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Corresponding author:
Eman Alshaikh;
Email: dr.eos@live.com

Pediatric Decontamination Considerations in CBRN Events: A Scoping Review

Eman Alshaikh MD, FIBODM[1,2,5], Fadi Issa MD[1,2], Attila J. Hertelendy PhD[1], Terri Davis MD[1,6], Jamla Rizek RN[1], David DiGregorio PA, MSEM[1], Ejemai Amaize Eboreime MD, PhD[3], Janice Kung[4], Amalia Voskanyan RN[1] and Greg Ciottone MD[1,2]

[1]Department of Emergency Medicine, Beth Israel Deaconess Medical Center, Boston, Massachusetts, USA; [2]Harvard Medical School, Boston, Massachusetts, USA; [3]Department of Psychiatry, Faculty of Medicine, Dalhousie University, Halifax, NS, Canada; [4]Geoffrey & Robyn Sperber Health Sciences Library, University of Alberta, USA; [5]Emergency Department, Rashid Hospital Trauma Center, Dubai Health, Dubai, UAE and [6]Florida State University, College of Medicine, Tallahassee, Florida, USA

Abstract

Introduction: Children are uniquely vulnerable to chemical, biological, radiological, and nuclear (CBRN) events due to anatomical, physiological, and psychological differences. Current decontamination practices are adapted from adult protocols.
Objective: To evaluate current practices, challenges, and special considerations in pediatric decontamination during CBRN events.
Method: A scoping review was conducted using six databases in accordance with PRISMA-ScR framework. Studies were eligible if they evaluated decontamination methods involving children (0-18 years) in real or simulated CBRN scenarios. Fourteen studies met the inclusion criteria, and data were thematically analyzed into four domains.
Results: Disrobing is widely recognized as a critical first step in the decontamination process, and 43% of the studies reviewed identified it as such. When done immediately and appropriately, it can remove a significant amount of contaminants. Although its effectiveness varies based on how much of the body is covered and the nature of the exposure. Dry decontamination was discussed in 21% of studies, and wet decontamination was the most commonly reported approach, appearing in 93%. Key pediatric challenges included hypothermia, psychological distress, separation from caregivers, and difficulties managing non-ambulatory or special needs populations. Few studies addressed age-specific protocols or long-term psychological impacts. The results are presented in procedural order to reflect the typical sequence of decontamination in CBRN response.
Conclusions: Current decontamination guidelines inadequately address pediatric-specific needs. There is a critical need for standardized, age-appropriate guidelines that integrate caregiver support and psychosocial considerations. A pediatric decontamination algorithm was developed to consolidate current evidence into a practical framework for CBRN mass casualty incidents.

Introduction

Chemical, biological, radiological, and nuclear (CBRN) events can occur accidentally, such as industrial chemical spills or nuclear power station accidents, or intentionally through acts of terrorism or warfare.[1] Regardless of the cause, these incidents present a significant risk to the community, particularly vulnerable populations.[2] Children are both more vulnerable and likely to be victims of these events.[3] In 1995, a chlorine gas attack threat at Disneyland, which was later confirmed as a hoax, demonstrated how children can be considered targets in high-profile public venues during potential CBRN threats.[4] Similarly, during the Tokyo subway sarin gas attack in 1995, 16 of the 5000 casualties were children.[5] While data indicate that more than one-third of disaster victims are children,[6] most of the research and preparedness on decontamination focuses primarily on the adult population.[7]

The pediatric population presents distinct physiological, anatomical, and developmental characteristics that significantly influence their vulnerability to chemical exposures. Children exhibit elevated respiratory and metabolic rates, potentially resulting in greater inhalational doses of aerosolized agents and consequently increased susceptibility to toxicity.[8,9] Furthermore, children possess a larger surface area-to-body mass ratio coupled with thinner, less keratinized integumentary surfaces, rendering them more vulnerable to systemic toxicity and hypothermia, particularly following decontamination procedures.[8] Their lower stature relative to adults positions them closer to ground level, enhancing exposure risk to hazardous substances with vapor densities greater than air, such as phosgene and chlorine, which tend to accumulate in lower atmospheric strata.[9]

The distinctive behavioral characteristics of pediatric populations also present significant challenges in chemical exposures. Inadequate communication during decontamination procedures can precipitate heightened anxiety states, diminishing cooperation and consequently complicating decontamination efficacy. Additionally, the appearance of emergency personnel in personal protective equipment (PPE) can elicit fear responses in children, exacerbating anxiety and potentially contributing to post-traumatic stress disorder (PTSD) development.[10,11] Empirical evidence supporting this vulnerability is demonstrated in post-disaster epidemiological studies; following the September 11, 2001, attacks on the World Trade Center, approximately 18% of children in New York City manifested symptoms meeting clinical thresholds for severe post-traumatic stress.[5] These behavioral, psychological, and developmental considerations collectively amplify risk profiles in pediatric populations during chemical emergencies, underscoring the imperative for age-appropriate emergency planning and response guidelines specifically tailored to address their unique psychosocial and developmental needs.

CBRN events result in a wide range of health effects and require specific response plans. One of the essential components is decontamination, which is the removal or neutralization of contaminants to safe levels for both health care providers and victims.[12] Despite the well-documented vulnerabilities of pediatric populations in CBRN events, the currently available decontamination guidelines are modified from adult practices, raising concerns about their safety and efficacy. There is limited research on pediatric-adjusted decontamination strategies, the effectiveness of hybrid decontamination, the optimal parameters for wet decontamination, and the psychological impact of decontamination procedures on children. Additionally, there is no standardized approach for decontaminating non-ambulatory children or those with special needs.

This scoping review aims to systematically evaluate current approaches to pediatric decontamination during CBRN events, with particular emphasis on methodological frameworks, implementation challenges, and pediatric-specific considerations. The goal is to critically examine existing literature, highlight evidence gaps, and inform the development of evidence-based, standardized age-specific decontamination guidelines for mass casualty preparedness.

Methods

Study Design

This scoping review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines (Figure 1).[13] The primary objective was to systematically review the existing literature on pediatric decontamination during CBRN events.

Eligibility Criteria

Studies were considered eligible if they:

- Included children aged 0-18 years, exposed to CBRN hazards.
- Involved decontamination during real or simulated CBRN events, including drills or exercises.
- Evaluation of decontamination methods (dry, wet, hybrid).
- Published in English.

Exclusion criteria included:

- Non-English publications.
- Studies not involving pediatric populations.
- Guidelines and protocols not focused on decontamination.

Eligibility criteria are summarized in Table 2. Inclusion and exclusion decisions were documented at each screening stage (Figure 1).

Search Strategy

A comprehensive literature search was conducted using six databases: Ovid MEDLINE, Ovid Embase, CINAHL, Scopus, Web of Science Core Collection, and the Cochrane Library (via Wiley). The search was conducted on December 19, 2024. A combination of controlled vocabulary (e.g., Medical Subject Headings [MeSH]) and relevant keywords related to CBRN decontamination, pediatric populations, and emergency response was used (Table 1).

