

A Systematic Review of the Efficacy of Full-Scale Simulation Exercises in Enhancing Hospital Disaster Preparedness

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A Systematic Review of the Efficacy of Full-Scale Simulation Exercises in Enhancing Hospital Disaster Preparedness

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Abstract—INTRODUCTION: A full-scale simulation exercise is a comprehensive drill designed to replicate a real-world emergency scenario, thereby identifying the strengths and weaknesses in current practices. The overarching goal is to enhance healthcare system resilience through improved protocols, as highlighted in this systematic review tailored for researchers. The study aims specifically to assess the impact of full-scale simulations on enhancing hospital disaster plans.

METHODS: Following PRISMA guidelines, this systematic review investigates the impact of full-scale simulation exercises on hospital disaster preparedness. The focus was on hospital staff involved in disaster and emergency preparedness training. The primary intervention was the execution of full-scale simulation exercises, and our research included various study designs, including randomised controlled trials and observational study designs. A comprehensive electronic database search was conducted, spanning PubMed, Scopus, Web of Science, and the Cochrane Central Register of Controlled Trials, from inception until October 9, 2023. The risk of bias was assessed using NIH tools.

RESULTS: The literature search yielded 2,398 results, with 28 publications finally included in the systematic review. Summarising a broad range of disaster preparedness simulation exercises with a specific focus on full-scale simulation (FSS), the studies consistently demonstrated a positive impact on participants' skills, as well as identifying safety issues in

hospital settings. Moreover, they revealed that simulations effectively addressed crucial areas for improvement in disaster response, including communication breakdowns, equipment deficiencies, and flaws in emergency plans. The studies utilised a multidimensional approach to evaluation metrics, encompassing non-technical skills, communication, teamwork, decision-making, and operational readiness. The exercises varied in duration from 30 minutes to multi-day simulations, covering a diverse range of disaster scenarios, such as mass casualties, viral epidemics, large aviation accidents, and terrorist attacks.

CONCLUSION: Full-scale simulation exercises are a preparatory learning tool to test facility and staff readiness for complex emergencies. This systematic review focused on the different exercise scenarios used to address critical aspects of disaster response, such as communication breakdowns, equipment deficiencies, and flaws in emergency plans. The scenarios and their duration were varied, and involved a multidimensional approach to evaluation. Such exercises enhance critical thinking and problem-solving skills, increase familiarity with potential emergencies, and build confidence in making judgments in real-world situations. In our opinion, there is a need for further programs that align simulation exercises with community resources for better preparedness in the face of public health disasters.

Index Terms—Disaster Preparedness; Disaster Readiness; Emergency Department; Emergency Response; Full-Scale Exercise; Full-Scale Regional Exercise; Hospital Emergency; Mass Gathering Events.

I. INTRODUCTION

A disaster is a natural or man-made occurrence that causes significant loss to human life, property, economy and environment, and disrupts the operation of the affected society or community to the point where outside assistance is required to address

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the deteriorating situation (1). In recent years, the world has seen an increase in extreme scenarios, including both man-made and natural disasters, conflicts, and societal upheavals. The Third UN World Conference on Disaster Risk Reduction in 2015 affirmed the widespread impact of such events on a global scale, resulting in more than 700,000 deaths and 1.4 million injuries. Additionally, it was projected that these calamities affected more than 1.5 billion individuals, resulting in economic losses surpassing 1.3 trillion US dollars (2,3). It is therefore critical to prioritise timely, effective, and long-term interventions for vulnerable populations. Recognising the importance of the effective management of catastrophic events will ensure greater emphasis on generating and sharing information and training in this field to assure preparedness and competence in such crucial situations (4,5).

According to the World Health Organization's Hospital and Health Facility Emergency Exercises Guidelines, there are five commonly utilised types of emergency exercise: orientation, tabletop, drill, functional, and full-scale simulation exercises (6). Simulation is a representation of real-life events and can take many forms, including computer software, case studies, written clinical scenarios, simulated patients (SPs), role-playing, or replicating reality with simple or advanced functionalities (7,8). This wide range of modalities allows for diverse and thorough simulation of real-world scenarios (7,8). Real simulation with actors has been used for almost 50 years, demonstrating its continued utility and efficacy in a variety of sectors (7,8).

Full-scale exercises are characterised by their leadership (typically conducted by controllers) and the involvement of participants across all levels of personnel (6). These exercises should simulate a realistic setting, including the activation of emergency operations centres, and their duration can range from two hours to more than one day (6). The preparation for such exercises is extensive, often requiring 1–1.5 years of development (6). This preparation includes significant time, effort, and resources, as well as the incorporation of preparatory drills, tabletop exercises, and functional exercises (6).

Full-scale simulation exercises in hospital disaster preparedness are immersive, all-encompassing drills designed to imitate real-world emergency circumstances, and involving the active participation of various hospital departments, including healthcare professionals, administrative workers, and support personnel (8–10). The scenarios are meticulously designed to simulate natural disasters, mass casualties, or infectious disease epidemics, putting the hospital's reaction and coordination capabilities to the test (11). The multidisciplinary approach ensures that teams collaborate effectively, and scenarios frequently vary to measure adaptation. Communication systems are exhaustively tested, and the entire exercise is analysed and followed by a thorough debriefing (10,11).

Understanding the influence of full-scale simulations on hospital disaster preparedness is critical for a number of reasons. For starters, it provides a detailed examination of the strengths and shortcomings of current practices, allowing hospitals to discover gaps and opportunities for development in their preparedness plans. The findings can be used to design more resilient and adaptive protocols to handle real-world difficulties, ultimately improving the resilience of healthcare systems in the face of calamities. This systematic review aimed to illustrate these points, and to provide further recommendations for future researchers.

II. METHODS

The findings of this study were reported in accordance with the PRISMA statement requirements (12), and all procedures were carried out in exact conformity with the Cochrane Handbook of Systematic Reviews and Meta-Analysis of Interventions (version 5.1.0) (13). Due to the heterogeneity of the studies, the narrative synthesis approach was used to report the findings.

Eligibility criteria

Studies were included in our review if they satisfied the criteria described in Table 1. We have excluded animal and in-vitro studies, studies with no full text available, studies presented solely as abstracts or

Table 1. Description of inclusion criteria

Arms	Description
Population	Hospitals and their staff who have participated in disaster and emergency preparedness training.

