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Designing a model for hospital preparedness against chemical weapons of mass destruction terrorist incidents: a mixed-method study

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Abstract

Introduction Health systems play a pivotal role in managing chemical weapons of mass destruction (WMD) terrorist incidents, particularly in reducing casualties and facilitating crisis management. The growing recognition of the need for precise and effective preparedness in these sectors underscores the importance of this research. The present study aimed to identify the essential components of hospital preparedness and to develop and validate a comprehensive model for hospital readiness in response to chemical WMD terrorist incidents.

Methods This study was conducted in 2025 using a three-phase exploratory sequential mixed-methods approach. First, a scoping review was conducted in accordance with Arksey and O'Malley's methodological framework and the PRISMA guideline to identify key components of hospital preparedness for chemical WMD terrorist incidents. Second, a qualitative study was conducted using semi-structured interviews, and the data were analyzed through a conventional content analysis approach to further identify preparedness components. Third, the components derived from the previous two phases were integrated and validated through two rounds of the Delphi technique. Ultimately, a comprehensive hospital preparedness model was developed.

Results Following integration of the scoping review and qualitative findings by an expert panel, 88 preparedness components were identified. After two rounds of the Delphi technique, 82 preparedness components were finalized and classified into 16 subcategories and seven main categories: specialized training and empowerment; psychological support and ethical considerations; security measures; specialized clinical and therapeutic processes; optimal management of surge capacity; integrated information and communication management; and contingency strategic management and planning. Finally, based on the Delphi assessment, the proposed preparedness model was approved by the expert panel.

Conclusions Hospitals facing chemical terrorism require a comprehensive preparedness strategy encompassing specialized training, psychological support, and robust clinical systems. Effective management, intersectoral

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coordination, and security measures are essential for an effective response. Implementing preparedness strategies aligned with the proposed model can significantly enhance health systems' readiness and resilience to chemical WMD threats.

Keywords Preparedness model, Hospital, Preparedness, Terrorist incidents, Chemical, Weapons of mass destruction

Introduction

Terrorism remains a pervasive global threat, affecting both developed and developing countries, and is considered one of the most significant human-made hazards, causing widespread fear and societal disruption [1–3]. The increasing intersection of terrorism with weapons of mass destruction (WMD), particularly chemical weapons, has heightened international concern due to their accessibility on the black market, rising usage, and hazardous properties, including toxicity, flammability, and explosiveness [4, 5]. Although international treaties prohibit chemical weapons, the threat of chemical terrorism persists and requires ongoing attention [5, 6].

Terrorist incidents involving WMD and chemical agents impose substantial economic, social, security, psychological, and medical burdens on healthcare systems. Pre-incident preparedness is therefore essential for effective management of these critical situations [3, 7]. During crises, high patient influx can overwhelm healthcare services, and inadequate preparedness may delay lifesaving care, increase casualties, and exacerbate physical and psychological harm to patients and staff [8–10]. Numerous studies have examined hospital preparedness for chemical WMD incidents, identifying challenges such as insufficient staff training, limited personal protective equipment (PPE), and inadequate decontamination protocols, all of which undermine emergency response effectiveness [11–13]. While targeted staff training and dedicated decontamination units have been shown to improve hospital response capacity to chemical attacks [14, 15], most research has focused on specific preparedness components and has been conducted primarily in developed countries. As a result, comprehensive, context-sensitive models that address the structural, organizational, and resource constraints of hospitals in developing and high-risk regions remain lacking. Addressing this gap is critical for designing preparedness frameworks that are both feasible and applicable in these settings.

The increasing frequency of terrorist events worldwide, particularly in the Middle East [16], highlights the urgent need for a localized hospital preparedness model tailored to chemical terrorism. Although several international hospital preparedness models exist, they are often generic and do not adequately address contextual realities [3, 17]. Most frameworks emphasize natural disasters or biological threats, leaving the specific challenges of chemical WMD terrorism insufficiently explored. Furthermore, these models rarely incorporate cultural, structural, and resource-specific factors unique to individual healthcare systems, limiting their practical relevance. Developing a localized model that addresses the distinct needs of hospitals and provides new perspectives on preparedness planning for chemical terrorism is therefore essential. This study was conducted to develop a national hospital preparedness model that addresses the unique challenges posed by chemical WMD terrorist incidents and supports effective preparedness planning.

Methods

The present study employed an exploratory, sequential, mixed-methods approach across three phases. The study aimed to identify key components of hospital preparedness for chemical weapons of mass destruction terrorist incidents through a scoping review, a qualitative phase using conventional content analysis, and the Delphi technique, ultimately leading to the development of a preparedness model.

