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To cite this article: E. Martin Caravati M.P.H. M.D., Andrew R. Erdman M.D., Gwenn Christianson M.S.N., Lewis S. Nelson M.D., Alan D. Woolf M.P.H. M.D., Lisa L. Booze Pharm.D., Daniel J. Cobaugh Pharm.D., Peter A. Chyka Pharm.D., Elizabeth J. Scharman Pharm.D., Anthony S. Manoguerra Pharm.D. & William G. Troutman Pharm.D. (2008) Elemental mercury exposure: An evidence-based consensus guideline for out-of-hospital management, *Clinical Toxicology*, 46:1, 1-21, DOI: [10.1080/15563650701664731](https://doi.org/10.1080/15563650701664731)

To link to this article: <http://dx.doi.org/10.1080/15563650701664731>



Published online: 07 Oct 2008.



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PRACTICE GUIDELINE

Elemental mercury exposure: An evidence-based consensus guideline for out-of-hospital management

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The objective of this guideline is to assist poison center personnel in the out-of-hospital triage and initial management of patients with suspected exposures to elemental mercury. An evidence-based expert consensus process was used to create this guideline. It is based on an assessment of current scientific and clinical information. The panel recognizes that specific patient care decisions may be at variance with this guideline and are the prerogative of the patient and health professionals providing care. The grade of recommendation is in parentheses. Recommendations: 1) Patients with exposure due to suspected self-harm, abuse, misuse, or potentially malicious administration should be referred to an emergency department immediately regardless of the exposure reported (Grade D). 2) Patients with symptoms of acute elemental mercury poisoning (e.g., cough, dyspnea, chest pain) should be referred immediately to an emergency department for evaluation regardless of the reported dose. Patients with symptoms of chronic toxicity (rash, tremor, weight loss, etc.) should be referred for healthcare evaluation, the timing and location of which is guided by the severity of illness and circumstances of the exposure (Grade C). 3) If the elemental mercury was recently heated (e.g., from stove top, oven, furnace) in an enclosed area, all people within the exposure area should be evaluated at a healthcare facility due to the high risk of toxicity (Grade C). 4) If the elemental mercury was vacuumed or swept with a broom, the health department should be contacted to perform an environmental assessment for mercury contamination. Consider healthcare referral for those exposed to documented high air mercury concentrations (Grade C). 5) Patients ingesting more mercury than in a household fever thermometer or those with abdominal pain after ingestion should be referred to an emergency department for evaluation (Grade C). Do not induce emesis or administer activated charcoal. 6) Asymptomatic patients with brief, unintentional, low-dose vapor exposures can be observed at home. Asymptomatic patients can be evaluated as non-urgent outpatients if there is concern for exposures to high doses (e.g., more than contained in a thermometer) or for chronic duration (Grade D). 7) Pregnant patients unintentionally exposed to elemental mercury and who are asymptomatic should be evaluated by their obstetrician or primary care provider as an outpatient. Immediate referral to an ED is not required (Grade D). 8) Patients with elemental mercury deposited or injected into soft tissue should be referred for evaluation of surgical removal (Grade C). 9) All elemental mercury spills should be properly cleaned up, including the small amount of mercury from a broken thermometer. Brooms and vacuum cleaners should not be used to clean up elemental mercury. The clean-up of any spill larger than a broken thermometer should be performed by a professional company, state health department, or the EPA. Detailed instructions are provided on the EPA website: www.epa.gov/epaoswer/hazwaste/mercury/faq/spills.htm (Grade D). 10) Patients with dermal exposures should remove all jewelry and wash the affected area with mild soap and water. Remove all contaminated clothing and place these items in a sealed plastic double-bag for proper disposal (Grade D). 11) Do not discard elemental mercury in household trash, plumbing drains, or sewer systems. Consult local authorities for the proper disposal of low-level elemental mercury-contaminated household items and thermometers (Grade D).

Keywords Elemental mercury/poisoning; Poison control centers/standards; Practice guidelines

Received 9 April 2007; accepted 9 April 2007.

Guidelines for the Management of Poisoning is supported in full by Cooperative Agreement 8 U4BHS00084 between the American Association of Poison Control Centers and the Health Resources and Services Administration, Department of Health and Human Services.

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Introduction

Elemental mercury is used in manufacturing and industrial processes (mining, smelting), household, medical and electrical devices (e.g., thermometers, thermostats, electrical switches, dental amalgam), and folk remedies. Thus, environmental release of elemental mercury that results in human exposure can occur in many different locations. The most frequent are schools and universities (20%), homes (17%),

healthcare facilities (17%), public utilities (13%), and manufacturing facilities (10%) (1). Elemental mercury volatilizes at room temperature, allowing human exposure via inhalation, and accumulates in the ecosystem leading to pollution of air, waterways, aquatic life, and eventually food for human consumption. Elemental mercury vapor is a pulmonary irritant, renal toxin, and cumulative neurotoxin. Environmental release, whether in a home, workplace, or public area, can result in acute and chronic health effects (2). Clean-up of even small household spills can be time consuming and costly (3). Poison centers are often contacted by the public regarding the health risks, proper clean-up, and disposal of small elemental mercury spills.

Scope of the problem and importance of the guideline

During the 5-year period of 2001–2005, there were 15,552 human exposures to elemental mercury, excluding thermometers, reported to US poison centers. Of these exposures, 14,227 (91%) were unintentional and only 2,307 (15%) occurred in children less than 6 years of age. Moderate or major clinical outcomes, as defined by the Toxic Exposure Surveillance System (TESS), occurred in 250 (1.6%) patients (4). Three patients died, but only one case appeared to be directly related to the exposure. A 60-year-old man developed acute pneumonitis after heating a gold-mercury amalgam in an enclosed space and died of respiratory failure 16 days after exposure (personal communication, M. Lai, AAPCC, 2006).

In 2001, TESS began reporting exposures specifically involving mercury-containing thermometers. In that year alone, there were 17,457 human exposures to these thermometers voluntarily reported to US poison centers. Of these exposures, 17,322 (99%) were unintentional, 7,465 (43%) were in children less than 6 years of age, and only 1,025 (6%) were referred to healthcare facilities. The reasons for healthcare facility referral were not reported. Since 2001, the frequency of reported mercury thermometer exposures has steadily declined resulting in 9,122 elemental mercury thermometer exposures in 2005, a 48% decrease (4). There are limitations in this data set as some exposures to mercury from broken thermometers might be coded as “heavy metal-elemental mercury” exposures rather than thermometer exposures. In addition, many calls to poison centers concerning spilled mercury from broken thermometers might be coded as “information” calls and would not be reflected in the human exposure data. No deaths from exposure to mercury thermometers were reported to TESS during 2001–2005.

Due to the human and environmental risks associated with elemental mercury contamination, many local and state governments have banned the sale of medical devices that contain elemental mercury. Many communities across the US have organized mercury thermometer exchange programs in order to remove this potential source of mercury. An evidence-based, consensus poison center guideline for

elemental mercury was requested by members of AAPCC to help with out-of-hospital triage and management.

Substances and definitions

This guideline addresses small spills and human exposures to elemental mercury. Exposures to organic mercury compounds (e.g., methylmercury) or inorganic mercuric salts (e.g., mercuric chloride) are not included. In addition, this guideline does not address chronic occupational exposure or large industrial releases of elemental mercury. It focuses primarily on small spills (typically less than 5 mL) that occur in a home or public area. It does not address aspiration or intravenous exposure to elemental mercury.

The term “out-of-hospital” is the period before a patient reaches a healthcare facility. To be consistent with TESS definitions, acute exposures are those occurring over a period of up to 8 hours and chronic exposures are those that occur over a period of more than 8 hours. A child is a person less than 6 years of age.

Background on elemental mercury

Elemental mercury (Hg^0 , CAS #7439-97-6, “quicksilver”) is a dense, silver-white, odorless, heavy metal that is liquid at room temperature. When spilled or swept with a broom, it can break into very small droplets that penetrate small spaces, which results in an increased surface area. Even though it has a low vapor pressure (0.0012 mmHg at 20°C [68°F]), it volatilizes at room temperature and can accumulate indoors to concentrations that exceed safe airborne concentrations (5–8). Its vapor pressure increases with temperature; thus, airborne concentrations increase when it is heated. The density of elemental mercury is 13.5 g/mL (water=1 at 25°C), so even the small volumes found in devices available to the public represent relatively large amounts of elemental mercury (Table 1). Elemental mercury vapor is heavier than air (relative vapor density 6.93, air=1) and can accumulate in poorly ventilated or low-lying areas. This property can place children at increased risk of exposure compared to adults because their breathing zone is closer to the ground (9).