Data Screening

All identified studies were imported into Covidence, a web-based platform for systematic review management. A total of 359 studies were identified from the database searches. After removing duplicate studies (n = 162), 197 studies remained for screening. Two independent reviewers (EA & JR) screened all study titles and abstracts based on the eligibility criteria (Table 2). If both reviewers agreed, the study proceeded to a full-text review, and disagreements were resolved by a third reviewer (FI). During title and abstract screening, 168 studies were excluded, leaving 27 full-text studies for detailed review. Of these, 13 were excluded for the following reasons: no full text available (n = 1), not focusing on pediatrics (n = 4), and absence of decontamination protocol (n = 8). Ultimately, 14 studies met all inclusion criteria and were included in the final review. The stepwise selection process is detailed in the PRISMA-ScR flowchart (Figure 1), ensuring transparency in study inclusion and exclusion.

Data Extraction and Analysis

Data extraction was performed by one reviewer (EA) and validated by a second reviewer (FI). Extracted data were organized using Microsoft Excel (2024) into a structured table summarizing study characteristics (author, year, age group), contaminant types, decontamination method (dry, wet, hybrid), decontamination protocol, special needs population, and psychological impact (Tables 3-4). This structured approach allowed for a comparison of the efficacy of decontamination across different materials and contaminants.

Results

The included studies, published between **2003 and 2017**, originated in the **United States (n = 13) and Canada (n = 1)**. While all studies focused on pediatric populations, most did not indicate a specific age range beyond the general term "pediatric." The studies examined a range of hazardous agents, including chemical, biological, and radiological contaminants. Seven studies addressed all three agents,[5,7,14–18] while one study focused on both chemical and radiological agents.[19] Three studies focused on radiological decontamination,[20–22] and another three examined chemical decontamination (Table 3).[8,23,24] The findings were categorized into four main themes: **pre-decontamination considerations, decontamination considerations, post-decontamination considerations, and pediatric special considerations**.

Theme 1: Pre-Decontamination Consideration

Disrobing was identified as a crucial **first step** in pediatric decontamination. S**ix studies (43%)** emphasized that removing

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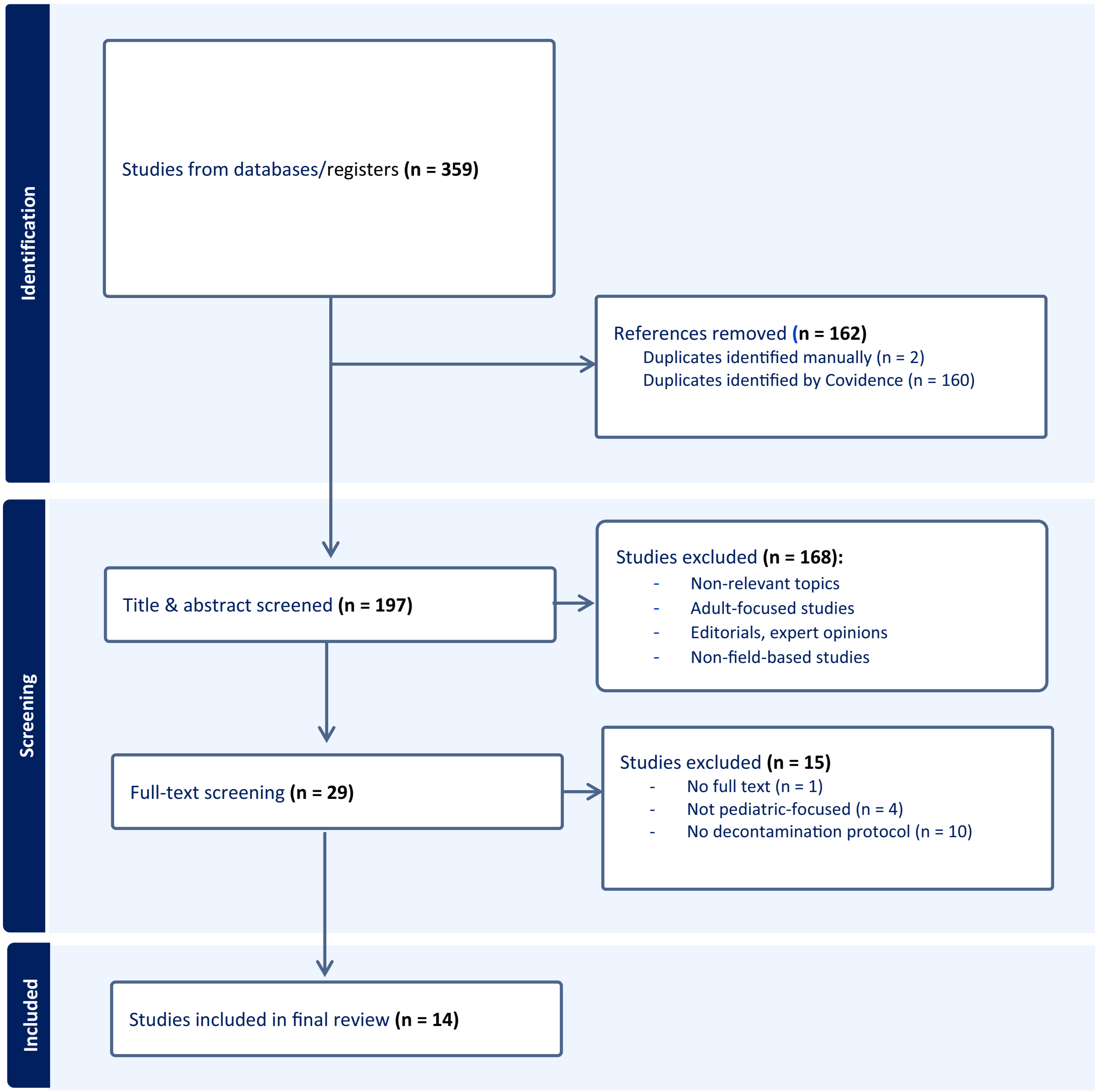

Figure 1. Study selection process following PRISMA-ScR guidelines.
Figure 1. PRISMA-ScR flow diagram illustrating the study selection process for the scoping review on pediatric decontamination in CBRN events. The process included identification, screening, eligibility, and inclusion phases. Adapted from PRISMA Extension for Scoping Reviews.[12]

contaminated clothing can eliminate **85-95 % of surface contaminants**, making it a highly effective initial intervention.[5,7,8,15,16,22] Two studies (14%) advise to use same sex responders to assist with disrobing.[7,19] Five studies (36%) addressing radiological decontamination recommended prioritizing life-threatening conditions before initiating decontamination procedures.[14,15,19–21]