Intervention	Full-scale simulation exercises are the intervention of major interest.
Outcome	Recognising the challenges associated with noncompliance, evaluating the time required to assemble a crisis management team, and investigating the effect of full-scale simulations on the quality of the disaster plan.
Study Design	Included in the study are randomised controlled trials, quasi-experimental trials, pilot studies, cluster trials, and other observational study designs. Cross-sectional, retrospective, and prospective cohort studies are examples.

posters, studies from overlapped databases, and various non-primary research sources such as reviews, book chapters, theses, comments, letters, and editorials.

Information sources and search strategy

We performed a comprehensive search of four

electronic databases (PubMed, Scopus, Web of Science, and Cochrane Central Register of Controlled Trials), from inception until October 9, 2023, using the queries described in Table 2.

Additionally, the references of the included studies were manually searched for potentially eligible studies.

Table 2. Description of different database search strategies

Database	Results	Search Strategy
PubMed	1,288	All Fields: ((Full-scale simulations OR Full-scale regional simulations OR Full-scale regional simulation OR FSRE OR Simulations scenarios OR Full-scale exercise OR FSEs OR Simulations Training OR Simulations system OR Simulations OR High-fidelity simulation OR Online simulations OR Simulating OR Simulator OR Simulation modelling OR Simulation modeling) AND (Preparedness OR Readiness) AND (Hospital)).
Scopus	538	Article title, Abstract, Keywords: (“Full-scale simulations“ OR “Full-scale regional simulations“ OR “Full-scale regional simulation“ OR FSRE OR “Simulations Scenarios“ OR “Full-scale exercise“ OR FSEs OR “Simulations Training“ OR “Simulations system“ OR “Simulations“ OR “High-fidelity simulation“ OR “Online simulations“ OR “Simulating“ OR “Simulator“ OR “Simulation modelling“ OR “Simulation modeling“) AND (“Preparedness“ OR “Readiness“) AND (“Hospital“)).
Web of Science	434	All Fields: (“Full-scale simulations“ OR “Full-scale regional simulations“ OR “Full-scale regional simulation“ OR FSRE OR “Simulations Scenarios“ OR “Full-scale exercise“ OR FSEs OR “Simulations Training“ OR “Simulations system“ OR “Simulations“ OR “High-fidelity simulation“ OR “Online simulations“ OR “Simulating“ OR “Simulator“ OR “Simulation modelling“ OR “Simulation modeling“) AND (“Preparedness“ OR “Readiness“) AND (“Hospital“)).
Cochrane	138	<i>Keywords, Title:</i> (“Full-scale simulations“ OR “Full-scale regional simulations“ OR “Full-scale regional simulation“ OR FSRE OR “Simulations Scenarios“ OR “Full-scale exercise“ OR FSEs OR “Simulations Training“ OR “Simulations system“ OR “Simulations“ OR “High-fidelity simulation“ OR “Online simulations“ OR “Simulating“ OR “Simulator“ OR “Simulation modelling“ OR “Simulation modeling“) AND (“Preparedness“ OR “Readiness“) AND (“Hospital“)).

Selection process

The retrieved references were screened in two steps: first, the titles/abstracts of all identified articles were screened independently by all the authors to determine their relevance to this review, and second,

the full-text articles of the identified abstracts were screened for final eligibility. The Rayyan platform was used to aid the selection process (14), and duplicates were eliminated using Endnote, a tool provided by Clarivate Analytics (Pennsylvania, USA).

Data collection process and data items

Data were extracted from a uniform data extraction sheet, and included: (1) Characteristics of the included studies, (2) Characteristics of the populations of the included studies, and (3) Outcome measures.

Risk of bias assessment

According to the Cochrane Handbook of Systematic Reviews of Interventions 5.1.0 (updated March 2011), we used the National Institutes of Health (NIH) quality evaluation tools for cross-sectional, cohort, case-control, and intervention studies to assess the quality of quantitative studies (15). We used Noyes et al.'s recommendations for qualitative investigations, and the Mixed Methods Appraisal Tool (MMAT) for mixed-method studies (16). Two reviewers worked separately on the evaluation, and any inconsistencies were handled through discussion with a senior reviewer (17). Each tool had its own set of criteria, on the basis of which the studies were graded as good, fair, or poor.

Data synthesis

Due to the great variation in the objectives, design and settings of the studies, we used a narrative synthesis method to describe the key characteristics and findings in tables. We did not plan to conduct meta-analysis or measure confidence in cumulative evidence, due to the substantial heterogeneity of the included studies (cross-sectional, cohort, mixed techniques, and qualitative research).

III. RESULTS

Literature search results

The literature search produced 2,398 results, 605 of which were duplicates. Following title and abstract screening, 59 papers were subjected to full-text screening, with 28 publications finally included in the systematic review. A further search within the references of the included studies yielded no other eligible papers. Figure 1 of the PRISMA flow diagram depicts the study selection process.

Characteristics of included studies

The varied range of studies included in this review provided useful insights into the successes and limitations associated with different techniques. The overarching observation across all of the studies was

the positive influence of simulations on participant education and readiness. Notably, full-scale simulation (FSS) emerged as a consistently successful approach to improve participants' skills and uncover potential safety issues in hospital settings. The details of the 28 studies included in this review are summarised in Table 3.

Details of the parameters of the included studies are laid out in Table 4. This includes each study's country of origin, design, setting, recruitment methods, participant count, and evaluation measures. The geographical diversity of the studies, from battle zones in Afghanistan to trauma clinics in the United States, reveals a truly global perspective on catastrophe preparedness. Such variety improves the dataset by documenting the various techniques required in diverse sociopolitical and healthcare environments. Prospective cross-sectional studies, pre-post intervention surveys, qualitative inquiries, mixed-method designs, and observational studies are among the study types available. The settings range from simulated hospital settings to real-world trauma centres, each offering a unique viewpoint on crisis management.

Evaluation metrics

The studies employ a broad spectrum of evaluation metrics, including non-technical skills, communication, teamwork, decision-making, and operational readiness. This multidimensional approach ensures a thorough evaluation of the skills and competencies required for effective disaster response. Regarding the evaluation method, most studies employed a combination of quantitative and qualitative assessments, such as surveys, standardised tools, and checklists, as described in Table 5. This all-encompassing strategy guarantees that participants' preparedness, teamwork, and crisis management abilities are well understood.

