Crude Oil Spill Exposure and Human Health Risks

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Objective: The objective of this study was to review and summarize published studies on human health effects of oil spill exposure. **Methods:** A systematic literature search was conducted for articles published on health effects of oil spill exposure. More than 250 articles were examined, and only those articles that dealt with health effects on human populations were included. The methodology, results, discussion, and conclusions for each study were reviewed and summarized. **Results:** Published studies are helpful in identifying acute and, to some extent, chronic health effects related to major oil spills. Nevertheless, many of these reports were focused on the behavioral health effects of the oil spill exposures in the affected population. **Conclusions:** These published studies clearly support the need for further assessment of the potential short- and long-term repercussions in human populations exposed to oil spills.

Learning Objectives

- Become familiar with the available research, and gaps in research, on the human health impact of exposure to crude oil spills.
- Outline the evidence for various types of health effects of oil spills, including worker safety, toxic effects, mental health effects, and ecosystem effects with consequences for human health.
- Identify the review's implications for future research and policy related to the potential health effects of oil spills.

Since the industrial revolution of the eighteenth century, the use of fossil fuels, specifically refined petroleum products, has increased exponentially. During this process, offshore oil production using floating drilling rigs and transportation of both crude and refined oil products using supertankers have also increased throughout the world. This has led to an increased number of accidental oil spills into the sea, posing potential health risks. Oil spillage into the marine environment has caused severe pollution. Although more than 40 oil spill disasters have occurred around the world, attention to their potential health effects has increased lately because of the recent Gulf oil spill in the United States.[1,2] These oil spills pollute water, air, and food because of the release of various toxic chemicals such as volatile hydrocarbons and trace metals.[3] Moreover, these spills are environmentally hazardous in that they often take months and years to cause disease and death.[4,5]

Crude oil spills are tragic environmental disasters that can cause severe health problems, disturb the ecosystem, and pollute the environment. They affect human health through both the chemical exposure and the psychological and socioeconomic impact on the affected individuals and their communities. Despite the considerable number of accidental oil spills that occurred around the world, only very few of them have been studied in terms of their potential effects on human health (Fig. 1). Potential health risks of crude oil spills can be divided into four categories. These include those related to (1) safety of the workers; (2) toxic effects in workers who work at the oil extraction platforms and those participating in cleanup activities of oil spills, visitors, and community members; (3) mental health effects from social and economic disruptions; and (4) ecosystem effects that have consequences on human health. Currently, most published literature tends to focus separately on the health effects in workers and their affected communities. Nevertheless, workers who responded to the accidental oil spills are integrated into their affected communities, and the ecologic, economic, and health effects of the spills are closely interconnected. Thus, oil spills cause great public concern, especially among people living in the affected coastal areas, and in the large numbers of volunteers who are mobilized to clean up the disaster spills.

The crude oil spills affect human health through their exposure to the inherent hazardous chemicals such as paraphenols and volatile benzene. The predicted routes of exposure to chemicals from the oil spill are inhalation, dermal contact, food and water ingestion, and contact with the beach sand. The major health consequences of crude oil spill exposures include abnormalities in the hematologic, hepatic, respiratory, renal, and neurological functions (Table 1).[1,6] The purpose of this review was to evaluate the current literature on the potential health consequences of oil spill exposures as a result of unforeseen disasters.

METHODS

A systematic literature review was conducted by searching for articles published on the human health effects of oil spill exposure using PubMed, Embase, and Google Scholar databases. The following search terms were applied: adverse human health effects, blood disorders, chemical exposure, endocrine toxicity, health impact, hematologic toxicity, hepatotoxicity, illness symptoms, oil spill exposure, oil spills, oil spill cleanup, psychological effects, and respiratory function. We also searched the reference lists in the publications that we obtained in an attempt to find additional relevant publications. Nonindexed journals were manually searched. The search was restricted to English language articles. Abstracts that have been published in English were also included in the study.

RESULTS

More than 250 articles were identified and only those articles that dealt with human populations were selected and included in this review. The methodology, results, discussion, and conclusions of each study were reviewed, and the information related to the health abnormalities and symptoms among cleanup workers and residents exposed to oil spills, and other individuals exposed directly or indirectly to the oil spills, is summarized below for each oil spill event.

Health Effects of the Deepwater Horizon Gulf Oil Spill (Gulf of Mexico, United States, April 20, 2010)

The explosion of the British Petroleum (BP) offshore drilling rig in the Gulf of Mexico on April 20, 2010, resulted in the second largest global oil spill in history (Fig. 2). The Deepwater Horizon drilling rig burned and ultimately sank in the ocean 2 days later.

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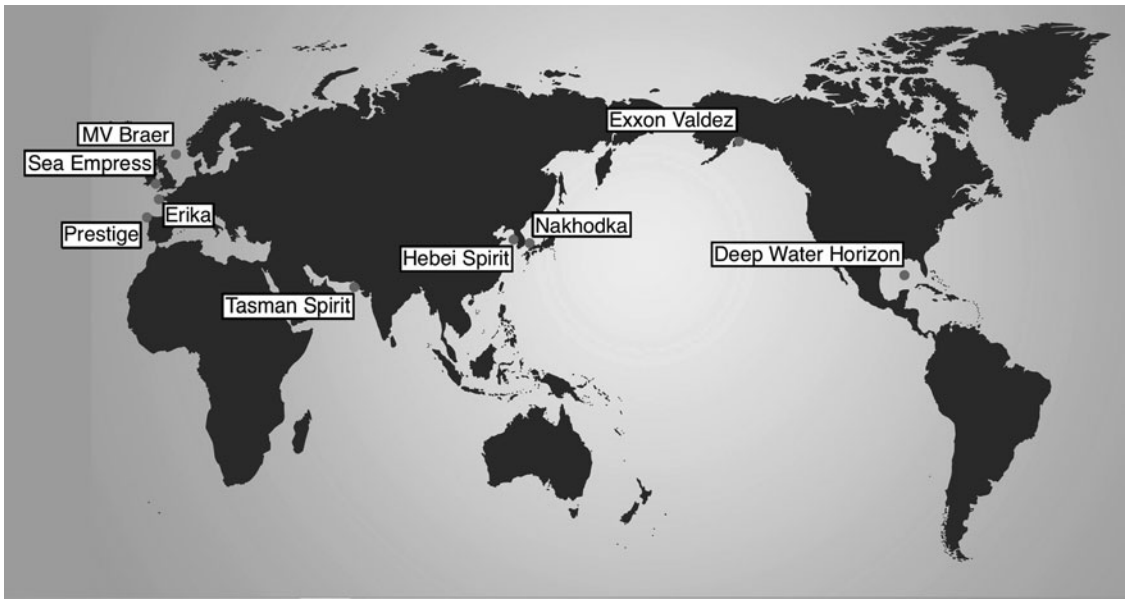

FIGURE 1. Location of major spill disasters around the world with studies investigating their potential effects on human health.

As a consequence, more than 200 million gallons (680,000 tons) of oil was reported to have poured into the Gulf of Mexico between the initial explosion on April 20, 2010, and the final closure of oil leak on July 15, 2010.[45] This catastrophic disaster contaminated a coastal zone spanning over 600 miles of shoreline from Florida to Alabama, Mississippi, Louisiana, and Texas with heavy crude oil. This catastrophic disaster disrupted the region's fishing industry, destroyed renewable natural resources, and caused significant wildlife injury and death. This disastrous spill has raised numerous questions about its potential impact on the health of those living in the oil-exposed regions and surrounding communities.