Phase 1: A scoping review

Search strategy

In the scoping review phase, conducted in 2024 and based on Arksey and O'Malley's six-stage framework [18], a comprehensive search was performed in major English and Persian databases, including Scopus, PubMed, Web of Science, Embase, Irandoc, and the Scientific Information Database (SID). Additional searches were conducted in Google Scholar and the reference lists of relevant studies. Keywords were selected using MeSH terms, related article keywords, and expert input. The search strategy was tailored for each database, and the PubMed search syntax is presented in Table 1.

Screening the studies

The Database search results were imported into EndNote software 9. Following the removal of duplicate entries, the titles, abstracts, and full texts of the remaining articles were assessed. Articles that failed to meet the inclusion criteria or were irrelevant to the research aims were excluded from the assessments. Two independent reviewers from the research team conducted all screening stages, and any disagreements were resolved through discussion and consultation with a third reviewer. The article screening procedure was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA-2020) guidelines [19, 20].

Table 1 The search strategy in the pubmed database

((preparedness[Title/Abstract] OR readiness[Title/Abstract] OR "disaster preparedness"[Title/Abstract] OR "emergency preparedness"[Title/Abstract] OR "Emergency response"[Title/Abstract] OR "hospital Management"[Title/Abstract] OR "hospital Response"[Title/Abstract] OR "medical preparedness"[Title/Abstract] OR "Surge Capacity"[Title/Abstract] OR "operational preparedness"[Title/Abstract] OR vigilance [Title/Abstract] OR "Disaster Planning"[MESH] OR "Disaster Planning"[Title/Abstract] OR "Disaster Management"[Title/Abstract] OR "Disaster Relief Planning"[Title/Abstract] OR "Emergency Care"[Title/Abstract] OR "medical countermeasures"[Title/Abstract] OR "emergency planning"[Title/Abstract] OR "victim management"[Title/Abstract] OR response[Title/Abstract] OR "hospital care" [Title/Abstract] OR "hospital preparedness"[Title/Abstract] OR "hospital readiness"[Title/Abstract] OR Resilience[Title/Abstract] OR "disaster risk reduction"[Title/Abstract] OR "DRR"[Title/Abstract] OR "medical readiness"[Title/Abstract] OR "readiness program"[Title/Abstract] OR counter-terrorism preparedness OR "medical facilities" [Title/Abstract] OR "medical facility"[Title/Abstract] OR "Health care facility"[Title/Abstract] OR "Health care facilities"[Title/Abstract]), and ("chemical terrorism"[MeSH] OR "chemical terrorism"[Title/Abstract] OR "chemical warfare"[Title/Abstract] OR "chemical warfare"[MeSH] OR "Chemical Hazard Release"[MeSH] OR "Chemical Hazard Release"[Title/Abstract] OR chemical*[Title/Abstract] OR "Hazardous Substances"[MeSH] OR "Hazardous Substances"[Title/Abstract] OR "Hazardous Material"[Title/Abstract] OR "Hazardous Chemical"[Title/Abstract] OR "Toxic Substance"[Title/Abstract] OR HAZMAT[Title/Abstract] OR "chemical Incident*"[Title/Abstract] OR "chemical accident"[Title/Abstract] OR "chemical Event" [Title/Abstract] OR "chemical occurrence" [Title/Abstract] OR "chemical hazard"[Title/Abstract] OR "chemical Threat"[Title/Abstract] OR "chemical Agent" [Title/Abstract] OR "chemical Terrorism"[MeSH] OR "chemical Terrorism"[Title/Abstract] OR chemical injuries[Title/Abstract] OR "chemical attack*"[Title/Abstract] OR chemical crisis [Title/Abstract] OR "chemical disaster"[Title/Abstract] OR "toxic material"[Title/Abstract] OR "nerve agent*"[Title/Abstract] OR "blister agent*"[Title/Abstract] OR "chemical risk*"[Title/Abstract] OR "chemical phenomenon"[Title/Abstract] OR "chemical emergency"[Title/Abstract] OR chemical catastrophe[Title/Abstract] OR chemical experience [Title/Abstract] OR chemical tragedy [Title/Abstract] OR "chemical action"[Title/Abstract] OR chemical happening [Title/Abstract] OR "nerve agent*"[Title/Abstract] OR "blister agent*"[Title/Abstract]), and ("Weapons of Mass Destruction"[Mesh] OR "Weapons of Mass Destruction"[Title/Abstract] OR "chemical weapons"[Title/Abstract] OR "Mass Destruction Weapon"[Title/Abstract] OR "Chemical Warfare Agents"[Mesh] OR "Chemical Warfare Agents"[Title/Abstract] OR Weapons[Mesh] OR Weapons[Title/Abstract] OR "weapon attacks"[Title/Abstract] OR "terrorist incident*"[Title/Abstract] OR Terrorism[MeSH] OR Terrorism[Title/Abstract] OR sabotage[Title/Abstract] OR "substance attacks"[Title/Abstract] OR WMD[Title/Abstract] OR "Terrorist attack*"[Title/Abstract] OR "terrorist event"[Title/Abstract] OR "mass casualty incident*"[Title/Abstract] OR MCI[Title/Abstract] OR "terrorism-related disaster event*"[Title/Abstract] OR terrorist accident* [Title/Abstract] OR terror[Title/Abstract]))