Theme 2: Decontamination Consideration

Wet decontamination was the most frequently used method, reported in 13 out of 14 studies (93%).[5,7,8,14–17,19–24] Three studies (21%) recommended dry decontamination using absorbent materials.[15,19,22] Another two studies (14%) addressed hybrid decontamination approaches.[15,17]

Two studies (14%) recommended water temperatures above 98°F (36.7°C),[7,16] while another two suggested using a slightly higher temperature of 100°F (37.8°C) to minimize the risk of hypothermia.[5,8] Five studies (36%) did not specify an exact temperature but emphasized the use of warm water.[17,19–21,24] One study (7%) recommended using the first available water at a comfortable temperature.[15] Low-pressure shower systems ≤60 psi (414 kPa) were preferred in four studies (29%) to reduce skin irritation and distress,[5,7,8,16] while three studies (21%) advised using low pressure without providing specific values.[19,20,24] The recommended shower duration varied, with three studies (21%) advising 5-6 minutes,[8,16,19] and one study (7%) suggested a longer duration of 8-10 minutes for exposures involving corrosives and nerve agents.[17]

Age-specific decontamination strategies were also addressed; three studies (21%) recommended caregiver-assisted decontamination for infants and toddlers (0-2 years) to reduce distress, and using secure plastic car seats, waterproof baskets, or stretchers to prevent slipping.[7,14,16] For children aged 2-8 years, three studies

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Table 1. Search strategy across databases for the pediatric decontamination scoping review

Database	Search terms and structure summary
MEDLINE (Ovid)	("CBRN" OR "bioterrorism" OR "mass casualty") AND ("decontamination") AND ("pediatric" OR "child" OR "infant")
Embase (Ovid)	Same structure as MEDLINE with adapted Embase subject headings
CINAHL	CINAHL headings for pediatric terms AND keywords for CBRN and decontamination
Scopus	Title/abstract/keyword search using proximity operators (e.g., "mass W/1 casualties")
Web of Science	Topic search with "CBRN", "decontamination", and "pediatric" using NEAR/x proximity logic
Cochrane Library	Keyword-based search with filters for pediatric population and decontamination studies

Note: The search was conducted across six databases using controlled vocabulary (e.g., MeSH) and keyword combinations tailored to each platform. Search terms were selected based on relevance to CBRN incidents, decontamination procedures, and pediatric populations. The full search strategy is available upon request.

Table 2. Inclusion and exclusion criteria

	Inclusion criteria	Exclusion criteria
Population	Studies involving children aged 0–18 years exposed to CBRN hazards	Studies not focused on pediatric populations
Intervention	Studies evaluating decontamination methods (dry, wet, hybrid)	Studies without decontamination protocols or do not focus on Pediatric interventions
Contaminant type	CBRN	Studies on unrelated exposures (e.g., environmental pollutants, drug toxicity)
Setting	Real-world incidents, field simulations, or emergency response exercises	Laboratory-only or animal studies lacking field relevance
Language	English-language publications	Non-English studies (due to translation limitations)
Outcomes	Reports on effectiveness, safety, or challenges of decontamination (e.g., hypothermia, compliance, PTSD)	Studies lacking measurable outcomes related to decontamination effectiveness or safety

Note: Only studies in English-language involving children (0-18 years) included in this systematic review. Non-English studies were excluded due to resource limitations for translation and verification. The criteria were guided by PRISMA-ScR recommendations for transparent and reproducible review methodology.

(21%) advised using simple explanations and visual aids to improve compliance.[20,22,23] Three studies (21%) suggested older children (8-18 years) could self-disrobe and shower independently,[7,14,16] and five studies (36%) preferred to have gender-segregated decontamination areas for privacy.[7,14,16,22,23]

Theme 3: Post-Decontamination Considerations

Preventing hypothermia was a major concern, with eleven studies (79%) emphasizing the importance of warming protocols.[7,14–20,22–24] Three studies (21%) advised maintaining warmth of the decontamination and post-decontamination zone by using the air-warming system, overhead heat lamps, and radiant warmers.[7,14,22] Eleven studies (79%) advised immediate drying and wrapping in towel or warm blanket, such as foil-type blanket, immediately after decontamination.[7,14–20,22–24] Six studies (43%) highlighted the importance of medical evaluation and monitoring for delayed symptoms, especially after chemical and radiological exposures.[8,15,17,19,23,24] Five studies (36%) recommended post-decontamination radiation surveys,[14,15,19,20,22] while three studies (21%) advised bioassay testing (e.g., nasal swabs, whole-body counting) for suspected internal contamination.[14,15,22]

Theme 4: Pediatric Special Consideration

Pediatric decontamination poses unique challenges for non-ambulatory children, those with special needs, and those with psychological distress management. Two studies (14%) recommended using specialized stretchers to ensure safety during decontamination.[7,16]

Two studies (14%) addressed the special needs population and recommended the involvement of a caregiver during decontamination.[7,16]

Psychological vulnerability of children was a significant concern, reported in nine studies (64%), with **eight studies (57%)** highlighting that separation from caregivers increased psychological distress and non-compliance.[7,8,14,16–19] Additionally, long-term psychological issues such as post-traumatic stress disorder (PTSD) were addressed in six studies (43%) and highlighted the importance of prolonged psychological follow-up.[7,8,14,16,20,22] The importance of having a child-friendly environment with the presence of public and mental health services was highlighted in three studies (21%).[7,16,18]

Discussion

To better clarify decontamination processes, it should be understood that in mass casualty incidents, self-showering for ambulatory patients can be employed for large numbers of victims. Wet decontamination units can also be deployed, which utilize soap and water by responders, including trying not to irritate the skin through aggressive wiping and avoiding contaminated fluid from entering the mouth, nose, or wounds. If possible, indoor decontamination facilities are ideal in colder temperatures to avoid hypothermia. If these facilities are unavailable, use of dry decontamination can serve as a substitute in some cases.

Pre-Decontamination Considerations

The decontamination process includes three stages: pre-decontamination, decontamination, and post-decontamination. The pre-decontamination phase includes triage, disrobing, and radiological assessment when needed. The JumpSTART pediatric triage algorithm is an effective tool in mass casualty incidents.[16,25] If life-threatening conditions are present, emergent interventions such as airway protection and hemorrhage control should precede decontamination.[26,27] F**ive studies (36%)** addressing radiological decontamination recommended prioritizing **life-threatening**

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Table 3. Pediatric decontamination considerations

