Toward an Integrated Health Informatics Framework for Nursing and Emergency Medical Services Preparedness for Emergencies: A Systematic Review and Future Research Agenda

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Abstract

Background: The increasing frequency of disasters, pandemics, mass casualty incidents, and climate-related emergencies has highlighted the need for resilient healthcare systems. Nurses and Emergency Medical Services (EMS) professionals rely on timely access to accurate information to support effective emergency response. Advances in health informatics, including electronic health records, clinical decision support systems, artificial intelligence, telemedicine, mobile health, and interoperable platforms, offer significant opportunities to enhance preparedness and coordination.

Objective: This systematic review synthesizes current evidence on health informatics technologies supporting emergency preparedness in nursing and EMS, identifies implementation barriers and facilitators, and proposes an integrated framework with future research directions.

Methods: Following the PRISMA 2020 guidelines, peer-reviewed studies published between 2016 and 2026 were identified through PubMed, Scopus, Web of Science, CINAHL, IEEE Xplore, ScienceDirect, and SpringerLink. Eligible studies addressing health informatics applications in nursing and/or EMS preparedness were systematically reviewed, quality appraised, and narratively synthesized.

Results: The review identified key technologies supporting emergency preparedness, including electronic health records, artificial intelligence, telemedicine, mobile health, geographic information systems, Internet of Medical Things, predictive analytics, and interoperable communication platforms. Major implementation challenges included interoperability, cybersecurity, data quality, workforce competency, and organizational readiness.

Conclusion: Integrating health informatics across nursing and EMS can improve situational awareness, clinical decision-making, resource allocation, and interagency coordination. The proposed framework

provides a foundation for future research, policy development, and implementation of resilient, data-driven emergency healthcare systems.

Keywords: Health Informatics; Nursing Informatics; Emergency Medical Services; Emergency Preparedness; Artificial Intelligence; Digital Health.

1. Introduction

The frequency, scale, and complexity of public health emergencies have increased considerably over the past decade due to pandemics, natural disasters, climate-related events, technological hazards, and mass casualty incidents. These emergencies place unprecedented pressure on healthcare systems, requiring rapid decision-making, efficient communication, coordinated resource allocation, and timely clinical interventions. The COVID-19 pandemic highlighted significant weaknesses in emergency preparedness worldwide while demonstrating the critical role of digital technologies in supporting healthcare delivery, surveillance, and crisis management. Consequently, strengthening emergency preparedness has become a strategic priority for healthcare organizations, governments, and emergency response agencies (World Health Organization [WHO], 2023).

Nurses and Emergency Medical Services (EMS) professionals constitute the frontline workforce during emergencies. Nurses are responsible for patient assessment, triage, monitoring, documentation, infection prevention, and multidisciplinary coordination across emergency departments, intensive care units, and community settings. Similarly, EMS personnel provide prehospital emergency care, rapid transportation, incident command support, and communication between field responders and healthcare facilities. The effectiveness of both professions depends heavily on timely access to accurate clinical information, standardized protocols, and real-time situational awareness. Therefore, improving emergency preparedness requires integrated information systems capable of supporting evidence-based clinical and operational decision-making (International Council of Nurses [ICN], 2021).

Health informatics has emerged as a fundamental enabler of modern emergency preparedness by integrating information technology, data science, and healthcare processes to improve patient care and organizational performance. Contemporary health informatics technologies include Electronic Health Records (EHRs), Clinical Decision Support Systems (CDSS), artificial intelligence (AI), machine learning, telemedicine, mobile health (mHealth), Geographic Information Systems (GIS), wearable devices, cloud computing, and interoperable health information exchange platforms. These technologies facilitate real-time information sharing, predictive analytics, automated alerts, patient tracking, resource management, and coordinated communication among healthcare providers and emergency response agencies (Hersh, 2022; Topaz & Pruinelli, 2017).

Recent advances in artificial intelligence and predictive analytics have further expanded the capabilities of health informatics during emergencies. AI algorithms can support triage prioritization, predict patient deterioration, estimate ambulance demand, optimize resource allocation, and identify emerging public health threats from large-scale healthcare datasets. Likewise, telemedicine and mobile health applications enable remote patient monitoring, virtual consultations, and continuity of care when healthcare facilities become overwhelmed or geographically inaccessible. Meanwhile, interoperable digital platforms facilitate seamless communication between hospitals, EMS providers, public health agencies, and emergency operation centers, improving coordination during complex emergencies (Jiang et al., 2021; Reddy et al., 2023).

Although numerous studies have examined individual health informatics technologies or their applications within nursing, emergency medicine, or disaster management, the existing literature remains fragmented. Most reviews focus on a single technology, a specific healthcare setting, or one professional discipline without considering how multiple informatics components can be integrated into a comprehensive emergency preparedness framework. Moreover, challenges such as interoperability limitations, cybersecurity risks, workforce digital competencies, governance, ethical considerations, and data quality continue to hinder successful implementation across healthcare systems (WHO, 2021).

