it is exceedingly difficult to enumerate and otherwise characterize the impacted population. Moreover, as is made clear in a number of the papers in this issue as well as from experiences with the December 2004 tsunami, impacts from disasters are generally more significant in developing countries, given limitations in the physical, medical, and communication infrastructures.

In developing countries, the infrastructure is often not available for in-depth surveillance systems that would allow for ideal epidemiologic studies. Lessons learned from the literature in both developed and developing countries therefore take on increased importance in determining high-risk populations and feasible prevention strategies. In developed countries such as the United States, census data and global information systems methods could be used to estimate the population at risk. However, US Census data will not necessarily provide the information needed when risk is differential over the area. For example, earthquake intensity may vary at geographic scales more refined than Census data can adequately address, particularly when one considers that many people may be away from their residence when the disaster strikes. This emphasizes that understanding the timing of the disaster (time of day, day of the week) as well as the nature of the disaster is important in developing appropriate methods to establish at-risk populations. For some applications, combining information from the US Census, Medicare, Medicaid, and other data sources will be necessary.

Regardless of the setting, care is needed in assessing possible biases in data collection. For example, if the prevalence of a syndrome is assessed by evaluating those who present at a clinic, the prevalence rate will be overestimated unless the selection process is considered. Such selection occurred early in the follow-up of health effects of service in the Persian Gulf War in that those presenting for care at Veterans Administration hospitals and clinics were not representative (1, 2), and studies of hospitalization rates in Veterans Administration facilities likely underestimated the rates in all hospitals (3).

To properly estimate the prevalence of disease, it is necessary to specify and implement case definition and ascertainment. Information can be obtained from multiple sources (phone surveys, death certificates, medical records), but careful implementation is needed to ensure low bias and low measurement error. Of particular concern are prevalence studies of PTSD and, more generally, of medically unexplained physical symptoms (MUPS). For example, the diagnostic definitions of PTSD continue to be revised, and often these health outcomes are self-reported. Therefore, in estimating PTSD prevalence, it is important to develop methods that can account for outcome misclassification and self-reporting, particularly if diagnosis does not occur in a clinical setting. In addition, in comparing estimated PTSD prevalence across studies, it is important to keep in mind that there are different scales for measuring PTSD and these measures have not been cross-validated. In cases with

multiple measures of a single theoretical construct or multiple studies using various measures, advanced statistical techniques such as structural equation models or Bayesian hierarchical models can facilitate integrated analyses, but rarely are data streams sufficiently robust in this context for this approach to be practical.

ESTIMATING THE EXPOSURE-RESPONSE RELATION

Exposures from disasters can vary dramatically. They may include 1) high air pollution levels from a building collapse, 2) drinking water contamination caused by flooding, 3) high temperatures from heat waves, or 4) physical debris from terrorist attacks or natural disasters. Exposures to a disaster can be assessed in multiple ways with increasing complexity. For example, exposure to a disaster can be defined as a binary or a continuous variable. A binary exposure indicates whether the person was physically in the location where the disaster occurred (subject to the above constraints in determining those at risk). This definition can be used most productively when the goal is to assess the acute adverse health events from a truly binary exposure, such as death or injuries associated with a bomb explosion or plane crash. In this case, we estimate the difference in the prevalence of disease between an exposed and not-exposed population and the associated 95 percent confidence interval.

A continuous exposure generally indicates the dose, as in air pollution levels due to a collapse of a building from earthquakes or the 9/11 disaster in New York City. This definition can be used when the goal is to estimate an exposure-response curve. However, rarely can retrospective assignment of exposure make use of optimal information about individual exposures or doses, and the lack of an appropriate unexposed comparison group can limit the ability to make inferences about disease occurrence. Co-ordination of environmental monitoring with health evaluation is often implausible in disaster settings but would clearly be necessary for optimal epidemiologic assessments. Even if resources are limited and logistical barriers daunting, efforts should be made to (at a minimum) collect or estimate exposures covering a similar spatial and temporal scale as the health-outcomes evaluation. Given the significant geographic heterogeneity in exposures and the likelihood of dramatic changes in exposures in the hours to days following a disaster, this is a challenging mandate but would certainly represent the ideal in any epidemiologic study of a disaster. The use of biomarker measurements, when appropriate to the exposure, outcome, and feasible monitoring timescale, may provide increased statistical power and the ability to capture exposure/dose gradients across the population.

