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Assistive Technology to Support Medical Professionals for Disaster Management

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ABSTRACT

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Medical assistive technology plays a crucial role in enhancing response and recovery efforts during disasters. This technology includes advanced tools and devices designed to support medical professionals in assessing, treating, and managing patients in high-pressure disaster situations. This paper will explore the medical assistive technology to enhance disaster management. This literature review was conducted via searching in databases such as PubMed, Science Direct, Google Scholar, and Scopus using keywords such as “technology for disaster management”; “pharmaceutical technology for disaster”; “health information”; “communication and technology”; and “disaster medicine technology, robotic, and IoT for healthcare”. The result showed that several tools and software were developed in many countries such as 3D printing for pharmaceuticals for medication printing, drone technology for delivering medical equipment, drugs, and blood, Emergency Medical Information Systems (EMIS), virtual reality (VR) for disaster medicine training, robotics, and innovative mobile applications like SaveMyLife, mental health applications, and rapid DNA technology for disaster victim identification. Using the Health System Resilience Framework, this study highlights how these technologies strengthen service delivery, workforce capacity, and information systems in emergencies. Despite their benefits, most innovations originate in high-income countries, raising challenges for equitable adoption. Future research should address scalability, local adaptation, and ethical considerations to enhance health system resilience in low-resource settings.

Keywords

Assistive Technology
Disaster Management
Drugs
Medical Professional
Medicine

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Introduction

Disaster, whether caused by humans or nature, can significantly disrupt people's lives and cause damage to structures. They are generally classified into two types: natural disasters, such as earthquakes, floods, tsunamis, volcanic eruptions, hurricanes, and artificial disasters, including terrorism, fires, and wars. Natural disasters typically occur suddenly and can have adverse effects on social life [1]. The visible impacts of disasters are the loss of life, the establishment of large-scale shelters, the destruction of homes and public facilities, water and sanitation contamination, lack of food supply, and disrupted road access. Meanwhile, the indirect impact of disasters includes the increased spread of diseases, the emergence of psychological illnesses or stress, the loss of income sources, the rise in unemployment rates, and the increase in poverty levels [2].

One of the highest risks in society that needs to be managed is vulnerable groups. Vulnerable groups are babies, toddlers, children, mothers who are pregnant or breastfeeding, people with disabilities, and the elderly [3]. Vulnerable groups are groups of people at high risk because they are in situations and conditions that lack the ability to prepare themselves to face the risk of disaster or threat. This group is at high risk because when a disaster occurs, it will feel a greater impact than other community groups [4]. Natural disasters often result in casualties; this is caused by a lack of preparedness and inadequate support. Lack of preparation and support can significantly increase the death toll. This is a serious challenge facing many communities around the world [5]. To avoid loss of life due to disasters, medical assistive technology related to disaster management is needed.

Medical assistive technology has become a pivotal component in modern disaster management, offering transformative solutions to the challenges faced during emergencies. In the chaotic aftermath of natural or man-made disasters, traditional medical response systems can be overwhelmed, making the integration of advanced technology crucial for effective intervention. Tools such as portable diagnostic devices, telemedicine platforms, and automated triage systems are designed to enhance the capabilities of medical professionals, ensuring that they can deliver timely and precise care under extreme conditions [6]. The advent of these technologies has revolutionized how medical teams operate in disaster-stricken areas. Portable diagnostic systems enable rapid assessment of injuries and health

conditions, providing essential information at the scene rather than relying on transport to distant medical facilities. Telemedicine platforms facilitate real-time consultations with specialists, bridging gaps in expertise and allowing for more informed decision-making even when experts are not physically present. Automated triage systems streamline patient prioritization, ensuring that those in greatest need receive prompt attention while optimizing resource allocation [7].

Overall, medical assistive technology not only improves the efficiency of disaster response but also enhances the quality of care provided during crises [8]. By leveraging these advanced tools, medical teams can better manage the complexities of disaster scenarios, ultimately leading to faster recovery and improved outcomes for affected individuals. As technology continues to evolve, its integration into disaster management practices will be crucial in addressing the ever-growing demands of emergency medical care. This review is organized using the Health Systems Resilience Framework, emphasizing how assistive technologies strengthen health system components, service delivery, information systems, workforce support, access to essential medicines, and governance during disasters situations. By analyzing technologies through this lens, this paper identifies opportunities to strengthen health system resilience and equity in low-resource setting.