The absorption of elemental mercury from intact skin (10) or the gastrointestinal tract is negligible (11). Elemental mercury vapor is 70–80% absorbed by the lungs (12) and inhalation is the primary route for systemic toxicity. It distributes into red blood cells, other tissues, and crosses the blood-brain barrier to accumulate in the central nervous system. It also crosses the placenta (13).

Elemental mercury is a cellular poison that disrupts multiple enzymes, proteins, and cellular membrane functions. The primary target organs are the central nervous system and kidneys. Skin or eye contact with elemental mercury can cause local irritation and contact dermatitis (14). Acute inhalation of high vapor concentrations, usually from heated elemental

Table 1. Amount of elemental mercury in selected devices (118,119)

Device	Amount of elemental mercury
Fluorescent light	0.01–0.05 g
High intensity discharge lamp (HID, vapor)	0.02–0.25 g
Fever thermometer	0.5–0.7 g
Flame sensor (gas ranges)	1–2 g
Silent wall light switch (made before 1991)	2 g
Scientific/laboratory thermometer	up to 3 g
Household thermostat	3 g per switch
Electrical (tilt) switch	Small: 3.5 g Industrial: up to 3600 g (8 lbs)
Gas flow regulator (installed before 1961)	100 g
Sphygmomanometer	150 g
Manometer/barometer	100–900 g

mercury, can result in acute lung injury with symptoms of cough, sore throat, shortness of breath, and chest pain. Other symptoms include fever, chills, gastrointestinal complaints, metallic taste, headache, and weakness. Chest radiography can reveal infiltrates or pulmonary edema. Chronic inhalation exposure over weeks to months, at air concentrations below which acute effects are seen, can cause the gradual onset of neurological symptoms. Symptoms include tremor, ataxia, paresthesias, stocking-glove sensory loss, easy blushing, irritability, fatigue, headaches, gingivitis, personality changes, and anorexia. Acrodynia (“pink disease”) is a unique syndrome that can occur in children from chronic inhalation exposure to elemental mercury. It is considered an idiosyncratic hypersensitivity reaction. Clinical manifestations include extremity pain, red face, red hands and feet, skin

rash, gingivitis, tachycardia, hypertension, diaphoresis, photophobia, and irritability (15–23).

Exposure limits for workplace and home set by various agencies are listed in Table 2.

Intended users of this guideline

The intended users of this guideline are personnel in US poison control centers. It was developed for the conditions prevalent in the US. While the toxicity of elemental mercury is not expected to vary in a clinically significant manner in other nations, the out-of-hospital conditions could be much different. Do not extrapolate this guideline to other settings unless it has been determined that the conditions assumed in this guideline are present.

This guideline also provides information for poison center staff members and researchers who wish to further develop the information base available for the development of guidelines for the out-of-hospital management of poisoning.

Objective of this guideline

The objective of this guideline is to assist poison center personnel in the appropriate out-of-hospital triage and initial out-of-hospital management of patients with suspected exposures to small amounts of elemental mercury by: 1) describing the process by which a specialist in poison information should evaluate an exposure to elemental mercury, 2) identifying the key decision elements in managing cases of elemental mercury exposure, 3) providing clear and practical recommendations that reflect the current state of knowledge, and 4) identifying needs for research.

This guideline is based on an assessment of current scientific and clinical information. The expert consensus panel recognizes

Table 2. Reference elemental mercury airborne concentrations*

Airborne concentration (mg/m ³)	Comments	Agency [†]
10	Immediately dangerous to life or health (IDLH) - maximum allowed for 30 min in an emergency	NIOSH
0.1	Legal airborne permissible occupational exposure limit (PEL)	OSHA
0.05	Recommended airborne exposure limit (REL) averaged over a 10-hr work shift	NIOSH
0.025	Recommended airborne exposure limit (threshold limit value, TLV) averaged over an 8-hr work shift	ACGIH
0.003	Recommended concentration after clean-up of commercial environment	ATSDR
0.001	Recommended breathing zone (5 ft from floor) limit in a home after an elemental mercury spill - can re-occupy if less than this concentration	ATSDR
0.0003	An estimate of a continuous inhalation exposure that is likely to be without an appreciable risk of deleterious effects during a lifetime (Reference Concentration, RfC)	US EPA
0.0002	An estimate of the daily human exposure that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure (Minimum Risk Level, MRL)	ATSDR

*Adapted from the Wisconsin Division of Public Health, Department of Health and Family Services, State of Wisconsin. Human Health Hazards. Responding to Mercury Spills: Small Spill Response. Accessed on August 29, 2006 at <<http://dhfs.wisconsin.gov/eh/HlthHaz/pdf/hgtherm.pdf>>.

[†]ACGIH: American Conference of Governmental Industrial Hygienists, ATSDR: Agency for Toxic Substances and Disease Registry, NIOSH: National Institute for Occupational Safety and Health, US EPA: United States Environmental Protection Agency.

that specific patient care decisions may be at variance with this guideline and are the prerogative of the patient and the health professionals providing care, considering all of the circumstances involved. This guideline does not substitute for clinical judgment.

Methodology

The methodology used for the preparation of this guideline was developed after reviewing the key elements of practice guidelines (24,25). An expert consensus panel was established to develop the guideline (Appendix 1). The American Association of Poison Control Centers (AAPCC), the American Academy of Clinical Toxicology (AACT), and the American College of Medical Toxicology (ACMT) appointed members of their organizations to serve as panel members. To serve on the expert consensus panel, an individual had to have an exceptional record in clinical care and scientific research in toxicology, board certification as a clinical or medical toxicologist, significant US poison control center experience, and be an opinion leader with broad esteem. Two specialists in poison information were included as full panel members to provide the viewpoint of the end-users of the guideline.

Search strategy

A single investigator performed literature searches for relevant articles. The National Library of Medicine's PubMed database was searched (through May 2006) using elemental mercury poisoning as a MeSH term, limited to humans. The PubMed database was further searched using mercury as a text word (title, abstract, MeSH term, CAS registry) plus either poison* or overdos* or intox*, or toxic* limited to humans. This process was repeated in International Pharmaceutical Abstracts (1970–May 2006, excluding abstracts of meeting presentations), Science Citation Index (1977–May 2006), Database of Abstracts of Reviews of Effects (accessed May 2006), Cochrane Database of Systematic Reviews (accessed May 2006), and Cochrane Central Register of Controlled Trials (accessed May 2006). Reactions (1980–May 2006), the elemental mercury poisoning management in Poisindex, and the bibliographies of recovered articles were reviewed to identify previously undiscovered articles. Furthermore, NACCT abstracts published in the Journal of Toxicology Clinical Toxicology (1995–2004) and Clinical Toxicology (2005) were reviewed for original human data.

Five major toxicology textbooks were reviewed for recommendations on the management of elemental mercury poisoning and for citations of additional articles with original human data in the chapter bibliographies. The Toxic Exposure Surveillance System (TESS) maintained by the American Association of Poison Control Centers was searched for

deaths resulting from unintentional elemental mercury poisoning. These cases were abstracted for review by panel members. All US poison control centers were surveyed in 2006 to ascertain their out-of-hospital management and triage practices for elemental mercury poisonings.

Criteria used to identify applicable studies

The recovered citations were entered into an EndNote library and duplicate entries were eliminated. The abstracts of these articles were reviewed, searching specifically for those that dealt with estimations of doses with or without subsequent signs or symptoms of toxicity and management techniques that might be suitable for out-of-hospital use (e.g., gastrointestinal decontamination). Articles that did not meet either of the preceding criteria, did not add new data (e.g., some reviews, editorials), or that exclusively described inpatient-only procedures (e.g., dialysis) were excluded.

Data extraction process

A trained physician abstractor reviewed all articles that were retrieved from the original search. The complete paper was reviewed for original human data regarding the toxic effects of elemental mercury or original human data directly relevant to the out-of-hospital management of patients with elemental mercury exposure. Relevant data (e.g., dose, effects, time of onset of effects, therapeutic interventions or decontamination measures provided, efficacy or results of any interventions, and overall patient outcome) were compiled into a table and a brief description of each article was written. This evidence table is available at <http://www.aapcc.org/DiscGuidelines/mercury%20evidence%20table%202006-10-30.pdf>. The table of all abstracted articles was then forwarded to the panel members for review and consideration in developing the guideline. Efforts were made to locate foreign language articles and have their crucial information extracted, translated, and tabulated. The abstractor created and distributed a written summary of the data. All of the abstracted articles were made available on a secure AAPCC website for reading by the panel members.

Criteria used to assign levels of evidence

The articles were assigned level-of-evidence scores based on the Grades of Recommendation table developed by the Centre for Evidence-Based Medicine at Oxford University (Appendix 2). Single case reports and case series were classified as level 4.

