A Review of Disaster-Related Carbon Monoxide Poisoning: Surveillance, Epidemiology, and Opportunities for Prevention

Shahed Iqbal, PhD, Jacquelyn H. Clower, MPH, Sandra A. Hernandez, BA, Scott A. Damon, MAIA, and Fuyuen Y. Yip, PhD

Objectives. We conducted a systematic literature review to better understand aspects of disaster-related carbon monoxide (CO) poisoning surveillance and determine potentially effective prevention strategies.

Methods. This review included information from 28 journal articles on disaster-related CO poisoning cases occurring between 1991 and 2009 in the United States.

Results. We identified 362 incidents and 1888 disaster-related CO poisoning cases, including 75 fatalities. Fatalities occurred primarily among persons who were aged 18 years or older (88%) and male (79%). Hispanics and Asians accounted for 20% and 14% of fatal cases and 21% and 7% of nonfatal cases, respectively. Generators were the primary exposure source for 83% of fatal and 54% of nonfatal cases; 67% of these fatal cases were caused by indoor generator placement. Charcoal grills were a major source of exposure during winter storms. Most fatalities (94%) occurred at home. Nearly 89% of fatal and 53% of nonfatal cases occurred within 3 days of disaster onset.

Conclusions. Public health prevention efforts could benefit from emphasizing predisaster risk communication and tailoring interventions for racial, ethnic, and linguistic minorities. These findings highlight the need for surveillance and CO-related information as components of disaster preparedness, response, and prevention. (*Am J Public Health.* 2012;102:1957–1963. doi:10.2105/AJPH.2012.300674)

Carbon monoxide (CO) poisoning is a leading cause of poisoning in the United States. Unintentional, non–fire-related (UNFR) CO poisoning results in more than 20 000 emergency department (ED) visits, more than 2000 hospitalizations, and nearly 450 deaths annually.[1–3] Health effects of CO exposure can range from viral-like symptoms such as fatigue, dizziness, headache, confusion, and nausea to more severe symptoms such as disorientation, unconsciousness, long-term neurologic disabilities, coma, cardiorespiratory failure, and death.[1,4–6] CO is a colorless, odorless, and tasteless nonirritant gas that is imperceptible to human senses.[7] Furthermore, CO exposure is often underdiagnosed or misdiagnosed as a result of the nonspecificity of the clinical effects.[8,9] Both of these factors make exposure to CO a serious health concern because individuals can be severely or fatally poisoned before even realizing that they have been exposed. UNFR carbon monoxide exposure occurs year-round, with a usual seasonal peak during the winter season, and has been reported to be a leading cause of mortality and morbidity in postdisaster situations when engagement in high-risk behaviors is more common (e.g., improper placement of generators, use of charcoal grills indoors).[1,2,10] Power outages during disasters or postdisaster cleanup and recovery have been found to be primarily responsible for a large number of fatal and nonfatal disaster-related CO exposures.[10] It is important to identify and characterize high-risk populations and circumstances leading to disaster-related CO exposures to better target public health interventions and health messaging.

For this study, we reviewed disaster-related CO poisoning articles in scientific journals that included cases occurring between 1991 and 2009 in the United States. The objective was to better understand the aspects of disaster-related CO poisoning surveillance, characterize the populations at risk, and determine potentially effective prevention strategies.

METHODS

In 2008, the Centers for Disease Control and Prevention (CDC) in collaboration with Research Triangle Institute (RTI), conducted a literature review for carbon monoxide prevention messaging development.[11] The literature review included articles on all UNFR CO poisoning articles from the following sources: CDC's Morbidity and Mortality Weekly Report (MMWR), EBSCOhost, Google News, Medline Plus, and ScienceDirect Freedom Collection. Twenty-four primary search terms (e.g., carbon monoxide, death, exposure, generators, storm, hurricane, poisoning) and 13 secondary search terms (e.g., risk factors, prevention, education, mass communication) were used.[11] For the purpose of this study, we identified only disaster-related articles from this search that included cases occurring between 1991 and 2007. Additionally, we conducted Web-based (e.g., Google, Yahoo!, PubMed) searches using "carbon monoxide poisoning" and "carbon monoxide poisoning + disasters" search terms. This Web-based search was expanded to include additional cases occurring in 2008 and 2009. CDC epidemiologists later reconciled results from the CDC–RTI search and additional Web-based search to create a final list of articles. Articles were excluded if they were not related to events in the United States, did not include specific disaster-related information, or did not have enough data on CO exposures.