References	Age group	Contaminant type	Method	Pre-decontamination	Decontamination	Age-specific decontamination	Post decontamination
16	0–18 years	Chemical, biological, radiological	Wet	• Triage using JumpSTART. • Disrobe (remove 85% of contaminants). • Keep families together unless separation is needed. Children (0–8 years): • Disrobe by the caregiver or hot zone (red zone) personnel. Older children (8–18 years): • Disrobe independently with supervision. • Grouped by sex for modesty issues.	• Duration: 5–6 mins • Temperature: 98°F (36.7 °C) • Pressure: ≤60 psi (414 kPa) • Soap for oily contaminant	Infants and toddlers (<2 years): • Place in a stretcher or containers with drainage during handheld. • Use handheld sprayers. • Airway protection. Young children (2–8 years): • Direct supervision by hot zone (red zone) personnel. Older children (8–18 years): • Shower independently with supervision.	• Drying and covering use warming blankets. • ID wristband. • Re-triage.
7	0–18 years	Chemical, biological, radiological	Wet	• Disrobe (remove >85% of contaminant). • Maintain family unity. Infants and toddlers (<2 years): • Disrobing performed by caregivers or hot zone (red zone) personnel. Young children (2–8 years) • Disrobing assisted by caregivers or hot zone (red zone) personnel. Older children (8–18 years): • Disrobe independently with supervision. • Use same sex to assist with undressing. • Sensitivity and modesty should be maintained.	• Duration: not specified • Temperature: 98°F (36.7°C) • Pressure: ≤60 psi (414 kPa)	Infant and toddler (<2 years): • Placed in secure baskets, plastic car seats, or stretchers. • Assistance from caregivers or hot zone (red zone) personnel. • Airway protection. Young children (2–8 years) • Direct supervision by hot zone (red zone) personnel. Older children (8–18 years): • Shower independently with supervision.	• Maintain warmth the decon and post decon zone by using air-warming systems, overhead heat lamps, and radiant warmers. • Dried and wrap in a towel or foil-type "space" blanket. • ID wristbands. • Re-triage.
14	0–18 years	Chemical, biological, radiological	Wet	Radiological contaminant: • Dosimeter survey. • Prioritize life-saving interventions over decontamination. • Maintain family unity. Older children: • Encouraged to self-disrobe with privacy considerations. • Gender-sensitive practices for modesty.	• Duration: not specified • Temperature: not specified • Pressure: not specified Chemical contaminant: • The shower removes most of the contaminants • Soap for oily contaminant Radiological decontamination: • Localized contaminant: soap and water • Generalized contaminant: full shower • Wound: saline irrigation, remove foreign bodies by forceps	Infants and Toddlers (<2 years): • Placed in secure baskets, carts. • Assistance from caregivers.	• Maintain warmth the decon and post decon zone by using air-warming systems, overhead heat lamps, and radiant warmers. • Drying and warming with towels or blankets. • Radiation survey. • Bioassay if needed.
24	0–18 years	Chemical	Wet	• Disrobing. • Bagging contaminated clothing. • Vapor contaminants: well-ventilated area is effective; decontamination is not necessary.	• Duration: not specified • Temperature: warm water • Pressure: low-pressure sprayers • Soap for oily contaminant • Airway protection.	Not specified	• Drying and warming with towels or blankets. • Medical evaluation and monitoring for delayed symptoms.

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Table 3. (*Continued*)

References	Age group	Contaminant type	Method	Pre-decontamination	Decontamination	Age-specific decontamination	Post decontamination
21	0–18 years	Radiological	Wet	• Disrobing. • Triage. • Prioritize life-saving interventions over decontamination. • Radiological survey.	• Duration: not specified • Temperature: warm water (only slightly above body temperature) • Pressure: not specified Radiological contaminant: • Generalized contamination: full shower • Localized contamination: soap and water	Not specified	Not specified
20	0–18 years	Radiological	Wet	• Maintain family units. • Radiological survey. • Prioritize life-saving interventions over decontamination. Older children: • Explain procedures. • Provide privacy for adolescents.	• Duration: not specified • Temperature: warm water • Pressure: low pressure • Avoid excessive scrubbing • Decontamination continues until surveys read <0.5 mR/hr or until no further contamination can be removed • Wounds: — Drap the area with waterproof material — Irrigate with sterile water using moderate jet stream pressure — Remove penetrating objects with forceps	Older children: • Shower by themselves.	• Drying and warming using blankets and warmers. • Radiation survey.
15	0–18 years	Chemical, biological, radiological	Dry/wet/hybrid	• Triage. • Disrobing removes 90–95% of contaminants. • Contaminated clothing sealed and removed. • Vapor contaminants: Well-ventilated area is effective, decontamination is not necessary. • Prioritize life-saving interventions over decontamination.	Chemical agent: A. Wet decon: Duration: for mustard and nerve agents, a minimum of 20 minutes • Temperature: use the first available water at a comfortable temperature • Pressure: not specified • Plain water is very effective • Hair should be thoroughly washed B. Dry decon: Use of absorbent, dry material C. Hybrid decon: Flour or talcum powder followed by wet tissue (nerve agents (sarin, VX) and vesicants (mustard gas) Radiological agent: • Dry decon: gross decontamination: brushing off loose particulate matter and removing clothing and shoes • Wet decon: wash uncovered skin with soap and water • If radioactivity persists in hair or scalp, further washing or cutting of hair may be necessary	Not specified	• Medical evaluation and monitoring for delayed symptoms. • Provide psychological support and comfort measures. • Provide warm blankets, food, toys, and distractions. • Reunification with caregivers. • Radiation survey. • Bioassay if needed.

(*Continued*)

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Table 3. (*Continued*)

References	Age group	Contaminant type	Method	Pre-decontamination	Decontamination	Age-specific decontamination	Post decontamination
					Biological agent: • Standard hygiene practices (washing with soap and water) are usually sufficient • Full decontamination is rarely required for biological agents Wound decon: • Flush with standard irrigating solutions		
22	0–18 years	Radiological	Dry/wet	• ID wristband. • Ensure children understand the process using clear, age-appropriate language. • Disrobe (removes >85% of contaminant). • Provide gender-specific areas to maintain privacy. • Radiological survey.	• Duration: not specified • Temperature: not specified • Pressure: not specified • Dry decon: use slightly damp cloths or towels to clean exposed skin and hair • Wet decon: use showers if contamination persists after dry decon • Responsible adults (e.g., teachers or caregivers) should supervise but may not directly assist	Not specified	• Keep children warm with blankets or other measures. • Provide reassurance to children & families. • Radiation survey. • Bioassay if needed.
18	0–18 years	Chemical, biological, radiological	Not specified	• Maintain family units. • Additional personnel are required to assist with disrobing.	• Parents or caregivers are encouraged to assist during decontamination	Not specified	• Use warming supplies (blankets, air warming systems, overhead heat lamps, and radiant warmers).
8	0–18 years	Chemical	Wet	• Disrobe (remove >85% of contaminant). • Clothing placed in labeled plastic bags. • Keep parents nearby when possible.	• Duration: 5 mins unless specific alternative recommendations are given • Temperature: 100°F (37.8°C) • Pressure: ≤60 psi (414 kPa) • Soap for oily contaminant	Not specified	• Medical evaluation and monitoring for delayed symptoms. • Reunification with parents. • Mental health support.
23	10–11 years	Chemical	Wet	• Conduct rapid medical assessment and triage. • Activate the hospital's emergency management plan. • Maintain privacy. • Place the cloth in a plastic bag. • Explain the procedure to children.	• Duration: 3–4 mins • Temperature: 90°F (32.2°C) • Pressure: not specified	Not specified	• Dried and wrapped in warm blankets. • Medical evaluation and monitoring for delayed symptoms.
17	0–18 years	Chemical, biological, radiological	Wet/hybrid	• Maintain family units. • Contaminated clothing placed in a biohazard bag. • Radiological survey. • Vapor contaminant: well-ventilated area is effective; decontamination is not necessary.	Chemical agent:Wet decon: • Duration: corrosive or nerve agent: 8–10 mins • Temperature: warm water • Pressure: not specified Hybrid decon: • Mustard gas: apply a dry powder and remove with a moist towel • Eye: flushing with copious amounts of water or a 1.26% isotonic sodium bicarbonate solution or normal saline • Radioactive agent: wash with water and soap	Not specified	• Dry immediately and provide warm clothing. • Medical evaluation and monitoring for delayed symptoms.