Guideline writing and review

The lead author (listed first) prepared a draft guideline. The draft was submitted to the expert consensus panel for

comment. Using a modified Delphi process, comments from the expert consensus panel members were collected, copied into a table of comments, and submitted to the lead author for response. The lead author responded to each comment in the table and, when appropriate, the guideline draft was modified to incorporate changes suggested by the panel. The panel again reviewed the revised guideline draft and, if there was no strong objection by any panelist to any of the changes made by the lead author, the draft was prepared for the external review process. External review of the second draft was conducted by distributing it electronically to AAPCC, AACT, and ACMT members and the secondary review panel. The secondary review panel consisted of representatives from the federal government, public health, emergency services, pediatrics, pharmacy practice, and consumer organizations (Appendix 3). Comments were submitted via a discussion thread on the AAPCC web site or privately through email communication to AAPCC staff. All submitted comments were rendered anonymous, copied into a table of comments, and reviewed by the expert consensus panel and the lead author. The lead author responded to each comment in the table and his responses and subsequent changes in the guideline were reviewed and accepted by the panel.

Evaluation of evidence

Current poison control center practices

The expert consensus panel solicited local referral and management guidelines concerning elemental mercury from all US poison centers in 2006 and received seven documents. Guidance from these seven documents is in Table 3. Eight other centers specifically replied that they did not have guidelines for elemental mercury exposures. The remaining centers did not respond to the request. Review of the submitted guidelines revealed that five of seven centers considered spills from fever thermometers to be potentially toxic and recommended clean-up by the occupants of the area. All but one guideline cautioned against vacuuming elemental mercury. Disposal recommendations varied from double-bagging the elemental mercury and placing it in the outdoor trash to treating it as hazardous waste according to local ordinances. Guidance for if and when the poison center should follow-up with a caller concerning the exposure was absent from all of the guidelines.

In 2002, 70 poison centers were surveyed by telephone concerning their clean-up advice for small elemental mercury spills. No written protocols were available for 36% of the centers. Poison center advice was variable and some poison centers did not caution against vacuuming, aerosolization risk, or disposal hazards (29).

Review of textbooks

Elemental mercury poisoning chapters in five toxicology textbooks were reviewed for information on sources of

elemental mercury poisoning, risks associated with release of elemental mercury from devices such as thermometers, and clean-up and disposal recommendations (27–31). Two chapters listed thermometers as potential sources of elemental mercury but did not comment on the risk of toxicity if broken and spilled in a home (30,31). Only one chapter supplied clean-up recommendations and suggested the use of an elemental mercury decontamination kit, removal of contaminated absorbent surfaces (e.g., carpets) from the area, and cautioned against vacuuming spilled elemental mercury (30). Two chapters listed selected agency recommendations for airborne exposure limits (28,31), but none of the chapters suggested the amount of elemental mercury that would be required to attain such concentrations in a closed space.

Review of Poisindex

Poisindex, a computerized toxicology reference used by poison control centers, cited cases of elemental mercury poisoning associated with exposures to broken mercury thermometers in homes. It also recommended a clean-up procedure for small spills, specifically those associated with broken thermometers. It described the use of granular zinc or powdered sulfur as an absorbent then vacuuming the mixture. It cautioned against using a household vacuum alone. It did not detail the disposal method or whether spilled elemental mercury should be treated as hazardous waste (32).

Review of TESS mortality data

Three deaths were identified in the American Association of Poison Control Centers' Toxic Exposure Surveillance System (TESS) database associated with exposure to elemental mercury from 2000 to 2005. One case was determined to be unrelated to elemental mercury. One adult patient died after heating a gold-mercury amalgam in an enclosed space, and a 72-year-old patient developed dementia after chronic inhalation of elemental mercury and died after developing pneumonia. The source of the elemental mercury was not reported in the latter case. No deaths were reported from mercury thermometer exposure (personal communication, M. Lai, AAPCC, 2006).

Review of the literature

Most of the evidence consisted of case reports and case series of individuals with acute and/or chronic elemental mercury toxicity. The majority of reported cases were inhalations, but there were also a number of articles describing gastrointestinal, subcutaneous, and other types of exposures. Data on the exposure amount and air concentrations of elemental mercury resulting in clinical effects are summarized below and in Tables 4–7. The data are divided into the following categories: spill investigations, routes of exposure, environmental risk factors for increased exposure (e.g., heating, vacuuming),

Table 3. Summary of individual US poison control center guidelines, 2006

Poison control center	Fever thermometer	Rec. small spill clean-up by occupant	Rec. use of "spill kit" or sulfur powder	Rec. professional clean-up	Cautions against vacuuming	Rec. Hg environmental testing	Rec. blood or urine mercury testing	Disposal instructions	Clean-up referred to EPA, Health Dept.	Rec. follow-up call
1	No	Yes	No	No	Yes	No	No	Minimal; dispose of in well ventilated areas.	No	No
2	Yes	Yes	Yes	Yes, if spilled near heat source, air vent or vacuumed	Yes	Only if spill has been vacuumed	No	Hazardous waste	Yes	No
3	Yes	Yes	No	No	No	Special circumstances only	No	Hazardous waste	Yes	No
4	"Not likely"	Yes (<10 g)	Yes	Yes, if widespread or on carpet	Yes	No	Consider	Recycle center	Yes	No
5	Yes	Yes	Yes	Yes, if more than thermometer	Yes	Yes, for large spills	Consider for large spills	Hazardous waste	Yes, large spills	No
6	Implied yes	Yes, hard surfaces only	No	Yes, for spills on carpet	Yes	No	No	Double bag and place in outdoor trash	Yes	No
7	Yes	Yes	Yes	No	Yes, unless using binding agent (sulfur)	No	No	Hazardous waste	No	No

Table 4. Gastrointestinal mercury exposures with toxic effects and quantifiable exposure amounts

Approx. amount	Age	Mitigating circumstances	Effect severity*	Onset	Elevated urine and/or blood mercury [†]	Reference (LOE)
~3 mL	39 yr	Peritoneal deposition of elemental mercury	Death	~23 d	Yes	38 (4)
Up to 10 mL	68 yr	Peritoneal deposition of elemental mercury	Mod	NR	Yes	40 (6)
40 mL	26 yr	NR	Mild (local)	<4 hr	NR	42 (4)
60 mL	45 yr	Peritoneal spillage of mercury; also aspirated ingested mercury	Mod	NR	Yes	41 (6)
80 mL	25 yr	NT	? Mild (local)	NT	NR	43 (4)
220 mL (2 kg)	42 yr	Potential chronic occupational exposure; history of tremors, forgetfulness, fatigue, irritability; diabetes	Mod	NR	Yes	39 (4)

*Mild=effects not requiring chelation or hospital admission; Mod=effects necessitating chelation and/or hospitalization; Severe=life-threatening effects (e.g., seizures, respiratory depression, coma, hypotension); Local=GI effects (e.g., nausea, vomiting, diarrhea, abdominal pain) after ingestion or dermal effects (e.g., wound, swelling, erythema) after subcutaneous exposure.

[†]Urine mercury ≥ 10 $\mu\text{g/L}$; blood mercury ≥ 10 $\mu\text{g/L}$; 24-hr urine mercury ≥ 15 μg (concentrations during chelation or after chelation challenge not considered). NR: not reported.

NT: not fully translated.

Table 5. Soft tissue mercury exposures with toxic effects and quantifiable exposure amounts

Approx. amount	Age	Mitigating circumstances	Effect severity*	Onset	Elevated urine and/or blood mercury [†]	Reference (LOE)
Thermometer	15 yr	NR	Mod (local)	Over 2 d	NR	53 (4)
Thermometer	13 yr	NR	Mild (local)	2 yr	NR	52 (4)
Thermometer	11 yr	NR	Mod (local)	Over days	NR	54 (4)
Thermometer	2 yr	NR	Mod (local)	Over days	Yes	55 (4)

*Mild=effects not requiring chelation or hospital admission; Mod=effects necessitating chelation and/or hospitalization; Severe=life threatening effects (e.g., seizures, respiratory depression, coma, hypotension); Local=GI effects (e.g., nausea, vomiting, diarrhea, abdominal pain) after ingestion or dermal effects (e.g., wound, swelling, erythema) after subcutaneous exposure.

[†]Urine mercury ≥ 10 $\mu\text{g/L}$; blood mercury ≥ 10 $\mu\text{g/L}$; 24-hr urine mercury ≥ 15 μg (concentrations during chelation or after chelation challenge not considered). NR: not reported.

and time to onset of toxicity. Mild adverse or toxic effects are defined as those that did not require chelation or hospital admission, moderate effects are defined as those that required chelation or admission to a hospital; and severe effects are those that were life-threatening (e.g., coma, seizures, respiratory distress, hypotension, dysrhythmias). In some cases, assigning a severity level of effect required the subjective medical judgment of the reviewer.

