# Hospital-Based Preparedness Measures for CBRNE Disasters: A Systematic Review

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**ABSTRACT:** Chemical, Biological, Radiological or Nuclear and Explosive (CBRNe) disasters have historically caused significant fatalities and posed global threats. The inadequate preparedness of hospital equipment for CBRNe incidents underscores the urgent need for hospitals to modernize and standardize their equipment to effectively manage these high-risk situations. The purpose of this systematic review was to examine hospital-based preparedness measures for CBRNe incidents. The PRISMA guidelines were followed for this review. A comprehensive search of English-language peer-reviewed literature from January 2010 to 2023 was conducted, identifying 2191 items from PubMed, ScienceDirect, EBSCO, and Google Scholar. The modified ROBINS-I instrument was used to assess bias, ensuring the reliability and validity of the studies. Data synthesis was conducted jointly by both authors. After eliminating duplicates and reviewing abstracts, 124 studies remained. Upon full-text examination, only 20 studies met the criteria for inclusion in this review. The review identified three key interrelated domains of preparedness: personal, technological, and structural measures. Most studies emphasized decontamination, Personal Protective Equipment (PPE), and detection, while the management of deceased bodies, transportation, and Points of Dispensing (PODs) were largely overlooked. These findings may assist hospital administrators and policymakers in enhancing their facilities' readiness for CBRNe emergencies.

**KEYWORDS:** CBRNe, hospital-preparedness, readiness, disasters, hazard vulnerability, risk assessment

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## Introduction

Globally, disasters are increasing with more devastating consequences than before.[1,2] Disasters are categorized into two types: man-made and natural. While literature on natural disasters is abundant, this review will focus on man-made disasters.[3] Chemical, Biological, Radiological, or Nuclear and Explosive (CBRNe) threats represent man-made incidents, accounting for an average of 35% of all community disasters.[4] Although CBRNe disasters have been reported for many years in emergency event databases, they receive less attention from the scientific community. Whether deliberate or accidental, these disasters can have harmful effects on communities.[5]

The deliberate type involves weaponized materials that can be delivered using various methods, including improvised explosive materials (IEDs), artillery shells, or bombs. Accidental disasters, on the other hand, involve non-weaponized CBRNe incidents, such as the release of hazardous industrial materials and substances that pose ecological dangers to living organisms.[6] Accidental disasters can also include foodborne pathogen and may be linked to the re-emergence of highly contagious diseases.[7-9]

Throughout history, many CBRNe disasters, both deliberate and accidental, have killed numerous people and posed global threats. Examples include the Fukushima and Chernobyl radiological incidents, the Seveso chemical incident, the planned release of sarin gas in Japan, and biological events such as the 2001 anthrax attacks in the United States.[10,11] The number of casualties from CBRNe disasters can range from a few individuals to entire populations.[12] The harm inflicted on casualties can be complex and multifaceted, including etiological, chemical, mechanical, thermal, or radioactive effects.[13] The burden is further intensified when decontamination—removal of contaminating agents—must take place near or even within hospital grounds.[14] As a result, responding effectively and efficiently to these events has become a critical public health issu.[12]

The impact caused by CBRNe incidents has disaster potential, making preparedness essential, particularly for healthcare systems.[15] Disaster preparedness involves planning protective actions that will occur immediately before, during, and after any type of incident, including CBRNe disasters.[9] Both hospital preparedness and staff readiness are necessary to effectively manage major emergencies and disasters, including CBRNe events.[16] During such disasters, hospital staff will have an expanded role that exceeds the standard of care.[17] To be properly prepared, they must have sufficient knowledge and skills to minimize the impact and mitigate the negative consequences of these disasters.[18]

Hospital staff are critical responders who identify and initiate action against potential or actual CBRNe threats, especially those working in emergency departments (EDs).[19] All CBRNe casualties exhibiting symptoms should be seen by physicians capable of diagnosing and managing them.[7] In terms of decontamination, hospital staff must be trained to use the necessary equipment, including proper use of Personal Protective Equipment (PPE).[20] Nurses, as the largest professional group in the healthcare sector, play a crucial role in managing

casualties and must therefore be skilled in providing care for the affected individuals and families.[21] A high degree of skill and dexterity is required to perform lifesaving medical interventions, even before decontamination, meaning these actions must be carried out while wearing PPE.[22]

Several studies have highlighted the need for specific preparation for CBRNe disasters.[5,23-25] A scoping review conducted by Skryabina et al,[16] analyzed published studies that described how regular exercises improve staff preparedness, including those related to disasters. It was reported that fewer publications focused on training hospital staff for chemical and radiological events, while many papers discussed training for biothreats. Additionally, the review identified the need for more incident-specific training and continuing education, particularly in areas such as response protocols, triage, and decontamination procedures.[16] Furthermore,a 2019 Delphi study classified effective measures for radiation or nuclear incidents in hospital emergency departments, categorizing them under staff, equipment, and system preparedness.[5] The purpose of this systematic review was to examine hospital-based preparedness measures for CBRNe incidents. The findings can help hospital administrators and policymakers enhance their hospitals' readiness for responding to CBRNe disasters.

## Methods

### *Design*

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. PRISMA serves as a tool for screening and extracting information from relevant scientific studies in systematic reviews. The registration number for this review in PROSPERO is CRD42024585258.