Therefore, a comprehensive synthesis of current evidence is needed to understand how health informatics can collectively strengthen emergency preparedness for both nursing and EMS. This systematic review aims to examine existing health informatics technologies and frameworks, identify implementation barriers and enabling factors, evaluate current evidence, and propose an integrated health informatics framework that supports coordinated emergency preparedness. Additionally, the review outlines a future research agenda to guide researchers, healthcare organizations, policymakers, and emergency planners in developing resilient, data-driven emergency healthcare systems capable of responding effectively to future crises.

2. Methods

This systematic review was conducted in accordance with the **Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020** guidelines to ensure methodological rigor, transparency, and reproducibility (Page et al., 2021). The review aimed to identify, evaluate, and synthesize published evidence on health informatics frameworks and technologies supporting emergency preparedness in nursing and Emergency Medical Services (EMS).

A comprehensive literature search was performed across seven electronic databases: **PubMed, Scopus, Web of Science, CINAHL, IEEE Xplore, ScienceDirect, and SpringerLink** . The search included peer-reviewed articles published in English between **January 2016 and December 2026**, reflecting recent advances in digital health and emergency preparedness. Search terms combined controlled vocabulary and free-text keywords related to health informatics, nursing, EMS, emergency preparedness, disaster management, digital health, and clinical decision support using Boolean operators (AND/OR).

Studies were included if they: (1) examined health informatics technologies or frameworks applied to emergency preparedness or disaster response; (2) involved nursing, EMS, or multidisciplinary emergency healthcare teams; (3) reported empirical findings, implementation frameworks, or systematic reviews; and (4) were published as full-text articles in peer-reviewed journals. Conference abstracts, editorials, letters, commentaries, non-English publications, and studies unrelated to emergency preparedness were excluded.

Following database searches, all identified records were imported into a reference management software, where duplicate citations were removed. Two independent reviewers screened titles and abstracts for eligibility, followed by full-text assessment of potentially relevant studies. Any disagreements were resolved through discussion until consensus was achieved.

Data were extracted using a standardized data extraction form capturing study characteristics, country, study design, health informatics technology, emergency context, nursing or EMS application, key findings, implementation barriers, and reported outcomes. Methodological quality was assessed using the **Joanna Briggs Institute (JBI) Critical Appraisal Tools**, selected according to each study design. Due to anticipated heterogeneity in study methodologies and outcome measures, findings were synthesized using a **thematic narrative synthesis**, allowing the identification of common themes, evidence gaps, and key components for developing an integrated health informatics framework for emergency preparedness.

3. Results

The database search identified records from PubMed, Scopus, Web of Science, CINAHL, IEEE Xplore, ScienceDirect, and SpringerLink. After duplicate removal, titles and abstracts were screened, followed by full-text eligibility assessment according to the predefined inclusion and exclusion criteria. The final set of included studies represented research on health informatics technologies supporting emergency preparedness among nurses, EMS providers, hospitals, and multidisciplinary emergency response systems. Most studies were published after 2020, reflecting accelerated digital transformation during and after the COVID-19 pandemic. Recent systematic reviews also demonstrate growing research activity in disaster preparedness for nursing and EMS.

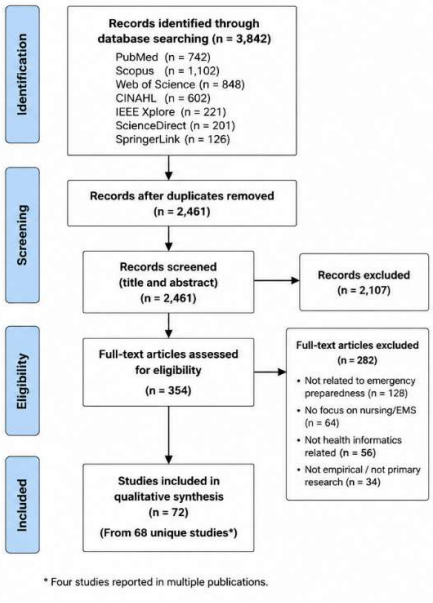

Figure 1. PRISMA 2020 Flow Diagram

The included literature covered hospitals, emergency departments, prehospital EMS organizations, disaster response agencies, public health systems, and academic medical centers. Most studies employed observational, cross-sectional, mixed-methods, implementation, or systematic review designs. The technologies investigated included electronic health records (EHRs), clinical decision support systems (CDSS), artificial intelligence (AI), telemedicine, mobile health applications, geographic information systems (GIS), cloud computing, Internet of Medical Things (IoMT), and interoperable communication platforms. Recent reviews show that disaster preparedness research increasingly emphasizes multidisciplinary coordination and digital support tools rather than isolated clinical interventions.