(*Continued*)

Table 3. (*Continued*)

References	Age group	Contaminant type	Method	Pre-decontamination	Decontamination	Age-specific decontamination	Post decontamination
5	0–18 years	Chemical, biological, radiological	Wet	• Triage. • Disrobe (remove up to 85–95% of contaminant). • Labeled and placed contaminant cloth in biohazard container.	• Duration: not specified • Temperature: 100°F (37.8°C) • Pressure: ≤60 psi (414 kPa)	Not specified	Not specified
19	0–18 years	Chemical, radiological	Dry/wet	• Maintain family units. • Triage. • Removing clothing and jewelry, double-bagged in plastic bags, sealed, and labeled. • Supervision by the same gender. • Radiological survey. • Prioritize life-saving interventions over decontamination. • Vapor contaminant: well-ventilated area is effective; decontamination is not necessary.	Wet decon: • Duration: minimum of 5 mins • Temperature: warm water • Pressure: high volume, low-pressure • Soap for oily contaminant, with soft sponge or cloth • Reactive skin decontamination lotion: for vesicants and organophosphorus nerve agents • Eyes and wounds irrigated using isotonic solutions Dry decon: • Solid particles or dust: removed by vacuuming	Not specified	• Drying and covering immediately. • Medical evaluation and monitoring for delayed symptoms. • Post-decon radiation survey.

Note: This table summarizes key characteristics and thematic findings extracted from each included study. Themes are organized by pre-decontamination, decontamination method, and post-decontamination practices.

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Table 4. Pediatric special considerations during decontamination: non-ambulatory care, special needs, and psychological impacts

References	Decon: non-ambulatory	Special needs	Psychological impact
16	• Disrobed by hot zone (red zone) personnel. • Caregiver assistance if possible. • Placed on stretchers. • Airway protection.	Developmentally delayed: • Require extra time to disrobe and may be fearful of the decontamination process. • The caregiver should assist the child through the entire process of decontamination. • If caregivers are not available, additional hot zone (red zone) personnel are required to assist. Children with medical devices: • Asymptomatic: — Visually inspect for solid or liquid foreign body. — Use a Geiger counter to assess for radioactivity. — If no visible contamination is found, it is safe to use. — If doubt, keep it in the hot zone (red zone) and replace it with a hospital device if possible. • Symptomatic: assume the device is contaminated. — Keep it in the hot zone. — Replace it with a hospital device if possible. • Others: — Eyeglasses: wash in the shower with the patient. — Prosthetic limbs: remove and thoroughly decontaminate.	• Fear, anxiety, and resistance to disrobing or showering. • More effect seen in younger age. • PTSD risk. • Child-friendly environment with social workers and child life specialists.
7	• Maintain airway positioning. • Move non-ambulatory children by using a scoop-style stretcher. • Place on side, not face up.	• Provide emotional support by child life specialists or trained volunteers. • Use visual aids (e.g., cartoons, posters, hand signals) to explain procedures. • Keep family together.	• Respond to stress differently. • High levels of stress, panic, and separation anxiety. • Keep family together to decrease anxiety. • PTSD risk. Child-friendly environment with social workers and child life specialists.
14	Not specified	Not specified	• Children are vulnerable to psychological trauma. • Keep family together to decrease anxiety. • PTSD risk.
24	Not specified	Not specified	• High potential for anxiety, fear, and stress.
21	Not specified	Not specified	Not specified
20	Not specified	Not specified	• Keep family together to decrease anxiety. • PTSD risk.
15	Not specified	Not specified	Not specified
22	Not specified	Not specified	• High levels of stress, anxiety, fear. • PTSD risk. • Long-term psychological follow-up is needed.
18	Not specified	Not specified	• Children are more vulnerable. • Children response to stress differently. • Public mental health services are essential for parent and children. • Increased separation anxiety, aggression.
8	Not specified	Not specified	• Children response to stress differently. • PTSD risk. • Can have emotional lability, insomnia, frequent crying, depression, fear, and "anniversary grief." • Decontamination can be frightening procedure.
23	Not specified	Not specified	• Distress, fear, crying.
17	Not specified	Not specified	Not specified
5	Required assistance from health care worker and family.	Not specified	Not specified
19	Sloped stretcher, designed for pediatric decontamination.	Not specified	Not specified

Note: This table summarizes data extracted on pediatric-specific considerations, including strategies for managing non-ambulatory children, children with special needs, and psychological challenges.

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conditions over immediate decontamination, while stable victims should have a radiological survey and undergo triage.[14,15,19,20,28]

Disrobing, the removal of contaminated clothing, is widely known as a critical first step in the decontamination process *performed in the warm zone (yellow zone)*.[5,7,8,15,16,22,29] While it is sometimes considered part of dry decontamination, the majority describe it as a separate intervention due to its immediate impact on reducing external contamination.[27,29] Its effectiveness depends on several factors, including the amount and type of clothing worn, the nature and direction of the contaminant exposure (e.g., overhead vs. horizontal), and the timing of the disrobing. In case of liquid contaminants, early disrobing is important to decrease the absorption through fabric layers. The fabrics of the clothing are also important; heavy or layered clothing can absorb and retain contaminants, potentially increasing secondary exposure via off-gassing.[29] When performed rapidly and correctly, disrobing alone can remove a significant amount of surface contaminants, reaching up to 85-95%.[5,7,8,15,16,22]

The contaminated clothing should be placed in designated sealed biohazard bags to avoid spreading of contamination.[5,8,15,17,19,23,24,30] When disrobing is conducted, attention to age-appropriate requirements and individual capabilities is important. Infants require caregiver assistance or trained personnel, young children benefit from guided support, and older children should disrobe independently with privacy.[7,14,16,22,23,31] Additionally, it's important for older children to use same-sex responders to assist with disrobing.[7,19]

Decontamination Considerations

Decontamination is a critical step in managing CBRN events. Different methods can be used to remove or reduce hazardous contaminants, including wet, dry, and hybrid methods. Hybrid decontamination combines wet and dry decontamination methods for maximum effectiveness. The decontamination methods used across the reviewed studies varied, highlighting a lack of standardized approaches for pediatric populations.