The duration of the exercises varies greatly, ranging from 30 minutes to a multi-day simulation. Such variation allows for flexibility based on the individual objectives of each exercise.

The studied simulations also span a wide range of disaster scenarios, including mass casualties, viral epidemics, large aviation accidents, and terrorist strikes, as illustrated in Table 5. This breadth guarantees a thorough approach to disaster preparedness, covering a number of potential obstacles that healthcare personnel may encounter.

Table 3. Summary of studies included in the present systematic review and meta-analysis

Study ID	Title	Aim	Results	Limitations	Conclusion
Arora 2014 (18)	Towards the Next Frontier for Simulation-Based Training Full-Hospital Simulation Across the Entire Patient Pathway	Evaluate efficacy of full hospital simulation	Outstanding skill evaluation reliability: considerable improvements in decision-making, trauma care, and situational awareness successfully transferred to civilian practice.	Self-report data limitations, military setting	HOSPEX enhances skills with minimal waste of resources.
Bartley 2006 (19)	What a Disaster?! Assessing Utility of Simulated Disaster Exercise and Educational Process for Improving Hospital Preparedness	Assess impact of audiovisual presentation and simulation for hospital disaster planning	Significant knowledge improvement but sub-optimal preparedness perceptions. Calls for increased efforts in hospital disaster preparedness.	Selection bias, small participant numbers	Disaster exercise benefits individuals, prompts plan review, and suggests ongoing, cost-effective strategies including educational tools, mandatory hospital-wide involvement, and hiring a full-time Emergency Management Officer.
Burke 2014 (20)	Using Mixed Methods to Assess Pediatric Disaster Preparedness in the Hospital Setting	Assess disaster response with a paediatric focus	Disaster exercise enhanced paediatric response readiness. Identified areas for improvement included communication, equipment, physician involvement, safety, security, staff roles, and triage exercises.	Potential selection bias, voluntary response bias, reliance on self-reported feedback	Focus on communication, responsibilities, safety, triage, and equipment enhances preparedness.

Carmichael 2021 (21)	Integration of In Situ Simulation into an Emergency Department Code Orange Exercise in a Tertiary Care Trauma Referral Center	Assess ISS impact on mass-casualty response	ISS improved participant education and revealed latent safety hazards through a realistic experience.	Actor-related issues, pharmacological situation not completely tested, no uniform data collection form	ISS enhances hospital response to MCI.
Campanale 2022 (22)	Hospital preparedness for mass gathering events and mass casualty incidents in Matera, Italy, European Capital of Culture 2019.	Enhance hospital preparedness for MCIs	Implementation and improvement of PEMAF plan through the MACSIM-PEMAF program, leading to potential instructors and official delivery to authorities.	NR	MGEs offer significant visibility and profit opportunities for the host community. However, they also pose a heightened risk of MCI. Thus, it is essential for the healthcare system to prioritise both prevention and preparedness to effectively address potential emergencies.
Clara 2021 (23)	Testing early warning and response systems through a full-scale exercise in Vietnam	Test early warning systems for COVID-19 pandemic in Vietnam using FSE	Effective MOH surveillance, successful triage, and risk assessment. Challenges noted in infection control and documentation.	NR	FSE highlights the importance of practicing surveillance before emergencies.
Cristal 2019 (24)	Integrating Simulation-Based Exercises into Public Health Emergency Management Curricula	Evaluate simulation in public health emergency management using	Positive feedback, experience correlated to obtaining internships, highlighting the	NR	Simulation-based activities improve public health readiness and resilience.

		simulation-based exercise	effectiveness of simulation-based activities.		
Djalali 2014 (25,26)	Does Hospital Disaster Preparedness Predict Response Performance During a Full-scale Exercise? A Pilot Study	Investigate the relationship between disaster preparedness and response during FSE	Selected hospital demonstrated 59% preparedness and 70% response performance. Successful application of Simple Triage and Rapid Transport (START).	Limited by single-hospital sample	FSE shows the viability of using standardised tools to assess preparedness and reaction.
Dube 2020 (26)	COVID-19 pandemic preparation: using simulation for systems-based learning to prepare the largest healthcare workforce and system in Canada	Assess simulation in COVID-19 education using real person exercise	COVID-19 response team conducted impactful simulations, addressing 2500 system issues. Tremendous impact on learners in urban and rural settings.	Limited to single institute, generalisation concerns	FSE is critical for COVID-19 readiness; emphasises the importance of quick, in-person simulation for effective healthcare planning.
Facho 2021 (27)	Small-Scale High-Fidelity Simulation for Mass Casualty Incident Readiness	Assess readiness for MCI using high-fidelity simulation	Enhanced confidence and realistic experience in high-fidelity MCI simulation. Positive perceptions guided hospital plans; scores averaged 5 for educational value, 4.8 for realism, and 4.8 for effectiveness.	NR	Simulation successfully increases participants' confidence regarding MCI.
Farahi 2021 (28)	A simulation–optimization approach for measuring emergency department resilience in times of crisis	Propose a simulation-optimisation approach to assess ED resilience during disasters	Simulation-optimisation evaluated healthcare responsiveness, providing insights into system behaviour in crisis settings.	NR	Simulation-optimisation enhances healthcare resilience.