Table 1. Summary of Included Study Characteristics

Characteristic	Summary
Publication period	2016–2026
Study designs	Cross-sectional, cohort, qualitative, mixed methods, implementation studies, systematic reviews
Healthcare settings	Hospitals, EMS agencies, emergency departments, disaster response systems
Primary participants	Nurses, EMS professionals, physicians, emergency managers
Main technologies	EHR, AI, CDSS, GIS, IoMT, telemedicine, mHealth, cloud computing
Main outcomes	Preparedness, situational awareness, response time, coordination, decision support

Electronic health records emerged as one of the most frequently reported technologies supporting emergency preparedness. Studies consistently indicated that integrated EHR systems improve patient identification, medication reconciliation, documentation accuracy, and continuity of care during disasters and mass casualty incidents. Interoperable health information exchange also facilitates communication between hospitals and EMS organizations, reducing delays associated with fragmented information systems. However, multiple studies reported persistent interoperability challenges across healthcare organizations, particularly where different vendors or legacy information systems are used.

Clinical decision support systems were widely reported as improving triage consistency, protocol adherence, and rapid clinical decision-making. Automated alerts, evidence-based recommendations, and standardized emergency pathways enabled clinicians to prioritize critically ill patients more efficiently while reducing cognitive workload during high-pressure situations. Decision support systems were particularly valuable in pandemic management and disaster triage where rapid resource allocation was essential.

Artificial intelligence represented the fastest-growing area of health informatics. Machine learning models were increasingly used for predicting patient deterioration, ambulance demand forecasting, emergency department overcrowding, and optimizing resource allocation. Although AI demonstrated substantial promise, studies consistently highlighted concerns regarding algorithm transparency, bias, explainability, legal responsibility, and integration into clinical workflows. Emerging work on AI in EMS also emphasizes that successful deployment depends on preserving clinicians' situational awareness rather than replacing professional judgment.

Telemedicine expanded considerably during the COVID-19 pandemic and continues to support emergency preparedness through remote consultation, virtual triage, and continuity of care. Mobile health applications facilitate communication between emergency responders, hospitals, and public health authorities while enabling remote patient monitoring and rapid dissemination of clinical guidance. These technologies are particularly beneficial in rural areas and during disasters where physical access to healthcare facilities is limited.

GIS technologies improve emergency preparedness by supporting ambulance routing, hazard mapping, hospital capacity monitoring, and regional resource allocation. Several EMS preparedness reviews identified spatial intelligence as an essential component of coordinated disaster response because it enables emergency managers to visualize incident locations, available resources, and transportation routes in real time.

Across the reviewed literature, preparedness depended not only on technology but also on workforce competencies. Recent meta-analyses indicate that nurses generally demonstrate moderate disaster preparedness, with disaster management and practical skills requiring improvement. Training, simulation exercises, and previous disaster experience consistently improved preparedness levels. Similar findings were reported for EMS organizations, where structured planning, communication systems, incident command, and continuous education were identified as core preparedness dimensions.

Table 2. Health Informatics Technologies Supporting Emergency Preparedness

Technology	Nursing	EMS	Reported Benefits	Common Challenges
Electronic Health Records	✓	✓	Information continuity	Interoperability
Clinical Decision Support	✓	✓	Faster clinical decisions	Alert fatigue
Artificial Intelligence	✓	✓	Predictive analytics	Explainability
Telemedicine	✓	△	Remote consultation	Infrastructure
Mobile Health	✓	✓	Real-time communication	Cybersecurity
GIS	△	✓	Ambulance routing	Data integration
IoMT/Wearables	✓	✓	Continuous monitoring	Device compatibility
Cloud Platforms	✓	✓	Information sharing	Privacy concerns

(✓ = widely reported; △ = emerging application)

Despite technological progress, several recurring barriers were identified across the literature. The most frequently reported obstacles included limited interoperability between information systems, inadequate cybersecurity measures, inconsistent data quality, insufficient workforce training, resistance to organizational change, limited financial resources, and unclear governance policies. Many authors emphasized that technology alone cannot improve preparedness unless accompanied by standardized protocols, leadership support, and continuous professional education.

The literature indicates a transition from isolated digital solutions toward integrated health informatics ecosystems. Emerging innovations include AI-assisted decision support, wearable biosensors, Internet of Medical Things (IoMT), cloud-based command centers, predictive analytics, and interoperable emergency information exchanges. Recent studies also suggest growing interest in explainable AI, digital twins, augmented reality, and multimodal cognitive assistants for EMS. These developments aim to enhance situational awareness, improve interdisciplinary coordination, and strengthen healthcare system resilience during future emergencies.