Table 2 Demographic characteristics of experts in qualitative phase

Work Experience			Education Level			Age			Gender		Descriptive Information
≤ 10	11–20	> 20	Doctorate	Master's	Bachelor's	≤ 40	41–50	> 50	Male	Female	
(15%)	(40%)	(45%)	(65%)	(20%)	(15%)	(15%)	(55%)	(30%)	(85%)	(15%)	**Frequency**

Extracting the data

Key information from selected articles was extracted using an extraction form that included the author's name, publication date, title, setting, study type, research purpose, and conclusions. After data extraction, the content analysis method was employed, and the results were summarized and reported [21–24]. The data were coded separately by two members of the research team.

Phase 2: Qualitative study

Study design

A conventional content analysis approach and semi-structured interviews were applied in the qualitative phase.

Study participants and sampling

In the qualitative phase, 20 experts with diverse professional backgrounds participated, including faculty members in health in emergencies and disasters, air emergency specialists, public information officers, nursing faculty members, secretaries of disaster risk management committees, nursing managers, pharmacy specialists, dermatologists, and general practitioners. Participants were selected using purposeful sampling with maximum variation to ensure a broad range of expertise and perspectives. Interviews were conducted until data saturation was achieved. (Table 2)

Inclusion criteria included adequate knowledge and experience in the field of health and chemical terrorist incidents, familiarity with hospital settings, and at least 3 years of professional experience. Unwillingness to participate in the study was considered the exclusion criterion.

Data collection

Face-to-face and online interviews, conducted with semi-structured questions, were used to collect data. If necessary, probing questions were asked to clarify the issue and focus the interview on the intended research aim. Permission was obtained to record the interviews. The time and location of the interviews were arranged in advance with the interviewees. The interviews lasted between 20 and 75 min, with an average of 45 min. An informed consent form was provided to each interviewee, along with assurances regarding the confidentiality of their information.

Data analysis

To analyze the data, the Graneheim and Lundman method was applied in this study [25]. Verbatim transcription was performed for each interview. Two researchers separately reviewed the transcripts. After extracting the initial codes and examining their differences and similarities, categories and subcategories were developed.

Rigor

Four indicators—credibility, confirmability, transferability, and dependability—were employed according to Lincoln and Guba's perspective to assess trustworthiness [26].

Step 3: Implementation of the Delphi technique for designing a model

Identifying the final components of the model from the opinion of experts

The initial components were extracted through two scoping reviews and qualitative stages. After discussing and comparing the components obtained from both stages, similar components were merged and titled according to the consensus of the majority of panel members, while repetitive components were removed. Ultimately, the final components were determined. The expert panel consisted of 10 professionals in the fields of disaster and health, selected through purposive sampling.

Validation of the components by the Delphi technique

To validate the integrated components, the Delphi technique was employed. This method systematically gathers and synthesizes expert judgments to achieve consensus on complex issues where empirical evidence may be limited [27]. The Delphi technique was selected because hospital preparedness for chemical weapons of mass destruction terrorist incidents is a multidimensional and specialized topic that requires input from experts across different disciplines. The iterative and anonymous nature of the Delphi process allows structured feedback, minimizes the influence of dominant individuals, and facilitates refinement and validation of components across successive rounds. According to the final components, a questionnaire based on two criteria (importance and feasibility) was developed and sent to 26 experts, including crisis managers, health experts, faculty members from the fields of health in disaster and emergency, and experts with a scientific and research background in the field of terrorist incidents and chemical attacks. Purposeful sampling was adopted to choose participants. The first section of the questionnaire addressed demographic information, and the second one focused on hospital preparedness against chemical weapons of mass destruction terrorist incidents' components. This questionnaire consisted of 88 questions, structured using a nine-point Likert scale (1: very low, 2: low, 3: relatively low, 4: below moderate, 5: moderate, 6: above moderate, 7: relatively high, 8: high, 9: very high). After collecting the questionnaires, median scores for each item were calculated. In the first round, components whose median score was ≥7 were accepted, those that scored a median score < of 4 were eliminated, and components with a median score between 4 and 6 entered the second round of the Delphi technique, and were approved if they achieved a median score of seven or above [28–30]. The median index was selected as the decision-making criterion rather than the mean to improve statistical validity and reduce the influence of outliers [30, 31]. SPSS version 26 software was used for data analysis.