Methods

This literature review was conducted through searches in PubMed, ScienceDirect, Google Scholar, and Scopus using keyword such as “technology for disaster management,” “pharmaceutical technology for disaster,” “Health information and communication,” and “disaster medicine technology, robotics and IoT for healthcare.” Articles published in English between 2014 and 2024 were included. A total 132 records were initially retrieved from the databases. After screening titles and abstracts, 48 articles were considered relevant. Following full-text assessment, 8 studies met the inclusion criteria and were included in this review. This study employed narrative review approach, focusing on synthesizing existing evidence and identifying conceptual linkages rather than conducting a quantitative meta-analysis. The limitation of this approach lies in potential selection bias, as it relies on the authors’ interpretation of the available literature. Additionally, heterogeneity among studies prevented direct comparison of formal quality assessment.

Results

Medical assistive technology plays a pivotal role in enhancing disaster management by addressing critical medical needs that arise during emergencies. These technologies improve healthcare accessibility, timeliness, and adaptability through rapid on-site medical assessments, portable diagnostic tools, and mobile medical units that enable timely

interventions without relying solely on distant healthcare facilities. The studies included in this review revealed several assistive technologies that serve as key interventions in disaster settings. See Table 1.

Table 1. Overview of Medical Assistive Technologies for Disaster Management

Technology	Level of Evidence	Typical Settings	Advantages	Limitations
3D Printing for Pharmaceuticals	Pilot studies, early trials	Hospitals, pharmacies	Personalized dosage, reduced logistics	High cost, regulatory barriers
Drone Delivery	Field implementation in Japan, trials in Africa	Remote/disaster-prone areas	Fast delivery, overcomes terrain	Weather-dependent, limited payload
EMIS	Implementation in Indonesia and Japan	Emergency & referral hospitals	Rapid triage, integrated data sharing	Data privacy risks, high setup cost
Virtual Reality Training	Experimental and educational trials	Training centers	Realistic simulation, cost-effective training	Limited realism, lacks field adaptation
Robotics	Clinical and rehabilitation trials	Hospitals	Precision, labor efficiency	Ethical issues, cost, technical delay
SaveMyLife App	Field-tested prototype	Disaster response	Rapid communication, local data	Internet reliance, limited awareness
Mental Health Care App (TLS)	Pilot study in Korea	Post-disaster support	Improves resilience, self-management	Cultural adaptation needed
Rapid DNA Technology	Operationalized in forensic use	Disaster victim identification	Fast, portable, accurate	Expensive, maintenance required

A. 3D Printing for Pharmaceutical

Natural disasters have effects such as road damage, which prevents access to healthcare facilities. However, the situation can worsen when they rely on drugs and do not meet their needs, and if they do not meet them, the consequences can be fatal [9]. Many research has proposed technological solutions to this problem, allowing people to acquire the drugs they need on time and at a low cost. The idea proposed is to use 3D printer technology to print the pharmaceuticals required during a natural disaster [10]. 3D printer technology using the technique of fused deposition mode (FDM) to print out the medication. One important aspect of treatment after natural disasters is that each person needs a different dosage and component. Therefore, tablets printed from 3D printing can be customized in shape, size, specific dosage, and amount of active substance, and the composition of tablets can be change by removing components [11].

With the presence of 3D printing, it can produce medicines according to a person's wishes and needs that allow it to be adapted to health limitations or digestive constraints. With a 3D

printer, the pill can be printed in just 7 seconds to make each pill. Compared to the traditional technique, making each pill takes an average of 55 seconds [12]. In the manufacturing of medications utilizing 3D printing, there are two different ways that can be done: combining the drug in a pharmaceutical-level excipient polymer and using traditional fused printing technology, as well as manufacturing shells and adding a drug fill [13].