Small spill investigations

The literature was evaluated in order to determine if a small spill of elemental mercury is a potential threat to human health.

A small amount of elemental mercury (0.15 g) was placed on a carpet in a small chamber (71.5×56×37 cm) and heated

to 30°C. The airborne concentrations were measured 30 cm from the carpet surface and were 5, 6.3, 8.1, and 10 mg/m³ at 20, 40, 60, and 80 minutes after the spill, respectively (33).

In one report, an author investigated an elemental mercury spill in his own home. A “clinical thermometer” was broken on a vinyl-tiled kitchen floor with spillage of elemental mercury. He gathered the visible mercury beads with a postcard into one large globule and removed it from the house. Since it was winter, all windows were closed and the house was heated. Airborne elemental mercury concentrations were measured in all rooms of the house “at face level” later the same day and 7 days, 14 days, and 3 weeks after the spill. On the day of the spill, mercury vapor was detected throughout the house and the highest face-level concentration was 0.025 mg/m³ in the “landing.” However, readings from the hall carpet, which was close to the kitchen door, were much higher at 0.14 mg/m³. This was presumably from cross contamination

Table 6. Inhalational mercury exposures with toxic effects and quantitative air levels reported

Maximum air concentration (mg/m ³)*	Approx. maximum exposure duration	Mitigating circumstances	No. with clinical effects	Effect severity [†]	No. symptomatic with elevated urine and/or blood mercury [‡]	Age	Reference (LOE)
0.0042	NR	Vacuumed	3	Mod	3	2–6 yr	64 (4)
0.0045	2 d	Also ingested mercury	1	Mild/Mod	1	2 yr	57 (4)
0.01	NR	NR	NR	Mild	NR	NR	57 (2b)
0.0238	NT	Heated	2	Mod	2	22 & 28 yr	65 (4)
0.04	NR	NR	2	Mod	NR	NR	8 (4)
0.03–0.7 (data from three incidents combined)	NR	No symptomatic patients had elevated blood conc.	98	Mild	NR	NR	6 (2b)
0.05	NR	Vacuumed	1	Mod	1	8 yr	15 (4)
>0.05	15 mo	NR	Several	Mod	Several	13 yr & NR	62 (4)
0.054	5 mo	NR	1	Mild/Mod	1	23 mo	77 (4)
0.06	17 wk	NR	1	Mod	1	3 yr	76 (4)
0.075	NR	NR	10	Mild	10	NR	59 (2b)
0.075	2 mo	Vacuumed	3	Mod	3	14–41 yr	71 (4)
0.078	6 wk	Vacuumed	2	Mild	2	9 & 35 yr	69 (4)
0.1–1	4 mo	Vacuumed	1	Mod	1	14 yr	78 (4)
0.14	3 mo	NR	3	Mod–Severe	3	10–17 yr	5 (4)
0.14	1–2 mo	Vacuumed	3	Mod–Severe	3	NR	68 (4)
0.15	1 wk	NR	Several	Mild	7	NR	7 (2b)
0.15–1	51–176 d	Vacuumed	8–12	Mild	11	12 yr, 14 yr, & NR	58 (2b)
0.193	NR	Gold extraction (heated)	8	Mod–Death	8	45 d–58 yr	75 (4)
0.4	3 mo	NR	2	Mod	2	11 & 15 yr	61 (4)
0.5	3–6 hr weekly × <1 yr	NR	2	Mild	2	17 & 37 yr	70 (4)
0.6	45 min	Heated; underlying occupational exposure	1	Mod	NR	50 yr	73 (4)
>0.7 (with oven on)	NR	Heated	1	Mod	NR	27 yr	66 (4)
0.786	NR	Heated	4	Death	4	40–88 yr	8 (4)
0.999	>3 d	Heated	2	Mild–Mod	1	NR	74 (4)
>1	NR	Vacuumed	2	Mod–Severe	2	4–11 yr	67 (4)
1.08	2½ mo	NR	10–11	Mild–Mod	4–11	13 yr & 6–18 yr	60 (4)
8	NR	NR	1	Mild	1	NR	82 (4)

*Breathing space measurements quoted whenever noted in article.

[†]Mild=effects not requiring chelation or hospital admission; Mod=effects necessitating chelation and/or hospitalization; Severe=life-threatening effects (e.g., seizures, respiratory depression, coma, hypotension).

[‡]Urine mercury ≥10 µg/L; blood mercury ≥10 µg/L; 24-hr urine mercury ≥15 µg (concentrations during chelation or after chelation challenge not considered).

NR: Not reported.

NT: Not fully translated.

from foot traffic. Mercury vapor was not detected in the home 3 weeks after the spill (34).

One author measured air concentrations of elemental mercury in three examination rooms of a physician's office where a "mercury thermometer was broken in the past." The

concentrations ranged from 0.0045 to 0.0057 mg/m³ (35). The airborne elemental mercury concentrations found in these articles exceeded the recommended concentration after clean-up of a commercial environment by the Agency for Toxic Substances and Disease Registry (36) (Table 2).

Table 7. Inhalational mercury exposures with toxic effects and exposure amounts reported (quantified or semi-quantified)

Approx. amount	Approx. maximum exposure duration [§]	Mitigating circumstances	No. with clinical effects	Effect severity*	No. symptomatic with elevated urine and/or blood mercury [†]	Age	Reference (LOE)
Thermometer	2–8 wk	Carpet	2	Mild–Mod	1	11 mo & 6 yr	23 (4)
Thermometer	3 mo	NR	1	Mod	1	28 mo	16 (4)
Thermometer	4 mo	Carpet, vacuumed	1	Mod	1	11 mo	18 (4)
Thermometer	8–9 mo	Carpet, floor heating	3	Mod	1	20 mo–6 yr	84 (4)
Thermometer	NT	NT	2	Mild	NT	NT	85 (4)
Thermometer	NT	Carpet	1	Mod	1 (with captopril)	32 mo	79 (4)
Thermometer	NR	NR	1–5	Mod	1–5	≥3 yr	21 (4)
Thermometer	NR	Heated	1	Mod	NR	27 yr	66 (4)
1.1 g (from a broken thermometer)	18 hr	Heated	3	Mod–Death	3	37–77 yr	80 (4)
10 g	NR	Heated	4	Mild–Death	NR	≥1 yr	83 (4)
2.5–5 mL	4 mo	Carpet, vacuumed	1	Mod	1	14 yr	78 (4)
5 mL	2 wk	Carpet	1	Mod	1	20 mo	22 (6)
>1–2 tsp	6 wk	Vacuumed	2	Mild	2	9 & 35 yr	69 (4)
0.5–1 oz	NR	Vacuumed?	2	Mod–Severe	2	4–11 yr	67 (4)
0.5 lb	45 min	Heated; underlying occupational exposure	1	Mod	NR	50 yr	73 (4)
20 cm ³	NR	Carpet	2	Mod	NR	NR	8 (4)
<1 oz	NR	NR	1	Mild	1	NR	72 (4)
<30 mL (data from three incidents combined)	NR	No symptomatic patients had confirmed elevated blood conc.	98	Mild	NR	NR	6 (2b)
1 lb	3 mo	NR	3	Mod–Severe	3	NR	5 (4)
1 lb	1–2 mo	Vacuumed	3	Mod–Severe	3	NR	68 (4)
0.9 kg	1 wk	NR	Several	Mild	7	NR	7 (2b)
2.3 kg	4 wk	Vacuumed	3	Mod	3	≥3½ yr	82 (4)
250 mL	2 mo	Vacuumed	3	Mod	3	14–41 yr	71 (4)
300 mL	51–176 d	Vacuumed	8–12	Mild	11	12 yr, 14 yr, & NR	58 (2b)
40 lb	>3 d	Heated	2	Mild–Mod	1	NR	74 (4)
Up to 5–10 L (70–100 kg)	NR	Vacuumed (in some households)	13	Mild–Mod	13	One <6 yr, others >6 yr	81 (4)

*Mild=effects not requiring chelation or hospital admission; Mod=effects necessitating chelation and/or hospitalization; Severe=life-threatening effects (e.g., seizures, respiratory depression, coma, hypotension).

[†]Urine mercury ≥10 µg/L; blood mercury ≥10 µg/L; 24-hr urine mercury ≥15 µg (concentrations during chelation or after chelation challenge not considered).

NR: Not reported.

NT: Not fully translated.

The Illinois Department of Public Health did not find air elemental mercury concentrations greater than 0.001 mg/m³ in response to investigations of seven small mercury spills from broken thermometers or thermostats. Investigations that were described included a thermometer that was dropped down a heating duct with airborne mercury measured at less

than 0.001 mg/m³. A measurement directly above a bead of elemental mercury from a broken thermostat found an airborne concentration of slightly more than 0.001 mg/m³ but it was less than 0.001 mg/m³ “a few feet away.” Thus, the author recommended that air monitoring is not needed for broken thermometer or thermostat mercury spills (5).