<p>Foo 2021 (29)</p>	<p>A 36-Hour Unplugged Full-Scale Exercise: Closing the Gaps in Interagency Collaboration between the Disaster Medical Assistance Team and Urban Search and Rescue Team in Disaster Preparedness in Taiwan</p>	<p>Evaluate preparedness and performance of DMATs in a simulated crisis scenario</p>	<p>Disaster scenario involving medical rescue teams showed effective command, control, and communication, and highlighted instances of noncompliance in health examinations.</p>	<p>Lack of comprehensive analysis, potential subjectivity</p>	<p>DMATs were successful but communication and evaluation skills need improvement.</p>
<p>Gillett 2008 (30)</p>	<p>Simulation in a Disaster Drill: Comparison of High-Fidelity Simulators Versus Trained Actors</p>	<p>Compare effectiveness of simulated versus actual actor-patients in MCI drills</p>	<p>High-fidelity simulators and live actors produced equivalent results in mass casualty drills, emphasizing the effectiveness of both.</p>	<p>Non-validated survey, Likert scale issues, lack of inter-rater reliability testing, non-identical paired cases, risk of learning bias</p>	<p>Simulators are as effective as live actors in MCI drills.</p>
<p>Gryth 2010 (31)</p>	<p>Evaluation of Medical Command and Control Using Performance Indicators in a Full-Scale, Major Aircraft Accident Exercise</p>	<p>Assess medical command and control in major aircraft accident using FSE at local and strategic levels</p>	<p>Performance indicators assessed medical command and control. Management and staff skills scored 15 and 17 at the strategic level, and 17 and 21 at the hospital level, respectively, revealing feasibility for future evaluations and real incidents.</p>	<p>Potential differences in exercise vs. real incidents, lack of absolute distinction between scores</p>	<p>Performance indicators are effective for evaluation of command and control in FSE.</p>
<p>Haverkort 2017 (32)</p>	<p>Developing the Fourth Evaluation Dimension: A Protocol for Evaluation of Video from the Patient's</p>	<p>Test feasibility of incorporating patient's perspective into traditional evaluations of</p>	<p>Equipping mock patients with point-of-view cameras in trauma drills enhanced communication training and identified areas for</p>	<p>Preliminary nature of study, images used by multiple observers</p>	<p>Point-of-view camera enhances trauma drill evaluation. Protocols should be optimised</p>

	Perspective During Major Incident Exercises	hospital using simulated training	improvement. The approach improved non-medical aspects and identified areas for training and process enhancement.		for effective utilisation of such footage.
Juelsgaard 2022 (33)	Healthcare professionals' experience of using in situ simulation training in preparation for the COVID-19 pandemic: a qualitative focus group study from a Danish hospital	Investigate impact of ISS on COVID-19 preparedness	Positive outcomes from simulations for healthcare professionals, emphasising improved teamwork and skills in PPE use.	Focus on specific hospital, potential response bias	ISS is valuable for pandemic preparation, at both organisational and individual levels.
Kohlhoff 2012 (34)	Evaluation of Hospital Mass Screening and Infection Control Practices in a Pandemic Influenza Full-Scale Exercise	Evaluate mass screening protocol, isolation, and triage in influenza FSE	Simulated pandemic mass screening protocol showed correct influenza status determination in 74% of cases, and effectiveness in addressing infection control. EPDS received positive evaluations from 95% of students, indicating increased knowledge, confidence, and preparedness for disaster situations. The hybrid approach proved cost-effective and time efficient.	NR	Mass screening and other infection control measures proved feasible and resulted in measurable outcomes during FSE.
Kaplan 2012 (35)	Use of an Emergency Preparedness Disaster Simulation with Undergraduate Nursing Students	Evaluate impact of EPDS on nursing students	Assessment of 16 hospitals showed widespread non-compliance, with communication problems	NR	EPDS enhances disaster preparedness, skills, and confidence, providing a cost-effective educational experience.
Klima 2012 (36)	Full-scale regional exercises: Closing the gaps in disaster preparedness	Assess FSRE in mass casualty disaster preparedness		Lack of training with technologies, communication issues	FSE is crucial for MCI readiness, as a communication gap

			(94%) and staffing issues (63%) being common.		remains in tabletop exercises.
McElroy 2019 (37)	Operation continued care: A large mass-casualty, full-scale exercise as a test of regional preparedness	Assess coordination in mass-casualty FXS	Triage analysis revealed strengths but highlighted communication failures and areas for improvement in data entry and resource requests.	NR	FXS aids preparedness, highlights communication and coordination flaws.
Obaid 2017 (38)	Utilization of Functional Exercises to Build Regional Emergency Preparedness among Rural Health Organizations in the US	Design and implement disaster exercises in rural areas to test efficacy	Functional exercises evaluated command staff, fostering regional collaboration. Revealed barriers to unified command and documentation issues.	Limited resources	Functional exercises vital for testing decision-making and response, offering insights beyond tabletop or short, full-scale exercises.
Rådestad 2012 (39)	Combining performance and outcome indicators can be used in a standardized way: a pilot study of two multidisciplinary, full-scale major aircraft exercises	Demonstrate feasibility of evaluating multidisciplinary, full-scale disaster exercises using combined indicators	Improved performance indicators, including preventable deaths and complications, were observed. Additionally, there were an adequate number of ambulances and injured victims considered.	Competency variations, need for real incident validation	Standardised evaluation using combined indicators allows for meaningful comparisons between exercises.
Rådestad 2023 (40)	Use of simulation models when developing and testing hospital evacuation plans: a tool for improving emergency preparedness	Evaluate hospital evacuation preparedness for MCI using simulation real-time exercise	Tabletop exercises improved evacuation plans and critical operations. In two exercises, 71.2% and 52.9% of patients were evacuated within 7 and 4 hours. Positive feedback on survey results and a desire for more exercises.	Limited generalisability due to varied exercises; low response rates; exercise did not include treatment during transport	Simulation exercises help planners create more efficient evacuation plans, protocols, and procedures for MCI.

					or upon arrival at facility
Shrestha 2022 (10)	Full-scale simulation exercise—A preparedness for trauma mass casualty incident: Nepal	Evaluate hospital incident command, triage, and patient transfer in FSS for MCI	Simulation exercise revealed gaps in knowledge and skills, indicating room for improvement in incident command, [mean score of 161 out of 220 (73.2%)], triage, and patient transferal.	Single site, observational design	Simulation identifies gaps and highlights areas for improvement.
Schumacher 2022 (41)	Full-scale simulations to improve disaster preparedness in hospital pharmacies	Evaluate impact of FSS on pharmacy emergency readiness	Simulation exercises improved task completion. Four hospital pharmacies initially completed 69%±6% of assigned tasks, increasing to 84%±7% in the second round. Average quality of actions improved from 3.0/5 to 3.6/5, and crisis team assembly time reduced from 23 to 5 minutes with challenges in communication and crisis management.	Small number of participating pharmacies, subjective assessments	FSS significantly improves readiness and staff knowledge.
Shah 2013 (42)	Waterworks, a Full-Scale Chemical Exposure Exercise: Interrogating Pediatric Critical Care Surge Capacity in an Inner-City Tertiary Care Medical Center	Assess PICU surge plan in chemical exposure exercise	Effective patient care transitions in chlorine overexposure simulation. Identified shortcomings in ED care.	Lack of post-instruction testing, potential ED overstaffing bias	PICU surge plan effective, but ED areas need attention.