The identified articles did not report data uniformly. There were differences in reporting by data source (e.g., EDs, hospitals, hyperbaric oxygen therapy [HBOT] facilities, poison centers, disaster medical assistance teams, syndromic surveillance, coroner's offices), by patient disposition (e.g., ED, treated on-site, hospitalization, HBOT recipient, death), by data collection period, by number and type of variables included, and by variable classification (e.g., age was not categorized uniformly). Only variables relevant to this analysis that were reported by a significant number of articles are included in this review. If multiple articles identified cases from the same event or cases were identified from different sources (e.g., hospitals, poison centers) and overlaps may have occurred, efforts were made to identify and exclude duplicate cases. For example, Audin and Mass[12] and Cukor and Restuccia[13] both identified CO poisoning cases after Hurricane Rita seen by the same disaster medical assistance team.[12,13] Only data from Cukor and Restuccia[13] were included in the analysis to avoid duplicate counts. Three CDC epidemiologists independently reviewed the articles and abstracted key information for this analysis.

RESULTS

We identified 24 disaster-related CO exposure articles from the original 2008 CDC–RTI literature review. Nineteen more articles from additional Web searches (e.g., Yahoo!, Google, PubMed) resulted in a total of 43 articles. Included were abstracts (n = 2), letters to editors (n = 2), MMWR articles (n = 13), and articles in peer-reviewed journals (n = 26). Data from 28 articles (15 journal articles, 11 MMWR articles, 1 letter to the editor, and 1 abstract) were included in this review.[12–39] Fifteen articles were excluded as they were either not conducted in the United States (n = 2), did not include specific disaster-related data (n = 7), or did not have enough data on CO exposure (n = 6).

Of the articles included, hurricanes were the subject of half, winter storms accounted for 46%, and floods constituted the remaining 4%. The most common sources of health outcome data for the disaster-related CO poisoning were from EDs and hospitals (68%), medical examiners or coroners (32%), HBOT facilities (29%), and poison centers (18%). A median of 2 data sources (range = 1–109) were included per article. Postdisaster case ascertainment period was variable (range = 2–93) with a median of 10 days.

As stated earlier, not all articles reported on every variable included in this review. Almost all articles (n = 27) reported case types (fatal vs nonfatal) and the majority reported case disposition by ED visits or treat and release (n = 16), hospitalization (n = 16), and HBOT recipients (n = 19). Twenty-five articles (89%) reported on poisoning cases and 15 reported on exposure incidents (13 articles reported on both). Age distribution was included in 15 (54%) articles, and gender and race/ethnicity were reported in 12 (43%). Twenty-five articles (89%) reported on time of case occurrence after disaster onset.

The articles captured a total of 362 incidents and 1888 cases of disaster-related CO poisoning; those that described both reported an average of 2 cases per incident. Of the cases, 89% were nonfatal and 4% were fatal, the remainder had an unknown mortality outcome. Half of the individuals received treatment in the ED or on-site medical care, 6% were hospitalized, and 20% were treated with HBOT (Table 1).

Fatal cases primarily occurred among persons who were aged 18 years or older (88%) or male (79%; Table 2). Conversely, the majority of nonfatal cases occurred among those who were female (58%). Whites represented the largest fraction of all cases. Hispanics, Asians, and Blacks accounted for 20%, 14%, and 22% of fatal cases and 21%, 7%, and 16% of nonfatal cases, respectively.

The most commonly identified symptoms of CO poisoning in 826 cases (10 articles) included headache (73%), nausea (54%), dizziness or lightheadedness (31%), vomiting (21%), and loss of consciousness (14%). The median carboxyhemoglobin (COHb) measurement was 14.1% (range = 0.2%–49.8% from 12 articles).

Generators were the source of CO for the majority of both fatal (76%) and nonfatal (59%) incidents; propane, kerosene, or gas-fueled heaters or stoves accounted for 25% of the nonfatal incidents (Table 3). By cases, generators remained the primary source of exposure for 83% of fatal and 54% of nonfatal cases. Propane or kerosene fueled heaters or stoves accounted for 24% of the nonfatal cases. Sixty-seven percent of all fatal cases in which a generator was the source of exposure were attributed to indoor placement of a generator (13 articles). Nearly 63% of nonfatal cases were from a generator improperly placed elsewhere (e.g. in an attached garage, outside near a window). Fourteen articles explicitly stated location of exposure; 97% of nonfatal cases of disaster-related CO poisoning and 93.5% of fatal cases occurred in residential settings. However, 6.5% of fatal cases were work-related.