### *Inclusion and exclusion criteria*

The studies included in this systematic search were obtained by following the steps proposed by Tawfiq and his colleagues for conducting systematic reviews incidents.[26] Additionally, the Population, Intervention, Comparison, and Outcome (PICO) tool was used to formulate a clear research question for this quantitative study. However, since this study was conducted without a comparison group (C), only P (Population), I (Intervention), and O (Outcome) were used to develop the research questions aimed at identifying effective factors in hospital-based preparedness for CBRNe incidents.[26] (1) The population considered in this review included healthcare facilities, hospitals, and emergency departments. (2) For the intervention, terms such as CBRN Disaster, CBRN Emergency, CBRN Accident, CBRN Incident, chemical incidents, radiological and nuclear incidents, biological incidents, CBRN, CBRNe, or CRN were included. (3) For the outcome, all literature addressing Readiness or Preparedness was considered.

The inclusion criteria for studies in this review were based on the study population, date, and study design. Articles were considered if their aim was to investigate factors required for hospital-based preparedness for CBRNe incidents or if they addressed the formulated research question. Studies were excluded if they were not in English, not full-text, focused on CBRNe preparedness in a prehospital setting, or were review articles, including systematic and scoping reviews.

### *Search strategy and studies selection*

To identify relevant studies, a systematic search was conducted in English-language, peer-reviewed articles published from January 2010 to December 2023, aiming to address the research purpose of this study. Titles and abstracts were searched in databases using keywords including "hospital" OR "emergency department," "CBRN Disaster" OR "CBRN Emergency" OR "CBRN Accident" OR "CBRN Incident" OR "chemical incidents" OR "radiological and nuclear incidents" OR "biological incidents" OR CBRN OR CBRNe OR CRN AND Preparedness. Boolean operators (AND, OR) were used separately or in combination with other keywords to refine the search results, allowing for the expansion, blending, or exclusion of particular terms to filter the findings effectively.

The titles of studies that fit the inclusion and exclusion criteria were initially reviewed. Studies relevant to the research question were then selected for further screening based on their abstracts. Next, the full text of the eligible studies was assessed for more in-depth screening. Finally, studies that focused on hospital-based preparedness for CBRNe disasters were selected. Initially, 2191 articles were retrieved from various databases, with 239 from PubMed, 177 from Science Direct, 45 from EBSCO, and 1730 from Google Scholar. A complete list of references from all papers was prepared in the next step. The titles were reviewed by the researchers, and papers unrelated to the study's purpose were eliminated. All search procedures were repeated to increase confidence in the results. Reference management was conducted using EndNote 21.

### *Data extraction*

The necessary data from the retrieved papers was extracted into an annotated table on Microsoft Word. This table captured the study title, author(s), countries, study design, study sample, and findings, as outlined in Table 1.

### *Risk of bias*

This systematic review addressed study bias using a multidimensional approach. We adapted the ROBINS-I instrument to account for the specific characteristics of non-randomized emergency preparedness studies, ensuring the reliability and validity of the included studies.[43] Confounding variables,

**Table 1.** Breakdown of the information in the included studies.

| | TITLE | PURPOSE | COUNTRY | DESIGN | SAMPLE | RESULTS | CITE |
|---|---|---|---|---|---|---|---|
| 1 | Hospital Emergency Readiness Overview Study | To examine Canadian emergency department preparedness at organizational level. | Canada | Cross-sectional descriptive study | 34 Hospitals that participated in the Hospital Emergency Readiness Overview | Risk assessment, General disaster preparedness, Bio-event preparedness, availability of equipment, and antidote availability | Kollek and Cwinn[27] |
| 2 | The identification of competencies for an NHS response to chemical, biological, radiological, nuclear and explosive (CBRNe) emergencies | To gain consensus from CBRNe experts and others to identify potential future CBRNe emergency planning competencies for hospital staff in UK | UK | Delphi approach. Experts completed round 2 and one further expert completed 61 out of 64 questions. All of the 15 experts had previously completed Round 1. | A total of 14 from UK CBRNe experts including military, civil responders, Fire fighters, Police as well as hospital emergency planners. | Awareness of local and national hazards; Knowledge of chemical agents.<br>Risk assessment; dynamic risk assessment skills.<br>Emergency planning, including major incident planning, business continuity management planning and how staff can engage with those plans.<br>Resource management, mainly accessing required funds, equipment, staff and volunteers in an emergency.<br>Availability of equipment.<br>Training and exercising.<br>Education about CBRN materials and sign and symptoms<br>Communication<br>Availability of action cards<br>Chain of command.<br>Command and control.<br>Vehicles and transportation management Recovery; management of contaminated bodies and buildings. | Linney et al[28] |
| 3 | Are emergency care nurses prepared for chemical, biological, radiological, nuclear or explosive incidents? | To identify areas where nurses require training in order to improve preparedness for a CBRNe incident. | Northern Ireland | Cross-sectional study using competency questionnaire | 50 Nursing staff across three Emergency Departments within one NHS Trust in Northern Ireland. | Six main areas were identified for training including: Management of (contaminated clothing, contaminated water, and contaminated dead bodies), Triage, Chain of command, PODs, Awareness of various types of PPE, and People and equipment decontamination. | Mitchell et al[29] |
| 4 | Preparedness of Belgian civil hospitals for chemical, biological, radiation, and nuclear incidents: are we there yet? Eur J Emerg Med. 2014;21(4):296-300. | A study conducted to assess hospital preparedness of Belgian hospital for CBRN incidences | Belgium | Cross-sectional study | 38 Hospitals | A serious gap in the Belgian hospitals' preparedness for CBRN incidences. At the surveyed hospitals the following were the main preparedness measures: accident planning, staff education and training, risk perception, PPE, decontamination, medical counter measures, contamination detection, presence of infection specialists, as well as Isolation measures | Mortelmans et al[30] |
| 5 | Survey of UK Health Care First Responders' Knowledge of Personal Protective Equipment Requirements | To assess the level of knowledge regarding PPE required in delivering Advanced life care in incidents involving specific chemical and biological incidences. These PPE needed for the protection of, eye, skin and respiratory system. | UK | Descriptive cohort study using a standardized and validated questionnaire | 98 Participants fill self-administered survey, | Knowledge regarding PPE with regarding specific chemical warfare agents and biological agents.<br>Results revealed limited knowledge regarding PPE in chemical related agents in comparison to biological agents.<br>Knowledge about unusual PPE equipment, decontamination procedures, and triage training. | Schumacher et al[31] |