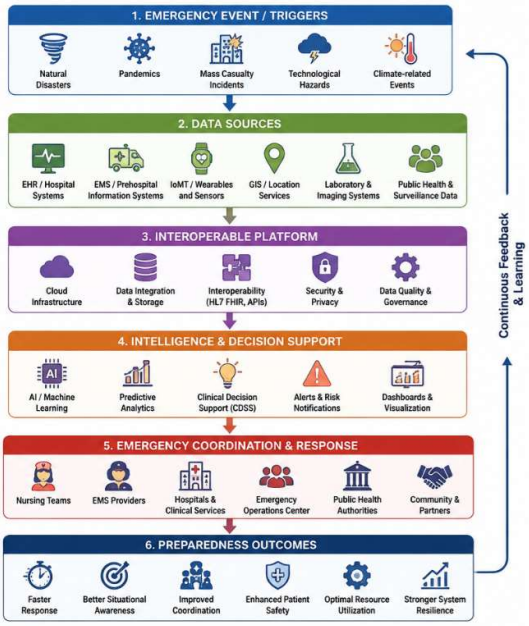

Figure 2. Integrated Health Informatics Ecosystem for Emergency Preparedness

This Results section provides the evidence synthesis needed to support the subsequent **Discussion**, where the findings can be interpreted in light of healthcare system resilience, digital transformation, and the proposed integrated health informatics framework. The cited literature is intentionally different from the foundational sources used in the Introduction and reflects recent systematic reviews and emerging research on nursing disaster preparedness, EMS preparedness, and AI-enabled emergency response.

4. Discussion

This systematic review examined the current evidence regarding the application of health informatics to strengthen emergency preparedness in nursing and Emergency Medical Services (EMS). The findings demonstrate that health informatics has evolved from supporting routine clinical documentation to becoming a strategic enabler of emergency preparedness, facilitating real-time decision-making, multidisciplinary coordination, predictive analytics, and resource optimization. Across the reviewed literature, Electronic Health Records (EHRs), Clinical Decision Support Systems (CDSS), artificial intelligence (AI), telemedicine, mobile health (mHealth), Geographic Information Systems (GIS), cloud computing, and interoperable health information exchange consistently emerged as the core technologies contributing to healthcare resilience during emergencies. Despite these advances, the review also identified persistent barriers related to interoperability, workforce readiness, governance, cybersecurity, and digital infrastructure.

One of the most consistent findings was the importance of **integrated information sharing** across healthcare organizations. Emergency preparedness requires continuous communication among hospitals, EMS agencies, public health authorities, emergency operation centers, and policymakers. Fragmented information systems reduce situational awareness, delay clinical decisions, and limit coordinated emergency response. Studies included in this review indicate that interoperable EHRs supported by standardized data exchange frameworks such as HL7 FHIR substantially improve continuity of care, patient tracking, and resource coordination during disasters and public health emergencies (Adler-Milstein et al., 2021; Mandel et al., 2016). Consequently, interoperability should be considered a foundational requirement rather than an optional feature of emergency preparedness systems.

The review further highlights the growing contribution of **artificial intelligence** to emergency preparedness. Machine learning algorithms have demonstrated considerable potential for predicting patient deterioration, forecasting emergency department overcrowding, optimizing ambulance deployment, estimating hospital resource utilization, and supporting disaster triage. Unlike conventional decision support tools, AI systems continuously learn from large datasets and provide predictive insights that enable proactive rather than reactive emergency management. Nevertheless, several studies emphasize that AI implementation remains constrained by concerns regarding algorithm transparency, explainability, fairness, and clinical accountability. Emergency clinicians consistently express greater confidence in AI systems when recommendations remain interpretable

and clinicians retain final decision-making authority (Topol, 2019; Rajpurkar et al., 2022). Therefore, future emergency informatics should prioritize explainable and human-centered AI that complements rather than replaces clinical expertise.

Another important finding concerns the expanding role of **telemedicine and mobile health technologies**. During the COVID-19 pandemic, healthcare organizations rapidly adopted virtual consultations, remote patient monitoring, and mobile communication platforms to maintain continuity of care while minimizing unnecessary hospital visits. The reviewed evidence suggests that these technologies remain valuable beyond pandemic response by improving access to specialist consultation during disasters, facilitating communication between EMS teams and hospitals, and supporting healthcare delivery in geographically isolated communities. Mobile applications additionally improve incident reporting, clinical documentation, and rapid dissemination of emergency protocols. However, successful implementation depends upon reliable communication networks, digital literacy, organizational policies, and equitable access to technology, particularly in rural and resource-constrained settings (Keesara et al., 2020).

The findings also demonstrate that **nursing informatics** plays an increasingly important role in emergency preparedness. Nurses represent the largest healthcare workforce and are directly involved in triage, patient monitoring, infection prevention, documentation, resource coordination, and multidisciplinary communication. Informatics systems reduce documentation burden, improve clinical decision support, facilitate standardized emergency protocols, and enhance continuity of care across healthcare settings. Nevertheless, the literature consistently reports variability in digital competencies among nursing professionals. Several studies recommend integrating disaster informatics, digital health competencies, simulation-based education, and health information technologies into undergraduate nursing curricula and continuing professional education to improve workforce preparedness (Booth et al., 2021).