For example, attempts to assess exposure to releases from the Khamisiyah munitions bunkers highlight some of the challenges. It was thought that nerve gas and other munitions were stored in these bunkers and that they were destroyed by US troops during the 1991 war in Iraq (1, 2). Concerns regarding possible exposure to the resulting plume prompted the Central Intelligence Agency to develop aerometric models for its direction and concentration. Veterans were notified if they were considered to be in the plume, then the

plume assessment was modified and veterans were renotified. Some veterans were "exposed" to reported exposure, and that information was later retracted. This psychological factor in the context of considerable exposure measurement error and a relatively high background exposure make it almost impossible to identify effects via an epidemiologic approach other than with extremely high relative risks.

Additional challenges occur in fully characterizing the health effects of disasters, including both direct/primary and indirect/secondary. Most of the epidemiologic studies presented in this issue focus on short-term health effects, although most recognize the importance of carrying out cohort studies to better understand the long-term psychological effects of exposure to a disaster. PTSD or MUPS are likely outcomes of almost any disaster, and they may not be incorporated into conventional summaries of disaster burdens. Similarly, secondary effects of disasters related to vector-borne diseases can be substantial. Since it is often more feasible to intervene to limit secondary effects than primary effects of an unexpected disaster, having detailed information about incidence, risk factors, and prevention measures for secondary impacts is crucial in implementing postdisaster public health programs. The lack of specificity in the definition and diagnosis of PTSD and MUPS, and the complicated nature of infectious disease transmission, provide challenges for epidemiologists but should not preclude inclusion of these effects.

Of course, there are numerous secondary impacts of disasters beyond psychological effects of exposure and vector-borne diseases. For example, a damaged transportation infrastructure can increase traffic accident risks, mental health burdens other than PTSD and MUPS are likely, and economic losses can influence health across a number of dimensions. While the nature of the secondary impacts will vary substantially by disaster and location, it is crucial for any epidemiologic analyses to be holistic and capture the array of significant impacts, especially in the medium to long term. Since many of these secondary effects may last for years beyond the disaster itself, long-term follow-up of the population is important. This goes beyond accurate enumeration of health impacts, because understanding the multiple pathways influencing population health can aid in the development of targeted intervention strategies.

Considering the unusual and very high levels of environmental factors that occur in a disaster (e.g., high pollution levels or high temperatures), it is important to use statistical methods that allow for a nonlinear exposure-response and that account for both exposure measurement error and outcome misclassification (4–7). However, for rare events, a very large sample size is needed to detect a threshold.

CROSS-SECTIONAL VERSUS COHORT STUDIES

Because of data limitations, epidemiologic studies of disasters often report only disease prevalence. Although estimation of the magnitude of disaster-related impacts can help in determining the resources required in both dealing with the aftermath of the disaster and developing the infrastructure to address future disasters, it does not assess the short- and long-term adverse health effects associated with exposure to a disaster. Ideally, we would follow a cohort design for estimating incidence of disease. The epidemiologic study design would include 1) definition of the population directly or indirectly exposed to the disaster, 2) enumeration of the population at risk, 3) development of a registry of adverse health outcomes experienced by the exposed population, 4) identification of a control (not-exposed) population, 5) collection of important risk factors and confounders for the exposed and not-exposed population, and 6) development of Cox-proportional hazards models for estimating the time to event of different adverse health outcomes.

PREDICTING THE FUTURE OCCURRENCE OF A DISASTER

The feasibility of developing effective predictions and the relative importance of prediction versus prevention differ by disaster type. For acute, instantaneous episodes (e.g., earthquakes, floods, tsunamis, terrorist attacks), it may be possible to identify high-risk geographic locations or time periods, but precise forecasting and development of early-warning systems are generally less applicable. For extreme events that deviate substantially from the historical record or previously estimated variability, our predictive ability is limited. In these cases, however, understanding who was at greatest risk from past disasters can help in the implementation of protective measures. For example, findings of mortality risks associated with home type could lead to building codes for sturdier home construction, and study findings addressing geographic patterning of risk could inform zoning decisions.