TABLE 1—Summary Findings on Disaster-related Carbon Monoxide Poisoning Cases: United States, 1991–2009

Variable	No. (%)
Total cases	1888 (100)
Case type	
Fatal cases	75 (4.0)
Nonfatal cases	1685 (89.3)
Unknown outcome[a]	128 (6.8)
Level of care	
Hospitalizations	111 (5.9)
Emergency department/treat and release/on-site medical care	941 (49.8)
Hyperbaric oxygen therapy	368 (19.5)
Unknown level of care	468 (24.8)

[a]One article did not provide information on case type.

TABLE 2—Demographic Characteristics of Those With Disaster Related Carbon Monoxide Poisoning: United States, 1991–2009

Variable	Total cases, No. (%)	Fatal cases, No. (%)	Nonfatal cases, No. (%)
Age (n = 1189), y			
< 18	422 (35.5)	4 (12.1)	418 (36.2)
≥ 18	766 (64.4)	29 (87.9)	737 (63.8)
Sex (n = 1209)			
Female	683 (56.5)	7 (21.2)	676 (57.5)
Male	526 (43.5)	26 (78.8)	500 (42.5)
Race/ethnicity (n = 1239)			
White	469 (37.9)	14 (28.0)	455 (38.3)
Black	204 (16.5)	11 (22.0)	193 (16.2)
Hispanic	265 (21.4)	10 (20.0)	255 (21.4)
Asian	93 (7.5)	7 (14.0)	86 (7.2)
Other/unknown	120 (9.7)	1 (2.0)	119 (10.0)
Missing	88 (7.1)	7 (14.0)	81 (6.8)

Finally, 88% of fatal cases and 53% of nonfatal cases occurred within 3 days of disaster onset, and all fatal and 97% of nonfatal cases occurred within 2 weeks (Figure 1).

DISCUSSION

This review of the literature is the first comprehensive assessment of disaster-related CO poisoning cases in the United States. Over 19 years, 75 deaths and nearly 2000 nonfatal cases were identified. Approximately 2631 unintentional CO poisoning deaths were identified in the United States during 1999 through 2004.[3] Only 19 (0.7%) disaster-related CO poisoning deaths during the same period were identified in this review. However, it should be noted that not all disaster-related CO poisoning deaths are published in journals, and usually only directly attributable CO poisoning deaths get reported. The total number of disaster-related CO poisoning cases estimated in this review is undoubtedly underestimated for the following reasons.

Underdiagnosis or Underreporting

Because of the nonspecificity of the symptoms, CO poisoning is often underdiagnosed or misdiagnosed as another illness.[1,4] In 1 study, approximately 30% of the CO poisoning cases were diagnosed incorrectly, and 43% of those were misdiagnosed as food poisoning.[8,9] Up to half of CO poisoning patients receiving treatment in ED may not receive an accurate diagnosis.[8,9,37,40–42] Also, a substantial proportion of CO exposure cases result in on-site treatment and do not require stay at a health care facility.[43] These cases are unlikely to be captured. Furthermore, not all accounts of disaster-related CO poisoning cases are published, and therefore we excluded an unknown number of cases from this review.

Geographic Area Restriction

Surveillance of CO cases is often limited to the geographic area that is most affected by disaster and excludes the population in other less affected areas. For example, although there were large scale power-outages over substantial periods of time in many states after Hurricane Katrina, only 5 gulf coast states (Alabama, Mississippi, Louisiana, Texas, Florida) with heavy Katrina damage had accounts of CO poisoning cases.[20,21,31,36] Similarly, during a 2009 ice storm in Kentucky, the CO poisoning surveillance focused on areas that were most greatly affected.[39]

Number of Data Sources

In the aftermath of a disaster, it is possible that some of the institutions that provide data (e.g. health care facilities, hyperbaric chambers) become nonoperational or operate under limited capacity. Therefore, surveillance and reporting of CO poisoning cases may be restricted. In this review, the number of facilities providing data on disaster-related CO poisoning varied (range = 1–109), but the median number was only 2 with 70% of the articles including cases from 4 or fewer facilities. Reporting by a handful of facilities may fail to include some of the CO poisoning cases.