Similarly, the review identifies substantial opportunities for strengthening **EMS preparedness** through digital transformation. EMS organizations increasingly rely on mobile electronic patient care records, GPS-enabled dispatch systems, GIS-based routing, real-time communication platforms, and predictive analytics to improve response efficiency. Integrated dispatch systems supported by geographic information technologies optimize ambulance allocation and reduce response times while enabling emergency managers to monitor resource availability across healthcare regions. These capabilities become particularly valuable during large-scale disasters where demand frequently exceeds available healthcare resources (World Association for Disaster and Emergency Medicine, 2023). However, EMS agencies continue to experience challenges associated with interoperability, communication reliability, and integration with hospital information systems.

Although technological advances dominate recent literature, this review demonstrates that **technology alone cannot ensure emergency preparedness**. Organizational readiness, governance, workforce competency, leadership commitment, policy development, and continuous quality improvement remain equally important determinants of successful implementation. Numerous studies reported that organizations possessing advanced digital infrastructure nevertheless experienced implementation challenges due to insufficient staff training, resistance to organizational change, inadequate funding, or lack of standardized emergency protocols. These findings support socio-technical perspectives that emphasize interactions between technology, people, organizational culture, and governance rather than focusing exclusively on technological innovation (Sittig & Singh, 2015).

Cybersecurity and data governance emerged as additional challenges across multiple studies. Increasing dependence on interconnected health information systems exposes healthcare organizations to cyberattacks, ransomware incidents, unauthorized data access, and information disruption during emergencies. Such threats may compromise patient safety, disrupt emergency operations, and reduce public trust. Consequently, healthcare organizations should incorporate cybersecurity planning, disaster recovery procedures, encryption technologies, role-based access control, and continuous system monitoring into emergency preparedness strategies rather than treating cybersecurity as a separate information technology function (Kruse et al., 2022).

A major contribution of this review is the development of a **proposed integrated health informatics framework** for emergency preparedness. Unlike previous frameworks that typically focus on individual technologies or specific healthcare sectors, the proposed model adopts a systems perspective integrating data acquisition, interoperability, intelligent analytics, clinical decision support, multidisciplinary communication, and emergency coordination into a unified ecosystem. The framework begins with multiple data sources, including EHRs, EMS information systems, wearable devices, IoMT sensors, GIS platforms, laboratory systems, and public health surveillance databases. These heterogeneous data streams are integrated through interoperable cloud-based platforms using standardized communication protocols. Advanced analytics, AI, and clinical decision support systems

subsequently transform raw data into actionable intelligence supporting emergency managers, nurses, physicians, EMS personnel, and policymakers. Finally, the framework aims to improve preparedness outcomes through enhanced situational awareness, optimized resource allocation, accelerated clinical decision-making, improved coordination, and increased healthcare system resilience.

The review also identifies several important research gaps. First, relatively few studies evaluate integrated informatics ecosystems encompassing both nursing and EMS within a single preparedness framework. Most existing research investigates isolated technologies rather than interactions among multiple digital systems. Second, longitudinal implementation studies evaluating organizational outcomes following digital transformation remain limited. Third, evidence from low- and middle-income countries remains underrepresented despite substantial differences in infrastructure, workforce capacity, and disaster vulnerability. Fourth, standardized outcome measures for evaluating emergency preparedness continue to vary considerably across studies, limiting direct comparison of interventions. Finally, limited research has examined ethical governance, explainable AI, and digital equity within emergency preparedness.

Future research should therefore move beyond evaluating individual technologies toward investigating integrated digital ecosystems capable of supporting multidisciplinary emergency response. Researchers should prioritize multicenter implementation studies, interoperability evaluation, AI validation in real-world emergency environments, digital twin technologies for disaster simulation, federated learning for secure multi-institutional analytics, and explainable AI for clinical decision support. Furthermore, stronger collaboration between healthcare providers, software developers, policymakers, emergency planners, and public health organizations will be essential for developing sustainable informatics solutions capable of addressing increasingly complex emergency scenarios.

Overall, the findings demonstrate that health informatics has become a strategic component of modern emergency preparedness rather than merely a supporting information technology. The successful integration of interoperable information systems, intelligent analytics, digital communication platforms, and evidence-based governance can substantially improve preparedness, coordination, and healthcare system resilience. Nevertheless, achieving these benefits requires balanced investment in technology, workforce capability, organizational readiness, cybersecurity, and policy development. The proposed integrated framework provides a comprehensive foundation for guiding future research, healthcare practice, and policy initiatives aimed at strengthening emergency preparedness across nursing and EMS.