*(Continued)*

**Table 1.** (Continued)

| | TITLE | PURPOSE | COUNTRY | DESIGN | SAMPLE | RESULTS | CITE |
|---|---|---|---|---|---|---|---|
| 6 | Are Dutch Hospitals Prepared for Chemical, Biological, or Radionuclear Incidents? A Survey Study | To assess the chemical, biological, radiological, and nuclear (CBRN) preparedness of Dutch hospitals | Netherland | Cross-sectional study. | All 93 Dutch hospitals with an emergency department (ED) were invited. | Staff training. Hospital-specific data, hospital accident planning, risk perception. Availability of PPE decontamination units and antidotes.<br>Radiation diagnosis, infectious disease specialists, and isolation measures | Mortelmans et al[23] |
| 7 | Hospital Preparedness and Response in CBRN Emergencies: TIER Assessment Tool. | Design a tool to assess hospital preparedness and response in CBRN incidences. | EU | Delphi approach | 13 Experts from 10 countries with experience of more than 5 years in practice or research in CBRN field. | The assessment tool provides a standardized method for the evaluation of hospital preparedness and response performance with respect to CBRN emergencies.<br>Categories of CBRN preparedness include Planning and organization<br>Safety and security<br>Standard Operation Procedures<br>Communication<br>Resources and equipment<br>Decontamination<br>Medical Management | Olivieri et al[32] |
| 8 | TIER competency-based training course for the first receivers of CBRN casualties: a European perspective | To identify competencies required by hospital staff to respond to CBRN incidences, define educational needs to develop these competencies, and implement a suitable delivery method. | EU | Qualitative study | Utilizing three-step modified Delphi method 15 experts were contacted. Eleven of these—both TIER researchers and external experts—agreed to participate. | Threat identification, health effects of CBRN agents, planning; hospital incident command system, decontamination and PPE availability, information<br>Management, safety, medical management; ethical considerations and psychological counseling. | Djalali et al[33] |
| 9 | Perception of preparedness of health care professionals in case of a nuclear, chemical, biological attack/ emergency in a tertiary care hospital | Assessing the preparedness of nuclear health care professionals perception in the event of an attack or CBN accident in a hospital | Pakistan | Descriptive Cross-sectional study | 200 Physician and nurses | Access to a specialist center, access to ventilators, access to bed and laundry, access to staff program<br>The number of training courses and programs passed by staff, presence of post graduate degree staff postgraduate degree was most prepared. | Azeem et al[34] |
| 10 | Emergency Preparedness Training for Hospital Nursing Staff, New York City, 2012 to 2016 | To illustrate a CBRNe curriculum components and approaches of delivery to improve the preparedness of nurses at hospital emergency department | USA | Interventional study | 11 Nurses who were trained by three nurse educators | Hospital Incident Command Structure-Chemical terrorism events<br>Types of chemical dangers, Bioterrorism emergencies.<br>Distinguishing radiological from nuclear terrorism incidences. Health effects from CBRN, Chemical terrorism events<br>Types of chemical incidents requiring decontamination and PPE.<br>Hospital role in decontamination.<br>Forms of bombs that intentionally Used, Physiologic consequences of bomb blasts and public health role in responding to CBRN and bomb blasts. | Jacobs-Wingo et al[35] |