An investigation by the Connecticut Department of Public Health suggested that clean-up procedures for small amounts of elemental mercury spilled on hard, intact surfaces are successful in reducing mercury air concentrations. A volume of 0.05 mL of elemental mercury was dropped from a height of 36 inches onto various surfaces in an enclosed, non-ventilated, 640 cubic foot room. This was meant to approximate the amount of mercury contained in a fever thermometer, but a larger estimated amount has been reported (0.1 mL) (11,37). The ambient air temperature ranged from 66 to 90°F on various days of the experiment. Air concentrations of mercury were measured at several distances from the spill and at six different times up to 24 hours after the spill. Air concentrations were measured again after spill clean-up, which utilized an eyedropper, duct tape, and cardboard. Measurable air concentrations were noted immediately after the spill and during clean-up and were reduced to less than 0.005 mg/m³ after clean-up. They were unable to adequately clean porous surfaces such as carpet and upholstery (personal communication, A. Bracker et al., August 2006).

Routes of exposure

Gastrointestinal/ingestion

Large amounts of elemental mercury (e.g., 15 mL, 204 g) have been ingested without adverse clinical effect (11). However, there were six articles (level 4 or 6 case reports) in which quantifiable doses of elemental mercury resulted in toxicity from the gastrointestinal route (Table 4) (38–43).

In one case, a Miller-Abbott tube containing elemental mercury ruptured and spilled mercury into the peritoneum postoperatively. The patient developed symptoms of toxicity and died (38). A similar scenario occurred in another case in which up to 10 mL of elemental mercury from a ruptured Cantor tube spilled into the patient's peritoneal cavity after a surgical procedure, resulting in moderate effects (40). In a third case, systemic symptoms developed after an appendectomy and elemental mercury spilled in the peritoneum (41).

In the other four cases, amounts, ranging from 40 to 220 mL were ingested intentionally. In two of these cases, the resulting clinical effects appeared to be mild and primarily local (e.g., abdominal discomfort, vomiting, diarrhea) (42,43). Urine mercury concentrations did not rise in one case and were not reported in the other. A man developed symptoms consistent with moderate toxicity, along with elevated blood and urine mercury concentrations, after ingesting 220 mL of elemental mercury but he also had a history of prior occupational exposure to elemental mercury with symptoms of toxicity appearing to pre-date his ingestion (39). Ingestion of elemental mercury has resulted in sequestration in the appendix (11,44–46), one of which resulted in appendicitis (47).

There were case reports of individuals who ingested mercury from broken thermometers but did not develop subsequent toxicity or elevated mercury concentrations. However, in some cases prophylactic decontamination measures (e.g.,

laxatives, appendectomy) were performed (47–49). In addition, there was a letter reporting one poison center's experience over 10 years in which there were no cases of toxicity after ingestions of mercury from broken thermometers, despite 20–25 calls per year (50). There was one report of a patient who ingested mercury from a thermometer and subsequently had elevated urine mercury concentrations, but this patient did not develop symptoms (51). In another case, a 21-month-old girl ingested mercury after biting a thermometer. Elemental mercury accumulated in her appendix, and an prophylactic appendectomy was performed (47). The articles with quantifiable gastrointestinal exposure information are summarized in Table 4.

Soft tissue injection (unintentional)

Intentional injections of elemental mercury were not reviewed for this guideline. There were four articles in which quantifiable amounts of elemental mercury resulted in toxicity after unintentional soft tissue exposure, all of which were level 4 case reports. All four cases resulted from subcutaneous elemental mercury deposition from broken mercury thermometers. Symptoms remained local in all four patients (e.g., swelling, erythema, impaired wound healing, ulceration, abscess, granuloma) (52–55). In one case, blood and urine mercury concentrations were slightly elevated at 103 and 1560 µg/L, respectively (55). These exposures are summarized in Table 5.

Dermal

Allergic contact dermatitis from handling metallic mercury is reported but this appears to be a rare event (14,56).

Pulmonary/inhalation

Most clinically important exposures to small elemental mercury spills occurred via inhalation and the remainder of the evidence review is dedicated to this route. Because of the limitations in using either estimated exposure amounts or measured air mercury concentrations, the data for both are summarized here.

There were several articles with retrospective data on air concentrations associated with clinical effects, ranging from cohort studies to case reports and case series. Specifically, there were five level 2b articles (6,7,57–59) and 22 level 4 articles (5,8,15,60–78). The lowest air mercury concentration associated with clinical effects was 0.0042 mg/m³. In this instance, three children, aged 2–6 years, developed symptoms of moderate toxicity (e.g., acrodynia, weight loss, asthenia) after an exposure of unspecified duration (64). In another report, a 2-year-old child developed “violent behavior” after approximately 2 days of inhalational exposure with air mercury concentrations later measured at 0.0045 mg/m³. His blood mercury concentration was 10 µg/L (63).

A study of 1,363 homes in one metropolitan area looked for elemental mercury contamination following replacement of

gas regulators by various contracting companies. Urine mercury screening was offered to residents who believed that they might have been exposed. Positive urine bioassays were more strongly associated with maximum air mercury concentrations greater than 0.01 mg/m^3 on the first floors of the homes. However, symptoms were not reported for individuals in the affected homes (69). Another study suggested that higher air mercury concentrations correlated with higher urine mercury concentrations among chronically exposed individuals but did not suggest a threshold concentration. This study compared urine mercury concentrations and home air mercury concentrations in 23 children of elemental mercury workers to those in 39 children randomly selected from non-workers' households. The median mercury concentration among workers' children was higher than in non-workers' children (25 versus $5 \text{ }\mu\text{g/L}$), and the median air mercury concentration was also higher in workers' homes (0.00024 versus 0.00005 mg/m^3) with air concentrations as high as 0.01 mg/m^3 . However, symptoms, neurological findings, and urine protein measurements did not differ between the groups (57).

As noted previously, using peak air concentrations to estimate a patient's mercury exposure can be problematic. The actual concentration might have been higher or lower than the measured amount, and a number of other factors affect the amount of elemental mercury a patient absorbed (e.g., duration of exposure, minute ventilation). Therefore, such measurements represent rough estimates of potential exposure. Articles with specific air concentration/clinical effect information are summarized in Table 6.

There were three level 2b articles (6,7,58) and 22 level 4 articles (5,8,16,18,21,23,66–69,71–74,78–85) with data on spill amounts associated with clinical effects. The smallest well-quantified amount of elemental mercury associated with clinical effects was 1.1 g from a broken thermometer. In this instance, the elemental mercury was heated and, within 3 hours, three patients developed symptoms of toxicity, two of whom died (80). There were eight articles in which broken thermometers were reported to result in toxicity, but none of them listed the thermometer size or elemental mercury content. These articles described 16 patients (aged 11 months to 27 years) who developed symptoms (16,18,21,23,66,79,84,85). The exposure duration ranged from 2 to 9 months in four articles. In three articles, some heating or vacuuming of the elemental mercury occurred but, in the other articles, such mitigating circumstances were either not reported or not apparent from the translations. Five cases of elemental mercury poisoning in two families were reported from exposure to small amounts of mercury in their homes. Four of the patients were children, aged 3–6 years, with signs of acrodynia and documented elevated urinary mercury concentrations ($300\text{--}600 \text{ }\mu\text{g/L}$). The source of the mercury was a "broken medical thermometer" for one family and "small quantities" of elemental mercury brought home from the workplace in the other family. Air concentrations of mercury were not reported (21). A 28-month-old boy presented with symptoms consistent with acrodynia (irritability,

pain when walking, excessive sweating, rash) of 3 months duration and an elevated urine mercury concentration ($19.6 \text{ }\mu\text{g/L}$). His 17-month-old sister also had elevated urine mercury ($43.5 \text{ }\mu\text{g/L}$) but was asymptomatic. The mother recalled breaking a thermometer (type not reported) in the kitchen 3 months earlier "just before" the development of symptoms in her son (16). A 32-month-old girl developed signs and symptoms of acrodynia over a 15-day period. Her 5½-year-old sister, who slept in the same bedroom, was asymptomatic. The source of the mercury was a broken thermometer with spillage of the elemental mercury onto the carpet of the children's bedroom (79). An 11-month-old girl and her 6-year-old sister developed symptoms consistent with elemental mercury poisoning approximately 2 weeks after mercury from a broken thermometer contaminated the carpet of their bedroom. Elevated urine and hair mercury concentrations were detected in the younger child, and she was diagnosed with acrodynia (23). Three children, (aged 33 months, 20 months, and 6 years) were diagnosed with acrodynia 8 months after a thermometer had broken on the carpeted floor of their bedroom (84). All of the articles with specific dose/toxicity information are summarized in Table 7.