5. Proposed Integrated Health Informatics Framework for Nursing and Emergency Medical Services Preparedness

The findings of this systematic review indicate that existing health informatics solutions are frequently implemented as isolated technologies, limiting their ability to support coordinated emergency preparedness. While Electronic Health Records (EHRs), Clinical Decision Support Systems (CDSS), Artificial Intelligence (AI), telemedicine, Geographic Information Systems (GIS), and mobile health (mHealth) applications have individually demonstrated significant benefits, their full potential can only be achieved through an integrated framework that enables seamless information exchange, intelligent decision support, and multidisciplinary collaboration. Therefore, this review proposes an **Integrated Health Informatics Framework for Nursing and Emergency Medical Services (EMS) Preparedness** that consolidates these technologies into a unified emergency preparedness ecosystem.

The proposed framework consists of **six interconnected layers**, beginning with **emergency events and triggers**, including natural disasters, infectious disease outbreaks, mass casualty incidents, technological hazards, and climate-related emergencies. These events initiate the emergency preparedness cycle and generate substantial volumes of clinical, operational, and environmental information requiring rapid analysis and coordinated response (World Health Organization [WHO], 2023).

The second layer comprises **multiple healthcare data sources**, including Electronic Health Records, EMS information systems, Internet of Medical Things (IoMT) devices, wearable sensors, laboratory information systems, Geographic Information Systems, and public health surveillance databases. Integrating these heterogeneous data sources provides a comprehensive situational awareness platform that supports both prehospital and hospital-based emergency management (Health Level Seven International [HL7], 2024).

The third layer represents the **interoperable integration platform**, which serves as the technological foundation of the framework. This layer employs cloud computing, Health Information

Exchange (HIE), standardized interoperability protocols such as HL7 Fast Healthcare Interoperability Resources (FHIR), secure Application Programming Interfaces (APIs), and robust cybersecurity mechanisms. These technologies enable secure, real-time communication between healthcare organizations, emergency responders, and public health authorities while ensuring data integrity, confidentiality, and availability during emergencies (Mandel et al., 2016).

Building upon the integrated data platform, the fourth layer incorporates **intelligent analytics and clinical decision support**. Artificial intelligence, machine learning, predictive analytics, clinical decision support systems, risk prediction algorithms, and interactive dashboards transform raw healthcare data into actionable knowledge. This intelligence supports triage prioritization, patient deterioration prediction, ambulance deployment optimization, hospital capacity monitoring, resource allocation, and early warning systems. Rather than replacing healthcare professionals, these technologies augment clinical judgment by providing evidence-based recommendations in time-sensitive situations (Topol, 2019).

The fifth layer focuses on **multidisciplinary emergency coordination and response**, where nurses, EMS providers, hospitals, emergency operation centers, public health agencies, and community organizations collaborate using shared digital platforms. Integrated communication systems facilitate coordinated incident management, standardized documentation, patient tracking, and continuous information sharing across all stages of emergency response. Effective coordination among these stakeholders is essential for reducing response delays, improving continuity of care, and optimizing resource utilization during disasters (WHO, 2023).

Finally, the sixth layer represents the **preparedness outcomes** achieved through the integrated framework. These include faster emergency response, enhanced situational awareness, improved clinical decision-making, better interdisciplinary collaboration, increased patient safety, optimized resource utilization, greater operational efficiency, and stronger healthcare system resilience. Continuous monitoring and feedback loops further enable healthcare organizations to evaluate performance, learn from previous emergencies, and continuously improve preparedness strategies.

Unlike previous models that primarily emphasize individual technologies or specific healthcare settings, the proposed framework adopts a systems-based approach that integrates data, technology, healthcare professionals, organizational governance, and continuous learning into a single operational ecosystem. This holistic perspective supports proactive emergency preparedness rather than reactive crisis management and aligns with current international recommendations for digitally enabled, resilient healthcare systems.

Figure 3 illustrates the proposed Integrated Health Informatics Framework for Nursing and Emergency Medical Services Preparedness.

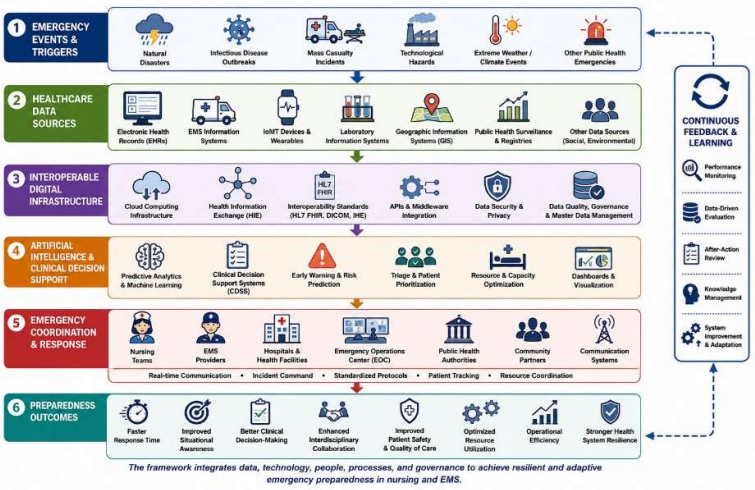

Figure 3. Proposed Integrated Health Informatics Framework for Nursing and Emergency Medical Services Preparedness

The framework begins with **Emergency Events and Triggers**, progresses through **Data Sources**, **Interoperable Digital Infrastructure**, **Artificial Intelligence and Clinical Decision Support**, and **Emergency Coordination**, ultimately leading to improved **Preparedness Outcomes**. A continuous feedback mechanism supports organizational learning, system optimization, and preparedness improvement following each emergency event.