*(Continued)*

**Table 1.** (Continued)

| | TITLE | PURPOSE | COUNTRY | DESIGN | SAMPLE | RESULTS | CITE |
|---|---|---|---|---|---|---|---|
| 11 | Preparedness for chemical crisis situations: experiences from European medical response exercises | To evaluate surge capacity and capability bottlenecks in 2 scenarios involving chemical warfare agent | EU | Interventional study | A total of 20 first responders and hospital specialists as well as 25 CBRNe specialists from 11 countries | Triage, decontamination, patient transport, ICU availability, pharmacological treatment options, and communication.<br>Decontamination, PPE, and respiratory support of victims and equipment, medical counter meagers.<br>Lines of communications, awareness and knowledge regarding CBRN terms as hot, warm, cold zones. | Davidson et al[36] |
| 12 | Developing a model for hospitals' emergency department preparedness in radiation and nuclear incidents and nuclear terrorism in Iran | To establish a national emergency department preparedness model when incurring a radiation and nuclear Incidents. | Iran | Analytical study using Delphi approach | 32 In emergency medicine specialists, nuclear medicine, medical physics, nuclear physics, radiobiology and radiation protection | 31 Preparedness factors are categorized into three main Categories of staff, stuff, and the system structure. | Ahmadi Marzaleh et al[5] |
| 13 | Evaluation of the medical chemical, biological, radiological, and nuclear awareness level of emergency healthcare professionals serving on different centers | To evaluate and compare knowledge and experiences about medical CBRN between two centers | Turkey | Descriptive cross sectional and comparative study | 67 Experts in health care departments | Hospital risk perception and evaluation of CBRN personnel, the status of hospital decontamination wards, the use of PPE, antidotes, CBRN drills training, and demographic information Dynamic, risk assessment, communication, planning, equipment preparation, training and drills. | Eyison et al[15] |
| 14 | Chemical, Biological, Radiological, or Nuclear Response in Queensland Emergency Services: A Multisite Study | To define the preparedness status of the emergency care services in Queensland and describe the response to a CBRN incidences. | Australia | Cross-sectional study | 6 Hospital sites were participated in this study | CBRN-focused education and training<br>PPE and decontamination facility<br>CBRN PLAN and ICS<br>CBRN surveillance capacity<br>Personal dosimeters and detection devices | Mackie et al[37] |
| 15 | Preparedness toward Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) threats among healthcare personnel in Pasir Gudang, Johor, Malaysia | To evaluate the level of preparation of HCP in Pasir Gudang, Johor Bahru. There are three key principles which affected the CBRNE's preparedness such as knowledge, training, and resilience factors. | Malaysia | Cross-sectional study | 114 Participants from four governmental agencies that mandate to respond as immediate responders for any incidents in the Pasir Gudang area. | CBRNE preparedness was moderate among HCP in the Pasir Gudang area, which was significantly associated with three independent variables (Knowledge, skills, and resilience). The impact of knowledge and resilience level proved to be strongly linked to CBRNe preparedness. Progressive exposure to CBRNe knowledge with more than 5 years of working experience demonstrated an advanced level of preparedness toward CBRNe disaster. The impact of knowledge and resilience level proved to be strongly connected to CBRNE preparedness. Therefore, initiatives to improve CBRNe preparedness will provide endless CBRNe awareness. | Yahya et al[38] |
| 16 | Effects of bloom's mastery learning model based on CBRN preparedness program on learning skills of nursing students: A randomized controlled trial | This study aimed to investigate the effectiveness of a Bloom's Mastery Learning Model-based CBRN Threat and Hazards preparedness Program for nursing students as a means for improving knowledge, attitudes, self-efficacy and skills. | Turkey | A parallel-group trial design and used a pretest-posttest design. | 104 Nursing students in the 4th year were randomized into intervention and control groups. The data from the participants were collected before the intervention, immediately after the intervention and in the 1st and 3rd months after the intervention. | CBRN knowledge, attitudes to CBRN, self-efficacy and skills concerning the CBRN.<br>A significant difference was seen between the groups in terms of knowledge, attitude and self-efficacy scores. It was observed that there was a significant difference between the 1st measurement and the 2nd, 3rd and 4th measurements. This was due to the increasing scores of the intervention group ($P < .05$). The CBRN Preparedness Program is effective in increasing nursing students' knowledge, attitude, self-efficacy and skill development about CBRN dander. | Aslan Huyar and Esin[39] |

*(Continued)*

**Table 1.** (Continued)

| | TITLE | PURPOSE | COUNTRY | DESIGN | SAMPLE | RESULTS | CITE |
|---|---|---|---|---|---|---|---|
| 17 | CBRN Disaster Hospital Response and Preparedness. An Italian Civilian Military Cooperation Teaching Model | To determine the needed skills and capabilities which needed to manage these events. Emergency | Italy | Interventional study | Training program enrolled at three hospitals | The use of PPE, and decontamination procedures. Hazard recognition, response role substance identification, response roles | Rossodivita et al[40] |
| 18 | Preparedness for chemical, radiologic and nuclear incidents among a sample of emergency physicians' and general practitioners'—a qualitative study | To describe Swedish emergency physicians' and general practitioners' preparedness work procedures and competence) regarding response to chemical, radiological and nuclear incidents. | Sweden | Qualitative descriptive study using semi-structured individual interviews | 5 EPs and 6 GPs were included in the sample. | Physicians' preparedness for CRN depends on being an expert and to seek expertise involving the need for education and training.<br>The need for prehospital information.<br>The availability and distribution of extensive resources.<br>Interorganizational cooperation<br>Route of communication with other specialties<br>Competence in Physical examination and treatment of contaminated victims<br>Competence in decontamination process<br>Experience and competence in victims initial assessment, stabilization, and treatment | Gyllencreutz et al[41] |
| 19 | Chemical, biological, radiological, and nuclear preparedness of public hospitals in Riyadh | The hospital preparedness for chemical, biological, radiological and nuclear disasters at Riyadh public hospitals | KSA | Cross sectional descriptive using checklist and questionnaire | 10 Hospitals participated out of the 11 invited hospitals | Studied Basic considerations, planning, training and awareness, Methods and modules for biological, Methods and modules for chemical and Methods and modules for radiological incident preparation. | Alahmari and Khan[25] |
| 20 | Evaluation of Emergency Department Personnel's Preparedness for Chemical, Biological, Radiation, and Nuclear Emergencies | To evaluate the CBRN preparedness levels of emergency department staff | Turkey | Cross-sectional study | Volunteers of 57 people, consisting of 3 emergency medicine specialists, 16 emergency medicine research assistants, 27 nurses, 11 nursing staffs. | Decontamination Procedures<br>Hospital Disaster and Emergency Plan<br>Self-Efficacy<br>CBRN Information Awareness<br>Operation Procedure Preparation<br>Warning and Equipment Information<br>Communication Information | Biçakçi and Biçakçi[42] |