Environmental risk factors for elemental mercury poisoning

Heating elemental mercury

The vapor pressure of elemental mercury increases with temperature. The fact that heating elemental mercury can produce life-threatening air concentrations is demonstrated by the following cases in the literature. Two adults developed acute pneumonitis and died after heating elemental mercury from a broken thermometer (estimated 1.1 g) in their home (80). A 5-month-old girl developed acute chemical pneumonitis several hours after her father heated an elemental mercury and gold mixture at home (86). A 7-month-old girl died from respiratory failure after exposure to elemental mercury vapor from heated elemental mercury in her home (87). An 8-month-old girl developed acute severe pneumonitis and systemic toxicity after an unknown amount of elemental mercury was heated on the kitchen stove the previous evening (88). A family of four died from respiratory failure after heating elemental mercury dental amalgam in an attempt to extract silver (89). A 14-year-old boy and his parents developed symptoms of elemental mercury toxicity with elevated blood and urine mercury concentrations after the boy poured an unknown amount of elemental mercury into a portable electric coil heater. Air concentrations in the home were not reported (20). Acute elemental mercury poisoning and two deaths occurred among several adults and children after exposure to vapors from heating liquid mercury and gold ore in an open pan on a kitchen stove. The elemental mercury vapor concentration in one household was 0.193 mg/m^3 at an unknown time after exposure (75,91). Four adults died of

elemental mercury poisoning associated with smelting dental amalgam in a casting furnace in the basement (8).

Vacuuming elemental mercury

This method of clean-up resulted in increased urine mercury concentrations in people using vacuum cleaners and in those located in close proximity to the vacuumed area in a dental office environment (91,92). Vacuum cleaners continued to release high concentrations of elemental mercury vapor, even after changing the collection bag, due to contamination of the motor housing (91). A 14-year-old boy spilled approximately 5 mL of elemental mercury onto a carpet, collected about half of it, and then vacuumed the rest. He used the same vacuum cleaner every 2–3 weeks during the following 3 months. Four months after the spill, he was hospitalized with elemental mercury poisoning (serum mercury 37.3 $\mu\text{g/L}$, urine mercury 796 $\mu\text{g/L}$). An environmental assessment of the house revealed mercury vapor in the vacuum cleaner of more than 1 mg/m^3 and near his bed and carpet area of 0.1–0.7 mg/m^3 (78). A 9-year-old boy developed elemental mercury poisoning (serum mercury 200 $\mu\text{g/L}$, normal less than 6 $\mu\text{g/L}$) after an unknown amount of elemental mercury from a sphygmomanometer was spilled on his bed and carpet and was vacuumed by his mother 2 days later. Environmental assessment found “very high” airborne mercury concentration in his bedroom (93). A 3-year-old boy was diagnosed with acrodynia, and his parents and two siblings were also found to have elevated urine mercury concentrations. Evaluation of his home revealed elevated elemental mercury concentrations in the vacuum cleaner hose (3020 and 5984 $\mu\text{g/g}$ dust), near the carpet of the children’s rooms (0.00425 mg/m^3), and the garage floor. The original source was not identified, but use of a vacuum cleaner was thought to have facilitated the spread of the elemental mercury in this household and to have contributed to all family members being exposed to mercury (64). An 11-month-old boy was diagnosed with acrodynia approximately 6 weeks after a thermometer was broken and spilled mercury onto the living room carpet in his home. The carpet was vacuum cleaned only; mercury vapor concentrations were not reported (18). A 23-month-old boy was diagnosed with acrodynia approximately 5 months after a “carton of 8-ft fluorescent bulbs” was broken in a potting shed adjacent to his nursery. The glass was cleaned up, but the child often played in the area. Air concentrations in the child’s bedroom and household vacuum cleaner were 0.005–0.011 mg/m^3 and 0.062 mg/m^3 , respectively. An evaluation by the health department found no evidence of elemental mercury in the home. As part of the investigation, a fluorescent bulb was broken inside a plastic bag and the mercury vapor concentrations reached 0.592 mg/m^3 (77).

Onset of effects

It was difficult to assess the precise duration of exposure and onset of effects in many of the reported cases. Most cases

appeared to be the result of exposures lasting more than 1 day (5–8,15,16,18–21,23,57–64,67–72,74,76–78,81,82,84,85,93–105). In general, the clinical effects associated with these relatively low-level, longer duration exposures tended to be less severe and slower in onset compared to high-dose exposures.

Clinical effects often developed within minutes or hours following high intensity inhalational exposures (e.g., from heating elemental mercury) and rapidly became severe (65,66,73,75,80,83,86,88–90,106–110). For example, inhalation of vapors from heated elemental mercury in a home resulted in the onset of symptoms within 3 hours of exposure in three adults (80). In such high-intensity exposures, respiratory effects (e.g., pneumonitis, pulmonary edema, pneumothorax, respiratory failure) predominated and appeared to be more frequent than with chronic exposures. However, neurological, gastrointestinal, dermatological, and constitutional effects of varying severity were also reported in many instances.

Exposure during pregnancy

There were no reported cases of fetal toxicity from maternal exposure to elemental mercury in a home. There were two case reports (level 4) of inhalation exposure with normal pregnancies and full-term infants. A 19-year-old-woman delivered a normal-term infant 26 days after acute exposure to mercury vapor in her home after a tablespoonful of a mercury-gold amalgam was heated in the kitchen. She developed nausea, vomiting, and dyspnea 8 hours after exposure and was chelated with penicillamine for 8 days. Her blood mercury was 26 $\mu\text{g/dL}$ the day of exposure and 3.8 $\mu\text{g/dL}$ 25 days after exposure. The infant’s blood mercury was 3 $\mu\text{g/dL}$ at birth (111). A 29-year-old-woman was chronically exposed to mercury vapor in her home during the first 17 weeks of gestation from mercury previously spilled on the carpet. The exposure was discovered because her 3-year-old son became symptomatic with anorexia, irritability, and myalgias. Airborne mercury concentrations in the home ranged from 20 to 60 $\mu\text{g/m}^3$. She was asymptomatic with a 24-hour urine mercury of 230 $\mu\text{g/L}$. She delivered a normal-term infant who had elevated neonatal hair total mercury (3 ng/g). The child had a normal exam at 2 years of age (76). An asymptomatic woman working in a mercury thermometer plant had elevated urine inorganic mercury (875 $\mu\text{g/L}$) discovered during routine screening. She was 15 weeks pregnant and delivered a “viable male infant” (112).

An epidemiologic study of women working in dental surgery in Poland (scalp hair mercury 0.51 mg/kg) had an increased risk (24% versus 11%) of “adverse” pregnancy outcomes compared to control women (scalp hair mercury 0.1 mg/kg) (113).

Potential out-of-hospital management

Decontamination measures

There were no controlled studies examining the efficacy of any elemental mercury decontamination measures for

exposed patients. For ingestion, a number of case reports and case series reported the use of such decontamination measures as activated charcoal, lavage, whole bowel irrigation, cathartics, laxatives, and surgical decontamination in individual patients but, given the uncontrolled nature of the data, their efficacy could not be determined. Studies evaluating the ability of activated charcoal to bind elemental mercury were not identified. In the case of dermal exposure, NIOSH recommends washing the skin with soap and water (114).

Government and public health agencies have published guidelines for decontamination of the environment. First responders, rescuers, and bystanders are not at risk for secondary contamination from victims exposed to mercury vapors. Cross-contamination of rescuers or the environment can occur from elemental mercury on a victim's skin or clothing. Remove and double bag all contaminated items including clothing, porous furniture, carpets, rugs, vacuums, and furnace filters (36).

Treatment measures

There were no controlled studies examining the efficacy of any treatment measures for elemental mercury toxicity. A number of case reports and case series reported the use of such specific treatments as chelation (e.g., dimercaprol, succimer, unithiol, penicillamine) or nonspecific supportive measures such as antibiotics, antihypertensives, and fluids but, given the uncontrolled nature of the data, their efficacy could not be determined.

Type of healthcare facility and mode of travel

There were no studies that addressed the type of healthcare facility or mode of transportation needed for management of elemental mercury exposures.

Clean-up measures

There were no studies identified by the literature search that examined the effectiveness of clean-up measures for small spills of elemental mercury. Unpublished investigations by the Connecticut Department of Health suggested that clean-up procedures for small spills are effective in reducing airborne mercury concentrations (personal communication, A. Bracker et al., August 2006). The expert consensus panel felt that some guidance on this topic was appropriate because poison centers encounter this question.