During the height of this disaster, nearly 2 million gallons of dispersants such as Corexit[46] was used to break down the oil slick.[45] The potential toxic concerns of the disaster included the oil constituents such as benzene, toluene, ethylbenzene, and xylene, gases and particulate matter from intentional oil burning; and the mixture of crude oil and Corexit dispersants. It is estimated that up to 170,000 people worked in some capacity to clean up the Gulf oil spill.[47] Since the BP rig explosion, a range of acute health problems have been reported as more than 40,100 emergency responders have worked to clean up the spilled oil. Acute problems alone were reported in 967 workers as of June 20, 2010, according to a report of the National Institute for Occupational Safety and Health (NIOSH).[48] Nevertheless, it is impossible to know how many of those treated for their health complaints and incidences of dizziness, nausea, fatigue, and fainting may have resulted from their toxic exposures. Neither the NIOSH nor other independent medical organizations have verified incident data reported by BP facility.[48] A large epidemiological study is being set up to investigate potential health effects associated with the cleanup activities after this spill.[49]

Research on the health consequences of those subjects exposed to the Gulf oil spill and dispersant use is emerging. Recently, we assessed the adverse health effects of the oil spill exposure from the Deepwater Horizon oil rig explosion in the Gulf of Mexico in subjects who were involved in the oil spill cleanup activity along the coast of Louisiana.[7,8] The study included a total of 117 subjects exposed to the oil spill and was compared with 130 unexposed subjects. Hematologic evaluation indicated that platelet counts were significantly decreased in the exposed group compared with those in the unexposed group to the oil spill (Fig. 3). Conversely, the mean hemoglobin and hematocrit levels were significantly increased among the oil spill-exposed subjects compared with the unexposed subjects. Similarly, the oil spill-exposed subjects had significantly higher levels of serum liver enzymes such as alkaline phosphatase, aspartate amino transferase, and alanine amino transferase compared with the unexposed subjects (Fig. 4). In addition, principal somatic symptoms and complaints by the oil spill cleanup workers included headache, shortness of breath, skin rash, cough, dizzy spills, fatigue, painful joints, night sweats, and chest pain (Table 2). The study concluded that cleanup workers exposed to the oil spill and dispersant experienced significantly altered blood profiles, liver enzymes, and somatic symptoms, indicating human exposure to oil spill has a potential to induce both hematologic and hepatic toxicity.

A research group led by Glenn Morris Jr[9,11] at the University of Florida initiated community-based studies along the Gulf coast during the time of the actual spill. The investigators sought to determine the acute level of distress (depression, anxiety), mechanisms of adjustment (coping, resilience), and perceived risk in a community indirectly impacted by the oil spill and to identify the extent to which economic loss could explain these factors. The findings of the study indicated that income loss after the spill seems to have more of a psychological health impact than the presence of oil on the immediately adjacent shoreline.[11] One year after the spill, mental health problems persisted in people who continued to sustain spill-related income loss.[9] Anxiety, depression, mood disturbance, and loss of vigor were significantly higher in people who had sustained spill-related income loss compared with those who had stable incomes. Overall, the study findings indicated that people who sustained spill-related income loss seem to be particularly vulnerable to psychological distress, suggesting a pattern of psychological disruption that was chronic in nature.

Another study by Osofsky and coworkers[12] assessed the mental health effects on the residents in the areas of southeastern Louisiana affected by the Deepwater Horizon oil spill. The study included telephone and face-to-face interviews with 452 residents assessing their concerns and direct impact. The findings of the study indicated that the greatest effect on their mental health was related to the extent of the disruption that the participants had in their lives, work, family, and social engagement. In addition, the affected population had increased symptoms such as anxiety, depression, and

TABLE 1. Summary of Studies on Oil Spills and Its Adverse Health Effects

Oil Spill Source	Date of Disaster	Location	Spill Size, tons	Size of Cohort	Observed Health Effects	References
Deep Water Horizon	April 20, 2010	Gulf of Mexico, United States	680,000	130 exposed	Reduced platelet counts, increased hemoglobin and hematocrit levels, and serum liver enzymes such as ALP, AST, and ALT.	D'Andrea and Reddy[7]
				117 unexposed	Headaches, shortness of breath, skin rash, cough, dizzy spills, fatigue, painful joints, night sweats, and chest pain	D'Andrea and Reddy[8]
				93 exposed	1 yr after the spill, mental health problems have persisted in people who continued to sustain spill-related income loss	Morris et al[9]
					Anxiety, depression, mood disturbance, and loss of vigor were significantly higher in people who had sustained spill-related income than in those who had stable incomes	
				469 exposed	Depression, anxiety, and mental illness were continued to persist even 1 yr after the disaster	Buttke et al[10]
				23 directly exposed 71 indirectly exposed	Estimates of human health impacts associated with the oil spill may underestimate the psychological impact in Gulf Coast communities that did not experience direct exposure to oil	Grattan et al[11]
				452 exposed	Increased symptoms such as anxiety, depression, and posttraumatic stress observed in the affected population	Osofsky et al[12]
Hebei Spirit	December 7, 2007	Daesan Harbor, South Korea	10,900	1,361 children	The risk of depressive symptoms was significantly higher in children whose schools were closest to the nearest contamined coastline compared to those farthest away	Ha et al[13]
				565 exposed	Eye irritation, headache, nose irritation, fatigue/fever irritation, and musculoskeletal pain were most common complaints by the subjects	Ha et al[14]
				442 exposed	Eye symptoms, headaches, skin symptoms, and neurovestibular symptoms lasted relatively longer than did back pain or respiratory symptoms	Na et al[15]
				288 exposed	Most common subjective symptoms included eye irritation, musculoskeletal symptom, headache, fatigue/fever, nasal irritation, and dermal irritation	Cheong et al[16]
					The severity and frequency of symptoms associated with the level of exposure to clean up work occurred in a dose-dependent manner	
				100 exposed	Subjects living in heavy and moderately oil-soaked areas had higher levels of anxiety and depression compared with those living in the minimally soaked areas	Lee et al[17]
				71 exposed	Prevalence of psychosocial distress	Song et al[18]
Tasman Spirit	July 26, 2003	Karachi, Pakistan	37,000	216 exposed 184 unexposed	Ocular symptoms, respiratory symptoms, headache, irritability, fever, and general fatigue	Janjua et al[19]
				50 exposed 50 unexposed	Cough, runny nose, eye irritation/redness, sore throat, headache, nausea, and general illness	Meo et al[20]
				20 exposed 30 unexposed	Reduced lung function	Meo et al[21]
				100 exposed	Increased lymphocytes, eosinophiles, and the serum glutamic pyruvic transaminase	Khurshid et al[22]

(Continues)