Forecasting can play a crucial role in events such as heat waves, which are acute in onset but where forecasting and communication are plausible mechanisms to reduce the impact of the disaster. In these cases, it would be most important for epidemiologic studies to identify the exposure regimen of concern (i.e., the combination of temperature and humidity that would lead to significant increases in mortality) as well as the demographic characteristics of high-risk persons, to provide targeted communication and outreach strategies. In heat waves, the most useful warning systems that have been developed take advantage of epidemiologic findings to determine weather situations or temperature/humidity thresholds of concern as a function of the climate of the city and the characteristics of the at-risk population (8). Studies using generalized additive models with nonparametric smoothing functions have captured the inherent nonlinearity of the weather-health relation (6), helping to isolate the conditions under which health risks become greatly elevated. Linking this epidemiologic evidence with standard weather forecasting can facilitate the prediction of high-impact weather systems and the development of subsequent responses.

SURVEILLANCE SYSTEMS

Surveillance systems are another important target of epidemiologic studies of disaster. Systems are designed so

that the number of casualties can be reduced and the ones that occur can be treated promptly and effectively. Although this task is daunting and impractical in some contexts, known geographic patterning of disasters (i.e., high-risk earthquake or flooding zones) can help narrow the scope of surveillance systems and prospective data collection. Moreover, many sorts of surveillance systems may serve purposes beyond disaster response, and the existing public health infrastructure can be leveraged. In some cases, the use of indicator outcomes can be extremely useful and can provide a simpler approach for determining whether a chronic disaster situation has reached a level of concern (vs. considering a substantial number of outcomes that may not have a direct impact on the design of intervention strategies).

THE MEDIA

Without question, media coverage plays an important role in the epidemiology of a disaster. It can be considered a potential intervention strategy, an indirect exposure, or an effect modifier. The ability of a society to use the media to provide warnings and forecasts can play a crucial role in limiting the short-term effects of disasters, particularly in the case of weather-related disasters. Indeed, many of the most significant interventions for heat waves, blizzards, and other weather phenomena may be tied to media coverage and outreach efforts. However, just as the media can limit primary exposures, it can be a contributor to secondary, psychologically driven health outcomes. By increasing the number of people exposed to a disaster and repeating traumatic images ad nauseum, the media can fuel anxiety and amplify the risk of PTSD or MUPS. In extreme cases, media coverage can even initiate a new syndrome, as seen in mass psychogenic illness. From a methodological perspective, the complex (and significant) roles of the media imply that it is critical to understand how media coverage has influenced affected populations, to better understand both primary and secondary outcomes. When considering the "environment" in which the disaster occurred, the role(s) of the media should be considered in concert with the physical, economic, and medical infrastructure of the society.

CONCLUSIONS

Ultimately, as perverse as it may sound, epidemiologists must view disasters as important opportunities to learn about the etiology of disease, the relation between exposures and responses, the efficacy of surveillance systems, the strength of emergency response measures, and the intervention strategies that may reduce the burden of future disasters. The unusually high exposures that occur during

disasters can provide a natural experiment that can inform the understanding of critical phenomena—for example, the outgrowth of air pollution epidemiology from the London smog episode of 1952. The presence of disease clusters either previously unobserved or unobserved at similar magnitude and scale can provide the statistical power to better identify high-risk populations and corresponding intervention strategies. All of the papers in this issue of *Epidemiologic Reviews* provide some insight into some of the above questions, yielding information that could ultimately reduce the impacts of future disasters. Future epidemiologic analyses of disasters should continue to refine biostatistical and epidemiologic methods to maximize the knowledge gained from these disasters, including methods to better capture long-term health implications, to determine high-risk subpopulations, and to assess exposure-response relations. Increased knowledge and systems development in these domains can best contribute to future disaster management activities.

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