Wallace 2010 (43)	Randomized controlled trial of high-fidelity patient simulators compared to actor patients in a pandemic influenza drill scenario	Compare resuscitation times in pandemic influenza high-fidelity simulation	High-fidelity simulator patients posed challenges in real-time disaster response training, with significantly longer procedures.	Small sample size, lack of real patient comparison	Potential challenges using simulators for real-time training.
Wexler 2017 (44)	Lessons Learned from an Active Shooter Full-Scale Functional Exercise In a Newly Constructed Emergency Department	Assess hospital response to active-shooter scenario	Noted strengths and weaknesses, including a lack of experience in mass casualty triage and communication breakdowns. Identified educational opportunities.	Artificial nature of drills, potential staff response discrepancies	Conducting an active shooter exercise provided valuable insights for improvement without impacting patient care.

ISS: Institutional Simulation Scenario, HOSPEX: Hospital Exercise, PEMAFA: Emergency Plan for Massive Influx of Injured, MCI: Mass Casualty Incident(s), EPDS: Emergency Preparedness Disaster Simulation, FSE: Full-Scale Exercise, FSRE: Full-Scale Regional Exercise, ED: Emergency Department, DMAT: Disaster Medical Assistance Team, FSS: Full-Scale Simulation, PICU: Paediatric Intensive Care Unit, MGE: Mass Gathering Event, MACSIM®: Mass Casualty Simulation Tool

Table 4. Parameters of included studies

Study ID	Country	Design	Setting	Recruitment	Number of mock cases	Number of participants	Evaluation metrics
Arora 2014	Afghanistan	Prospective, cross-sectional pre/post training study	UK Defense Medical Services' Hospital Simulator and the conflict zone in Afghanistan	NR	NR	288 participants (surgeons, anaesthesiologists, physicians, and nurses)	Nontechnical skills, communication, teamwork, decision making, situational awareness, leadership, operational readiness, patient care, hospital environment, emergency procedures

Bartley 2006	Australia	Pre/post intervention survey	Geelong Hospital, Victoria	2004 October	NR	50 members of medical, nursing, and administrative staff	Factual knowledge, self- assessment, improvement of personal preparedness post-intervention Communication, equipment and supplies usage, paediatric safety, staffing, training, and specific stations such as Incident Command (IC), Triage, and Treatment.
Burke 2014	United States	Qualitative study	Three Los Angeles (California USA) hospitals	2011 May	NR	20 volunteers	Knowledge of organisational modalities, understanding of operative areas, Hospital Command Group, information signaling, MCI phases, triage, action cards, staff redistribution, surgical triage, 'damage control', surge capacity factors, MCI closure mechanisms
Campanale 2022	Italy	Mixed method design of quality improvement and pre/post educational intervention design	Madonna delle Grazie Hospital	2016	NR	193 participants including physicians, nurses, managers, and support staff	Time evaluation, triage process, communication, formalise centralisation of requested resources
Carmichael 2021	Canada	Qualitative study	Adult care trauma centre in Ottawa, Ontario, Canada	NR	20 patients	NR	

Clara 2021	Vietnam	Event-based surveillance	Quang Ninh province and Hanoi city, with participation of public health partners at community, district, provincial, regional and national levels	2018 August	One case	NR	Detection, reporting, triage, verification, risk assessment
Cristal 2019	United States	Qualitative study	Colorado School of Public Health Hospitals	2016	NR	NR	Participants' perceptions of the curriculum, its applicability to their future careers, and the overall learning experience
Djalali 2014	Italy	Pilot study	A hospital in the Piedmont region of Italy	2013 May	General hospital, approx. 300 beds	NR	Organisation, operational and contingency plans, critical services, resource availability Surge planning, identification of latent safety threats, testing and design of COVID-19 processes, evaluation of medical management and infection prevention, categorisation of outcomes based on SEIPS 2.0 system,
Dube 2020	Canada	Qualitative study	Healthcare system in the province of Alberta, Canada.	2020	NR	NR	

							iterative development of cognitive aids
Facho 2021	United States	Qualitative study	Kern Medical Center Emergency Medicine Department Bakersfield, CA	NR	NR	Three patients in round 1; another three in round 2	Instrumental skills for physicians, other tasks for nurses and non-physicians
Farahi 2021	Iran	Qualitative study	Adult ED of the Persian Gulf General Hospital in Bushehr, Iran	2021	NR	NR	ED scenarios, regular operations, crisis response, workload integration, scenarios shaped by historical data, patient interarrival times adjustment for diverse intensity levels
Foo 2021	China	Observational study	Nan Hospital of China Medical University	2018 November	NR	30physicians, 65 nurses, and 74 logistical personnel	Technical proficiency of Disaster Medical Assistance Teams (DMATs), barriers to cooperation between DMATs and Urban Search and Rescue (USAR) teams during a simulated earthquake exercise
Gillett 2008	United States	Prospective cohort study	Kings County Hospital Center in Brooklyn, New York, and Tampa	December 2006 and March 2007	NR	78 hospital staff members	Different scenarios, tasks such as triage, obtaining vital signs, applying oxygen, initiating stabilising

			General Hospital in Tampa, Florida				interventions, completing surveys, providing appropriate disposition
Gryth 2010	Sweden	Qualitative study	NR	2008 October	NR	NR	NR
Haverkort 2017	Netherlands	Proof-of-concept study	Major Incident Hospital (MIH) in Utrecht, Netherlands	2014 to 2015	Two mock cases	NR	Review of captured footage to gain insights into patient experience
Juelsgaard 2022	Denmark	Qualitative focus group study	Danish University Hospital	2020 April-May	NR	22 healthcare professionals	ABCDE approach, PPE and medical equipment, transportation, communication, decision making in critical cases
Kaplan 2012	United States	Qualitative study	American Association of Colleges of Nursing and associated Hospitals	2008 to 2011	NR	90 undergraduate nursing students	Communication, supplies usage, paediatric safety, triage, treatment
Klima 2012	United States	Qualitative study	Multi-agency over 16 areas	NR	280 volunteer patients	NR	Communication, command structure, decontamination, staffing, patient tracking
Kohlhoff 2012	United States	Qualitative focus group study	Brooklyn, New York hospitals	NR	354 volunteer victims	NR	Standardised mass screening and infection control items with coordination, communication

