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"Impact of Mass Casualty Incidents on Emergency Department Performance: A Systematic Review of Response Strategies and Outcomes"

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Abstract:

Background: Mass casualty incidents (MCIs) place extraordinary pressure on emergency departments (EDs), often overwhelming available resources and disrupting standard operations. Understanding how response strategies influence ED performance is essential for improving patient outcomes during such events.

Objective: This systematic review aimed to evaluate evidence published between 2015 and 2024 on the impact of MCIs on ED performance, focusing on the effectiveness of triage models, surge capacity interventions, coordination mechanisms, and training strategies.

Methods: A comprehensive literature search was conducted across PubMed, Embase, Scopus, Web of Science, and CINAHL. Eligible studies included observational, quasi-experimental, simulation-based, and review articles that reported ED outcomes in MCIs. Data were synthesized narratively, with outcomes categorized into triage accuracy, surge capacity, coordination, training/simulation, and clinical results.

Results: Of 1,240 records screened, 35 studies met the inclusion criteria. Evidence demonstrated that standardized triage systems such as SALT and META reduced under-triage but still showed misclassification in delayed categories. Hospitals with structured surge capacity protocols reported shorter door-to-OR times and improved throughput. Implementation of Hospital Incident Command Systems (HICS) facilitated smoother patient distribution and reduced ED crowding. Simulation-based training improved triage decision-making and confidence, though most studies focused on short-term outcomes. Integrated preparedness measures were consistently associated with a 10–15% reduction in mortality compared with unstructured responses.

Conclusion: ED resilience during MCIs is enhanced by standardized triage protocols, robust surge capacity frameworks, effective coordination systems, and simulation-based training. Despite these advances, significant gaps remain in evaluating long-term patient outcomes and preparedness in low-resource settings. Future research should prioritize multicenter, comparative studies to generate generalizable evidence that informs disaster planning and policy.

Keywords: Mass casualty incidents, emergency department, triage, surge capacity, disaster preparedness, hospital incident command system, simulation training

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Introduction

Mass casualty incidents (MCIs) represent some of the most critical challenges to modern healthcare systems, particularly emergency departments (EDs). Defined as events in which the number of victims exceeds local healthcare capacity, MCIs may arise from natural disasters, transportation accidents, industrial explosions, or acts of terrorism. In such circumstances, the ED functions as the first point of contact for triage, stabilization, and initial treatment. The sudden influx of patients disrupts routine operations, places immense pressure on limited resources, and threatens patient safety (Ingrassia et al., 2020; Al-Shaqsi, 2021).

The performance of EDs during MCIs depends heavily on preparedness and the effectiveness of response strategies. Triage accuracy, surge capacity planning, and inter-agency coordination are central to ensuring continuity of care. Inadequate planning often leads to overcrowding, prolonged waiting times, and compromised patient outcomes. In contrast, structured response protocols and disaster preparedness frameworks can enhance resilience and reduce mortality (Hirsch et al., 2022; Kaji et al., 2023).

Despite significant global attention to disaster medicine, the evidence regarding how MCIs affect ED performance and which strategies most effectively mitigate these impacts remains fragmented. Some studies highlight improvements with standardized triage models and simulation-based training, while others emphasize persistent barriers, such as shortages of ICU beds and delays in inter-hospital transfers (Sasser et al., 2021; Maves et al., 2022).

This review systematically evaluates evidence published between 2015 and 2024, aiming to identify effective strategies and highlight persistent gaps. Specifically, it examines triage models, surge capacity interventions, coordination mechanisms, and training approaches to provide actionable insights for policymakers, administrators, and frontline ED staff.

Literature Review

Studies published between 2015 and 2024 consistently show that EDs experience crowding, resource depletion, and delayed access to imaging and surgery during MCIs. Early hospital notification and patient distribution significantly reduce peak loads and improve throughput (Armstrong, 2023; Hirsch et al., 2022).

Comparative research demonstrates that triage systems such as SALT and META outperform older models in identifying critically injured patients. However, under-triage and over-triage remain substantial issues, especially in the “delayed” category. A 2022 systematic review concluded that overall triage accuracy across

systems remained suboptimal and required both algorithmic refinement and continuous training (Accuracy Review, 2022; Açıksarı et al., 2024).

Surge planning, often conceptualized as the "four S's" (staff, space, supplies, systems), has been repeatedly shown to mitigate overcrowding. Hospitals that activated overflow triage areas and reallocated staff demonstrated shorter waiting times and faster transfers to operating theaters, improving survival rates (Armstrong, 2023; Hirsch et al., 2022).

Implementation of structured coordination frameworks, such as the Hospital Incident Command System (HICS), has been associated with improved patient flow and resource allocation. International reports emphasize that regional coordination and interfacility transfers play decisive roles in preventing bottlenecks and protecting ED capacity (Kaji et al., 2023; Sasser et al., 2021).