Wet decontamination emerged as the most frequently reported method, utilized in 93% of the studies. However, not all chemical exposures are suitable for water-based decontamination.[32] Certain chemical warfare agents (CWAs), such as sulfur mustard and cyanogen chloride, can react with water, making wet decontamination unsafe.[3,23,29,32] Moreover, in the case of liquid contaminants, the application of water to the skin may increase the dermal absorption via a phenomenon known as the "rinse-in" or "wash-in" effect.[29,33–35]

In such scenarios, dry decontamination using absorbent material (e.g., towels, gauze) is preferred, especially for liquid chemical exposures like sulfur mustard. Wet decontamination is generally preferred in case of caustic or non-liquid (e.g., powder or particulate) chemical contaminant.[3,23,29,32] The Primary Response Incident Scene Management (PRISM) guidelines emphasize that emergency wet decontamination should only be used when dry methods are contraindicated, and recommend careful consideration of the chemical's properties and volatility.[29]

Additionally, in cold settings, dry decontamination should be considered to avoid hypothermia, a risk that is especially significant in children.[32,36] Victims exposed to vapors or gaseous contaminants often do not require full decontamination and may be sufficiently managed by removal from the source and exposure to fresh air.[15,19,37] Similarly, for individuals only exposed to ionizing radiation, decontamination is not required.[27]

Unlike adults, children have a higher body surface area-to-mass ratio and an immature thermoregulation system, making them more vulnerable to heat loss during decontamination.[16,38] They also have an increased rate of dermal absorption,[37] highlighting the critical need for rapid pediatric decontamination. This urgency is further emphasized by the fact that the effectiveness of decontamination decreases with time.[39] According to the PRISM guidelines, the use of the first available material is recommended for the rapid removal of contaminants.[29,40]

The reviewed studies show that when wet decontamination is indicated, using water alone is usually effective in removing most contaminants. However, for oily or non-water-soluble agents, it is recommended to add mild soap and use gentle scrubbing with a soft sponge or cloth.[3,14–16,19,24,32] Given children's unique physiological and psychological vulnerabilities, decontamination methods should be specifically adapted to their needs. The water pressure should be strong enough to clean the skin effectively without being painful or causing injury. Handheld sprayers that are designed for adjustable and low water pressure, not more than 60 psi (414 kPa), are recommended to ensure safety.[5,3,31,41–43] Water temperature is another critical factor to ensure both efficacy and safety of decontamination. Rotenberg et al. advised using the first available water at a comfortable temperature.[15] Heon & Foltin and Freyberg et al. suggest maintaining water at or above 98°F (36.7°C) to prevent hypothermia.[7,16] Similarly, the American Academy of Pediatrics and Chung et al. recommended using water at a temperature of 100°F (37.8°C).[3,5] This advice aligns with the 2007 clinical guidelines from the Association of Women's Health, Obstetric and Neonatal Nurses and the National Association of Neonatal Nurses, recommending bath water temperature for newborns between 100°F (37.8°C) and just under 104°F (40.0°C) to avoid heat loss.[21] The risk of hypothermia increases when water temperatures are below 98°F (36.7°C).[43,44]

The act of drying the skin after any form of wet decontamination is a key step. This simple but important measure helps to remove residual contaminants from hair and skin, and reduces the risk of spreading the contamination. Additionally, drying can help in preventing post-decontamination hypothermia, especially in children,[29] and the process is termed "Dry-Wet-Dry" in Advanced Hazmat Life Support (AHLS).[45]

Pediatric populations demonstrate heightened vulnerability to CBRN exposures due to their distinct physiological characteristics, particularly their elevated respiratory rates and smaller body mass, which necessitate time-sensitive decontamination interventions. The literature recommends optimal decontamination duration parameters ranging from 3 to 5 minutes for standard contaminants.[3,16,19,23] Some literature suggests decontaminating corrosives and nerve agents for approximately 8-10 minutes (Mueller, 2006), while Rotenberg et al. (2003) recommend at least 20 minutes in some chemical agents, such as mustard and nerve agents, when using hypochlorite solutions.[15,17] There are, however, no universal agreements regarding these timeframes; extended decontamination time may be needed depending on the agent, surface, and clinical context. Although a neutral pH is a desirable endpoint in certain situations, such as eye decontamination,[45] there is no universal pH target for all decontamination processes. The primary goal is to mitigate chemical injuries and ensure the effective removal of the agent. Current evidence-based guidelines stipulate that the comprehensive decontamination process, encompassing pre-decontamination preparation through post-decontamination evaluation, should be completed within ≤1-hour temporal window

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to effectively minimize pediatric exposure duration and associated toxicological sequelae.[16]

Victims with localized radiological contamination can be decontaminated by washing the affected area with mild soap and water, but those with generalized contamination require a full shower.[14,21] Contaminated wounds containing radioactive material need to be irrigated thoroughly with sterile saline.

Zhao et al. (2016) and Reynolds et al. (2013) have suggested that retained foreign bodies should be carefully removed using forceps before proceeding with medical wound closure as indicated.[14,20]

However, the removal of retained foreign bodies should be guided by anatomical location, provider scope of practice, and clinical setting. In prehospital environments, visible foreign bodies located in **tourniquetable extremities** may be removed when permitted, ideally with hemorrhage control measures in place. On the other hand, foreign bodies located in the **neck, chest, abdomen, pelvis, or junctional regions of the extremities** should be removed in health care settings equipped for surgical intervention, due to the risk of uncontrolled bleeding following removal.

Thornton and Veenema (2015) and Lin et al. (2013) recommended continuing decontamination until radiation surveys show <0.5 mR/hr or until no further contamination is detectable.[20,46] In contrast, more recent guidance, including the Joint Trauma System Clinical Practice Guideline (2024) and Radiation Emergency Medical Management (REMM), recommends a more practical target of reducing external contamination to ≤2 times the background radiation level, with decontamination typically limited to two cycles. Additional cycles with the aim of total elimination of contamination may be unjustified and may pose a risk of skin damage.[27,47]