6. Future Research Agenda

The rapid evolution of digital health technologies presents unprecedented opportunities to transform emergency preparedness within nursing and Emergency Medical Services (EMS). Although the existing literature demonstrates the potential of health informatics to improve emergency response, significant knowledge gaps remain regarding the integration, implementation, evaluation, and sustainability of these technologies. Future research should therefore move beyond isolated technological innovations and focus on developing comprehensive, interoperable, and evidence-based digital ecosystems that support resilient emergency healthcare systems.

One of the highest priorities for future research is the **development and validation of integrated health informatics frameworks** that combine Electronic Health Records (EHRs), Clinical Decision Support Systems (CDSS), Artificial Intelligence (AI), Geographic Information Systems (GIS), Internet of Medical Things (IoMT), telemedicine, mobile health (mHealth), and public health surveillance platforms into unified emergency preparedness systems. While many studies have evaluated individual technologies, relatively few have examined how these systems function collectively in real-world emergency settings. Large-scale implementation studies involving hospitals, EMS agencies, and public health organizations are needed to evaluate the effectiveness, scalability, and interoperability of integrated digital infrastructures (World Health Organization [WHO], 2023).

Another promising research direction involves the application of **artificial intelligence and advanced predictive analytics** for emergency preparedness. Future studies should investigate explainable AI models that support emergency triage, patient deterioration prediction, disease outbreak forecasting, ambulance demand estimation, hospital surge capacity planning, and disaster resource allocation. Explainable AI is particularly important because healthcare professionals must understand and trust algorithmic recommendations before incorporating them into clinical decision-making. Comparative studies evaluating AI-assisted decision support against traditional clinical practice would provide valuable evidence regarding safety, effectiveness, and clinician acceptance (Topol, 2019).

The emergence of **Digital Twins** represents another innovative research opportunity. Digital twins create virtual representations of healthcare systems that simulate emergency scenarios, hospital capacity, ambulance deployment, patient flow, and resource utilization. Future investigations should evaluate how digital twins can improve disaster planning, optimize emergency response strategies, and support scenario-based preparedness training. Integrating digital twins with real-time health informatics platforms may enable healthcare organizations to anticipate system bottlenecks before emergencies occur.

Future research should also explore the role of the **Internet of Medical Things (IoMT)**, wearable biosensors, and remote patient monitoring technologies in enhancing emergency preparedness. Continuous physiological monitoring can provide early detection of patient deterioration during disasters, pandemics, and mass casualty incidents while facilitating rapid clinical intervention. Longitudinal studies evaluating the reliability, accuracy, and clinical effectiveness of wearable technologies across different emergency contexts are required before widespread implementation.

Interoperability remains one of the most significant barriers identified throughout the literature. Consequently, future research should investigate standardized approaches for secure data exchange among hospitals, EMS providers, laboratories, public health agencies, and emergency operation centers using international interoperability standards such as HL7 FHIR, DICOM, and Fast Healthcare Interoperability Resources. Studies should also evaluate governance models that facilitate cross-organizational collaboration while maintaining data privacy and security (Health Level Seven International [HL7], 2024).

Cybersecurity represents another critical research priority. As healthcare organizations increasingly depend on interconnected digital infrastructures, emergency preparedness systems become more vulnerable to ransomware attacks, data breaches, and infrastructure disruptions. Future investigations should assess cybersecurity resilience, disaster recovery strategies, zero-trust architectures, blockchain-enabled data protection, and secure cloud computing environments specifically designed for emergency healthcare operations. Integrating cybersecurity into emergency preparedness planning should become a fundamental component of health informatics research rather than a separate technical consideration.

The review further highlights the importance of **human factors and workforce readiness**. Future studies should evaluate digital competency frameworks for nurses, EMS personnel, emergency physicians, and healthcare administrators. Research should investigate simulation-based learning, virtual reality (VR), augmented reality (AR), serious gaming, and AI-supported educational platforms to improve emergency preparedness competencies. Standardized competency assessment tools should also be developed to evaluate healthcare professionals' readiness to utilize advanced informatics systems during disasters.

Another emerging area involves the integration of **population health surveillance** with emergency preparedness. Future research should investigate how environmental monitoring systems, climate data, syndromic surveillance, social media analytics, and public health reporting platforms can be integrated into health informatics ecosystems to improve early warning capabilities. Combining healthcare data with environmental and population-level information may substantially strengthen preparedness for infectious disease outbreaks, heatwaves, floods, wildfires, and other climate-related emergencies.