Designing a model

Based on components from the previous stages, the research team designed a preliminary model of hospital preparedness against chemical WMD terrorist incidents. To evaluate and finalize the designed model, it was presented to 10 experts in disaster management and health, along with the model's assessment indicators. Their opinions were comprehensively reviewed and analyzed.

Ultimately, the model was approved based on seven main criteria and 16 sub-criteria, as determined by expert consensus. The cause-and-effect relationship between variables was not considered in this model.

Results

Findings of step 1: A scoping review

Following the identification of 8,604 articles in the Databases (PubMed: 1357, Scopus: 3442, Embase: 2733, Web of Science: 1072), a total of 28 articles were included in the study after screening. By reviewing those articles, components of hospital preparedness against chemical WMD terrorist incidents were extracted. Using thematic analysis and handling all phases of the scoping review, the research team identified six themes and 25 subthemes. The six main themes included organizational policies, training and evaluation, medical and therapeutic, logistics and support, decontamination and protection, and information and communication.

Findings of step 2: A qualitative study

Through conventional content analysis and 20 semi-structured expert interviews, relevant study components were identified and classified into four main categories, including human resource empowerment, psychological and ethical considerations, incident management, and specialized processes.

Findings of step 3: Implementation of the Delphi technique for designing a model

In both rounds of the Delphi process, 20 of the 26 participants completed the questionnaire. The participants' age range was 31–72 years, and their work experience ranged from 5 to 40 years. The majority of them were male (75%, 15 individuals). The Delphi process was conducted in two rounds to achieve expert consensus on hospital preparedness components for chemical weapons of mass destruction terrorist incidents. In the first Delphi round, six components with median scores below 4 were

eliminated, while 47 components with median scores of 7 or higher were accepted. The remaining components, with median scores ranging from 4 to 6, were advanced to the second Delphi round for further evaluation based on expert feedback. Following statistical analysis of the second round, all 35 remaining components achieved median scores of 7 or higher, resulting in consensus on 82 components in total. The finalized components were subsequently categorized into seven main criteria and 16 sub-criteria, forming the foundation of the proposed hospital preparedness model. Detailed results of both Delphi rounds are presented in the Supplementary Table.

The validation of this designed model was confirmed by experts. Following two rounds of the Delphi technique, the expert panel reached consensus, and the proposed preparedness model was accepted. (Table 3)

Seven main criteria including specialized training and empowerment (educational capacity building, feedback and performance improvement system, motivational and promotional strategies), psychological support and ethical considerations (development of mental health services, adherence to ethical standards), security measures (protective-control measures, crowd management), specialized clinical and therapeutic processes (optimal management of pharmaceutical-therapeutic resources, development of operational and specialized protocols), optimal management of surge capacity (organization of equipment and infrastructure, human resource management), integrated information and communication management (development of communication programs, development of communication infrastructure, development of intra- and inter-organizational collaboration, coordination and Integration), contingency strategic management and planning (identification of threats and enhancement of resilience, designing and developing operational plans). Figure 1 presents the schematic of the model. The model was created in Adobe Illustrator. Supplementary Figure provides further details.

Discussion

Overall, the findings of this study are largely consistent with the global literature, which emphasizes the importance of training, surge capacity management, communication systems, security, and clinical preparedness in hospital responses to chemical incidents. Similar components have been reported in studies from developed countries, particularly regarding the critical role of specialized training, decontamination capacity, PPE availability, and incident command systems. However, this study highlights several context-specific features relevant to the Iranian and broader developing-country context. Unlike many studies conducted in high-income settings, financial constraints, limited access to specialized equipment, insufficient laboratory capacity, and infrastructure limitations emerged as more prominent challenges. Additionally, greater emphasis was placed on psychological support, ethical considerations, cultural and religious sensitivities, and the protection of staff families, reflecting the sociocultural characteristics of the Iranian context. Compared with generic international models, the proposed preparedness model incorporates resource-related, structural, and governance factors specific to Iran's healthcare system, thereby enhancing its applicability and feasibility in developing and high-risk settings. In the following sections, these dimensions are discussed in more detail in comparison with existing evidence.