Age-specific decontamination strategies are critical, as children at different developmental stages exhibit varying levels of cooperation and physiological vulnerabilities. Infants and toddlers (0-2 years) should be accompanied by a caregiver whenever possible to reduce anxiety. Assistance from decontamination personnel is essential to ensure a proper and thorough process.[7,14,16] Caregivers should not carry the child during decontamination, because of the possibility of injury from a fall or dropping the child due to slippery conditions.[43,44] Holding children at this age can be challenging even for the decon team, especially while wearing chemical-resistant gloves. To reduce risk, the literature advises placing children in car seats made of plastic or other waterproof material (without the cushion), secure baskets with draining holes, or stretchers.[7,14,16] These tools help facilitate safe handling and transfer during the decontamination process. In case this equipment is not available, it is recommended that two responders handle any transfer of children in the shower. The child should be held tightly and securely, close to the body of the caregiver, with the head supported in one palm and the body straddling the arm.[7] Maintaining a patent airway is critical in pediatrics due to their large occiputs, especially in infants. Proper airway positioning must be maintained manually or through *spinal motion restriction (SMR)*.[7,16] Additionally, to reduce the aspiration risk, it's advised to place the child on their side and not face up during decontamination.[7] Young children (2-8 years) often exhibit fear and non-compliance during decontamination, requiring reassurance and structured support. They should be accompanied through the shower by a caregiver or trained responder to ensure proper and thorough decontamination.[17,20] Older children and adolescents (8-18 years) are generally capable of self-decontamination but require privacy considerations to improve compliance.[17,20,44]

On the other hand, the reviewed studies acknowledged that caregivers may not be able to decontaminate themselves and their children at the same time. Assistance from a trained responder to perform decontamination is indicated in these cases.[7,16] This logistical challenge remains unresolved in current pediatric CBRN response planning and raises concerns about the feasibility of current guidelines during mass casualty events.

Non-ambulatory children of any age group will require specialized handling during decontamination due to their inability to walk or maintain airway protection. These children must be disrobed by trained decontamination personnel, placed on a stretcher, and either escorted through the shower system or hand sprayed.[16] Maintaining airway patency is critical, as the child cannot protect their airway during the process. For school-aged children, scoop-style stretchers may be used to maintain a lateral position, although their weight necessitates more personnel for safe handling. To improve efficiency, conveyor-like roller systems compatible with backboards or scoop stretchers can facilitate smoother patient movement through decontamination zones.[7]

Post-Decontamination Considerations

Post-decontamination care for children should address drying and warming, medical reassessment, psychological support, identification, family reunification, and final discharge. Addressing warming protocols is essential during and post-decontamination to decrease the risk of hypothermia. This includes keeping the decontamination and post-decontamination zone warm by using an air-warming system, overhead heat lamps, radiant warmers, and heated blankets such as foil-type blankets.[7,14–20,22–24]

Medical reassessment is another important aspect of post-decontamination care, including re-triage, contamination checks, and monitoring for delayed symptoms.[8,15,17,19,23,24] Rapid identification of radioactive materials using dosimeters and spectroscopy tools ensures safety.[14,15,19,20,22,48] If internal radiological contamination is suspected, bioassay testing such as nasal swabs, urine/stool sampling, or whole-body counting is advised.[14,15,22]

Pediatric Special Considerations

Children with special needs, such as developmental delays, cognitive impairments, or dependence on medical equipment, require tailored approaches during decontamination. These children may need extra time, short and simplified step-by-step instructions, and non-threatening techniques to avoid sensory overload.[16,49] This is particularly important in children with autism spectrum disorder (ASD), who may show behavioral outbursts when they are overwhelmed by bright lights, loud sounds, unfamiliar surroundings, and physical contact.[50,51] Partnering with caregivers is essential in children with special needs, as they best understand the child's triggers and coping strategies.[7,16,51] Equipment-dependent children (e.g., with ventilators, hearing aids, insulin pumps) pose unique risks; devices should be inspected and decontaminated appropriately or replaced when needed.[16]

Decontamination can be highly stressful for children, with both immediate and long-term psychological impacts.[14,16,18] Their heightened vulnerability is due to cognitive immaturity and limited understanding of threats, which can be exacerbated when separated from caregivers, exposed to unfamiliar personnel in PPE, and disrobing and showering in front of strangers.[7–9,14,16–20] Smaller children are more prone to fear and panic and may resist the decontamination process.[6,14,31]

Children respond to stress differently,[7,8,18] this can manifest as fear, stress, panic, and separation anxiety.[7,8,16,18,22–24] In some

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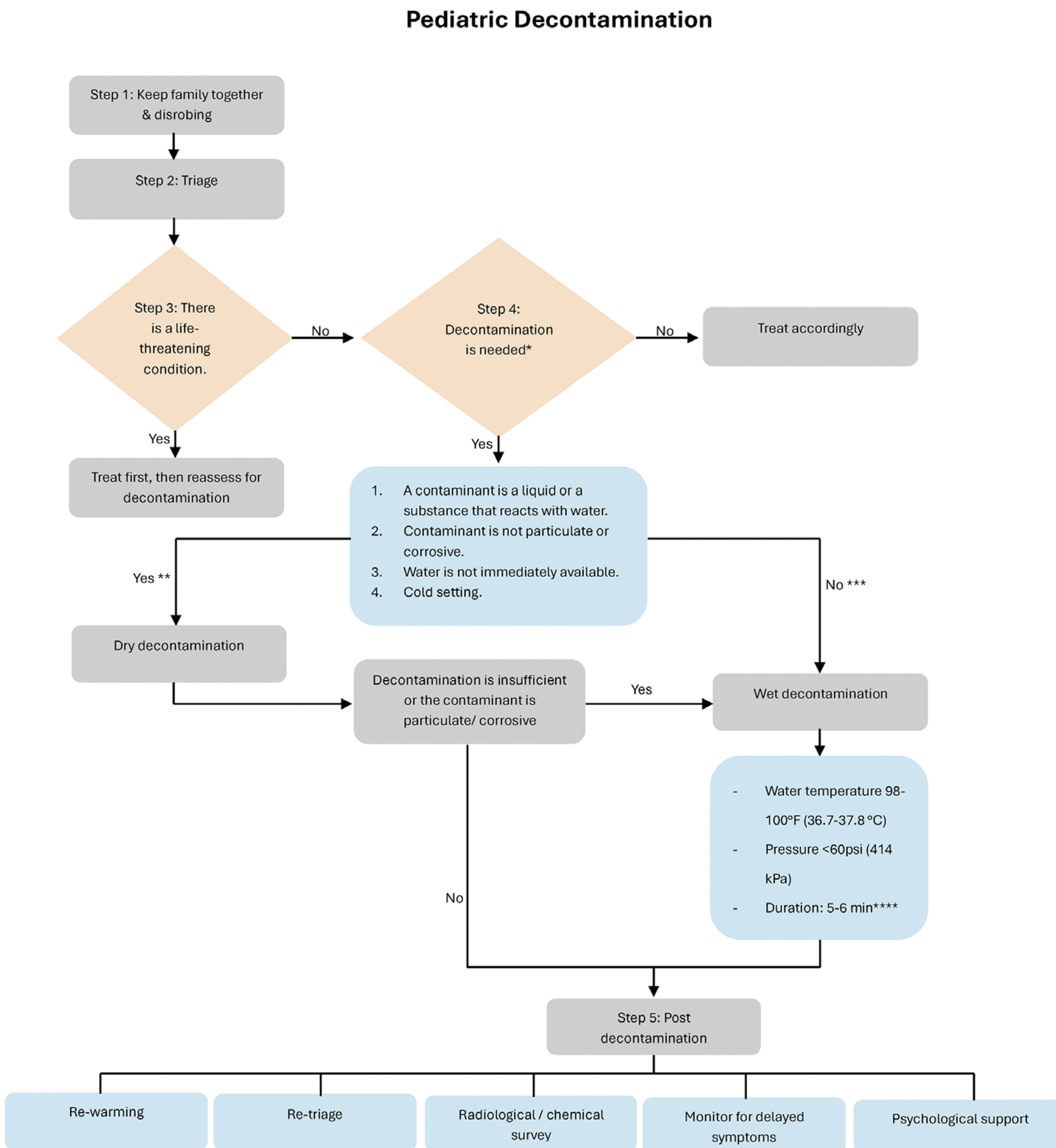