TABLE 3—Source of Exposure in Disaster-related Carbon Monoxide Poisonings: United States, 1991–2009

Variable	Total, No.	Generator, No. (%)	Heater/Stove,[a] No. (%)	Grill,[b] No. (%)	Automobile, No. (%)	Other/Unknown, No. (%)
Incident type	399	186 (46.6)	67 (16.8)	94 (23.6)	2 (0.5)	76 (19.0)
Fatal incidents	21	16 (76.2)	2 (9.5)	3 (14.3)	0 (0.0)	0 (0.0)
Nonfatal incidents	235	138 (58.7)	58 (24.7)	21 (8.9)	2 (0.9)	38 (16.2)
Case type	1159	644 (55.6)	268 (23.1)	211 (18.2)	32 (2.8)	108 (9.3)
Fatal cases	59	49 (83.1)	1 (1.7)	6 (10.2)	2 (3.4)	0 (0.0)
Nonfatal cases	1099	595 (54.1)	267 (24.3)	205 (18.7)	30 (2.7)	108 (9.8)

[a]Propane or kerosene heaters or gas stoves.
[b]Charcoal/gas grill or briquettes.

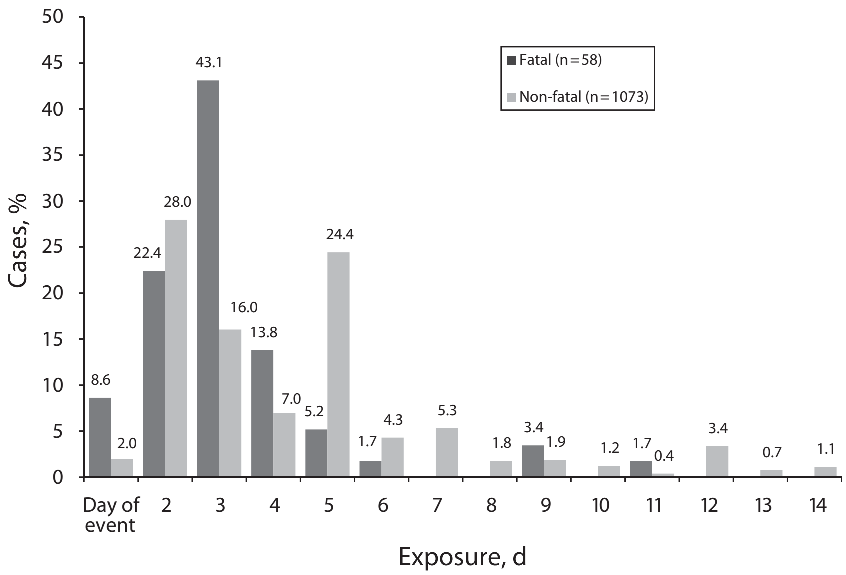

FIGURE 1—Occurrence of fatal and nonfatal carbon monoxide poisoning cases (n = 1131) by days after disaster onset: United States, 1991–2009.

Postdisaster Case Ascertainment Period

Disaster-related CO poisoning surveillance is often conducted as a part of emergency response or preparedness. CO poisoning cases are, therefore, not reported until the apparent "emergency" or "crisis period" is over. Among the 25 articles that included information on case ascertainment period, the median was 10 days (range = 2–93 days) with 73% being 2 weeks or less. However, power outages and engagement in high-risk behaviors (e.g., improper placement of generators, fuel powered clean-up equipment use) might have continued, albeit at a lower frequency, past the initial postdisaster period.

Differential Case Definition

No standard case definition was followed in identifying CO poisoning cases. Different facilities (e.g., hospitals, poison centers, HBOT facilities) used varying case definitions based on *International Classification of Disease* codes, symptoms and a positive history of CO exposure, or COHb levels, and sometimes based on a combination of 2 or more of the above. Some articles did not provide a case definition. This might have led to misclassification, underreporting, and even overreporting of some cases. The Council of State and Territorial Epidemiologists defines confirmed cases of CO poisoning as cases with COHb levels of 12% or more.[44] Although the levels of reported COHb levels varied (range = 0.2%–49.8%) in this review, the mean COHb level was 17.8% and the median was 14.1%. The median indicates that it is likely that the majority of cases included in this review were true cases of CO poisoning.