TABLE 1. *(Continued)*

Oil Spill Source	Date of Disaster	Location	Spill Size, tons	Size of Cohort	Observed Health Effects	References
Prestige	November 19, 2002	Galicia, Spain	63,000	466 exposed 156 unexposed	Higher persistence of respiratory symptoms even 5 yrs after exposure	Zock et al[23]
				501 exposed 177 unexposed	Increased risk for lower respiratory tract symptoms and structural chromosomal alterations	Rodriguez-Trigo et al[24]
				6,780 exposed	Increased prevalence of lower and upper respiratory tract symptoms	Zock et al[25]
				2,700 exposed	Reduced health-related quality of life, increased body pain, and deteriorated mental health	Carrasco et al[26]
				799 exposed	Proper health protection briefing associated with greater use of protective devices and lower frequency of health problems (itchy eyes, nausea/vomiting/dizziness, and throat and respiratory problems)	Carrasco et al[27]
				858 exposed	Headache, back pain, dizziness, dermatitis, and respiratory problems	Chamosa et al[28]
					DNA damage and lower levels of CD4 cells, interleukins (IL) such as IL-2, IL-4, IL-10, and interferon-γ	
				711 exposed	Conjunctivitis, headache, sore throat, breathing difficulty, vomiting, skin rash, and abdominal pain	Bosch[29]
				799 exposed	Headache, itchy eyes, throat and respiratory symptoms, and dizziness, nausea, and vomiting	Suarez et al[30]
Crude oil pipeline rupture	May 2000	Etiama Nembe, Nigeria	Not reported	210 exposed 210 unexposed	Higher prevalence for diarrhea, sore eyes, itchy skin, and occupational injuries in exposed subjects	Ordinioha and Sawyer[31]
Erika	December 12, 1999	Brittany, France	20,000	Risk assessment	Increased risk for developing skin tumors in exposed individuals	Dor et al[32]
				Risk assessment	Increased risk for developing skin irritation and dermatitis and very limited risk for developing skin tumors were described for people who had been in bare-handed contact with the oil	Baars[33]
				3,669 exposed	The main described acute symptoms were lumbar pain, migraine, dermatitis, ocular irritation, respiratory problems, and nausea	Schvoerer et al[34]
					Duration of the cleaning work was identified as a risk factor	
Nakhodka	January 2, 1997	Oki Island, Japan	6,000	282 exposed	Headache, itchy eyes, sore throat, and leg/lumbar back pain were principal symptoms experienced by the subjects	Morita et al[35]
					The principal risk factors for developing symptoms were number of days worked, and direct contact with fuel oil, and female sex	

(Continues)

TABLE 1. *(Continued)*

Oil Spill Source	Date of Disaster	Location	Spill Size, tons	Size of Cohort	Observed Health Effects	References
Sea Empress	February 15, 1996	Milford Haven, United Kingdom	72, 000	794 exposed 791 unexposed	Perceived risk was associated with raised anxiety and nontoxicologically related symptoms reported in exposed subjects	Gallacher et al[36]
				539 exposed 550 unexposed	Significantly higher anxiety and depression scores, worse mental health and self-reported headache and sore eyes and throat in exposed subjects	Lyons et al[37]
MV Braer	January 5, 1993	Shetland, Scotland	85,000	344 exposed 77 unexposed	Poor health, tiredness, fever, throat, skin and eye irritations, and headaches in exposed subjects	Campbell et al[38]
				420 exposed 92 unexposed	Headache, throat irritation, itchy eyes, skin irritation, nausea, and tiredness	Campbell et al[39]
				44 children after 3 d and 56 children after 9–12 d	No differences in the peak expiratory flow rate between the two groups of children	Crum[40]
Exxon Valdez	March 24, 1989	Alaska, United States	37,000	125 exposed	Symptoms of depression, anxiety, and posttraumatic stress disorder were associated with conditions of resource loss and avoidant coping strategies	Arata et al[41]
				568 exposed 221 unexposed	High levels of psychological stress in affected subjects	Gill and Picou[42]
				437 exposed 162 unexposed	Oil spill-exposed subjects experienced scores several times higher for the parameters measured compared with the unexposed subjects	Palinkas et al[43]
				559 exposed	Depressive symptoms were significantly associated with the level of exposure	Palinkas et al[44]

ALP, alkaline phosphatase; ALT, alanine amino transferase; AST, aspartate amino transferase.

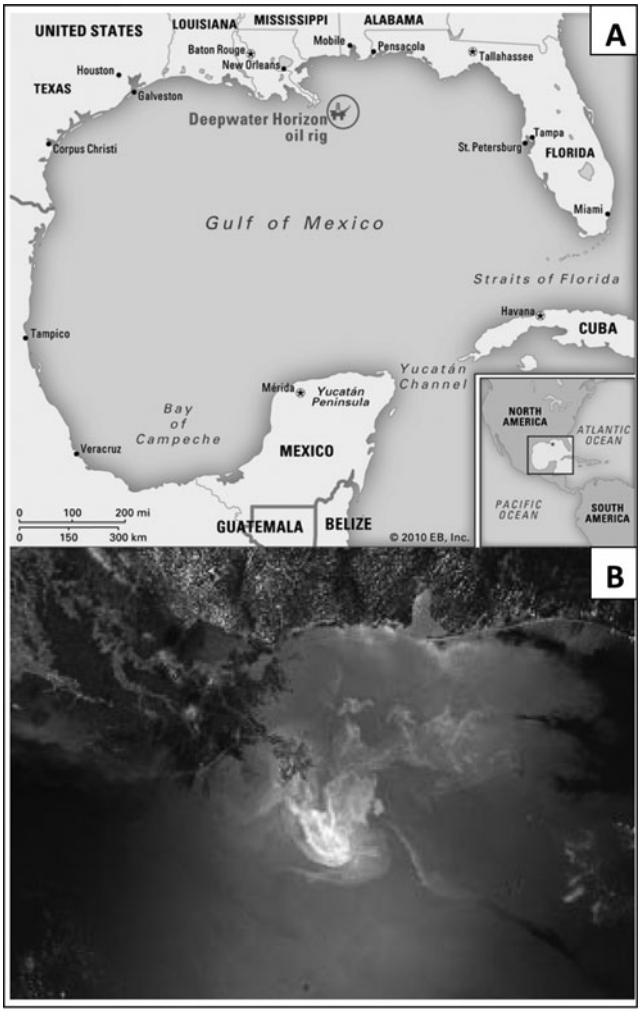

FIGURE 2. The Deepwater Horizon oil drilling rig. (A) The location of the Deepwater Horizon oil rig explosion in the Gulf of Mexico, 50 miles off the Louisiana coast (Source: http://www.britannica.com/blogs/2011/04/deepwater-horizon-oil-spill-year-picture-essay-day/ By courtesy of Encyclopedia Britannica, Inc, Copyright 2010; used with permission). (B) Satellite view of the Deepwater Horizon oil spill slick by the United States National Aeronautics and Space Administration in the Gulf of Mexico (Source: http://www.nasa.gov/topics/earth/features/oilspill/index.html. Accessed January 15, 2013).

posttraumatic stress. Similarly, Buttke et al[10] evaluated the mental health needs of coastal communities in the states of Alabama and Mississippi after the Deepwater Horizon oil spill. The study included a total of 469 residents from the coastal communities in the states of Alabama and Mississippi. The findings of the study revealed that between 15.4% and 24.5% of the respondents experienced depressive symptoms, with 21.4% to 31.5% reporting symptoms consistent with an anxiety disorder, and 16.3% to 22.8% reporting 14 mentally unhealthy days or more within the past 30 days. The investigators repeated the assessment 1 year later in 2011 to determine any long-term mental health needs and changes and compared them with those observed in 2010.[50] Depressive symptoms after 1 year (in 2011) still persisted in 8.8% to 15.1% of individuals compared with 15.4% to 24.5% of individuals in 2010, with 13.2% to 20.3% reporting symptoms consistent with an anxiety disorder compared with 21.4% to 31.5% of individuals assessed in 2010.

Hebei Spirit Oil Spill (Taean Coast, South Korea, December 7, 2007)

On December 7, 2007, the Hong Kong oil tanker Hebei Spirit laden with 209,000 tons of crude oil bound from the United Arab Emirates to Daesan Harbor on the western coast of South Korea crashed into a crane ship, spilling approximately 10,900 tons of oil into the sea.[51] The spilled oil rapidly spread and contaminated 1052 km of the western coastline. Emergency response operations were performed involving numerous volunteers and workers to clean up the oil spill, raising concerns about their health.