* Vapor / gas contaminants decontamination usually not indicated.
** Answer yes to any of the list
*** Answer No to all the list
**** The duration of decontamination extended in case the contaminant is corrosive or nerve agent to a minimum of 8-10 min.
***** Maintaining warmth of the decon zone by using air-warming system, overhead heat lamps, and radiant warmer. Also, use a warm blanket, such as a foil-type blanket.

Figure 2. Pediatric decontamination algorithm for CBRN mass casualty incidents.

Figure 2. This synthesized framework algorithm outlines a stepwise approach to pediatric decontamination in CBRN events, based on thematic analysis of 14 studies included in the scoping review. It incorporates key stages in pediatric decontamination and highlights the critical pediatric considerations such as hypothermia prevention, psychological support, and caregiver involvement.

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cases, long-term psychological trauma may develop, including PTSD,[7,8,14,16,20,22] or more subtle behavioral manifestations, such as regression or somatic symptoms. They may require long-term follow-up and access to mental health support.[16,52]

Clear, age-appropriate communication and caregiver involvement with social workers and child life specialists help reduce distress and improve cooperation.[14,18,20] When children can't be with their caregivers, support from trained professionals knowledgeable about pediatric issues, such as social workers or mental health specialists, can provide comfort and reassurance.[7,16,18] Early family reunification, with a designated reunification zone and offering regular caregiver updates, is key to emotional recovery.[53] Maintaining family unity during the decontamination process significantly reduces distress and improves overall cooperation.[7,14,20]

Effective communication with children in high-stress environments is difficult, especially when responders are wearing their full PPE, as this can be terrifying to children and inhibit clear verbal instruction.[3,16,24,54,55] Short, simple instructions along with visual aids and demonstrations, such as posters or cartoon videos and hand signals, are essential to ensure compliance.[16,18,22] Turning off loud monitoring alarms can further reduce anxiety.[22] Preschool and school-aged children benefit from seeing their friends also undergo procedures.[22]

To integrate findings across the pre-decon, decon, and post-decon phases, a consolidated pediatric decontamination algorithm was developed based on the thematic synthesis of the included studies (Figure 2).

An integrated stepwise framework for pediatric decontamination during CBRN events, synthesized from the thematic analysis of the 14 included studies, is presented in Figure 2. The algorithm begins with pre-decontamination triage and initial disrobing, which can help to remove up to 85-95% of contaminants, emphasizing the prioritization of life-saving interventions when necessary. It progresses through decision points of whether decontamination is indicated, and, if indicated, what methods should be used, dry or wet decontamination, based on contaminant type, available resources, and pediatric-specific vulnerabilities like hypothermia risk.

The framework considers key age-appropriate considerations at each phase, including maintaining caregiver presence when feasible, adjusting water temperature and pressure for physiological safety. It also addresses post-decontamination priorities, such as rapid warming, reassessment for residual contamination, and psychological support. By consolidating disparate recommendations across studies, this algorithm provides a systematic, child-focused approach that can help the responders provide safer and more effective pediatric care during CBRN events. Testing the pediatric decontamination framework during simulated and real-world settings can help validate the framework and assist in the future development of standardized decontamination guidelines.

Study Limitations

This review is limited by the small number (n = 14) of pediatric-specific studies on decontamination, as most studies focus on adult populations. Variability in decontamination guidelines and study settings affects the direct comparisons and leads to limited generalizability of results. Another limitation is the large proportion of research conducted in high-resource countries, often the US and Canada, which may not accurately represent low-resource or conflict-affected settings where pediatric needs and CBRN threats differ. Furthermore, non-English studies were excluded because of resource constraints, which may potentially exclude relevant international data. Finally, grey literature and non-peer-reviewed materials, including government manuals, operational guidelines, and training documents, were excluded from the formal analysis to maintain methodological consistency.

Conclusion

This scoping review identified important gaps regarding pediatric decontamination during CBRN events. Most existing decontamination processes are adapted from adult guidelines, which may not sufficiently consider the physiological and psychological vulnerabilities of children, including hypothermia risk, decontamination of pediatrics with their caregivers, and special needs populations.

The most frequently used method in the pediatric approach is wet decontamination; however, dry and hybrid methods may offer advantages, especially in addressing hypothermia. Using child-friendly techniques, such as a low-pressure system at ≤60 psi (414 kPa) and warm water with a temperature between 98 and 100°F (36.7 and 37.8°C), is essential to ensure both safety and cooperation.

The involvement of caregivers, social workers, and child life specialists, along with the use of age-appropriate communication tools, can significantly improve compliance and emotional resilience during the decontamination process. Despite these strategies, there is a lack of standardized, pediatric-specific guidelines that address age, cognitive development, and special needs. To address these gaps, we have created a pediatric decontamination algorithm (Figure 2) that synthesizes current evidence into a structured, child-centric approach for CBRN mass casualty events. Future research should focus on testing and validating this algorithm in simulated and real-world settings to improve pediatric preparedness and response. Additionally, future research should focus on the optimization of hybrid decontamination strategies, the development of evidence-based guidelines for pediatric decontamination addressing special needs populations, and psychological impacts.

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Author contribution

- **Eman Alshaikh (EA):** Conceptualization, methodology, literature search, data extraction, writing, visualization (Algorithm Design), writing—review and editing the manuscript.
- **Fadi Issa (FI):** Supervision, writing, review, and editing the manuscript.
- **Attila J. Hertelendy (AH):** Supervision, review, and editing the manuscript.
- **Terri Davis (TD):** Screened articles and reviewed the manuscript.
- **Jamla Rizek (JR):** Screened articles and reviewed the manuscript.
- **David DiGregorio (DD):** Conceptualized the study and reviewed the manuscript.
- **Ejemai Eboreime (EE):** conceptualized the study and reviewed the manuscript.
- **Janice Y. Kung (JK):** Search strategy development and reviewed the platform setup.
- **Amalia Voskanyan (AV):** Conceptualized the study and reviewed the manuscript.
- **Gregory Ciottone (GC):** Senior supervision, edited the manuscript, final review, and approval of the manuscript.

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