Selective Populations

Some of the articles focused on specific populations,[37] specific types of events,[17] or exposures.[22] This may result in underreporting of cases.

The selection of geographic area and population under surveillance, data collection period, or inclusion of health care or other facilities for disaster-related CO poisoning surveillance depends on, among other factors, the type and extent of disaster, the availability of resources and infrastructure, and the evidence-driven best judgment of public health personnel. However, standardization of case definition, data collection methods and tools, and the surveillance system will help to better understand the exact burden of disaster-related CO poisoning, identify high-risk populations, and develop appropriate prevention messages. Given the impediments and disruptions in the wake of a natural disaster, it is likely that the development of a well–laid-out disaster response plan, involvement of and partnership with stakeholders (e.g., disaster management personnel, media), identification of data sources, establishment of effective communication channels, and data sharing agreements (e.g., with hospitals, emergency medical services, medical examiner's offices) before disaster onset will result in a more coordinated and effective public health effort.

Female individuals and children (<18 years) constituted the majority of nonfatal cases whereas 79% of individuals who died were male. These findings are consistent with previous reports.[1–3] Higher mortality among men has been assumedly a result of engaging in high-risk behaviors such as using fuel-burning tools or appliances.[2,3] Biologically, children are more susceptible to CO poisoning because of higher basal metabolic rates and tissue oxygen demands. They manifest symptoms early but are also likely to recover sooner as a result of higher ventilation rates.[45,46] The higher nonfatal poisoning observed among women is likely because they, similar to children, manifest symptoms at lower levels of CO exposure because of a lower red blood cell count.[47] These factors might lead to earlier exposure recognition and, therefore, a lower exposure and shorter recovery time among women and chidren.[48]

Twelve articles provided data on the race/ethnicity of the CO poisoning cases. According to the 2000 US Census, Whites constituted 81%, Blacks 12%, Asians 4.2%, and Hispanics 3.5% of the US population.[49] Racial/ethnic minorities represent a disproportionate fraction of both fatal and nonfatal disaster-related CO exposures. For example, after a 2002 ice storm in North Carolina, Hispanics accounted for 23% of all injuries and 65% of all CO exposures but represented only 5% of the population.[14] Also, of the 7 studies that assessed the English language proficiency of the CO poisoning cases, 5 found that in more than 20% of cases (range = 23%–56%), the individual was not fluent in English or English was not the primary language spoken in the household. Excessive CO-related morbidity or mortality among minority, immigrant, or non–English-speaking populations has been reported by some studies.[14–16,19,27,37,39] High-risk behaviors for CO poisoning, such as use of charcoal grills, have also been associated with racial/ethnic or cultural origin.[10,15,50,51] These findings have significant public health implications in terms of targeted intervention and dissemination of multilingual prevention messages to prevent disaster-related CO poisoning among racial/ethnic and linguistic minorities. It is of note that the reporting was not uniform or complete in most studies; therefore, careful and continuous review of the evidence is needed to determine disparities in disaster-related CO poisoning.

Generator use was implicated in most of the fatal and nonfatal cases and was the primary source of CO exposure for all posthurricane studies (14 articles). Nearly 67% of the fatal cases resulted from using the generator indoors or in a basement. Indoor placement is particularly dangerous because CO content in the exhaust from a typical portable generator (5.5 kW) is equal to that of 6 idling automobiles.[12,29,52,53] In many cases, placing a generator outside in an attached garage, near open doors or windows, or near the air conditioning vent can still put residents at risk for CO poisoning. Accordingly, 10 of the 30 fatalities in this review were from generators placed outside. Although the recommended distance for the placement of a generator outside of a home is now recognized as a minimum of 20 feet,[54,55] the public should be encouraged to place generators as far from their homes as possible, but also at a safe distance from any nearby dwellings. Approximately 17% to 31% of disaster-affected populations have reported using generators for restoring power after disasters.[56,57] Communicating the risks of improper generator placement can impact a large segment of the population. Still, the need for electricity, fear of theft, lack of portability or of an adequately long electric extension cord, and the risk of operating a generator in wet conditions can all pose challenges to the safe operation of portable generators.[29]