Chemical incidents are among the most common technological disasters in recent years, and hospitals, as the primary care units, play a vital role in responding to them [32]. These events pose complex challenges to health systems worldwide due to their ability to cause widespread casualties and lasting damage [6, 33–35]. Despite the increasing threats and incidents related to WMD, including chemical and radiological incidents, studies show that the level of preparedness of hospitals in Iran and many other countries remains inadequate [2, 11–13, 34]. A hospital prepared to respond effectively and promptly to terrorist incidents involving chemical weapons of mass destruction is one that, in addition to developing infrastructure and resources, pays serious attention to specific dimensions and processes [34]. Based on the findings of our study, a hospital prepared to respond effectively and promptly to terrorist incidents involving chemical weapons of mass destruction is one that, in addition to developing infrastructure and resources, pays serious attention

Table 3 Evaluation of the hospital preparedness model against chemical weapons of mass destruction terrorist incidents

Row	Assessment indicators	Strongly disagree	Disagree	Agree	Strongly agree	Score
1	Effectiveness of the proposed model	-	-	40%	60%	4
2	Simplicity (understandability) of the proposed model	-	-	60%	40%	3
3	Coherence and integration between the components of the proposed model	-	-	20%	80%	4
4	Comprehensiveness of the proposed model	-	-	20%	80%	4
5	Sequence of the components of the proposed model	-	-	60%	40%	3
6	Proportion between the components of the proposed model	-	-	40%	60%	4
7	Appropriateness of the proposed model	-	-	30%	70%	4

Score median(1) = Average, Score median (2) = Good, Score median (3,4) = Excellent

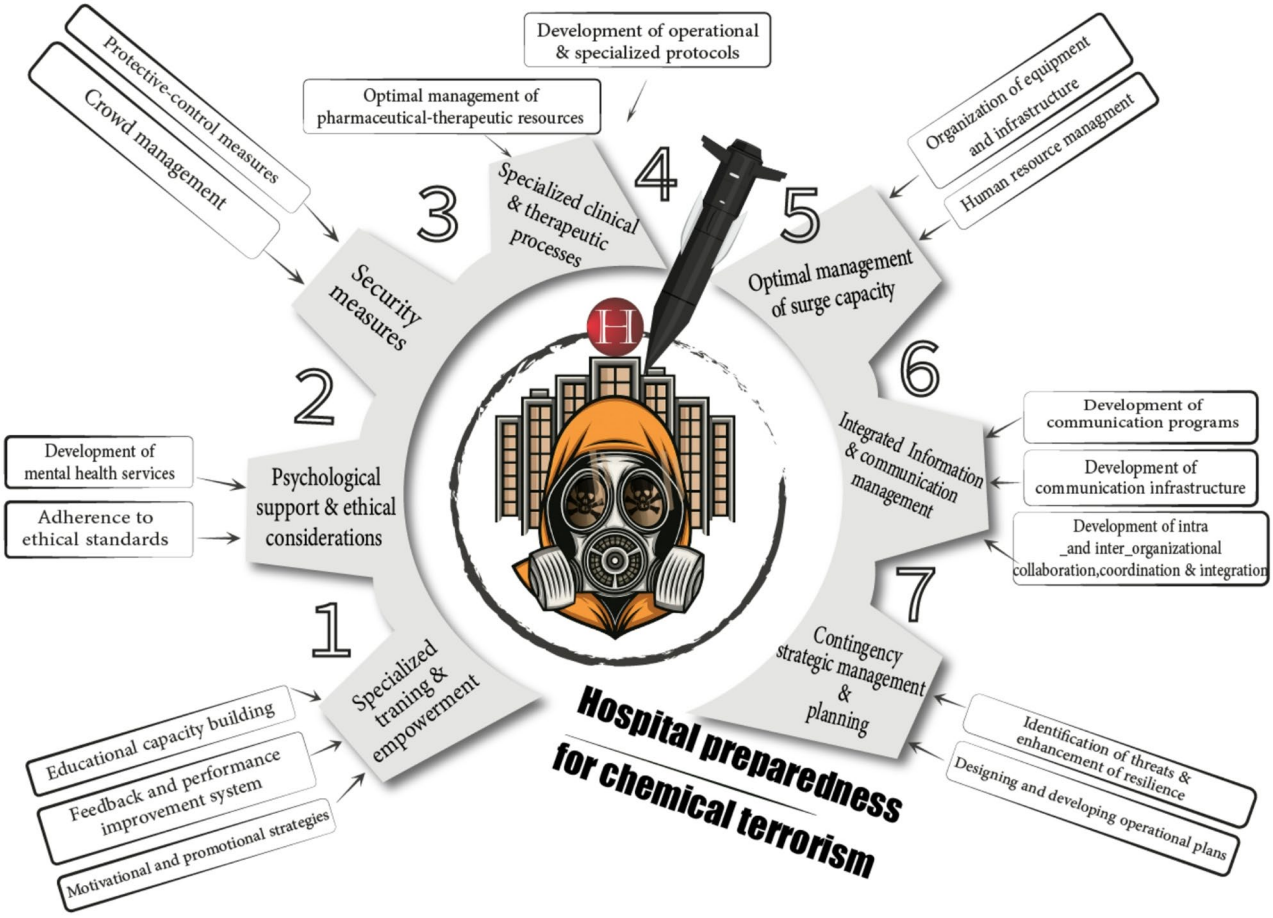

Fig. 1 The model of hospital preparedness against chemical weapons of mass destruction terrorist incidents