A study by Cheong and coresearchers[16] examined the association between crude oil exposure and physical symptoms among residents participating in the cleanup of the oil spill. Oil spill-exposed subjects were given a questionnaire survey regarding their subjective physical symptoms, sociodemographic characteristics, and cleanup activities after their exposure to the oil spill. A total of 288 residents responded to the questionnaire. In addition, urinary metabolites such as volatile organic compounds, and polycyclic aromatic hydrocarbons as well as heavy metals, were analyzed in 154 of the subjects and compared with 39 residents who were not exposed to the oil spill. The study demonstrated that the severity and frequency of symptoms associated with the level of exposure to clean up work occurred in a dose-dependent manner. At 8 weeks after the disaster, the most common subjective symptoms included eye irritation (86.1%), musculoskeletal symptom (86.1%), headache (84.7%), fatigue/fever (83.3%), nasal irritation (83.3%), dermal irritation (81.7%), sore throats (73.6%), back pain (73.6%), bronchial irritation (72.2%), nausea/vomiting (72.2%), memory/cognitive disturbance (62.5%), visual disturbances (61.1%), palpitation (56.3%), and abdominal pain (50.0%). Nevertheless, no major abnormalities in the urinary exposure biomarkers were observed in the oil spill-exposed subjects.

Song and coworkers[18] evaluated the psychological health in residents participating in the cleanup of the Hebei Spirit oil spill. Eight weeks after the disaster, a community survey was conducted in 71 men and women participating in the cleanup operation. The study found that the overall prevalence of high-risk psychosocial distress among the study group was 64.2%. Overall, the study findings revealed that the oil spill had a significant impact on the psychological health of people participated in the cleanup activity.

Lee et al[17] investigated the acute health effects of the Hebei Spirit oil spill on the residents of Taean, South Korea. A total of 100 subjects were interviewed using a structured questionnaire on the characteristics of residents, the cleanup activities, the perception of the oil hazard, depression and anxiety, and their physical symptoms. Subjects living in heavy and moderately oil-soaked areas had higher levels of anxiety and depression compared with those living in the minimally soaked areas. In addition, the study found that the oil spill-exposed subjects had increased risks of physical symptoms such as headaches, nausea, dizziness, fatigue, tingling of their limbs, hot flushing, sore throat, cough, runny nose, shortness of breath, itchy skin, rash, and sore eyes. Overall, the findings of the study suggested that exposure to crude oil was associated with various acute physical symptoms.

In another study, Na and coworkers[15] investigated the duration of health problems of people involved with cleanup efforts of the Hebei Spirit oil spill. One year after the disaster, the study examined a total of 442 subjects who had participated in the cleanup activity. The results indicated that eye symptoms (9.7 months), headaches (8.4 months), skin symptoms (8.3 months), and neurovestibular symptoms (6.9 months) lasted relatively longer than did back pain (1.8 months) or respiratory symptoms (2.1 months). Interestingly, the remission of headaches had a negative correlation with female sex (hazard ratio, 0.57; 95% confidence interval [CI], 0.34 to 0.95),

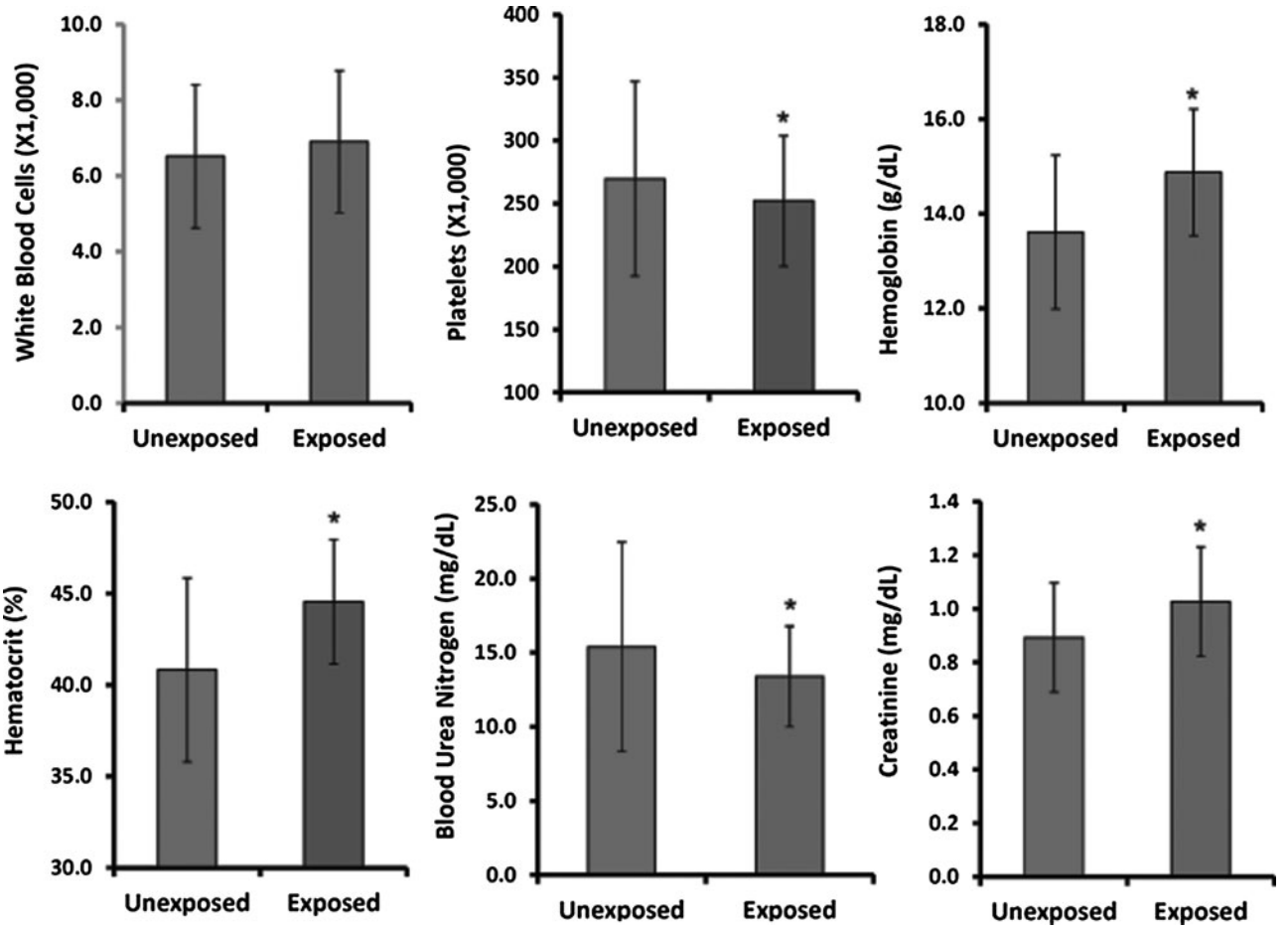

FIGURE 3. Comparison of hematologic indices such as white blood cells, platelets, hemoglobin, hematocrit, blood urea nitrogen, and creatinine between oil spill-exposed and unexposed subjects. *$P < 0.01$.