Indoor use of charcoal grills was also a major source of disaster-related CO exposures, particularly for winter storms. It has been suggested that persons of Asian, Middle Eastern, or African origins or persons from warmer climates where solid fuel burning indoors for cooking or heating purposes is common might be inclined to use charcoal briquettes or grills indoors.[10,15,37,50,51,58] Differences in CO exposure source by disaster type can guide development of disaster-specific prevention messages that might also lead to differential regional strategies for prevention. The Northeast and the Midwest regions of the country are more likely to experience adverse CO-related health events from ice and winter storms or blizzards, whereas the South experiences more hurricane-related events. Although federal mandates require CO warning labels on both generators and charcoal bags,[10,59,60] multilingual education or warning materials distributed with sales of generators and charcoal bags might be helpful in targeting specific minority populations and reducing the risk of CO poisoning. Also, most CO poisoning cases occurred in residential settings, highlighting the importance of having battery powered or battery backup CO alarms in homes to prevent CO poisonings during power outages after disasters and in nonemergency situations.[19,61] Installing a battery powered or battery backup CO alarm at home is mandated by many state and local governments and is a primary recommendation from CDC for the prevention of CO poisoning.[55]

Predisaster risk communication might result in better public health effectiveness in reducing disaster-related CO exposures, because most cases occur within days of event onset, and most natural disasters and subsequent high-risk behaviors (e.g., generator use during power outages) are quite predictable. Absent a generator engineering solution (e.g., auto shutoff, integrated CO alarm) and more effective policies requiring CO alarm installation, surveillance and risk communication are currently the 2 major components of disaster-related CO poisoning prevention. CDC's current national communication strategy for CO prevention is based on 3 components: (1) improving awareness of the dangers of CO poisoning, (2) advocating the use of CO alarms, and (3) promoting proper use and maintenance of fuel-burning appliances (including generators and furnaces). A key component of CDC's communications efforts has been targeting of racial/ethnic and linguistic minorities through the sharing of basic guidelines on UNFR carbon monoxide poisonings and other materials available in 17 languages.[55] These materials are made available to state and local public health partners for appropriate use in their communities on both an emergency and nonemergency situations. Recently, in cooperation with a range of public and private partners, CDC conducted outreach via Spanish-language radio stations, prepared video footage adaptable to multiple languages, and developed other materials designed for diverse audiences.[55] This communication model could be effective in predisaster risk communication. Predisaster risk communication should take into account the racial/ethnic and linguistic makeup of at-risk population and effectively utilize the local mass media (e.g., local non-English newspapers, radio, or TV stations) and community platforms (e.g., shopping centers, community centers).

Despite the magnitude of the health burden posed by CO poisoning among postdisaster populations, the public does not always perceive CO poisoning as a major health concern or is not aware of safe health practices.[56,62,63] Although evidence suggests that receiving health information on CO poisoning before, during, and after a disaster might lead to safer health practices, information is sometimes not widely received by affected populations.[23,26,57] Effective communication in pre- and postdisaster situations, overall, is critical to improving public understanding, awareness, and cooperation. These findings emphasize the continued need for communicating CO-related health information and surveillance of CO poisoning cases as a central component of public health emergency preparedness, response, and prevention efforts during natural disasters. ■

About the Authors

Shahed Iqbal, Scott A. Damon, and Fuyuen Y. Yip are with the Air Pollution and Respiratory Health Branch, Division of Environmental Hazards and Health Effects, National Center for Environmental Health, Centers for Disease Control and Prevention, Atlanta, GA. Jacquelyn H. Clower is with Cazador, contracted to Air Pollution and Respiratory Health Branch, Division of Environmental Hazards and Health Effects, National Center for Environmental Health, Centers for Disease Control and Prevention. Sandra A. Hernandez is with the National Center for Environmental Health, Centers for Disease Control and Prevention.

Correspondence should be sent to Shahed Iqbal, PhD, 1600 Clifton Road NE, MS D26, Atlanta, GA 30333 (e-mail:siqbal@cdc.gov). Reprints can be ordered at http://www.ajph.org by clicking the "Reprints" link.

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Note. *The findings and conclusions in this article are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.*

Contributors

S. Iqbal originated and conceptualized the design of the study, reviewed articles, and led the writing of the article. J. H. Clower and S. A. Hernandez assisted in study design, literature review, analysis, and writing of the article. S. A. Damon and F. Y. Yip helped in finalizing the review elements and writing of the article.

Human Participant Protection

The article included de-identified data from already published articles, and so no protocol approval by the institutional review board was needed.

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