to specialized training and empowerment, psychological support and ethical considerations, security measures, and specialized clinical and therapeutic processes. Optimal management of surge capacity, integrated information and communication management, and strategic management and planning for contingencies, focused on identifying threats and enhancing resilience, are other vital elements of such a hospital. The integrated implementation of these dimensions maximizes the hospital's capacity to respond quickly, coordinately, and effectively to chemical crises.

Specialized training and empowerment are the foundation for effective hospital preparedness in the face of chemical terrorist incidents. Educational capacity building, including needs assessment and the creation of a continuous, structured, indigenous, and technology-based training system, can enhance staff skills. Training professional groups, including clinical and non-clinical staff, technical support personnel, clinical toxicologists, and security personnel, enhances operational preparedness in real-world crisis situations. Additionally, training non-professional groups, such as schoolchildren, students, patients, companions, and volunteers, can reinforce correct behavior during an incident. Specialized training programs in this area encompass a diverse range of skills, including raising awareness of hazards and institutionalizing a safety culture; identifying and assessing chemicals; performing specialized triage; performing decontamination; and using PPE correctly and effectively [12, 13, 36–44]. The regular implementation of training courses, whether through discussion sessions, simulated and scenario-based exercises, or real-world operations in internal and external environments, plays a fundamental role in consolidating learning. Additionally, designing and publishing educational content on social media and other online channels, as well as exchanging experiences among employees, helps strengthen the organization's knowledge capital. Establishing an evaluation and feedback system to identify strengths and areas for improvement, and utilizing motivational strategies, can significantly increase active employee participation. In line with the findings of this study, evidence from other research also emphasizes that specialized training, especially through practical exercises, plays a crucial role in enhancing hospitals' preparedness to respond to chemical incidents [13, 36, 45, 46]. Some effective strategies in

this field include adapting educational programs to meet the needs of different groups in society and incorporating specialized training in chemical threat management into medical university courses [47, 48]. In this regard, including simulations, practical field exercises, multimedia educational content, and executive instructions in the form of comprehensive, integrated educational programs has been proposed as one of the requirements for improving employee preparedness [36, 37, 49, 50]. Such programs should thoroughly cover topics such as the proper use of PPE, standard decontamination procedures, psychological crisis management, and treatment measures related to chemical trauma. Furthermore, evaluating the effectiveness of these training interventions requires methods such as performance tests, systematic collection of participant feedback, gap analysis, and review of results from exercises and simulated operations [39, 43, 45]. There is an urgent need for adequate, continuous training courses for all emergency personnel, including doctors, nurses, service personnel, and patient transporters, to increase their knowledge and awareness of incidents and of how to properly use PPE [4, 33].

Psychological and ethical dimensions are a vital complement to clinical and technical interventions. Developing mental health services, including the presence of a mental health team at the time of the incident, the provision of short-term and long-term interventions for victims, staff, and relatives, and post-incident support programs, will reduce psychological impacts. Adhering to ethical standards, such as paying attention to cultural and religious considerations and maintaining privacy, increases public trust and reduces social tension. During these incidents, emergency workers are concerned about the safety of their families and loved ones, which reduces their focus on caring for the injured [2, 33]. They may also experience adverse psychological symptoms [33]. Various studies emphasize the importance of paying attention to psychological consequences for victims and providing appropriate psychological interventions [43, 47] as well as psychological support for victims, relatives, and staff [44, 51] in improving preparedness to face these events. Providing psychological support and care systems helps reduce employee stress and burnout, as well as address the psychological effects of incidents [33, 44]. Additionally, adhering to ethical principles, such as respecting privacy, prohibiting photography, and ensuring a safe space for changing clothes, is crucial to protecting human dignity during cleanup operations. Adherence to basic ethical principles, including respect for privacy, a ban on photography, and the provision of a safe environment for changing clothes, especially when decontaminating patients who require the complete removal of clothing, plays a crucial role in maintaining human dignity during cleanup operations and emergency care [41, 51].

Protective and control mechanisms are also vital elements of managing chemical terrorist incidents. Security measures include detecting and reporting suspicious events, controlling entry and exit points, verifying clients' identities using intelligent systems, and deploying trained security personnel. Protecting sensitive equipment and supplies, being prepared for combined and multi-stage threats, and managing crowds of clients and companions are other important measures in this area. The security of hospitals and staff against secondary terrorist attacks or overcrowding is inadequate and requires cooperation with police and security forces for crowd control and protection. Additionally, measures must be taken to track staff on duty and ensure their safety at the scene [11, 33].