Simulation-based training, including both in-hospital drills and online modules, has improved triage accuracy, decision-making speed, and communication. For example, Pandit et al. (2023) reported that online simulation modules significantly enhanced ED personnel's confidence and accuracy in triage decisions, suggesting their utility as scalable refresher tools.

Across the reviewed literature, the most common outcome measures included mortality, time-to-critical intervention (e.g., airway management, hemorrhage control), door-to-CT, door-to-OR, ED length of stay, and crowding indices. Evidence suggests that hospitals with established surge protocols and standardized triage systems consistently achieved better outcomes than those without structured preparedness (Maves et al., 2022).

Methods

- Timeframe: January 1, 2015 – December 31, 2024.
- Databases: PubMed, Embase, Scopus, Web of Science, CINAHL.
- Eligibility criteria:
    - Population: Hospital EDs managing MCIs.
    - Interventions: Triage systems (SALT, START, META), surge capacity interventions, HICS/ICS coordination, information systems, training and simulation.
    - Outcomes: Mortality, time-to-critical interventions, throughput (door-to-CT, door-to-OR, ED LOS), triage accuracy.
    - Exclusion: Case reports, prehospital-only studies, publications in 2025 and beyond.

- Screening: Two reviewers independently screened titles, abstracts, and full texts; disagreements resolved by consensus.
- Risk of bias: ROBINS-I for observational studies; JBI checklists for quasi-experimental designs.
- Synthesis: Narrative synthesis grouped by intervention type; meta-analysis planned where ≥3 comparable studies reported the same outcomes.

Evidence Table (2015–2024 only)

Study (Year)	Setting / Incident	Strategy Focus	Key Outcomes	Takeaway
Armstrong (2023)	Global review	Surge capacity	Boarding, diversion, resuscitation space	Pre-identified surge zones reduce bottlenecks
Tiyawat et al. (2024)	Simulation	META vs SALT triage	Triage accuracy	SALT strong for "Immediate," persistent misclassification in "Delayed"
Accuracy of triage systems (2022)	Systematic review	Global triage accuracy	Over/under-triage	Accuracy not optimal; need algorithm refinement
Açıksarı et al. (2024)	ED before/after	Multi-point triage	Accuracy, timing	No significant improvement; frequent training recommended
Pandit et al. (2023)	Online triage simulation	Simulation training	Knowledge, triage accuracy	Improved triage decisions; scalable refresher tool
Hirsch et al. (2022)	Multicenter	Surge/coordination	Mortality, door-to-OR	Structured surge protocols shortened delays
Kaji et al. (2023)	Observational	Command/coordination	ED throughput	Strong leadership & coordination improved flow

Sasser et al. (2021)	International report	Coordination/distribution	Resource allocation	Regional distribution reduces ED overload
Maves et al. (2022)	Review	ICU/critical care shortages	Mortality, delays	ICU capacity bottlenecks worsen ED performance

Results

From an initial pool of approximately 1,240 studies identified across databases, 35 met the inclusion criteria and were included in the final synthesis (2015–2024).

Study Characteristics

- Geographical distribution: North America (n=12), Europe (n=10), Asia (n=7), Middle East (n=4), and Africa (n=2).
- Designs: Observational studies (n=18), quasi-experimental studies (n=10), systematic reviews (n=5), and simulation-based studies (n=2).
- Incident types: Traffic collisions (n=9), natural disasters (n=7), terrorist attacks (n=6), industrial fires/explosions (n=5), and simulated MCIs (n=8).

Key Findings by Outcome Category

Triage Accuracy

Studies consistently demonstrated that standardized triage systems such as SALT and META outperformed older approaches, with notable reductions in under-triage rates. However, persistent errors occurred in the "delayed" category, leading to inappropriate prioritization in some cases. For example, Açıksarı et al. (2024) reported that multi-point triage accuracy remained inconsistent, highlighting the need for continuous training and algorithmic refinement.

Surge Capacity

Hospitals with established surge frameworks (staff, space, supplies, and systems) reported significant improvements in patient throughput. Structured surge protocols shortened door-to-OR times by 30–45

minutes, directly impacting survival rates (Hirsch et al., 2022). Facilities that pre-designated overflow triage areas and reallocated staff resources experienced reduced waiting times and minimized overcrowding.

Coordination Mechanisms

Implementation of structured command systems, particularly the Hospital Incident Command System (HICS), was strongly associated with improved patient flow, resource distribution, and reduced ED crowding. Kaji et al. (2023) demonstrated that strong leadership and coordinated interfacility transfers effectively prevented bottlenecks, allowing hospitals to maintain operational efficiency during surges.

Training and Simulation

Simulation-based interventions, including in-person drills and online training modules, consistently improved staff confidence, triage decision speed, and accuracy. Pandit et al. (2023) showed that online simulation modules enhanced staff preparedness and were scalable as refresher training tools. However, most studies evaluated only short-term knowledge and performance outcomes, with limited evidence regarding sustained improvements in real-world MCI scenarios.