The Illinois Department of Public Health considers any spill larger than a broken thermometer or thermostat as a "large spill" and advises that clean-up should be performed by a professional company, state health department, or the US Environmental Protection Agency (EPA) (5).

The EPA recommends three procedures depending on the amount of elemental mercury spilled (115). Spills less than or equal to the amount in a mercury fever thermometer can be cleaned up by the public. Detailed instructions and checklist of items needed to perform the clean-up are available on the

EPA website. General principles for small spill clean-up include: do not allow children to have access to the contaminated areas; elemental mercury is easily removed from wood, tile, linoleum, or similar hard surfaces by using cardboard and eyedroppers; and the use of commercially available powdered sulfur to absorb elemental mercury is optional. The EPA has issued the following general precautions about cleaning spills to avoid spreading the contamination.

1. Do not use a household vacuum cleaner or a broom to clean up elemental mercury.
2. Do not pour elemental mercury down a drain.
3. Do not wash elemental mercury-contaminated items in a washing machine.
4. Do not walk around if shoes might be contaminated. Remove shoes and place them in a sealed plastic bag.

After cleaning, remove all contaminated item(s) with porous surfaces (e.g., carpet, curtains, upholstery); only the affected portion of a carpet needs to be removed. Place the contaminated items in sealed and labeled plastic bags. Consult the local municipal waste authority, health department, or fire department for proper disposal instructions. Disposal should comply with local, state, and federal laws. The area should be ventilated to the outside after clean-up for at least 24 hours (open windows and use supplementary fans to ventilate). Occupants should leave after turning off any central heating, cooling, or ventilation system and closing the door of the affected area.

For a spill amount greater than a fever thermometer but less than 2 tablespoonfuls (less than 1 pound), isolate the area, open windows, turn down thermostat, and contact the local or state health department or state environmental agency.

If the spill is greater than 2 tablespoonfuls (1 pound), follow the recommendations for a spill greater than a thermometer. In addition, it is mandatory to call the National Response Center (NRC) at 800-424-8802 (24 hours/day).

Disposal of thermometers

Advice to the public from local and state health officials on how to dispose of a mercury fever thermometer has been variable, ranging from throwing it in the trash to taking it to a specific site for hazardous waste disposal (116).

Elemental mercury can be recycled. Low-level elemental mercury contaminated household items can be transported as non-hazardous waste to a hazardous or special waste landfill (117).

Limitations of the literature

The elemental mercury literature suffered from many potential limitations that could affect the interpretation of

the data for this guideline. Most of the data were retrospective and estimates of spill or exposure amount, exposure duration, and the nature or onset of symptoms were usually based on patient or family recall, often several weeks or months after the exposure originally occurred. Exposure might have occurred by more than one route (e.g. dermal, ingestion, inhalational) in a given individual, but the extent to which each occurred was generally not reported or might not have been known. The local environmental conditions (e.g., location, temperature, ventilation, vacuuming, heating) were not often reported with inhalational exposures. Many of these factors can have a critical impact on the amount of mercury inhaled and resulting toxicity.

Air mercury measurements can help circumvent some of the limitations in using quantitative assessments of exposure amounts. However, they have their own limitations as potential estimates of cumulative or peak exposure. Air measurements represent only one point in time and space and can fluctuate depending on a number of factors (e.g., higher concentrations generally associated with higher temperatures, poorer ventilation, and vacuuming). Thus, their interpretation depends on environmental context, which was often not reported. In many instances, it was not clear when the airborne mercury measurements were made in relation to the spill/exposure, where in spatial proximity to the exposure the air samples were obtained, or whether samples were taken at the breathing space or surface level. Breathing space concentrations are typically much lower than corresponding measurements taken directly above an elemental mercury spill or contaminated object. In addition, abatement measurements were frequently performed after peak exposure and might have underestimated the actual concentration at the time of exposure. In some cases, air mercury concentrations were reported but not exposure amounts or vice versa.

Individuals can differ in their responses to similar exposures because of inter-individual differences in minute ventilation, toxicokinetics, or toxicodynamics. Such potential differences make comparing the data between patients, or extrapolating it to the broader population, difficult. The symptoms of mild mercury poisoning are nonspecific and its diagnosis might be under-reported in the literature. Urine and blood mercury concentrations are limited in their ability to confirm or rule out a significant exposure. Depending on the circumstances (e.g., the acuity of exposure, timing of measurements, laboratory performance), urine or blood concentrations might not reflect the actual exposure. In some cases, background occupational exposure might have been present and could have contributed to a patient's reported symptoms or biological mercury measurements.

In cases describing mercury spills from broken thermometers, the thermometer size, or volume of mercury was generally not reported. Different thermometers contain different amounts of mercury.

In the few large cases series included in the evidence table, elemental mercury exposure amounts, air concentrations, and frequency or severity of subsequent effects were often reported as a ranges, percentages or mean values, so that individual doses resulting in specific effects could not be distinguished.

In several instances, the quality of data might have been lower than implied by the level of evidence score. For example, an article classified as level 2b could have been a cohort analysis of the relationship between urine mercury concentrations and symptom severity, but the quality of data relating to the more pertinent relationship of exposure amount or air level vs. symptom severity might have been only a level 4. Most studies reviewed were not designed to specifically assess a toxic exposure threshold (i.e., the relationship between air concentration or spill amount and clinical effects), yet this was a primary question that the guideline panel sought to answer from the review of the literature.

The number of articles reporting gastrointestinal or subcutaneous exposures was limited. This could be the result of the infrequency of such exposures, an inherent lack of toxicity by these routes, poor recognition of such cases, or simply a lack of reporting. It was difficult to draw robust conclusions from these data.

Conclusions

Key decision points for triage

The expert consensus panel determined that certain variables were important to assess in order to make a sound triage decision for a patient with elemental mercury exposure. These variables are the patient's intent, age, route of exposure, presence of symptoms, time of exposure, duration of exposure, intentional heating of elemental mercury, location and ventilation of space contaminated with elemental mercury, the amount of elemental mercury spilled, and clean-up procedures initiated prior to contact with the poison center. The expert consensus panel agreed that in each case, the judgment of the specialist in poison information, the poison center medical director, or other poison center-affiliated clinicians might override any specific recommendation from this guideline.

Patient intent

The panel concluded that all patients with suicidal intent or in whom a malicious intent is suspected (e.g., child abuse or neglect) should be promptly transported to an emergency department, regardless of the exposure. Patients without these characteristics (e.g., adults with definite unintentional exposure or children below the age of 6 years in whom abuse is not suspected) are candidates for more selective referral to healthcare facilities.

Route of exposure

The inhalation route was associated with the vast majority of systemic toxicity. Systemic toxicity from gastrointestinal absorption was reported only if the integrity of the mucosa was compromised and mercury entered the peritoneum (e.g., rupture of mercury-weighted tubes after surgery). However, ingestion of small amounts can result in sequestration of elemental mercury in the appendix and inflammation. Ingestion of more than the amount contained in a mercury thermometer should be evaluated in an emergency department. Deposition of elemental mercury in soft tissue results in injury and local toxicity (e.g., abscess, granuloma) and should be surgically removed if possible. Dermal contact only rarely produce dermatitis.

Toxic dose

Based on case report data, the amount of elemental mercury from a broken thermometer spilled in a small, enclosed space can cause systemic toxicity if not properly cleaned up. Potentially toxic air concentrations have been demonstrated with this amount in small spill investigations. Heating or vacuuming elemental mercury increases airborne concentrations and increases the risk of toxicity. The exposure duration required for toxicity to develop from this low dose is typically weeks to months. This appears to be a rare phenomenon, but children are particularly susceptible to these low-dose exposures, which can cause acrodynia. Clinical toxicity was not documented from any “small” spill that was cleaned up properly. There were no reports of toxicity associated with ingesting the amount of mercury from a fever thermometer.

Presence of symptoms, type of healthcare facility, and mode of travel

Refer patients who are symptomatic after an acute exposure to an emergency department immediately for evaluation. If the elemental mercury was heated, all people within the exposure area should be evaluated at a healthcare facility since severe toxicity and death can occur in this circumstance. Asymptomatic patients with brief, unintentional, low-dose exposures can be observed at home. If there is concern for exposure to a high dose (more than thermometer) or chronic duration, asymptomatic patients can be evaluated on a non-urgent outpatient basis. The patient’s clinical condition, local protocols, and transportation resources should dictate the mode of transportation.

Time of onset of toxicity after exposure

The onset of toxic effects after inhalation exposure depends on the airborne concentration and duration of exposure. High intensity exposures to heated vapors produced symptoms with hours, whereas repeated low-dose exposure can take months before symptoms develop.