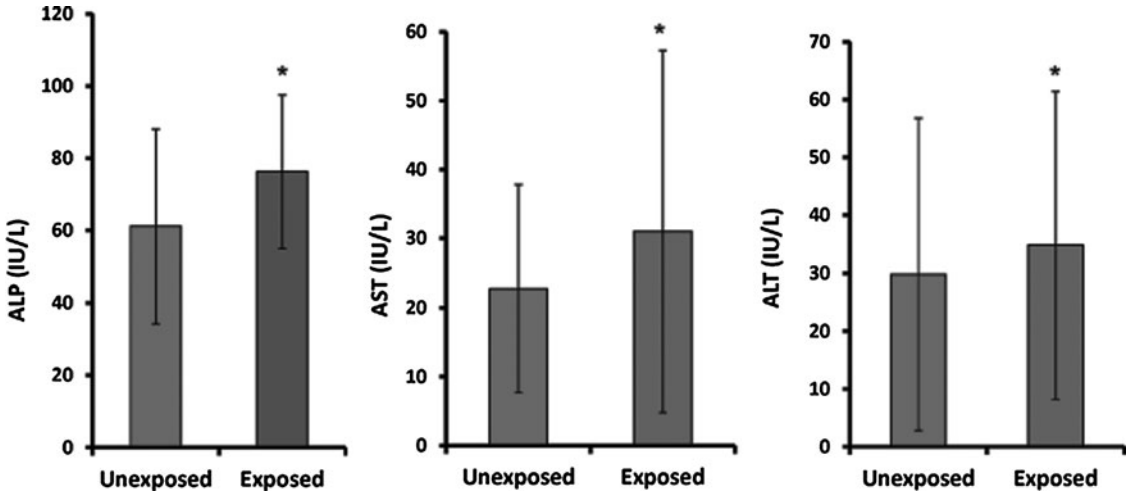

FIGURE 4. Comparison of serum hepatic enzymes such as ALP, AST, and ALT between oil spill-exposed and unexposed subjects. ALP, alkaline phosphatase; ALT, alanine amino transferase; AST, aspartate amino transferase. *$P < 0.01$.

TABLE 2. Major Somatic Symptoms Experienced by the Oil Spill Cleanup Workers After Exposure to Oil Spill and Dispersant

Symptom	Oil Spill-Exposed Subjects* *n* (%)
Headaches	90 (77)
Shortness of breath	83 (71)
Skin rash	69 (59)
Cough	60 (51)
Dizziness	60 (51)
Fatigue/weakness	58 (50)
Painful joints	57 (49)
Night sweats	48 (41)
Chest Pain	44 (38)
Heartburn	38 (32)
Diarrhea	32 (27)
Loss of appetite	28 (24)
Memory loss	27 (23)
Double vision	21 (18)
Numbness	21 (18)
Ankle swelling	17 (15)
Nosebleeds	15 (13)
Difficulty swallowing	13 (11)
Hearing loss	12 (10)
Pain	11 (9)
Blindness	9 (8)
Constipation	9 (8)
Skin lesions	8 (7)
Painful urination	8 (7)
Loss of balance	7 (6)
Discoordination	6 (5)
Burning on urination	5 (4)

*$N = 117$.

and the remission of eye symptoms had a negative correlation with the total hours of daily participation in the cleanup operation (hazard ratio, 0.24; 95% CI, 0.06 to 0.95).

Recently, Ha et al[14] have assessed the exposure status and acute health effects on volunteers who participated in the Hebei Spirit oil spill cleanup activity. The study included a total of 565 volunteers who participated in the cleanup activity. Their physical symptoms were evaluated using a survey questionnaire. In addition, urinary metabolite levels of volatile organic compounds and polycyclic aromatic hydrocarbons were analyzed in 105 university student volunteers before and after the cleanup operation. Assessment of their health problems revealed that the most common symptoms among the volunteers were eye irritation (46.9%), headache (42.0%), nose irritation (41.6%), fatigue/fever irritation (37.4%), and musculoskeletal pain (35.9%). Nevertheless, these physical symptoms were not associated with the levels of urinary metabolites that were evaluated.

Very recently, the same research group[13] evaluated the mental health effects of the oil spill on the children living in the affected area, where most of their families were victims of the disaster. Of the 1467 children who responded to the questionnaire at baseline, 1361 were included in the analysis. The study showed that children whose schools were located closest to the contaminated coastline had a significantly higher symptom risk of depression compared with those who lived farthest from the affected areas (odds ratio [OR], 2.73; 95% CI, 1.40 to 5.33). Nevertheless, no significant association was observed between anxiety symptoms and distance.

Tasman Spirit Oil Spill (Pakistan July 27, 2003)

On July 27, 2003, Tasman Spirit, carrying 67,000 tons of Iranian light crude oil bound from Iran to Pakistan, ran aground in the channel of the Karachi port, Pakistan, and sustained hull damage that ruptured the tanker. The ship broke apart and an estimated 35,000 tons of crude oil spilled into the sea and contaminated 10 km of the residential coastline. Prevailing high speed winds, strong wave actions, and high temperatures deteriorated the conditions further, spreading the oil and increasing evaporation of its volatile contents. The crude oil fumes and mist of hydrocarbons with strong pungent odors were dispersed, raising the health concerns among the residents living along the coastline.

In the wake of this disaster, Janjua and coworkers[19] conducted a study that included an exposed group of 216 adults of both sexes living on the affected coastline and two control groups living 2 km ($n = 83$) and 20 km ($n = 101$), respectively, away from the affected area. Surveys of the acute symptoms related to eyes, respiratory tract, skin, and the nervous system, as well as documentation of allergies, tobacco consumption, and perceptions on the effect of their health and anxiety about their health effects were performed. Subjects exposed to the oil spill experienced a higher incidence of symptoms involving the eyes, throat, skin as well as headaches and general malaise than those unexposed subjects living away from the contaminated coast. Moreover, the study findings indicated that oil spill exposure was associated with acute symptoms arising in residents near the spill, indicating an adverse effect on their health. In addition, the authors found a clear pattern of decreasing symptoms with increasing distance from the incident site.

A study by Meo et al[20] investigated the health complaints among subjects involved in oil cleanup operations during a spill from the Tasman Spirit disaster. Specifically, the study evaluated the respiratory and general health complaints that arose in 50 apparently healthy, non-smoking male subjects exposed to crude oil during oil cleanup operations and compared them with 50 matched unexposed subjects. Their health complaints were evaluated on the basis of a comprehensive interview. Significantly higher rates of health complaints including cough (38%), runny nose (36%), eye irritation/redness (32%), sore throats (28%), headaches (28%), nausea (24%), and general illness (18%) were observed in subjects participating in the oil cleanup operations compared with their matched controls.

In an earlier report, the same research group assessed the lung function in 20 subjects exposed to the Tasman Spirit oil spill and compared them with their 30 matched controls. The results of the study indicated that subjects exposed to the oil spill experienced significant reductions in their lung functions compared with their matched controls (P values ranging from 0.001 to 0.02 for the different lung function parameters).[52] In another report,[21] these authors investigated the effect of the duration of exposure to the polluted air environment on the lung function in subjects exposed to the Tasman Spirit tanker oil spill. The study findings indicated that subjects exposed to polluted air for periods longer than 15 days had a significant reduction in their lung function, specifically, reduced forced vital capacity, forced expiratory volume in the first second of expiration, forced expiratory flow in 25% to 75%, and maximal voluntary ventilation.

A study by Khurshid et al[22] investigated the hematological and biochemical abnormalities in 100 oil spill-affected subjects 4 to 6 months after the Tasman Spirit tanker disaster. Their findings indicated that there were slight increases in the levels of lymphocytes, eosinophiles, and the serum glutamic pyruvic transaminase in 11 subjects, indicating the health risk in the oil spill-affected subjects.