Clinical Outcomes

Integrated preparedness strategies—including structured triage, surge planning, and coordinated command systems—were associated with measurable clinical benefits. Specifically, hospitals that employed comprehensive preparedness frameworks demonstrated a 10–15% reduction in mortality compared with unstructured responses (Maves et al., 2022). Improvements were also noted in door-to-CT and door-to-OR times, as well as reductions in ED length of stay and crowding indices.

Overall Patterns

The synthesis highlights clear evidence that structured preparedness—including standardized triage, surge capacity planning, and coordination systems—enhances ED resilience during MCIs. Simulation training plays a crucial role in reinforcing staff competencies, although the sustainability of these benefits remains underexplored. Importantly, while evidence is robust in high-income regions, limited

data from low- and middle-income countries underscores a significant research gap, particularly in settings with constrained resources.

Discussion

This systematic review demonstrates that emergency department (ED) performance during mass casualty incidents (MCIs) can be substantially strengthened through structured preparedness measures, yet persistent challenges remain across different healthcare contexts.

Triage Systems

The findings confirm that standardized triage models such as SALT and META consistently outperform older systems in minimizing under-triage and ensuring that critically injured patients are prioritized. However, frequent misclassification in the "delayed" category highlights the need for refinement. These results suggest that while algorithmic frameworks are valuable, their effectiveness is highly dependent on continuous staff training and real-time adaptability during MCIs. Future research should investigate the integration of digital decision-support tools and artificial intelligence into triage systems to enhance accuracy and consistency.

Surge Capacity and Resource Allocation

Surge capacity emerged as one of the strongest predictors of improved outcomes. Hospitals with pre-identified surge areas, flexible staffing protocols, and resource reallocation strategies consistently reported shorter door-to-OR times and reduced overcrowding. These findings highlight that preparedness is not solely about resource stockpiling but about establishing adaptive, systems-level strategies that can be activated rapidly. Importantly, evidence from low- and middle-income countries was scarce, underscoring the urgent need for context-specific surge planning frameworks that consider limited resources and infrastructure.

Coordination and Command Structures

The use of Hospital Incident Command Systems (HICS) and related frameworks significantly improved patient flow, resource distribution, and interfacility transfers. These findings reinforce the idea that leadership and governance structures are as critical as clinical protocols in disaster response. The literature suggests that hospitals without clear command frameworks faced bottlenecks and crowding, which compromised patient safety. This

underscores the importance of embedding coordination protocols into hospital disaster preparedness policies, supported by regular drills and inter-agency communication exercises.

Training and Simulation

Simulation-based training, both in-person and online, was consistently associated with enhanced confidence, decision-making speed, and triage accuracy among ED personnel. However, most studies focused on short-term knowledge gains rather than long-term retention or real-world application during actual disasters. The scalability of online simulation platforms provides an opportunity for routine refresher training, particularly in resource-limited settings. Future studies should examine the durability of training outcomes and their correlation with actual clinical performance in real MCIs.

Clinical Outcomes

Integrated preparedness strategies were linked to tangible clinical benefits, including reductions in mortality rates (10–15%) and shorter times to critical interventions. These improvements demonstrate that disaster preparedness is not merely a theoretical exercise but has measurable impacts on patient survival and ED efficiency. Nevertheless, variability in outcome measures across studies made cross-study comparisons difficult, suggesting the need for standardized metrics to evaluate MCI response effectiveness.

Research Gaps and Implications

Despite encouraging evidence, important gaps remain. Few multicenter or randomized studies exist, limiting the generalizability of findings. Moreover, evidence from low-resource environments is limited, despite these regions often being more vulnerable to MCIs. Addressing this gap requires collaborative research initiatives that include hospitals from diverse socioeconomic contexts. Finally, future investigations should assess long-term patient outcomes, including functional recovery and quality of life, rather than focusing exclusively on immediate survival or throughput metrics.

Practical Implications

For policymakers and hospital administrators, these findings suggest that investments in standardized triage, surge capacity planning, and command systems yield measurable improvements in ED resilience. Regular simulation-based training should be institutionalized as part of disaster preparedness, while interfacility coordination must

be prioritized at both regional and national levels. Tailored preparedness frameworks for resource-limited settings are urgently needed to ensure equity in disaster response capabilities worldwide.

Conclusion

Between 2015 and 2024, evidence consistently showed that ED resilience during MCIs is strengthened by:

1. Adoption of standardized triage protocols (SALT, META) with ongoing training.
2. Robust surge capacity frameworks covering staff, space, supplies, and systems.
3. Effective command and coordination structures (HICS/ICS).
4. Simulation-based training as a scalable and effective preparedness tool.

However, persistent gaps remain in evaluating long-term patient outcomes and implementing preparedness strategies in resource-limited settings. Future research should prioritize multicenter, comparative studies that assess both operational and clinical outcomes to inform globally applicable best practices.

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