McElroy 2019	United States	Qualitative study	7 trauma centres, 30 acute care hospitals and free-standing emergency departments, and 42 emergency medical services agencies	2017 April	445 volunteer patients	NR	Patients' entry, triage accuracy, communication, coordination, performance, points of improvement, resources request, patient tracking, OHTrac utilisation, communication assessment
Obaid 2017	United States	Quasi-experimental design	Three rural Nebraska (USA) regions by the Center for Preparedness Education (CPE) at the University of Nebraska Medical Center (Omaha, Nebraska USA)	2010 to 2013	NR	83 command centres, including 667 participants	Command staff, identification of areas for improvement, advancing regional collaboration among diverse response partners and other parameters of Homeland Security Exercise Evaluation Program
Rådestad 2012	Sweden	Pilot study (quantitative evaluation study)	Two multidisciplinary FSE (major aircraft accident) in two regions in Sweden	2008 to 2010	99 victims	131 and 69 health care workers, respectively	prehospital, regional, and hospital command and control, as well as regional and hospital staff procedure skills. Key points include response time, communication effectiveness, resource allocation, media interaction, and staff

Rådestad 2023	Sweden	Qualitative study	Two emergency hospitals within region of Stockholm	2019	NR	145 participants in Exercise 1; 95 participants in Exercise 2	coordination during disaster exercises. Transfer, patients evacuated, time to evacuate, decision-making, leadership, resource management, simulation system effectiveness, proposed evacuation plans, communication procedures, participants' perceptions
Schumacher 2022	Switzerland	Prospective multicentre design	Group of Swiss French-speaking hospital pharmacists (Groupe ment des Pharmacies Hospitallers Romans)	2018 August to 2020 August	NR	NR	Simulation responses, communication, disaster management, logistical activities, pharmaceutical assistance, quality of actions using Likert scale
Shah 2013	Switzerland	Prospective single-centre simulated disaster drill	Kings County Hospital Center's (KCHC) Paediatric Intensive Care Unit (PICU)	2012 July	22 patients with 14 family members needed evaluation	36 (medical students or emergency medicine residents), 9 of these patients	Transportation, delivery of appropriate therapy, ED care, discharge process, educational materials
Shrestha 2022	Nepal	Observational study	Six hospitals in Nepal	2021	NR	NR	Hospital incident command area, patient care, triage, treatment areas, emergency signal, internal and external

Wallace 2010	United States	RCT	Emergency Department at Kings County Hospital Center, Brooklyn	2008 July	NR	12 cases	coordination mechanism, organisation issues Identification of respiratory and circulatory compromise, provision of definitive airway, initiation of vasopressors through a central line, disposition
Wexler 2017	United States	Qualitative study	ED at WellSpan York Hospital, a Level 1 trauma centre in south-central Pennsylvania	NR	NR	NR	Communication, recognition instructions response, evacuation preparedness

Table 5. Description of disaster details

Study ID	Type of Disaster	Simulation Exercise	Duration of exercise	Team members	Evaluation process	Summary of process flow
Arora 2014	Trauma care centres stress management	Full hospital simulation, 'Hospital Exercise' (HOSPEX)	NR	Participants (surgeons, anaesthesiologists, physicians, nurses), controller, organisers	IMPACT tool for skills assessment	Live-in simulator covering crisis management, teamwork, and simulated surgeries
Bartley 2006	Hospital disaster	Simulated disaster exercise	NR	Medical, nursing, and administrative staff	Pre- and post-intervention survey	Educational presentation and disaster simulation exercise

Burke 2014	Mass causality (earthquake)	Full-functional disaster exercise	3 hours, 40 minutes	Participants, controller, observers	Quantitative and qualitative assessment using anonymous surveys	Voluntary disaster response simulation with physicians, nurses, and nonclinical personnel
Campanale 2022	Mass casualty Incident (MCI)	Mass Casualty SIMulation (MACSIM) educational program	NR	Participants (including physicians, nurses), managers, support staff	Pre- and post- self-administered semi-quantitative questionnaires	Educational events for hospital personnel using MACSIM to improve MCI preparedness
Carmichael 2021	Mass causality	Institutional simulation scenario (ISS)	50 minutes	Trained observers, emergency medicine team, simulation faculty, participants, controllers, exercise design teams	EM team compiled data; debriefing meetings held	Simulated mass shooting with 20 victims, testing hospital response within 50 minutes
Clara 2021	Severe viral pneumonia cases with confirmed MERS-CoV	Full-scale exercise (FSE)	3 days	Participants, controller, evaluator, management staff	10 evaluators monitoring against capability targets	FSE to evaluate response to severe viral pneumonia cases with confirmed MERS-CoV
Cristal 2019	Hospitals disaster medicine	Simulation-based exercises	NR	NR	NR	Assessment of disaster management using earthquake mass causality disaster
Djalali 2014	Hospitals disaster medicine	Full-scale exercise (FSE)	Approx. 60 minutes	Participants, controller, observers	Preparedness evaluation checklist	Transfer of patients to hospital with Simple Triage and Rapid Transport (START) procedure

Dube 2020	COVID-19 pandemic	Simulation-based learning	NR	Participants, evaluators, controllers	NR	Over 400 acute care simulations to prepare for the COVID-19 pandemic
Facho 2021	Mass casualty incident (MCI)	High-fidelity simulation	NR	Physicians, cases, evaluators, controllers	Evaluation checklist	Mass casualty incident with urgent interventions by physician team
Farahi 2021	Hospitals disaster medicine	Simulation-optimisation approach (hybrid approach)	Less than 4 hours	Physicians, cases, evaluators, controllers	Evaluating ED system	Simulation replications for performance measures
Foo 2021	Mass causality (earthquake)	Unplugged full-scale exercise	NR	Physicians, nurses, logistical personnel	Regular meetings, radio communication monitoring, on-site observation	Testing disaster medical assistance teams' response in earthquake scenario
Gillett 2008	Mass casualty incidents (MCI)	High-fidelity simulators	NR	Simulators, participants, evaluators	Trained evaluators	Simulated mass casualty events in subway station and football stadium
Gryth 2010	Major aircraft accident	Full-scale exercise	NR	Participants, evaluators, controllers	Trained observers, performance indicators	Simulated commercial airplane crash at major airport
Haverkort 2017	Mass casualty Incident (MCI)	Simulation exercise (full-scale trauma drill)	Hours to minutes (not well described)	Participants, controller, evaluator, mock patients	Point-of-view cameras	Mock patients with cameras simulate trauma drills for protocol development
Juelsgaard 2022	COVID-19 pandemic	Full-scale in-situ simulation training	3 weeks	Participants (university professionals), controller, observer (interviewers)	Focus group interview	Hospital-wide simulation task force proposed for knowledge sharing