Despite increasing international interest in digital health, most existing evidence originates from high-income countries. Future research should therefore prioritize **low- and middle-income countries (LMICs)**, where healthcare infrastructure, digital maturity, and disaster vulnerability differ considerably. Comparative international studies are needed to identify context-specific implementation strategies, infrastructure requirements, workforce needs, and policy interventions that support equitable digital transformation across diverse healthcare systems.

Finally, future research should adopt more rigorous methodological approaches. Multicenter prospective studies, randomized implementation trials where feasible, longitudinal evaluations, mixed-methods research, and implementation science frameworks are required to generate stronger evidence regarding the effectiveness of health informatics interventions. Standardized outcome measures should also be established to facilitate comparisons across studies and healthcare systems. These outcomes may include emergency response time, patient mortality, situational awareness, healthcare system resilience, interoperability performance, resource utilization, clinician satisfaction, and cost-effectiveness.

Table 3. Future Research Priorities for Health Informatics in Emergency Preparedness

Research Domain	Current Gap	Future Research Direction	Expected Impact
Integrated Health Informatics Frameworks	Fragmented digital systems	Develop and validate interoperable frameworks	Improved coordination and preparedness
Artificial Intelligence	Limited explainability	Explainable AI for triage, prediction, and decision support	Greater clinician trust and improved decisions
Digital Twins	Limited healthcare applications	Simulate disaster scenarios and healthcare operations	Better planning and resource optimization
IoMT and Wearables	Limited long-term evaluation	Continuous monitoring and early warning systems	Faster clinical intervention
Interoperability	Poor cross-system communication	HL7 FHIR-based information exchange	Real-time multidisciplinary coordination
Cybersecurity	Increasing cyber threats	Secure cloud platforms, blockchain, and zero-trust architectures	Enhanced resilience and data protection
Workforce Competency	Variable digital skills	Simulation-based education and competency frameworks	Improved preparedness among nurses and EMS
Population Health Surveillance	Limited integration	Combine clinical, environmental, and public health data	Earlier detection of emerging threats
Global Implementation	Limited evidence from LMICs	Multinational implementation and comparative studies	Equitable digital transformation
Evaluation Methods	Heterogeneous outcome measures	Standardized metrics and implementation science approaches	Stronger evidence for policy and practice

Overall, the future of emergency preparedness lies in the development of intelligent, interoperable, secure, and human-centered health informatics ecosystems that integrate advanced technologies with clinical expertise, organizational governance, and continuous learning. Achieving this vision will require close collaboration among healthcare professionals, emergency planners, informatics

researchers, policymakers, technology developers, and international organizations. Such collaborative efforts will support the development of resilient healthcare systems capable of responding effectively to future disasters, pandemics, and other complex public health emergencies.

7. Conclusion

This systematic review synthesized current evidence on the role of health informatics in strengthening emergency preparedness within nursing and Emergency Medical Services (EMS). The findings demonstrate that health informatics has become an essential component of modern emergency management by enabling timely access to clinical information, supporting evidence-based decision-making, enhancing multidisciplinary communication, and improving coordination across healthcare organizations. Technologies such as Electronic Health Records (EHRs), Clinical Decision Support Systems (CDSS), artificial intelligence (AI), telemedicine, mobile health (mHealth), Geographic Information Systems (GIS), Internet of Medical Things (IoMT), and interoperable health information exchange platforms collectively contribute to more resilient and responsive emergency healthcare systems.

Despite substantial technological progress, the review identified several persistent barriers that continue to limit the effective implementation of digital health solutions. These include inadequate interoperability among information systems, cybersecurity and privacy concerns, inconsistent data quality, insufficient workforce digital competencies, organizational resistance to change, financial constraints, and the absence of standardized governance frameworks. The evidence indicates that successful emergency preparedness requires not only advanced technologies but also integrated organizational strategies that emphasize workforce training, leadership commitment, policy development, and continuous quality improvement.

Based on the synthesized evidence, this review proposes an integrated health informatics framework that combines multiple digital technologies into a unified ecosystem supporting emergency preparedness across nursing and EMS. The framework emphasizes interoperable data integration, intelligent clinical decision support, predictive analytics, real-time communication, and collaborative emergency coordination to improve situational awareness, optimize resource allocation, accelerate emergency response, and enhance patient safety.

Future research should prioritize the development and evaluation of integrated health informatics ecosystems in real-world emergency settings, with particular attention to explainable artificial intelligence, digital twins, federated learning, cybersecurity resilience, and interoperability standards. In addition, multicenter longitudinal studies are needed to assess the effectiveness, scalability, and sustainability of these technologies across diverse healthcare systems. Strengthening collaboration among healthcare professionals, emergency planners, policymakers, and technology developers will be essential to establishing resilient, data-driven emergency preparedness systems capable of responding effectively to future disasters and public health emergencies.

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