Prestige Oil Spill (Galicia, Spain, November 19, 2002)

On November 19, 2002, the big oil tanker Prestige foundered 130 miles from the coast of Galicia, on the northwest side of Spain and spilled more than 19 million gallons (67,000 tons) of bunker oil. As a result, more than 1000 km of Spanish and French coasts was contaminated by the oil spill.[25,30,53] More than 300,000 volunteers and hundreds of thousands of emergency responders participated in the cleanup activities, including many local fishermen.[24] The cleanup activities entailed direct contact with the oil, posing a health risk to the emergency responders.

Suarez and coworkers[30] retrospectively evaluated the acute health effects in 799 cleanup workers from two less affected regions on the Cantabrian coast of Spain. The overall prevalence of symptoms was not high: neurovegetative symptoms (11%), headache (8%), eye problems (8%), throat irritation and respiratory problems (8%), back pain (5%), and injuries (7%). Surprisingly, the authors found that skin irritation was not commonly reported (seamen, 5%; salaried workers, 3%; volunteers, 2%; and bird cleaners, 0%).

In a subsequent report, these investigators[27] provided additional data on the same study relating to the health information received by participants before they started work on the cleanup, their use of protective clothing, and subsequent acute health problems. The most well-informed groups were the paid workers (94% of them received information) and the least well-informed were the seamen (68%). Receiving health information was associated with the use of protective measures. The people who did not receive such information had a higher risk for all symptoms, especially itchy eyes (OR, 2.67; 95% CI, 1.13 to 6.28), neurovegetative symptoms (OR, 2.09; 95% CI, 1.07 to 4.08), and problems affecting their throat and respiratory system (OR, 2.08; 95% CI, 1.02 to 4.24).

Bosch[29] reported on the health information released by the Galician Health Department on those subjects who sought medical attention for their complaints. During this period, 711 cleanup workers requested an examination for their symptoms. These symptoms included conjunctivitis (167), headaches (138), sore throat (137), breathing difficulty (115), vomiting (103), skin rashes (73), and abdominal pain (42).

Various studies examined the potential genotoxic effects on cleanup workers of the Prestige oil spill after the disaster. The findings of these studies revealed increased genotoxic endpoints[54] and altered endocrine status[55] in the oil spill-exposed subjects compared with the unexposed subjects. In addition, cytogenetic effects related to the exposure to oil from the Prestige tanker were seen in cleanup workers.[53]

Zock and coworkers[25] evaluated the prevalence of respiratory symptoms in local fishermen more than 1 year after having participated in the cleanup work of the Prestige oil spill. Initially, data using a questionnaire survey were obtained from 6780 fishermen with response rates of 76% and 63% of them who had participated in the cleanup operations. The questionnaire survey revealed that participation in the cleanup operation was associated with an increased prevalence of lower and upper respiratory tract symptoms, even 1 year after the oil spill exposure. Moreover, the authors found that the respiratory tract changes were linked to various types of cleanup activities and the risk increased with the degree and duration of the cleanup effort, and with a less frequent use of protective face masks. Two years after oil spill cleanup operations, the investigators reinterviewed the fishermen and evaluated their respiratory status for any changes.[24] Specifically, they assessed the respiratory effects and chromosomal damage in 501 local fishermen who were most exposed to the oil spill and compared the outcomes with those of 177 unexposed subjects. The findings of the study showed that the oil spill-exposed subjects had an increased risk for lower respiratory tract symptoms (risk difference, 8.0; 95% CI, 1.1 to 14.8) and structural chromosomal alterations (risk difference, 27.4; 95% CI, 10.0 to 44.8) compared with the unexposed subjects.

A further follow-up study was conducted 4 years after the baseline survey and over 5 years after exposure to the Prestige oil spill to examine the long-term respiratory abnormalities in oil spill cleanup subjects.[23] This study included 466 exposed and 156 nonexposed fishermen who were involved in the oil spill cleanup. Although the prevalence of lower respiratory tract symptoms had slightly decreased in both groups, it remained higher among the exposed (relative risk ratio, 1.4; 95% CI, 1.1 to 1.9), indicating the persistence of respiratory symptoms even 5 years after exposure.

Chamosa et al[28] assessed the acute genetic toxicity by undertaking a longitudinal epidemiological survey of 858 volunteers and workers involved in the cleanup of the Prestige oil spill. Assessment of their perception of health problems revealed that the most common symptoms among the volunteers (excluding injuries) were headaches (19%), back pain (15%), and dizziness (11%); and to a lesser degree dermatitis (4%) and respiratory problems (4%). The paid workers reported back problems (30%), headaches (12%), irritated eyes (10%) and throat (9%), and respiratory problems (4%). In addition, the study found that volunteers, especially those working on the beaches, had DNA damage and lower levels of CD4 cells, interleukins (IL) such as IL-2, IL-4, and IL-10, and interferon-γ compared with their own preexposure levels.

Carrasco and coworkers[26] assessed the health-related quality of life and mental health in the affected population of the Prestige oil spill disaster. Using a random sampling stratified by age and sex, the study included a total of 2700 residents who were selected from seven coastal and seven inland Galician towns. The 36-item short form health survey assessment showed coastal residents as having a lower likelihood of registering suboptimal health-related quality of life values in physical functioning (OR, 0.69; 95% CI, 0.54 to 0.89) and bodily pain (OR, 0.74; 95% CI, 0.62 to 0.91), and a higher frequency of suboptimal scores in mental health (OR, 1.28; 95% CI, 1.02 to 1.58). Overall, the findings of the study suggested the possibility of a slight impact on the mental health of residents in the oil spill-affected areas.

Crude Oil Pipeline Rupture (Etiama Nembe, Nigeria, May 2000)

In May 2000, a crude oil pipeline of the major oil-producing company ruptured in Etiama Nembe, in Bayelsa State, Nigeria. The surrounding local communities were contaminated heavily with the spilled oil. To investigate the health effects of this oil contamination, Ordinioha and Sawyer[31] conducted a study among the residents in the affected community. Using an interviewer they administered questionnaires and had focus group discussions as part of the study tools. The study investigators assessed the acute health effects of the oil spill in 210 exposed subjects, and their outcomes were compared with those of 210 unexposed subjects. The findings of the study indicated that exposure to the spilled crude oil was associated with significant increases in the prevalence of several physical symptoms including diarrhea (OR, 4.6; $P < 0.0001$), cough (OR, 4.13; $P < 0.0001$), headaches (OR, 3.84; $P < 0.0001$), sore throats (OR, 6.49; $P < 0.0001$), itchy eyes (OR, 10.93; $P < 0.0001$), itchy skin (OR, 13.48; $P < 0.00001$), and occupational injuries (OR, 5.29; $P < 0.0005$).

Erika Oil Spill (Brittany, France, December 12, 1999)

On December 12, 1999, the oil tanker Erika wrecked and sank 55 km off the French coast at Penmarch Point on the south coast of Brittany, resulting in more than 20,000 tons of heavy oil being released into the open sea. The weather conditions and currents in the vicinity of the spill caused the oil slick to spread along 400 km of the coastline, from western Brittany to the northern tip of the islands

of Ré and Oléron, raising health concerns in the oil spill-impacted area.

To investigate the impact of this oil spill disaster on the health of those living in the affected areas, Schvoerer et al[34] performed a cross-sectional epidemiological survey on the basis of a self-administered questionnaire in 3669 volunteers and paid workers who participated in the cleanup activities. The response rate was low (43%), and information was collected from 1465 people. The study showed that 7.5% of the subjects experienced some type of injury and 53% experienced some kind of health problems such as lumbar pain (30%), migraines (22%), and dermatitis (16%). To a lesser degree, participants also reported eye irritation (9%), respiratory problems (7%), and nausea (6%). The length of time spent working on cleanup activities was identified as a risk factor for all of the health problems experienced by the subjects who participated in the cleanup operation.