Kohlhoff 2012	Influenza pandemic	Full-scale exercise	1 day	Participants (university professionals), controller, observer	Evaluation using standardised forms	Simulating pandemic influenza outbreak with adapted case definition
Kaplan 2012	Mass causality (tornado disaster)	Emergency preparedness disaster simulation (EPDS)	30-45 minutes	Team leader, triage staff nurse, bedside assistants, controller	Pre- and post-simulation surveys with self-reported, anonymous responses	Tornado hitting an assisted living facility with injuries and fire
Klima 2012	Mass causality	Full-scale regional exercise (FSRE)	NR	Participants, controllers, exercise design teams, evaluator	Third-party evaluators, after-action evaluation	Simulated terrorist assault with train derailment, involving 281 volunteer patients
McElroy 2019	Mass causality	Operation Continued Care full-scale exercise	NR	Participants, communication team, resource request team, triage team, OHTrac input team	Post-exercise analysis in after-action report/improvement plan	Staged terrorist assaults at three locations, involving 445 mock victims
Obaid 2017	General disaster preparation	Six functional exercises	3 hours	Command centres, participants, controllers, observers	Homeland Security Exercise Evaluation Program (HSEEP; Washington DC, USA)	Six functional exercises to improve regional planning and collaboration
Rådestad 2012	Major aircraft accident	Full-scale exercise	292 minutes	Participants, controller, observers	External evaluators were registered using standardised performance indicators and patient outcome indicators.	Aircraft crash scenarios with 99 and 100 victims in 2008 and 2010

Rådestad 2023	Mass casualty incidents (MCI)	Mass Casualty Simulation system (MACSIM)	11 hours	Command group, physicians, nurses, support staff	Post-exercise surveys and open-ended questions for feedback	Two exercises testing evacuation plans and application
Shrestha 2022	Trauma mass-casualty Incidents	Full-scale simulation exercise	30 minutes	Participants, controller, evaluator	Standardised evaluation tool	Assessment of disaster management capabilities in six hospitals
Schumacher 2022	Mass causality (road traffic accident and terrorist attack)	Full-scale simulation exercise	3-4 hours	Participants, assessors	Harvard School of Public Health's Emergency Exercise Evaluation Toolkit	Simulated road traffic accident and terrorist attack scenarios
Shah 2013	Mass causality (influx of critically ill children)	Full-scale chemical exposure exercise	90 minutes (patient briefing from 24 hours prior)	Patients, participants, evaluators, controller	Homeland Security Exercise and Evaluation Program (HSEEP) terms for a full-scale exercise	Drill involving victims of chemical exposure, evaluating surge response and medical management
Wallace 2010	Influenza pandemic	High-fidelity simulator patients and human actor patients in a surge setting	NR	Participants (physician, residents, nurse, technician), 12 patients	Standardised data collection tool, checklist	Comparison of resuscitation times for simulator and human actor patients in ED
Wexler 2017	Mass casualty (active shooting)	Full-scale active shooter exercise	NR	Participants, controllers	Closed-circuit video and portable video cameras were utilised to provide feedback for debriefing	Full-scale exercise in ED with an active shooter scenario

NR: Not reported.

Effectiveness of simulations

The included studies systematically revealed crucial areas for disaster response improvement, shedding light on communication breakdowns, equipment deficiencies, and flaws in specific emergency plans. For example, Djalali (2014) highlights the successful implementation of Simple Triage and Rapid Transport (START) in catastrophe scenarios, demonstrating the practical benefits of such simulations for real-world settings. Simulation appears useful not only as an educational aid, but also as a diagnostic tool that identifies weaknesses which might otherwise go undetected.

Identification of gaps, challenges, and limitations

However, it is essential to approach the findings with a nuanced understanding, considering the limitations across various studies. When evaluating the results, potential biases, short sample sizes, and actor-related issues should all be considered. Recognising the diversity in simulation approaches—from high fidelity simulators to functional exercises and in-situ simulations—enhances our understanding of the broad landscape of disaster preparedness research.

Recommendations and implications

These studies go beyond theoretical concerns to provide practical ideas for improving hospital readiness. Suggestions include mandating hospital-wide involvement, appointing dedicated Emergency Management Officers, and utilising simulation-optimisation methodologies. As we work our way through these collective findings, it becomes clear that disaster preparation simulations not only increase education and readiness, but also serve as a platform for continual improvement within the healthcare system.

IV. DISCUSSION

Disaster preparation simulation exercises are critical to assessing and improving the performance of healthcare systems. This systematic review investigates specifically the role of full-scale simulation exercises (FSSE) and identifies gaps to enhance the response of healthcare systems to disasters.

Our study emphasises the effectiveness of FSSE as a reliable real-world approach, and highlighted their role in the identification and solution of specific safety issues that are often hidden and unpredictable. The success stories of these simulation methodologies include those of Carmichael et al. (21) and Farahi et al. (28), who demonstrated their

use of training in real-world circumstances. Furthermore, their net benefits extended beyond individual skills development. Additionally, several studies, such as those by Kohlhoff et al. (34), and Obaid et al. (38), emphasised a significant impact on healthcare systems, with a crucial role in evaluating decision-making, encouraging regional collaboration, and providing insights.

Simulation not only validates readiness, but also acts as a diagnostic tool for identifying the ideal disaster response. According to Shrestha 2022 (10) and Cristal 2019 (24), high-quality simulations provide opportunities for improvement by identifying issues such as communication breakdowns, equipment deficiencies, and weaknesses in specific emergency plans. As evidenced by Foo (29), the integration of disaster medical assistance teams (DMATs) ensures effective command, control, and communication, while allowing for improvement in health assessments.

The wide variety of simulated scenarios, ranging from trauma centre stress management to mass casualty catastrophes involving earthquakes, pandemics, and active shooter scenarios, exemplifies these exercises' adaptability in dealing with diverse crisis situations and ensures a comprehensive approach to disaster preparedness and prediction, which improves response in real-life situations. Furthermore, the range of exercise durations, from 30-minute simulations to multi-day events, provides flexibility in fulfilling diverse training requirements. The variety of evaluation measures used in different studies of high-stress simulations, including checklists, quantitative and qualitative surveys, and specialised evaluation tools, reflects the multifaceted nature of disaster preparedness. In addition to the conventional focus on technical abilities, nontechnical factors such as communication skills, teamwork, decision-making, healthcare infrastructure, and operational readiness are also examined.