participant selection, intervention classification, variations from intended interventions, missing data, outcome assessment, and reported result were evaluated. Two researchers independently reviewed each study to minimize subjectivity, with a third reviewer resolving disputes or reaching consensus. Detailed results were documented in a "risk of bias" table. This methodological framework enabled a thorough examination of the research, identifying potential biases that could influence the conclusion regarding hospital preparedness for CBRNE emergency.

The tables also provide comprehensive evaluations of the methodological quality of the studies included in this systematic review, as measured by the risk of bias assessment results. Each study was evaluated based on predetermined criteria, including attrition bias, reporting bias, detection bias, performance bias, and selection bias. The tables highlight varying degrees of bias, with some studies showing a low risk in most domains, while others exhibited a high or unclear risk in certain areas. This variability underscores the need for careful interpretation of the review's findings, as studies with higher risks of bias may influence the overall conclusions. The results are presented in tabular form, allowing for a transparent comparison of study quality and a better understanding of the potential impact of bias on the review's outcomes.

## Results

As a result of the database searches, 2191 studies were identified. Using EndNote, 311 duplicate studies were removed. After thoroughly screening titles and abstracts, 1757 studies were found to be irrelevant to the study's purpose and were excluded at this stage. Subsequently, 124 full-text articles were assessed for detailed review. Of these, 104 studies were excluded due to inadequate methodology or lack of peer review. Studies focusing on preparedness outside of the hospital context, such as prehospital settings, were also excluded. Additionally, studies addressing internal hospital disasters, such as chemical spills, fires, or engine explosions, were excluded. Ultimately, 20 studies were deemed relevant for this systematic review, as illustrated in the PRISMA flowchart, which outlines the search and selection process (Figure 1).

The exclusion criteria for full-text studies included prehospital orientation, systematic or comprehensive review design, and a focus on disasters other than CBRNe. The included studies were conducted in 16 countries: Canada, the United States (USA), the Kingdom of Saudi Arabia (KSA), Europe (EU), the United Kingdom (UK), Iran, Austria, Belgium, Northern Ireland, Turkey, Sweden, the Netherlands, China, Italy, Pakistan, and Malaysia. All these studies focused on hospital preparedness for CBRNe incidents. Studies from Asia, Europe, North America, and Australia were also included. Notably, no studies from Africa or South America were identified. In terms of preparedness measures, the terminology used across the selected studies was nearly identical. Interestingly, 50% of the studies were conducted within the last 5 years, with 5 studies published in 2023, 2 in 2020, and 3 in 2019. The increasing global concern about CBRNe readiness highlights the significance of this systematic review.

The selected studies have employed a variety of research approaches, including cross-sectional, qualitative, interventional, and descriptive comparative research, as well as descriptive comparative research. Stratified analyses were conducted to address the heterogeneity resulting from the different study designs used in the systematic review. These analyses grouped studies based on their design types (eg, randomized controlled trials versus observational studies) to assess the independent effects of each study.

All ten investigations employed a cross-sectional design. Of these, five focused specifically on the preparedness of workers in CBRNe-related situations. A 2012 study by Mitchell et al[29] used a competency questionnaire to examine the knowledge, skills, and attitudes of hospital staff in Northern Ireland regarding events involving CBRN materials. Similarly, Azeem et al[34] investigated perception of preparedness in CBRNe incidents through a survey involving medical nurses, graduate students, and postgraduates. Yahya et al,[38] conducted a cross-sectional study in Malaysia to assess staff preparedness for CBRNe in three areas: knowledge, training, and resilience. However, a study by Schumacher et al[31] was more specific in the field of CBRNe preparedness. The researchers used a questionnaire to evaluate level of knowledge regarding PPE required when providing advanced life care support for patients contaminated with CBRN materials in specific chemical and biological incidences. The necessary PPE included equipment to protect the eyes, skin, and respiratory system. The most recent study on CBRN preparedness, conducted in 2024, distributed a questionnaire in the emergency department to evaluate staff preparedness and identify the necessary measures for responding to CBRNe incidents.[42]

The remaining five5 cross-sectional studies focused on investigating hospital preparedness. Kollek and Cwinn[27] conducted a study by emailing 315 hospital emergency departments across Canada, revealing a significant gap in the Canadian healthcare system's disaster preparedness, particularly in CBRN readiness. Mortelmans et al[23,44] conducted two studies in 2014 and 2017 in Belgium and Netherland respectively, respectively, using the same questionnaire in both cross-sectional studies. In 2020, a cross-sectional study was conducted in Kingdom of Saudi Arabia (KSA) utilizing the CBRNe questionnaire which was prepared in 2009 by the Centre for Excellence in Emergence Preparedness in Canada.[25] In 2022, another cross-sectional study enrolled in Australia by Mackie et al[37] conducted another cross-sectional study in Australia, investigating both personal capacity and hospital surge capacity in response to CBRN incidents.