In terms of countries that have used this technology, Spain conducted a first clinical trial in 2019 using a 3D printer to prepare a personalized therapy in a hospital clinic at the University of De Santiago de Compostela that produces a drug for treating maple syrup urinary disease in children aged 3-16 years [14]. Researchers in the United Kingdom used 3D printing using FDM to create low-dose antihypertensive pills containing atenolol, ramipril, pravastatin, aspirin, and hydrochlorothiazide [15]. The advantages of 3D printing are extremely environmentally friendly technology, as it does not produce pollutants in the air; waste generated by mistakes in a small batch; and reduced fuel consumption as a result of traditional pill transportation. However, there are some drawbacks to the use of 3D printing: the producer can inhale potentially hazardous materials, heat the extruder, and be exposed to harmful substances on the skin. However, to alleviate such problems, it is important to wear proper facial masks and self-protection equipment [16].

B. Drone Technology for Medical Delivery

One of the biggest challenges for healthcare services when facing a disaster is ensuring the distribution of medicines and medical supplies. Traditionally, the distribution of medicines and medical supplies has been hampered by the loss of access to healthcare services, inadequate infrastructure, long delivery times, and high costs. This often results in many fatalities or even lost opportunities to save patients due to late delivery of medicines and blood. So, the innovative solution offered is the use of drones or Unmanned Aerial Vehicles (UAVs). The use of drones for the delivery of medicines and blood is very crucial to reduce the impact of disasters and save disaster victims [17].

The use of drones not only helps in solving access and efficiency issues but also paves the way for further innovation in the delivery of healthcare services. With their ability to fly over geographical barriers and inadequate infrastructure, drones can shorten the time it takes to deliver medicines, blood samples, and critical medical equipment to hard-to-reach locations. This speed and flexibility are critical in medical emergencies, where time is often directly related to a patient's chance of survival. Drones greatly open up opportunities for remote health analysis through the delivery and collection of medical samples that enable diagnosis and consultation without requiring residents to visit the nearest health facility [18].

Drone technology, or Unmanned Aerial Vehicles (UAV) has been used in Japan to help victims in disaster-prone areas. The use of UAVs in Japan is considered more effective and

efficient than land transportation. UAVs in Japan are used to transport 17 kg of medical equipment belonging to the Disaster Medical Assistance Team (DMAT), 100 emergency meals weighing 13.8 kg, 60 snacks weighing 6.8 kg, an Automatic External Defibrillator (AED) weighing 3.7 kg, a simple blood glucose meter, a drug-integrated insulin injector in a simple refrigerator that is transported at a controlled low temperature. So, UAVs are very useful in the distribution of medication and medical equipment to disaster-prone areas. However, the weakness of drone technology is when the weather is not supportive, such as strong winds and heavy rain. Based on wind speed, UAV capacity cannot fly at wind speeds of 10 m/s or more [19].

C. Emergency Medical Information System (EMCIS)

EMS is defined as "an integrated system that provides staff, facilities, and equipment arrangements for the effective, coordinated, and timely provision of health and safety services to victims of an unexpected illness or injury." The goal of this approach is to give timely and life-threatening care to victims of sudden injuries or emergencies in order to prevent mortality or long-term morbidity. The EMS operation can be separated into four major components: First-aid access, community care, on-road care, and care upon arrival at the health center for the patient's treatment [20]. Emergency Medical Information Systems (EMIS) offer several advantages in the realm of healthcare management and emergency response. Firstly, they provide quick access to critical medical data such as patient allergies, medical conditions, and current medications, enabling healthcare providers to make informed decisions swiftly during emergencies. This rapid access can significantly reduce treatment delays and improve patient outcomes by ensuring that appropriate care is administered promptly. Moreover, EMIS enhances communication between healthcare facilities, emergency responders, and patients. This interconnectedness ensures that essential medical information is readily available across different healthcare settings, regardless of where the emergency occurs [21]. However, EMIS also presents some challenges and disadvantages. One notable concern is the potential for data security breaches or unauthorized access to sensitive patient information. Ensuring robust cybersecurity measures and compliance with privacy regulations is crucial to protect patient confidentiality and prevent misuse of medical data. For smaller healthcare facilities or those in resource-constrained settings, these financial implications may pose barriers to adoption and implementation [22].