Dor et al[32] performed a human health risk assessment after decontamination of the beaches polluted by the Erika oil spill. Specifically, the authors evaluated important oil constituents such as polycyclic aromatic hydrocarbons in samples of sand, water, and the surface of rocks from the cleaned-polluted beaches as well as from beaches that were not exposed to the oil spill. Risk assessments after the oil spill suggested a low risk of cancer among the workers and persons visiting the decontaminated beaches.

Baars and coinvestigators[33] assessed the health risks for people involved in the cleanup activities including tourists with an emphasis on the carcinogenic properties of the crude oil on the basis of the known toxicological properties of its components and made assumptions on the levels of exposures during the performance of different activities. Although they found an increased risk for developing skin tumors in exposed individuals, it was considered to be very limited because of the short contact time with the oil.

Nakhodka Oil Spill (Oki Island, Japan, January 2, 1997)

On January 2, 1997, the Russian oil tanker Nakhodka, carrying more than 19,000 tons of fuel oil wrecked and broke up northeast of the Oki islands in the Sea of Japan. More than 6000 tons of its cargo escaped into the sea and contaminated more than 500 km of the coastline. Cleanup operations were hampered by rough seas and the inability to bring in machinery because of the remote location. Therefore, cleanup was performed manually using ladles, shovels, and buckets. This raised the health concerns not only in those involved in the oil spill cleanup but also in residents living along the coastline.

To determine the health impact of this disaster, Morita et al[35] investigated the acute effect of exposure to the oil spill and subsequent cleanup efforts on the health status of the local residents. The study included a total of 282 subjects (men and women) who engaged in the cleanup operation. An interview on their health status and determinations of several hydrocarbon metabolites in their urine was carried out. The mean number of days worked on cleanup activities was 4.7 days for men and 4.3 days for women; 17% of the subjects had worked on cleanup activities for more than 10 days. The interview was guided by a questionnaire, and data were gathered on each subject's daily participation in the cleanup operation, direct exposure to fuel oil, as well as their state of health and symptoms after their exposure. Similar to the findings of Campbell and colleagues,[39] the subjects evaluated in this study also experienced headaches (9% in men and 28% in women), itchy eyes (21% in men and 36% in women), sore throats (13% in men and 21% in women), and leg/lumbar back pain (34% in men and 38% in women). Moreover, their study found that there was a positive correlation between the number and duration of the symptoms reported and the number of days worked. The principal risk factors for developing symptoms were number of days worked, and direct contact with the fuel oil, and female sex. Measurements of hydrocarbon metabolites in the urine showed that only three subjects had high levels of hydrocarbon metabolites (hippuric acid), which then returned to normal when a follow-up analysis was performed 4 months later.

Sea Empress Oil Spill (Milford Haven, United Kingdom, February 15, 1996)

On February 1 5, 1996, the oil tanker Sea Empress, carrying a cargo of 140,000 tons of crude oil, ran aground on the rocky shoreline at the entrance of the Milford Haven harbor in southwest Wales, United Kingdom. By the next week, more than 72,000 tons of crude oil spilled into the sea, contaminating approximately 200 km of the coastline. The oil spill from this tanker had strong pungent odors associated with it, leading to health complaints from the residents of the coastal towns. A population-based retrospective cohort study by Lyons et al[37] assessed the residents' acute physical and psychological health impact from their exposure to the Sea Empress oil spill. The vicinities of the affected area included Milford Haven, southwest Wales. A questionnaire survey was completed by 539 exposed and 550 unexposed subjects sampled at random from the family health services authority age-sex register. The study findings, after adjustment by age, sex, and smoking status, showed that the subjects living in the exposed areas had elevated levels of anxiety and depression, worse mental health and headaches (OR, 2.35; 95% CI, 1.56 to 3.55), sore eyes (OR, 1.96; 95% CI, 1.06 to 3.62), and sore throats (OR, 1.70; 95% CI, 1.12 to 2.60). Overall, the study results indicated that subjects living in the oil spill-exposed areas experienced higher rates of physical and psychological symptoms than those living in the unexposed areas.

On the basis that exposure to a complex emergency has a substantial psychological component, Gallacher and coworkers[36] investigated the health impact of physically and psychologically mediated exposure to a complex emergency in oil spill-exposed subjects. A cross-sectional analysis of a self-reported questionnaire with responses was collected from 794 oil spill-exposed and 791 unexposed subjects who lived in six different coastal towns—four of them physically exposed to the oil spill, two unexposed to the oil spill was undertaken. Anxiety, depression, and symptom reporting were used as measures of the health impact of the oil spill. Their findings revealed that the perceived risk was associated with raised anxiety and nontoxicologically related symptom reporting (OR, 2.28; 95% CI, 1.57 to 3.31; $P < 0.001$), whereas physical exposure to the oil spill was only associated with toxicologically related symptom reporting. In addition, the study found that the impact of raised perceived risk on the population was greater than that of physical oil exposure, involving more persons over a wider area.

MV Braer Oil Spill (Shetland, Scotland, January 5, 1993)

On January 5, 1993, the oil tanker MV Braer on passage from Norway to Quebec lost engine power and drifted. A combination of strong winds and local currents grounded and wrecked it upon on a rocky shoreline at the Garths Ness near Shetland, Scotland.

Over the next 6 days, it leaked its cargo of 25 million gallons (85,000 tons) of Norwegian Gullfaks crude oil into the sea. The maximum discharge occurred as the ship broke up on January 11, 1993. Concerns were raised about the health consequences among the population exposed to oil spill.

A cross-sectional study by Campbell et al[39] assessed the health consequences among 420 subjects exposed to the MV Braer oil spill and compared them with 92 unexposed subjects. Specifically, the investigators looked at the general perception of health, peak expiratory flow, hematology, liver and renal functions, and urine toxicology in the oil spill-exposed and unexposed subjects. The findings of the study showed that the subjects exposed to the oil spill, specifically during the first and second days after the spill, experienced

headaches, throat irritation, and itchy eyes. No significant differences were observed between the groups for any of the biological markers in the study. Nevertheless, there was a greater proportion of detections of urinary hippuric acid in the exposed group than in the unexposed group (34% vs 16%; $P < 0.002$).

In a subsequent report, the investigators evaluated longer-term effects in the same populations (344 exposed and 77 unexposed subjects).[38] Among the oil spill-exposed subjects, 7% perceived their health to be poor compared with none of the unexposed group and a significantly higher number of the exposed subjects considered their health to have deteriorated since the incident. Comparison of the symptoms of the exposed subjects 2 weeks before with their symptoms immediately after the incident showed an increase in tiredness and fever, and fewer throat, skin and eye irritations, and headaches (OR, 1.86; 95% CI, 1.19 to 2.92).

In another study, Crum[40] evaluated the peak expiratory flow rate in two groups of children aged 5 to 12 years who were residing within 5 km of the Braer shipwreck. In the first group of 44 children, the investigators evaluated the peak expiratory flow rate 3 days after the disaster, and in the second group of 56 children measurements were performed between 9 and 12 days after the oil spill. The findings of their study showed no differences in the peak expiratory flow rate between the first and second groups.

Exxon Valdez Oil Spill (Alaska, United States, March 24, 1989)

On March 24, 1989, the 987-foot supertanker Exxon Valdez ran aground on Bligh Reef (approximately 25 miles from the city of Valdez, Alaska), spilling more than 11 million gallons (260,000 barrels, or 37,000 tons) of crude oil into the pristine environment of the Prince William Sound. The resulting oil slick contaminated 44,000 km^2, including more than 1900 km of the coastline, and caused widespread environmental damage that was exacerbated by controversial cleanup techniques.