The Delphi approach is the most commonly used method after the cross-sectional approach. Three of the included

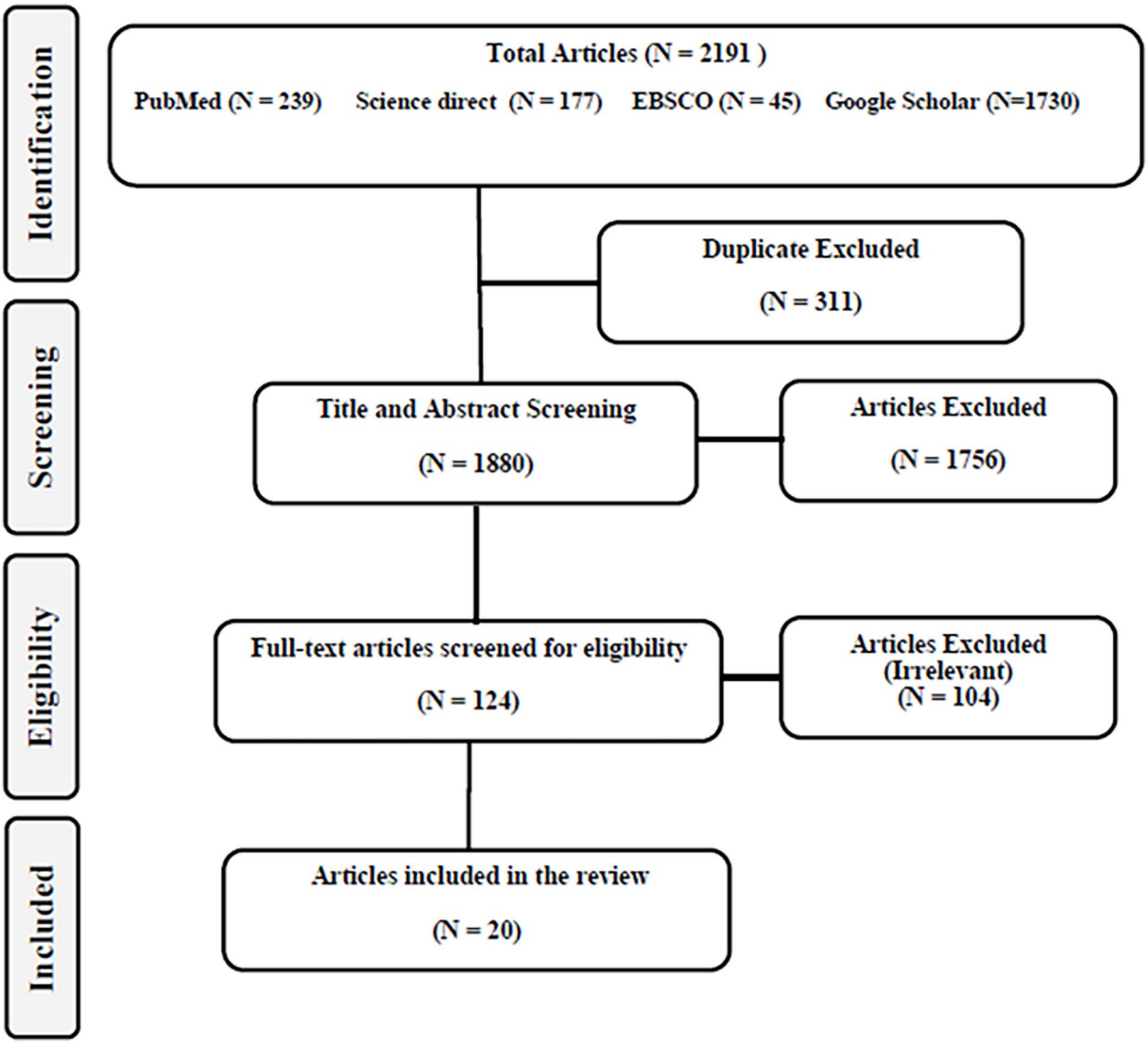


**Figure 1.** The PRISMA flowchart illustrates the search method and the selection process.

studies used the Delphi methods to examine various aspects of preparedness measures in incidences involving from CBRN materials.[28] In 2011, Linney et al[28] targeted 14 UK CBRNe experts, including hospital ED staff and planners from both military and civil responders, as well as insights of fire fighters and police to obtain a consensus on what should comprise future emergency planning competencies in CBRNe incidences for staff of UK hospitals. In 2017, Olivieri et al[32] applied the Delphi approach across Europe by gathering expert agreement from 10 countries to design an assessment tool that serves as a standardized method for evaluating hospital preparedness levels. Similarly, Marzaleh et al[5] used the Delphi approach to develop a national model for ED preparedness in nuclear and radiological incidents, incorporating 31 factors related to "staff, stuff, and system" to achieve comprehensive preparedness.