Specialized clinical and therapeutic processes include the optimal management of pharmaceutical resources and specialized equipment, the development of specific therapeutic and clinical protocols, the formation of triage and decontamination teams, and the strengthening of laboratory infrastructure for the rapid identification of chemical agents. These measures ensure the integrity of the treatment response and reduce intervention time, thereby increasing the overall effectiveness of medical responses. To achieve this effectiveness, it is essential to use standard clinical protocols that are adaptable to specific circumstances while maintaining sufficient flexibility. In addition, the establishment of specialized treatment centers and the use of treatment algorithms tailored to the type of chemical agent, including nerve agents or corrosive substances, have been recommended as effective solutions in various studies [37, 39, 44, 46, 52–56].

Optimal management of surge capacity is particularly important, as hospitals often face patient volumes exceeding capacity during crisis situations. Organizing equipment and infrastructure includes establishing fixed and mobile decontamination facilities, quarantine spaces, separate entry and exit routes, ventilation and air-purification systems, and defense systems. Additionally, human resource management, continuity of critical facilities, management of contaminated waste, transportation, and bed allocation are key indicators in this area.

Hospitals' ability to quickly increase capacity (beds, staff, and equipment) in large-scale incidents is limited [2, 11, 57], including rapidly evacuating existing patients, creating temporary treatment spaces (such as hallways or parking lots), and mobilizing additional staff [57]. It is worth noting that the lack of sufficient financial resources to purchase Chemical, Biological, Radiological, and Nuclear (CBRN) personal protective equipment and to equip hospitals in general is the primary factor contributing to neglecting proper preparedness [9, 51]. Hospitals are reluctant to spend large sums on low-probability incidents, and government financial support is essential [51]. Many hospitals lack adequate infrastructure for the triage

of infectious patients, including isolation and decontamination areas with special showers, as well as proper ventilation systems and effective waste and sewage management [2, 4, 57]. Most hospitals also lack adequate diagnostic laboratory services for analyzing and identifying chemical or biological agents, and need to strengthen their laboratory capabilities. Therefore, the government should ensure adequate financial support to equip hospitals and provide appropriate physical infrastructure (such as isolation and decontamination spaces) [11, 33, 51]. Providing adequate decontamination space in various weather conditions, especially cold, and creating rest areas for personnel in hot environments is essential to prevent heatstroke. Environmental conditions should also be considered during mass triage, and vulnerable groups, such as chronically ill patients, the elderly, and children, should be identified [58, 59]. Various studies emphasize the need for planning tailored to employees' needs and for providing appropriate interventions in the event of chemical incidents to enhance response preparedness [12, 51, 56]. Also, in the process of developing hospital preparedness operational plans, special attention to chemical terrorist incidents has been raised as an essential requirement [13, 41, 51]. Total hospital capacity, bed occupancy rate, availability of critical equipment such as ventilators and defibrillators, and detailed staffing levels, including the number of physicians, nurses, and emergency department readiness, are essential for enhancing awareness and strengthening hospital preparedness for chemical terrorist incidents [60].

Effective and accurate communication in response to emergencies, especially chemical terrorist incidents, directly impacts the quality and efficiency of the response. To this end, it is essential to develop communication plans that include clear frameworks, emergency command centers (EOCs), emergency statements, the designation of official spokespersons, information sharing systems, dedicated telephone lines, and secure networks. Additionally, strengthening intra- and inter-agency cooperation and coordination through memoranda of understanding, as well as the use of public facilities in emergencies, enhances the efficiency of the response. The lack of sufficient cooperation and coordination at the intra-departmental, intra-organizational, and inter-organizational levels is a major obstacle [9, 33]. Multi-layered coordination with relevant organizations, such as the police, fire department, and Red Crescent, as well as with pre-hospital emergency services, is essential [2, 57]. Effective and integrated information and communication systems are also needed [33].

Crisis-specific communication systems and defined information protocols, both at the intra- and inter-organizational levels, are key factors for an effective response in emergency situations [43, 47]. In addition, public health advisories related to chemical exposure should be communicated to the public through multiple and multifaceted channels, including emergency alerts, mass media, and other communication tools, so that critical information such as early symptoms, protective measures, and access to facilities is communicated widely and quickly [55, 61].

Contingency strategic management and planning develop preventive approaches and operational plans appropriate to critical situations. Measures include assessing the structural, non-structural, and functional risk and vulnerability of the hospital, identifying strengths and weaknesses in mass casualty management, planning to identify and deal with chemical agents, using Geographic Information Systems (GIS), forming specialized teams to evaluate and continuously improve systems, including preparedness requirements in hospital accreditation, and encouraging investment in disaster preparedness.