Radestad (40) demonstrates the utility of a simulation model in refining hospital evacuation preparations for mass causality crises. Their system makes it easier to build effective and practical evacuation plans, protocols, and procedures for actual crisis scenarios.

This is the first systematic review of its kind, and highlights the effectiveness of full-scale simulation (FSS) in enhancing participants' skills and uncovering hidden safety issues in hospital settings during disaster preparedness exercises. It systematically identifies crucial areas for improvement that are addressed by simulation

exercises, including communication breakdowns, equipment deficiencies, and flaws in specific emergency plans. Additionally, it evaluates the range of simulation approaches used in disaster preparedness research. Mahdi et al. summarised the extensive process of developing various exercise types, evaluation mechanisms, simulation exercise design models, and guidelines for simulation exercise development (45). Their work underscores the importance of a logical and scientific approach to evaluating disasters in simulation exercises, and touches on the positive impact of simulations and the importance of their evaluation. Meanwhile, the geographical variance of the included studies highlights the dynamic nature of disaster preparedness (45).

The inclusion of a wide variety of study designs, such as prospective cross sectional studies, pre-post intervention surveys, qualitative investigations, and mixed methods approaches, reflects the diversity of organisational complexities, views and attitudes, and provides a comprehensive picture of emergency and disaster readiness. An important point emphasised by this study is the significance of collaboration at all levels and teamwork during disaster response, involving patients, volunteers, healthcare professionals, and administrative personnel. Furthermore, a thorough understanding of the various stakeholders' roles, expectations, and soft

skills during rapid action response is critical to ensure comprehensive and effective preparedness measures.

As with many studies, ours has limitations, foremost of which is the heterogeneity across the studies due to different participant demographic, simulation methodologies, and evaluation criteria.

V. CONCLUSION

This systematic review confirms the benefits of full-scale simulation exercises in disaster preparation and improving healthcare system readiness. A wide range of methodological approaches were reviewed, involving different crisis scenarios and training projects. Many areas for improvement were identified, and our evidence supports the notion of enhancement and sustainability of disaster preparedness through simulation and evidence-based practice.

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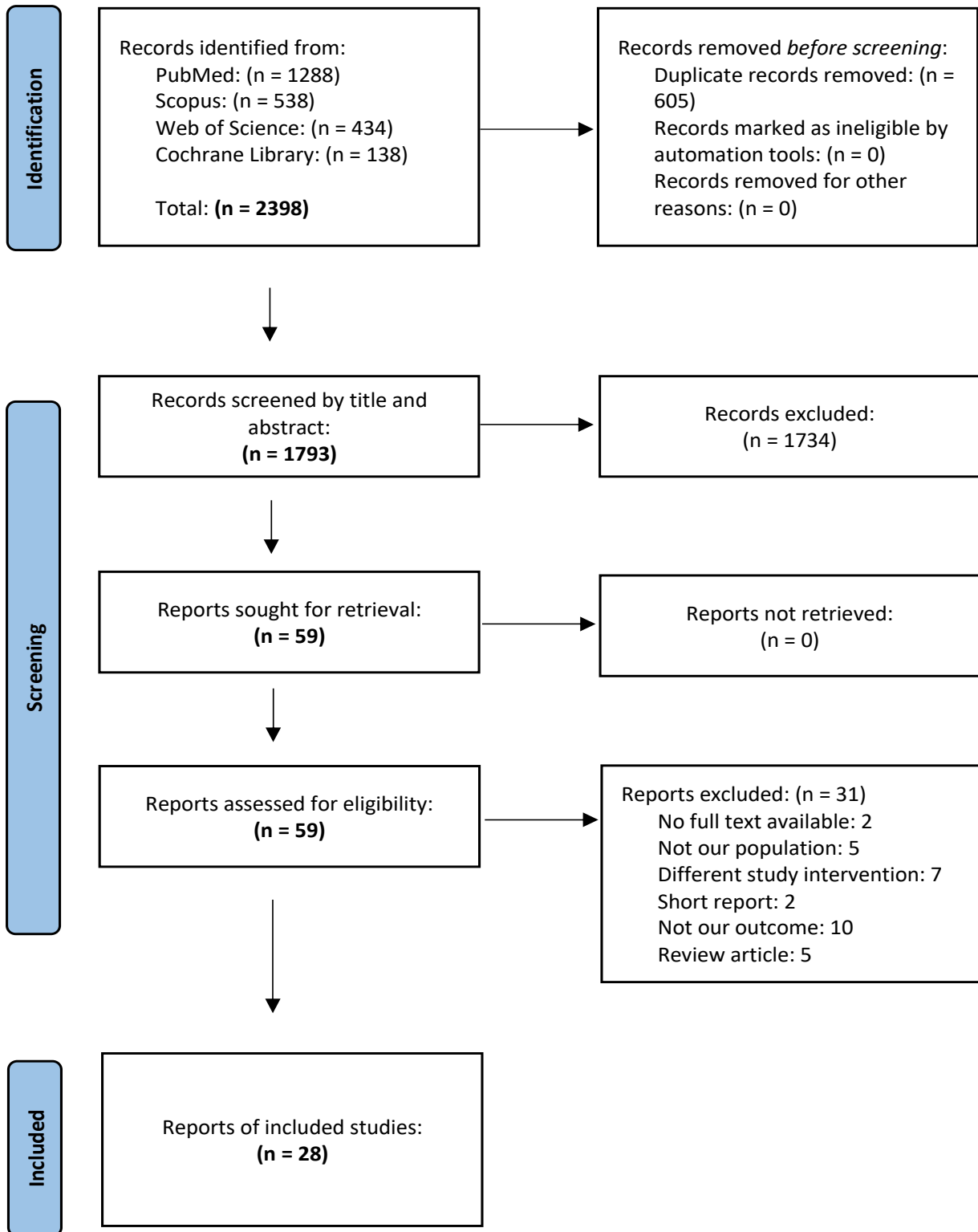


Figure 1. PRISMA flow diagram of studies' screening and selection