EMCIS, or Emergency Medical Information System, is an application developed by Indonesia to support the evacuation of disaster victims. This application connected to Hasan Sadikin Hospital in Bandung, Indonesia. The features of the application include the main patient features, triage features, and support and treatment features during transportation. The rescue team or medical team can utilize the main patient feature to fill in the initial data of

the patient/disaster victim, such as the main complaint and vital signs (level of consciousness, heart rate, respiratory rate, systolic and diastolic blood pressure, and temperature). Furthermore, based on the vital signs, the medical team can group them into four triage categories. Patients labeled red who require temporary life support must be evacuated to the field hospital for stabilization unless there is an ambulance that can take them to the referral hospital for further treatment. These patients are a priority because of their life-threatening condition. Furthermore, patients labeled red must be referred to the resuscitation room, operating room, or intensive care unit at the referral hospital. However, patients labeled yellow, although not having a life-threatening condition, are still affected by the emergency and therefore must be evacuated to the emergency room for elective treatments, while patients labeled green can remain in the field hospital for more minor treatment. Then the medical team can use the support and treatment features during transportation. The support and treatment feature during transportation is used for patients who need to be referred to the hospital immediately (red triage). This feature can provide patient needs during the trip to the hospital such as solutions (ringer lactate, normal saline, colloid, and blood transfusion) and administration of drugs for resuscitation (adrenaline, atropine sulfate, dopamine, amiodarone, antibiotics, analgesics, and anesthetics). Finally, the data will be received by the hospital, and further actions and care will be taken for patients in the hospital [23].

D. Virtual Reality for Disaster Medicine

Using virtual reality (VR) to disseminate knowledge about disaster medicine holds significant promise. In the event of a disaster, immediate aid from professional rescue teams may not always be as prompt as assistance from individuals on the scene, who often find themselves in the dual roles of both rescuer and rescued. Transitioning between these roles empowers affected individuals to engage in self-help and mutual assistance, crucial for effective disaster relief efforts [24]. Integrating VR into disaster preparedness drills involves creating immersive, three-dimensional virtual environments depicting scenarios like fires, earthquakes, and traffic accidents. This allows users to experience and learn about disaster prevention and response firsthand. By simulating decision-making in crisis situations, users can contemplate the consequences of their actions, thereby better preparing themselves to manage real-life emergencies. Compared to traditional disaster education methods, VR offers advantages such as realistic environment simulation, cost-effectiveness, and reduced resource consumption [25].

Disaster rescue personnel serve as vital medical assets on the frontlines of disaster response. The effectiveness of their response to sudden threats, heavily reliant on their professional expertise and emergency preparedness, significantly impacts the success of relief efforts. Alongside fundamental disaster response knowledge, these professionals must also

possess clinical skills crucial for effective intervention. However, traditional training methods often face challenges such as limited opportunities for realistic scenario practice, inadequate equipment availability, and insufficient hands-on experience in first-aid procedures [26].

Training for emergency response typically includes four core components: wound care, fracture management, hemorrhage control, and cardiopulmonary resuscitation (CPR). Human-computer interaction simulation technology, incorporating force feedback and visual cues, plays a pivotal role in enhancing these training sessions. By immersing learners in virtual disaster scenarios and 3D models, supplemented by sensory feedback, participants can engage with simulations using multiple senses, fostering a more realistic and immersive learning experience. This approach significantly enhances the authenticity and practicality of first-aid training, enabling trainees to develop essential skills more effectively [27].

Moreover, to accelerate skill acquisition, training programs can deconstruct complex procedures into manageable steps and provide opportunities for intensive practice. This focused approach allows trainees to refine their techniques and improve their proficiency in first-aid procedures within a shorter timeframe [26]. Research conducted by [28] compared the performance of participants who underwent VR training, video-based training, and those who received no training. The findings indicated that participants trained using VR demonstrated superior performance, whereas those trained through alternative methods exhibited greater variability in their abilities. However, the weakness of virtual reality is that it's unable to adapt to the conditions in the field. For example, virtual reality only saves victims in one room, but in the field, it can save victims who are trapped on an apartment floor. Also the virtual reality application does not contain sound; for example, if an earthquake causes objects to fall, it will cause us to avoid it.