Although several studies exist on the ecological impact of the Exxon Valdez oil spill, very few studies evaluated its impact on human health, especially the psychological, psychiatric, and social effects. A study by Palinkas and coworkers evaluated and compared the levels of depressive symptomatology between 188 indigenous Alaskan Native people and 371 European Americans, residing in 13 communities of Alaska (11 in the region directly exposed to the oil spill itself and 2 control communities). The findings of this study suggested that cultural differences played an important role in the perception of the psychological impact produced by the Exxon Valdez oil spill. The group of European Americans showed a certain moderating effect of the damage in relation to perceived family support; however, this factor did not significantly influence the Alaskan Native group. These results emphasized the role of cultural differences in the perception of and capacity to overcome the psychological impact.

Later, the same group of researchers[44] examined the association of the oil spill exposure and subsequent cleanup activity with the prevalence of generalized anxiety disorder, posttraumatic stress disorder, and depressive symptoms, using a community survey in 13 communities of Alaska. The investigators conducted a community survey of 599 men and women approximately 1 year after the spill. Of the 599 subjects, 437 were from 11 regions directly exposed to the oil spill disaster and 162 from two regions that were not exposed to the oil spill. Prevalence of a generalized anxiety disorder and posttraumatic stress disorder was found to be present in 20.2% and 9.4% of those studied, respectively. The prevalence of depression scale scores above 16 and 18 was 16.6% and 14.2%, respectively. Importantly, oil spill-exposed subjects experienced scores several times higher for the parameters measured compared with the unexposed subjects. Furthermore, women were particularly vulnerable to the exposure effects of the oil spill and cleanup activities; they had a prevalence of generalized anxiety disorder. In a later report, these investigators confirmed the prevalence of a posttraumatic stress disorder that was associated with ethnic differences among individuals affected by the Exxon Valdez oil spill. In both ethnic groups (indigenous Alaskan and European Americans), the authors found high levels of social disruption 1 year after this disaster. Furthermore, participation in spill cleanup activities was associated with a significant posttraumatic stress disorder in the indigenous Alaskan Native people, but not in European Americans.

A study by Arata et al[41] conducted a survey regarding current mental health functioning in 125 commercial fishermen of Cordova, Alaska, 6 years after the Exxon Valdez oil spill. The study evaluated the economic and social impacts of the oil spill and their coping and psychological functioning using a mailed survey. The study findings indicated that symptoms of depression, anxiety, and posttraumatic stress disorder were associated with resource loss and avoidant coping strategies. Similarly, Gill and Picou[42] found high levels of event-related psychological stress in populations affected by the Exxon Valdez oil spill. With regard to the effect of this oil spill on other health effects, specifically hematological, hepatic, pulmonary, and cardiac effects, there are no studies available in peer-reviewed literature.

CONCLUSIONS

Oil spills have occurred worldwide on various scales, but research on their health effects is limited. Oil spills affect human health through exposure to inherent hazardous chemicals including paraphenols and aromatic hydrocarbons such as volatile benzene. Depending on the severity, oil spill exposure can cause dermal, hematologic, hepatic, respiratory, renal, endocrine, neurologic, or other systemic and somatic effects. Although these oil spills differ in the specific constituents of oil, nature of human exposures, and the duration of cleanup workers, and other community volunteers to the exposure, similar patterns of health effects have been reported in the literature. Evaluating the oil spill exposure effects on human health and in response or cleanup activities is complex. Factors such as the composition of the spilled oil and weathering, the diverse range of exposures and potential adverse health effects, the unique characteristics of the affected populations, and the ongoing nature of the oil spill can increase the assessment complexity.

Published studies have identified acute and, to some extent, chronic health effects related to major oil spills. Nevertheless, many of these reports focused on the acute health effects of the oil spill exposures, specifically evaluating physical symptoms and psychological behavior in the oil spill-affected populations. In addition, many of the published studies have a cross-sectional design. Studies with longitudinal designs are more meaningful to evaluate the dynamic changes seen over a specific follow-up time. Studies evaluating the changes in hematologic, cardiac, renal, and other vital organ functions in exposed population are sparse, and we have yet to learn and understand the full extent of these adverse effects of the oil spills. Recent studies by D'Andrea and Reddy[7,8] demonstrated that cleanup workers exposed to the BP oil spill and dispersant experienced significantly altered blood profiles, liver enzymes, and somatic symptoms. These findings indicate that exposure to oil spills may lead to detrimental health effects. Additional studies are being conducted to explore how exposure to the oil spill may affect the pulmonary and cardiac functions of those subjects who participated in the cleanup operation. Nevertheless, to fully understand the importance and nature of these effects, further longitudinal and mechanistic studies on the health effects of oil spill exposures are warranted. As the health impact from oil spills is long-lasting, close follow-up studies are necessary to determine the long-term health effects in affected population. In addition, there is a need for a national policy to respond to emergency oil accidents, which are likely to happen in the future as long as we use fossil oil as a source of energy. Because accidental oil

spills will occur again, it is crucial that those responsible for organizing cleanup operations take appropriate measures such as providing adequate protective gear for cleanup workers and assess their health status before, during, and after their cleanup activities and monitor them for adverse effects. To further protect the health of persons involved in oil spill cleanup activities, it may necessary in the future to establish registries to assist in systematically assessing possible adverse health outcomes in those exposed cleanup workers over time.

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CME QUESTIONS

(1) Which of the following health effects were reported in subjects exposed to the 2010 Deepwater Horizon spill in the Gulf of Mexico?

a) Decreased platelet counts and increased hemoglobin and hematocrit levels
b) Elevated serum enzyme levels
c) Somatic symptoms including headache, shortness of breath, and skin rash
d) All of the above

(2) Which of the following factors was significantly associated with acute and chronic psychologic distress after the Deepwater Horizon spill?

a) Income loss related to the oil spill
b) Mechanisms of adjustment (coping, resilience)
c) Presence of oil on the adjacent shoreline
d) All of the above

(3) Which of the following has been identified as a risk factor for health problems in cleanup workers, in studies performed after multiple oil spills?

a) Female sex
b) Older age
c) Somatization disorder
d) Time spent working on cleanup activities

(4) Which of the following is/are true of research on the 1989 Exxon Valdez oil spill in Alaska?

a) Several studies assessed the environmental impact of the disaster but very few looked at the human health effects.
b) Cultural differences affected the psychologic impact of the spill, including higher rates of posttraumatic stress disorder in indigenous Alaskan Native people involved in cleanup activities.
c) No studies have evaluated other health effects of the Exxon Valdez spill, including the hematologic, hepatic, pulmonary, and cardiac effects.
d) All of the above are true.

(5) Which of the following statements is *not* accurate, based on the concluding discussion by D'Andrea et al?

a) "Depending on the severity, oil spill exposure can cause dermal, hematologic, hepatic, respiratory, renal, endocrine, neurologic, or other systemic and somatic effects."
b) "Studies evaluating the changes in hematologic, cardiac, renal, and other vital organ functions in exposed population are sparse and we have yet to learn and understand the full extent of these adverse effects of the oil spills."

c) "[T]o fully understand the importance and nature of these effects, further longitudinal and mechanistic studies on the health effects of oil spill exposures are warranted."
d) "Because large oil spills are highly variable and increasingly rare, a national policy to respond to emergency oil accidents does not appear justified."