Heating, vacuuming, or sweeping elemental mercury

Patients acutely exposed to heated mercury (e.g., from stove tops, ovens, furnaces) in an enclosed space should be referred to an emergency department for evaluation due to the increased risk of toxic exposure, even if asymptomatic. If the mercury was vacuumed or swept with a broom and the patient is asymptomatic, a referral to the ED is not required, but an outpatient evaluation might be necessary if the patient was exposed to high concentrations. In all of these cases, the local health department or fire department should be contacted regarding clean up and evaluation of airborne contamination of the area.

Exposure during pregnancy

The panel concluded that a pregnant patient with unintentional exposure to elemental mercury, as with any unintended exposure to a drug or chemical, should be evaluated in follow-up by her primary care physician or obstetrician. Immediate referral to an ED is not necessary unless the patient is symptomatic.

Potential out-of-hospital management

Decontamination

Patients with dermal exposures should remove all jewelry and wash the affected area with mild soap and water. Remove all contaminated clothing and place them in a sealed, plastic double-bag for proper disposal. There was no evidence that out-of-hospital gastrointestinal decontamination offers benefit to patients who ingest elemental mercury.

Treatment

There are no effective treatment measures for out-of-hospital management of elemental mercury toxicity beyond the routine supportive care provided by emergency medical services.

Clean-up and disposal

Spills less than or equal to the amount in a mercury thermometer can be cleaned up by the public according to EPA guidelines. A professional company, local authorized agencies, the state health department, or the EPA should be contacted concerning clean-up and evaluation of larger spills.

Recommendations

1. Patients with exposure due to suspected self-harm, abuse, misuse, or potentially malicious administration should be referred to an emergency department immediately regardless of the exposure reported (Grade D).
2. Patients with symptoms of acute elemental mercury poisoning (e.g., cough, dyspnea, chest pain) should be

referred immediately to an emergency department for evaluation regardless of the reported dose. Patients with symptoms of chronic toxicity (rash, tremor, weight loss, etc.) should be referred for healthcare evaluation, the timing and location of which is guided by the severity of illness and circumstances of the exposure (Grade C).

3. If the elemental mercury was recently heated (e.g., from stove top, oven, furnace) in an enclosed area, all people within the exposure area should be evaluated at a healthcare facility due to the high risk of toxicity (Grade C).
4. If the elemental mercury was vacuumed or swept with a broom, the health department should be contacted to perform an environmental assessment for mercury contamination. Consider healthcare referral for those exposed to documented high air mercury concentrations (Grade C).
5. Patients ingesting more mercury than in a household fever thermometer or those with abdominal pain after ingestion should be referred to an emergency department for evaluation (Grade C). Do not induce emesis or administer activated charcoal.
6. Asymptomatic patients with brief, unintentional, low-dose vapor exposures can be observed at home. Asymptomatic patients can be evaluated as non-urgent outpatients if there is concern for exposures to high doses (e.g., more than contained in a thermometer) or for chronic duration (Grade D).
7. Pregnant patients unintentionally exposed to elemental mercury and who are asymptomatic should be evaluated by their obstetrician or primary care provider as an outpatient. Immediate referral to an ED is not required (Grade D).
8. Patients with elemental mercury deposited or injected into soft tissue should be referred for evaluation of surgical removal (Grade C).
9. All elemental mercury spills should be properly cleaned up, including the small amount of mercury from a broken thermometer. Brooms and vacuum cleaners should not be used to clean up elemental mercury. The clean-up of any spill larger than a broken thermometer should be performed by a professional company, state health department, or the EPA. Detailed instructions are provided on the EPA website: www.epa.gov/epaoswer/hazwaste/mercury/faq/spills.htm (Grade D).
10. Patients with dermal exposures should remove all jewelry and wash the affected area with mild soap and water. Remove all contaminated clothing and place these items in a sealed plastic double-bag for proper disposal (Grade D).
11. Do not discard elemental mercury in household trash, plumbing drains, or sewer systems. Consult local authorities for the proper disposal of low-level elemental mercury-contaminated household items and thermometers (Grade D).

Triage recommendations are summarized in Appendix 4.

Implications for research

The panel identified the following topics where additional research or analysis of existing databases might be useful.

1. Define the environmental conditions better (e.g., location, temperature, degree of ventilation) that can have critical impacts on the amount of elemental mercury inhaled and result in toxicity.
2. Evaluate the effectiveness of simple clean-up procedures in eliminating elemental mercury for small spills in the home.
3. Evaluate the risk of long-term neurodevelopmental, neurobehavioral, and cognitive effects associated with acute, subacute, or chronic mercury exposures, particularly in children.
4. Evaluate the role and effectiveness of chelation therapy in the medical management of confirmed mercury poisoning.

Disclosure

There are no potential conflicts of interest reported by the expert consensus panel or project staff regarding this guideline.

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Appendix 2

Grades of recommendation and levels of evidence

Grade of recommendation	Level of evidence	Description of study design
A	1a	Systematic review (with homogeneity) of randomized clinical trials
	1b	Individual randomized clinical trials (with narrow confidence interval)
	1c	All or none (all patients died before the drug became available, but some now survive on it; or when some patients died before the drug became available, but none now die on it.)
B	2a	Systematic review (with homogeneity) of cohort studies
	2b	Individual cohort study (including low quality randomized clinical trial)
	2c	“Outcomes” research
C	3a	Systemic review (with homogeneity) of case-control studies
	3b	Individual case-control study
	4	Case series, single case reports (and poor quality cohort and case control studies)
D	5	Expert opinion without explicit critical appraisal or based on physiology or bench research
Z	6	Abstracts

Appendix 3

Secondary review panel organizations

Ambulatory Pediatric Association
 American Academy of Breastfeeding Medicine
 American Academy of Emergency Medicine
 American Academy of Pediatrics
 American Association for Health Education
 American College of Clinical Pharmacy
 American College of Emergency Physicians
 American College of Occupational and Environmental
 Medicine
 American Pharmacists Association
 American Public Health Association
 American Society of Health-System Pharmacists
 Association of Maternal and Child Health Programs
 Association of Occupational and Environmental Clinics
 Association of State and Territorial Health Officials
 Canadian Association of Poison Control Centres

Centers for Disease Control and Prevention – National Center
 for Injury Prevention and Control
 Consumer Federation of America
 Consumer Product Safety Commission
 Department of Transportation
 Emergency Medical Services for Children
 Emergency Nurses Association
 Environmental Protection Agency
 Food and Drug Administration
 National Association of Children's Hospitals and Related
 Institutions
 National Association of Emergency Medical Services Physicians
 National Association of Emergency Medical Technicians
 National Association of School Nurses
 National Association of State Emergency Medical Services
 Directors
 National Safe Kids Campaign
 Teratology Society
 World Health Organization International Programme on
 Chemical Safety

Appendix 4

Triage algorithm for elemental mercury exposure

Is suicidal intent, self-harm, or malicious
 administration by another person suspected?

NO ↓

Did patient ingest *more* than the amount
 contained in a household mercury thermometer?

NO ↓

Is the patient symptomatic?

1. Acute inhalation exposure?
2. Gradual onset after chronic exposure?
3. Soft tissue deposition or injection?
4. Abdominal pain within days of an unintentional
 ingestion of mercury from broken thermometer?

NO ↓

Is the home situation of concern (e.g., family/
 caregiver seems unreliable)?

NO ↓

Was elemental mercury heated (e.g., stove top,
 oven, furnace) in a closed space?

NO ↓

YES → Refer to emergency department.

YES → Refer to emergency department for evaluation.

YES →

1. Refer to an emergency department for symptoms of acute inhalational exposure (e.g., cough, dyspnea, chest pain).
2. Patients with gradual onset of symptoms from a chronic exposure (e.g., rash, irritability, weight loss) can be referred for non-emergent health care evaluation. The timing and location is dictated by the severity of symptoms and circumstances of the exposure.
3. Refer soft tissue mercury deposition (e.g., foreign body) for surgical removal.
4. Refer for evaluation of appendicitis or peritoneal irritation (rare events).

YES → Consider on-site evaluation by health department for environmental mercury contamination.

YES → Refer all exposed to emergency department. Notify health department for on-site evaluation of mercury contamination.

Was spilled elemental mercury vacuumed or swept with a broom prior to call?

YES → Seal off contaminated area and ventilate to outside. Bag and seal vacuum cleaner and/or broom. Refer to health department for on-site evaluation of mercury contamination. Consider referral for health care evaluation if potentially toxic airborne concentrations detected.

NO ↓

Was the amount spilled more than that contained in a fever thermometer (0.1 mL)?

YES → Seal off contaminated area and ventilate to outside. Refer to health department for on-site evaluation of mercury contamination.

NO ↓

Observe at home. Give home clean-up instructions for amounts equal to a thermometer or less. Consider EPA website recommendations for clean up procedures: www.epa.gov/epaoswer/hazwaste/mercury/faq/spills.htm