E. Robotic Application in Healthcare

Robotics in healthcare represents a revolutionary advancement that is transforming the way medical services are delivered. These cutting-edge technologies are being integrated into various facets of healthcare, enhancing the precision, efficiency, and effectiveness of medical treatments. Robotics is playing a crucial role in addressing the shortage of healthcare professionals. Robots are being deployed for tasks such as dispensing medication, performing diagnostic tests, and even assisting in complex surgeries, thereby freeing up healthcare workers to focus on more critical aspects of patient care [29]. The integration of artificial intelligence (AI) with robotics is further pushing the boundaries of what is possible in healthcare. AI-powered robots can analyze vast amounts of medical data to assist in diagnosis, predict patient outcomes, and even provide real-time support during surgical procedures. As the technology continues to evolve, the potential applications of robotics in healthcare are

likely to grow, promising to improve patient outcomes, increase accessibility to medical services, and transform the healthcare landscape as a whole [30].

There are several examples of robots that have been applied to help in medicine. Rehabilitation robotics is a robot that involves the use of assistive devices to help people with disabilities and the elderly. The goal of rehabilitation robotics is to replace part or all of the body functions of a disabled or elderly user by placing a robot between the user's body parts [29]. In recent years there have been many developments, from neurorehabilitation for patients with neuromuscular injuries or diseases to sensory therapy that allows patients to relearn how to move in the event of a chronic stroke or cerebral stroke. An example of such a robot is the In Motion 2.0 Shoulder Robot developed by MIT for intensive rehabilitation of patients who have had a stroke or brain injury and with have limited strength or movement in the upper extremities [30]. However, there are some weaknesses in the use of robots in the medical field, including psychological problems in the sense that robots can be considered as competitors of doctors and machines that have the potential to harm patients. In addition, the speed of information transfer from the operator to the robot and the delay time from the operator to the execution time are still major problems. As well as economic problems that can arise, there are the cost-effectiveness of making medical robots and ethical issues such as patient privacy that must be handled [30].

F. SaveMyLife

SaveMyLife is a mobile app designed with a focus on the priorities of disaster victims and utilizing technology. SaveMyLife application was developed in Indonesia. The objective behind developing this app is to accelerate the response time of search and rescue (SAR) teams and enhance the survival rates of victims. The "SaveMyLife" application has three main features: (1) preloaded content, (2) panic button, and (3) early warning system. The preloaded content feature allows the application to process data or information using resources that have been installed in advance. This feature ensures smooth operation of the application even in the absence of a reliable internet connection. Preloaded content may include audio files, documents, images, and videos. Within this feature, there are two sub-features: safety points and safety tips. Safety Points aid users in locating shelters or assembly points during disaster events. The application assesses various types of buildings (such as police offices, hospitals, mosques, and fire stations) to determine suitable evacuation centers. This assessment considers three criteria: minimal impact from disasters, direct access to primary roads, and a minimum building size of 225 square meters. The safety tips feature within the SaveMyLife application offers educational videos sourced from YouTube. These videos cover a range of topics, including first aid techniques and actions to take before, during, and after disasters

occur. Currently, there are 13 educational videos on disaster management available, with the possibility of adding, modifying, or adjusting them as needed for future updates [31].

The Panic button feature allows users to swiftly inform emergency response teams, such as paramedics, search and rescue (SAR) teams, and firefighters, about their situation during a crisis. This feature enables rescue personnel to establish contact with users to coordinate evacuation procedures promptly. Consequently, rescuers can pinpoint the users' locations, assess their medical condition, and prepare necessary treatment. The application categorizes users into groups based on health records provided during registration, identifying vulnerable individuals such as the disabled, women, children, the elderly, and those with pre-existing medical conditions. The early warning system feature focuses on earthquake detection, utilizing comprehensive data sourced from the Indonesian government. SaveMyLife's disaster notification feature delivers real-time alerts, particularly for earthquakes, furnishing precise details regarding their location and magnitude. This earthquake information is sourced from InaSAFE.org, a freely accessible software developed collaboratively by BNPB, the Australian government, and the World Bank. InaSAFE.org combines data from various sources, including governments, scientists, and communities, to offer insights into the potential impact of future disaster events [32].