Hospitals face challenges such as inadequate crisis management, insufficient comprehensive and operational planning, and a lack of specific frameworks, guidelines, or standards for passive defense [9, 33]. Additionally, existing plans are often unsatisfactory and not fully implemented, so it is necessary to develop comprehensive, operational plans based on hospital capacities, assign responsibilities, and establish specific protocols and roadmaps [33]. In this regard, the design and development of operational plans include the development of a comprehensive Emergency Operation plan (EOP), a Hospital Incident Command System (HICS) for chemical incidents, hospital leveling, budget planning and management support, management of surgeries and intensive care, provision of services to specific groups, management of deceased and contaminated bodies, continuity of vital arteries, a casualty information recording system, triage cards, and documentation of actions (After Action Report). This combined approach covers both preventive and operational response dimensions and increases the hospital's resilience and efficiency in the face of chemical terrorism incidents. An incident command system must be established before incidents occur. Departmental responsibilities should be clearly defined to facilitate an effective response and maintain staff safety. This approach ensures unity of command and optimizes resource utilization [4, 34]. Teymouri et al. (2022) also identified challenges, including structural deficiencies, a lack of specialized equipment, inadequate decontamination facilities, and poor adherence to operational standards. The study emphasizes the need to strengthen infrastructure and provide sufficient funding for the purchase of personal protective equipment. In addition, the role of policymakers' support in developing facilities and formulating operational plans is also considered [62].

Strengths and limitations of the study

This study presents a comprehensive, context-sensitive model for hospital preparedness against chemical terrorist incidents, specifically tailored to the Iranian and broader developing-country context. The model incorporates key dimensions, including specialized training and empowerment; psychological support and ethical considerations; security measures; specialized clinical and therapeutic processes; optimal surge capacity management; integrated information and communication management; and contingency strategic management and planning. The use of an exploratory sequential mixed-methods design—comprising a scoping review, qualitative content analysis, and the Delphi technique—facilitated a thorough literature review and structured validation through expert consensus. The systematic involvement of multidisciplinary experts throughout the Delphi process further strengthened the model's scientific rigor and practical applicability.

Several limitations warrant consideration. The Delphi panel consisted solely of national experts, which may restrict the generalizability of the findings to other countries or healthcare systems. Additionally, the model has not yet been empirically tested in real chemical incidents or large-scale simulation exercises, leaving its practical effectiveness unverified. Implementation of certain model components may also depend on resource, infrastructure, and equipment availability, which can vary among hospitals.

Conclusions

Hospital preparedness for chemical terrorist incidents necessitates a comprehensive approach that extends beyond infrastructure and equipment. Essential elements include ongoing specialized training, psychological and ethical support, development of clinical protocols, surge capacity management, and coordinated internal and external communication. Government policy and financial support are also critical for strengthening resilience. The implementation of integrated and intersectoral strategies can substantially enhance hospitals' capacity to respond effectively and efficiently to chemical emergencies.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Author contributions

Zoha Dorri and Samaneh Mirzaei: Conceptualization, Data collection, drafting of the manuscript. Leila Mohammadinia, Zoha Dorri and Samaneh Mirzaei: Study design, Methodology, Supervision. Zoha Dorri: Data analysis, Interpretation of results.Farzan Madadizadeh: Statistical analysis, Validation. AbbasAli Dehghani Tafti, Azadeh Fatehpanah: Critical revision of the manuscript, Project administration. Zoha Dorri and Samaneh Mirzaei: Literature review, Editing and proofreading. All authors contributed to the study, read, and approved the final version of the manuscript. The authorship criteria for each author were met according to the recommendations of the International Committee of Medical Journal Editors, which read and approved the final version.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethical approval

This doctoral dissertation received ethical approval from the Ethics Committee of Shahid Sadoughi University of Medical Sciences in Yazd (IR.SSU.SPH.REC.1403.073) and was conducted in accordance with the ethical principles of the Declaration of Helsinki. The authors affirm that no data fabrication, duplicate publication, or plagiarism occurred during the conduct of this research. A component of the developed model is publicly accessible at https://share.google/nhX4kK04jdR7BSjZa.

Consent to participate

Verbal informed consent was obtained from all individuals prior to their enrollment in the study. Trained research staff provided detailed explanations regarding the study's purpose, procedures, potential risks and benefits, and participants' rights, including voluntary participation and withdrawal at any time without penalty. The assigned investigator documented both the verbal consent and its confirmation in the research log.

Consent to publish

Not Applicable.

Competing interests

The authors declare no competing interests.

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