Regarding qualitative studies, Djalali et al[33] focused on identifying the fundamental competencies required for staff to optimally respond to CBRNe incidents, as well as the necessary components of a CBRNe educational program to develop these competencies. In another qualitative study, Gyllencreutz et al[41] described the components of CBRNe preparedness among ED physicians working in tertiary hospitals in Sweden. The researchers emphasized issues related to different collaboration aspects as a measures for optimal CBRNe preparedness. Althought four studies in their method section they acknowledged using interventional approaches, only one study conducted by Huyar and Esin[39] utilized a parallel-group trial design and used a pretest post-test design to investigate the effectiveness and usefulness of a mastery learning model based on CBRNe for nursing students. Their study emphasized the ability of the program to enhance nursing students' knowledge, attitude, self-efficacy, and skill development in the CBRNe field. Lastly, only one study was descriptive comparative, which compared between two centers regarding medical staff knowledge and experiences about CBRNe incidences. The study emphasized a set of preparedness measures advised for the best response of emergency responders based at hospitals. Basic information of the included studies is summarized in Table 1.

The data synthesis process was conducted by the two authors. Any discrepancies in interpretation between the reviewers were resolved through consensus, ensuring the reliability of the results. The synthesis of the included studies helped shape the domains of CBRNe preparedness measures. This systematic review focused on hospitals as the study context, where preparedness measures are essential for an optimal response. For the purposes of this review, preparedness measures were grouped into three interrelated domains: personal, technological, and structural measures, as shown in Table 2. Among the three domains, structural measures were the least frequent and least emphasized. Education and training were highlighted in nearly all the included studies, with decontamination, PPE, and detection also being underscored in most. However, transportation, Points of Dispensing (PODs), and mortality management were largely neglected, with only one study mentioning them.

## Discussion

Current levels of readiness and training for hospital personnel in relation to CBRNe incidents are notably inadequate in many healthcare settings. This review highlights the critical need for robust preparedness protocols, as many hospitals lack comprehensive, recurring training programs tailored specifically to CBRNe scenarios. This deficiency not only compromises the safety and effectiveness of healthcare professionals but also weakens an institution's ability to respond to such incidents comprehensively. Our findings reveal varying levels of preparedness, which can be attributed to factors such as unequal resource allocation, differing assessments of CBRNe risks, and the complexity of providing specialized training that covers the broad range of potential hazards.

Further examination reveals that medical facilities that incorporate routine, scenario-driven exercises and interprofessional training demonstrate a tendency for staff to be more prepared and confident when faced with CBRNe crises. Such training improves not only practical abilities but also communication and coordination between departments, which are critical during actual events.[45] The findings of this systematic review underscore the importance of implementing a consistent, ongoing training program that is regularly updated to reflect the latest advancements in response strategies and the evolving CBRNe threat landscape.

A hospital's implementation of protective measures in response to CBRNe threats underscores the critical importance of well-coordinated safety protocols and prepared infrastructure. Our review findings suggest that while many hospitals have developed initial response plans, there remains a significant gap in operational readiness and the effective execution of these plans.[11,16,46] The literature highlights that this inconsistency introduces considerable risks in the context of CBRNe incidents, which require immediate and coordinated action.[47,48] Additionally, we found that hospitals often prioritize theoretical planning over practical, real-world simulations that test these plans under stressful conditions. This approach could hinder healthcare personnel's ability to efficiently implement preventive measures during actual CBRNe events.[48]

Furthermore, the assessment emphasizes the necessity for healthcare facilities to embrace a comprehensive strategy regarding CBRNe readiness, incorporating preventive measures in addition to emergency response.[49] Enhancing hospital response capabilities can be achieved through the implementation of advanced detection and decontamination technologies, regular multi-departmental exercises, and advanced training modules. Evidence suggests that establishing specialized CBRNe units within healthcare facilities, equipped with trained personnel and specialized apparatus, can significantly improve institutional resilience. However, our research reveals that many studies highlight obstacles to these advancements, often impeded by financial and logistical constraints.[50,51] This finding suggests that additional policy and government assistance is necessary to guarantee that hospitals possess the necessary resources to efficiently handle CBRNe threats. Therefore, this systematic review advocates for a fundamental reassessment of existing approaches, suggesting that healthcare settings transition from reactive to proactive CBRNe preparedness planning.

The readiness of hospital equipment for CBRNe incidents highlights the critical need for modernization and standardization to manage such high-risk situations effectively. Our systematic review reveals significant variability in the availability, up-to-date status, and suitability of equipment across surveyed hospitals. This discrepancy could severely hinder the ability to respond effectively during a CBRNe incident.[42] Essential equipment such as decontamination units, PPE, and advanced diagnostic tools often face limitations in availability or are outdated, compromising healthcare professionals' ability to respond safely and efficiently. Additionally, numerous studies in our review indicated that the unique challenges posed by CBRNe agents could not be addressed due to the lack of specialized equipment, exposing a deficiency in hospitals' current preparedness strategies.[33,52] Moreover, the review reveals that most studies were conducted in North America, Europe, and parts of Asia, with few from Africa and South America. Regional differences in healthcare systems, policies, and demographics will likely affect the outcomes, potentially limiting the generalizability of the study findings.