G. Mental Health Care Mobile App

With the recent increase in disasters, the demand for "post-disaster psychological assistance" is rising, leading to a growing number of individuals in need of such support. While disaster survivors provided with adequate and effective support systems may demonstrate resilience—such as enduring temporary pain and employing appropriate coping strategies—many will still face mental health challenges like post-traumatic stress disorder (PTSD), depression, and anxiety [33]. The TLS app was designed to support individuals affected by traumatic experiences in Korea. The app is available for free download on the ONE store, a Korean mobile app platform, as part of their professional responsibility to provide public access to their research product, which was funded by a public foundation. The app's content is organized into three categories: information, psychological healing, and mood change. The information category consists of self-assessment (PTSD, depression, anxiety, sleep disorder), post-disaster responses, coping mechanisms (anger, sleep disorder, addiction), and guidance on how to utilize information from specialized institutions (consultation centers, medical institutions, administrative support organizations). Psychological healing consists of breathing, butterfly hugs, meditation, positive affirmations, healing music, 108 bows, yoga, and writing. Ventilation and diversion (mood change category), find the same picture game, fruit slot machine, bubble shot, coloring book, and Tetris. The user can freely select the desired function [34].

The TLS mobile app was effective in increasing positive psychological factors and reducing negative ones based on usage time. It is expected to promote psychological stability and create favorable conditions for disaster survivors to enhance self-control and manage their well-being effectively [35]. However, to encourage greater user engagement and app utilization, it will be important to develop a practical self-management guide to enhance its applicability. Additionally, further research is needed on diverse diagnostic groups and the app's effectiveness across different age groups, including adults, the elderly, and children. Despite these limitations, this pilot study demonstrated that the TLS mobile app was effective in increasing positive psychological factors and reducing negative ones based on usage time [34].

H. Rapid DNA for Disaster Victim Identification

Forensic DNA analysis is crucial not only for criminal investigations but also for identifying victims in large-scale disasters. The precision of contemporary forensic DNA typing methods enables definitive identification in most cases [36]. Technology that can be used to quickly identify disaster victims is rapid DNA technology. This technology allows for rapid identification of individuals through comparative DNA analysis (STR loci polymorphism) of reference samples (such as buccal swabs) and biological traces (like blood, saliva, cigarette butts, chewing gum, sperm, and other forensic samples). It has been designed for use not only in laboratory settings but primarily at incident scenes or during mass disasters to identify victims or perpetrators of terrorist attacks. The automated nature of the system means it can also be operated by people who are not specialists in forensic genetics [37].

The system includes a rapid device, disposable cartridges for biological samples, and appropriate software. At the front lower part of the device, there is a main cartridge containing gel and capillaries necessary for the electrophoresis process, with a capacity for approximately 150 operational cycles. After installing the main cartridge, a control cartridge must also be placed; this cartridge holds an allelic ladder (a set of common alleles for a given STR locus), a negative control (for checking device sterility), and a positive control (with a known genotype). Two types of disposable cartridges are used: the ACE Sample Cartridge for comparative material (e.g., buccal swabs from a single source) and the EXT Sample Cartridge for analyzing biological traces collected at the scene. Both cartridges are equipped with a reagent kit that includes 21 autosomal STR loci and 3 sex markers. The system processes samples in about 1 minute for placement and analyzes DNA profiles in under 90 minutes. The entire analytical process, from DNA isolation and PCR to capillary separation and genotype analysis, is completed efficiently [38].

The introduction of Rapid DNA technology has transformed the identification of human remains in mass fatality incidents. This technology can produce DNA profiles from human remains in as little as 2 hours. Unlike traditional methods, which require manual sample

handling and data interpretation by highly skilled scientists in a laboratory, Rapid DNA simplifies the process. Its field-forward advantages are substantial: (1) samples can be collected and analyzed on-site, reducing transport time and increasing the likelihood of obtaining results before remains deteriorate significantly; (2) non-specialists can produce STR results, allowing for a higher volume of samples to be processed in less time; and (3) results are available in under 2 hours, with user-friendly data management software enabling real-time searches for identity and kinship matches, thereby accelerating the identification of the deceased and facilitating family reunification [39].

Discussion

A. Overview of Technologies

Table 1 provides an overview of eight major categories of medical assistive technologies currently utilized in disaster management, each addressing different operational gaps within emergency health systems. Technologies such as 3D printing and drone delivery primarily strengthen logistical capacity by ensuring rapid access to essential supplies, particularly when traditional supply chains are disrupted. 3D printing offers on-demand production of pharmaceuticals, medical equipment, and customized tools, reducing dependency on centralized manufacturing sources. Meanwhile, drone technology enhances the reach and efficiency of medical logistics by delivering blood products, vaccines, and medications to remote or inaccessible areas more rapidly than ground transport. Additionally, Emergency Medical Information Systems (EMIS) facilitate real-time information flow, streamline triage processes, and improve situational awareness among healthcare providers. Virtual reality (VR) platforms contribute to workforce preparedness by providing immersive training environments that simulate disaster scenarios, allowing responders to practice communication, coordination, and decision-making skills without real-world risk.

Beyond logistics and training, several technologies highlighted in Table 1 directly support clinical care and population-level health needs during disasters. Robotics enhances operational safety by performing high-risk tasks such as search and rescue, hazardous material handling, or assisted patient transport. Mobile health applications, including platforms like SaveMyLife and mental health support tools, increase community-level access to information, early warning systems, and psychosocial support—critical components often overlooked during emergencies. Rapid DNA identification technology addresses the needs of disaster victim identification, enabling faster reunification of families and more efficient management of mass-casualty incidents. Although these technologies demonstrate significant potential, their implementation is frequently constrained by high costs, technological infrastructure requirements, and limited interoperability across health systems. This highlights the need for

context-specific adaptation, equitable access strategies, and stronger integration mechanisms to maximize the impact of medical assistive technologies in diverse disaster settings.

B. Quantitative Impact Metrics

Quantitative impact metrics presented in Table 2 demonstrate a measurable improvement in the efficiency and responsiveness of disaster management when medical assistive technologies are deployed. Drone delivery systems consistently show one of the most substantial effects, reducing transportation time for critical medical supplies by up to 70% in challenging terrains and isolated regions. This reduction directly addresses one of the most significant bottlenecks in emergency response delayed logistics thereby enabling more timely treatment and stabilizing patient outcomes. Similarly, Emergency Medical Information Systems (EMIS) improve workflow efficiency by reducing patient triage time by approximately 40% during simulated and real-world drills. The speed of triage decision-making is essential in mass-casualty events, where delays in prioritizing care can lead to preventable morbidity and mortality. Likewise, rapid DNA identification technology shortens victim identification from several days to less than two hours, significantly accelerating disaster victim management and facilitating family reunification, legal processes, and dignified handling of remains.

Table 2. Quantitative Impact Metrics

Technology	Quantitative Metrics Reported	Typical Outcome Measure	Source
3D Printing for Pharmaceuticals	Printing time reduced from 55s to 7s per pill	Time efficiency	[12]
Drone Delivery	Reduced delivery time by 70% compared to land transport	Response time	[18]
EMIS	40% faster triage processing in simulated disaster drills	Patient triage speed	[23]
Virtual Reality Training	25–40% improvement in CPR accuracy after VR-based training	Skill proficiency	[28]
Robotics	30% reduction in rehabilitation time in stroke patients	Recovery rate	[30]
SaveMyLife App	35% faster victim localization compared to manual coordination	Rescue time	[31]
Mental Health Care App (TLS)	20% reduction in PTSD and anxiety scores after 4-week use	Psychological well-being	[34]
Rapid DNA Technology	90-minute average identification time vs. 3–5 days conventional	Identification time	[39]

Despite these promising improvements, several limitations are evident in the quantitative evidence available. Many studies report performance metrics from pilot projects or small-scale trials rather than from large disaster events, raising concerns regarding external validity and real-world applicability. Additionally, few technologies have been evaluated for cost-effectiveness, reliability under adverse environmental conditions, or sustainability in low-resource settings. The absence of standardized measurement frameworks further complicates

comparisons across technologies, as studies often use different metrics, methodologies, and outcome definitions. These gaps highlight the urgent need for rigorous evaluation designs, including controlled field studies, longitudinal follow-ups, and multicenter collaborations, to generate more robust impact data. Such evidence is essential to guide policymakers in prioritizing investments and scaling technologies that demonstrate not only efficiency but also equity, resilience, and long-term feasibility.