## Recommendations

Given the significance of these findings, hospitals are strongly encouraged to evaluate their equipment policies and ensure adherence to international CBRNe response standards. Regular training on the operation of advanced CBRNe response equipment and prioritizing the acquisition of such tools are essential measures to maintain staff preparedness and expertise. Furthermore, the implementation of standardized equipment protocols and cooperation agreements within hospital networks could enhance overall

**Table 2.** CBRNE preparedness measures.

| | PREPAREDNESS MEASURES | REFERENCED STUDIES[A] |
|---|---|---|
| Personal | - Knowledge/awareness/education regarding CBRN education about types of bombs, knowledge about Physiologic effects of bomb blasts.<br>Skills in decontamination of people and equipment.<br>- Training/exercises<br>- Higher degrees and qualification<br>- Competence, resilience, and self-efficacy<br>- Previous experience and being expert<br>- Awareness of local and national hazards<br>- Risk perception and situation awareness<br>- Task management, cultural competency, harsh environment skills, physical endurance.<br>- Psychological support; and ethical considerations. | 1-6; 8-20 |
| Technological | - Availability of decontamination equipment, medical counter measures, antidote, and Strategic National Stockpile, ICU, laboratories, and Isolation facilities.<br>- Incident Command system (ICS)<br>- Access to a specialist center, access to ventilators, access to bed and laundry<br>- Substance identification,<br>- Availability of action cards<br>- Chain of command<br>- Command and control<br>- Decontamination facility and Decontamination Teams<br>- Waste management and management of dead bodies<br>- Detection devices and personal dosimeters<br>- Triage and PODs.<br>- Lines of communication | 1-14; 17-20 |
| Structural | - Threat identification<br>- CBRN surveillance capacity<br>- Transportation issues and management of vehicles on-site.<br>- Information management<br>- Chain of command<br>- Communication plans both Internal and external<br>- Disaster plans<br>- Security considerations<br>- Interorganizational cooperation | 2, 4, 6-8, 10, 12-14, 19-20 |

[a]Numbers refer to studies in Table 1.

readiness by ensuring that all affiliated institutions have immediate access to critical resources during a CBRNe incident. This would ensure that hospitals are uniformly equipped to respond to emergencies. This systematic review highlights the importance of adopting a comprehensive approach to managing hospital equipment, with a focus on universal standards, technological advancement, and sustainability within healthcare settings.

We recommend that new interdisciplinary research projects be undertaken to address these challenges. Policymakers should also develop standardized procedures and protocols to enhance the overall response to CBRNe incidents. Additionally, we suggest establishing a framework for feedback from healthcare practitioners and stakeholders, in line with the findings of this review. There is also a need for more research in underrepresented regions. Policymakers and stakeholders should support initiatives that fund research and projects in these areas to improve CBRNe readiness. This can be achieved by increasing funding, grants, and other resources. Furthermore, policymakers and hospital administrators should prioritize implementing targeted training programs focused on hands-on, scenario-based CBRNe response exercises. Investment in advanced detection and decontamination technologies, which have been identified as the most effective in systematic reviews, should also be a priority.

## Limitations

This systematic review of hospital CBRNe preparedness has several limitations typical of the subject matter. The diverse study designs and methodologies among the included research articles present a significant challenge. Many studies relied on self-reported data, which can introduce bias into the findings. Variations in population, environment, and levels of readiness complicate the process of synthesizing data and drawing general conclusions. Differences in hospital resources, regional perceptions of risk, and government support may limit the generalizability of the results and lead to potential distortion of findings.

Managing deceased bodies received the least attention in the reviewed studies, likely due to the ethical and legal considerations involved. The sensitivity of these issues may discourage researchers from prioritizing them. Additionally, information related to deceased bodies is often considered confidential, which can limit accessibility. Transportation and the operational efficacy of Points of Dispensing (PODs) were not addressed in detail but were rather viewed in a broader context. Most studies were highly focused and did not account for systemic logistical issues. Collecting such data requires collaboration between various agencies, including public health departments, emergency medical services, forensic science, and hospitals.

## Conclusion

This study examines the evidence regarding critical hospital preparedness measures needed for CBRNe emergencies. The comprehensive assessment of CBRNe readiness in hospital settings highlights significant public health and safety concerns. It identifies both notable strengths and critical shortcomings in the preparedness strategies of healthcare facilities worldwide. While some medical facilities have the necessary resources and protocols to manage CBRNe crises, the majority lack adequate training, equipment, and procedures. This is especially true in low-resource regions, where the study emphasizes the need for increased funding and standardized preparedness processes to improve response capabilities. Collaboration between agencies, regular comprehensive training, and equipment modernization are essential for reducing public health risks and ensuring hospitals are prepared for CBRNe incidents. Proactive and coordinated hospital preparedness requires a global standard that can be adapted to fit local resources and needs, ensuring that every hospital is equipped to manage CBRNe incidents effectively.

## Author Contributions

EQ: Conceptualization, methodology, Data Collection and Curation, writing first draft.
MA: Conceptualization, methodology, editing and writing the final draft, supervision, correspondence.

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