C. Technology Readiness and System Integration

Technology readiness levels (TRLs) presented in Table 3 illustrate substantial variability in the maturity of medical assistive technologies used in disaster management. Technologies such as Emergency Medical Information Systems (EMIS) and rapid DNA identification have reached high operational readiness (TRL 9), indicating that they have been tested, validated, and deployed effectively in real-world disaster scenarios. Their maturity reflects robust supporting infrastructure, established legal frameworks, and strong institutional adoption, enabling seamless integration into emergency workflows. In contrast, innovations like virtual reality (VR) training tools and 3D printing technologies remain in intermediate development stages (TRL 6–7), where effectiveness has been demonstrated in controlled environments but large-scale deployment is still limited. These technologies require further field evaluations, cost-effectiveness analyses, and operational feasibility studies to determine how they can be reliably scaled, particularly in resource-constrained settings. Mobile-based applications, such as SaveMyLife and mental health support apps, tend to demonstrate high scalability but vary widely in their real-world performance due to differences in digital literacy, connectivity, and user adoption.

Table 3. Synthesis of Technology Readiness and Health System Building Blocks

Technology	Technology Readiness Level	Supported Health System Component	Scalability Potential	Equity Consideration
3D Printing for Pharmaceuticals	7	Access to essential medicines	Medium	Requires high investment
Drone Delivery	8	Service delivery	High	Effective in rural areas
EMIS	9	Health information systems	High	Needs cybersecurity safeguards
Virtual Reality Training	6	Health workforce (training)	Medium	Limited access in LMICs
Robotics	7	Service delivery / Workforce	Low	Cost-prohibitive
SaveMyLife App	8	Community engagement	High	Accessible via smartphones
Mental Health Care App (TLS)	7	Health service delivery	High	Language and culture dependent
Rapid DNA Technology	9	Emergency response / Governance	Medium	Limited field deployment

When examined through the WHO Health System Building Blocks framework, the technologies reviewed show differing contributions to system integration and resilience. High-TRL technologies such as EMIS and rapid DNA systems strengthen the health information and governance components by improving coordination, transparency, and decision-making across agencies. Meanwhile, drone delivery, 3D printing, and VR training primarily reinforce service delivery, logistics, and workforce preparedness—areas crucial for maintaining continuity of care during disasters. However, integration challenges persist, particularly in low- and middle-income countries where infrastructure limitations, regulatory gaps, and financial constraints hinder the adoption of advanced technologies. Ensuring equitable integration requires context-specific adaptation, capacity building, and ethical oversight to prevent widening disparities in disaster response capabilities. Ultimately, aligning technological maturity with system needs and resource capacity is essential to achieve sustainable, resilient, and scalable disaster health management frameworks.

Building on this system-level integration, the contribution of these technologies to overall health system resilience can be understood across three key dimensions:

- absorptive capacity: the ability of health systems to maintain essential services during crises, exemplified by drones and EMIS;
- adaptive capacity: the ability to modify service delivery models, supported by innovations such as 3D printing, telemedicine, and VR training; and
- transformative capacity: the potential for long-term system change driven by robotics and digital applications.

Despite these benefits, disparities in access, affordability, and infrastructure across countries highlight the need for context-specific innovation and ethically guided deployment to ensure equitable implementation, especially in low-resource settings.

Conclusion

The integration of advanced technologies in healthcare and disaster response is revolutionizing disaster management practices by enhancing efficiency, accessibility, and adaptability during emergencies. Technologies such as 3D printing for pharmaceuticals, drone delivery systems, Emergency Medical Information Systems (EMIS), virtual reality (VR), robotics, mobile applications like SaveMyLife and mental health support apps, as well as rapid DNA identification tools, play crucial roles in enabling timely and personalized medical interventions in disaster settings. Collectively, these innovations strengthen disaster preparedness and response by improving medical logistics, accelerating on-site assessments, and supporting continuity of care. However, most of these technologies have been developed and implemented predominantly in high-income countries, highlighting the urgent need for capacity building, ethical frameworks, and localized research to ensure their equitable

adoption in low-resource settings. This review is expected to serve as a reference for future researchers aiming to advance disaster-related health technologies, particularly in low-income countries.

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Conflict of Interest

The authors declare no conflict of interest.

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