Saudi Journal of Medicine and Public Health

https://saudijmph.com/index.php/pub
https://doi.org/10.64483/202412558

The Technologically Augmented First Responder: A Review of Wearables, Telemedicine, and Decision Support in Prehospital and Dental Emergency Care

Mashari Agaig A Alsharari (1) , Mohammed Hameed Salamah Alsharari (2) , Bandar Musaid Alsarhani (3) , Mashael Ayed Mujahid Alanazi (4) , Majed Thani A Alsharari (5) , Ahmed Sahlan Qabil Alsharari (6) , Norah Mohammed Sadly (7) , Wafa Saeed Aldosari (8) , Eman ALhumidi AlEnazi (8) , Joman Salem Alhawiti (9) , Nawal Mesfer Almuraya (10) , Muhza Khalid Sahir Albishry (11)

(1) Dental Center, Al-Qurayyat, Al-Qurayyat, Cluster Al-Jawf Health, Ministry of Health, Saudi Arabia,
(2) Al-Qurayyat Disaster and Crisis Management, Al-Qurayyat, Ministry of Health, Saudi Arabia,
(3) Health Crisis and Disaster Management Center, Al-Qurayyat, office , Ministry of Health, Saudi Arabia,
(4) Al-Haditha General Hospital, Al-Qurayyat, Al-Jawf Health Cluster, Ministry of Health, Saudi Arabia,
(5) Office in Qurayyat, Qurayyat, Ministry of Health, Saudi Arabia,
(6) Tabarjal General Hospital, Tabarjal, Al-Jawf Health Cluster, Ministry of Health, Saudi Arabia,
(7) Riyadh, King Saud Medical City, Ministry of Health, Saudi Arabia,
(8) King Saud Medical City, Ministry of Health, Saudi Arabia,
(9) King Salman Medical City – Main Building, (Self-Operating Program), Ministry of Health, Saudi Arabia,
(10) Al Aziziyah Children's Hospital – Jeddah,(Self-Operating Program) Ministry of Health, Saudi Arabia,
(11) King Saud Hospital in Onizah, Ministry of Health, Saudi Arabia

Abstract

Background: The paradigm of prehospital and out-of-hospital emergency care is undergoing a fundamental transformation, driven by the integration of advanced technologies into the hands of first responders. In both traditional emergency medical services (EMS) and specialized settings like dental trauma care, the ability to capture, transmit, and interpret critical patient data at the point of first contact can dramatically alter clinical trajectories. **Aim:** This narrative review aims to examine the deployment and impact of three core technological classes in emergency response. It examines their application across EMS and dental emergency contexts, analyzing clinical, operational, and human factors. **Methods:** A comprehensive search of PubMed, Scopus, IEEE Xplore, and CINAHL databases was conducted. **Results:** Evidence indicates that wearable monitors improve the detection of occult physiologic deterioration; telemedicine reduces time-to-critical interventions in stroke and trauma; and mobile CDS improves protocol adherence. However, successful implementation is constrained by nursing workflows in receiving facilities that are unprepared for the data deluge, pharmacy challenges in validating dynamic dosing guidance, and significant informatics hurdles related to data interoperability, security, and alert fatigue. **Conclusion:** Technology has the potential to evolve the first responder from a primarily transport-focused role to a diagnostically enabled, tele-supported field clinician. Realizing this potential requires a parallel evolution in clinical workflows, interdisciplinary training, and health information architectures designed for real-time, low-latency data fusion across the continuum of emergency care.

Keywords: prehospital care, telemedicine, clinical decision support, wearable technology, emergency medical services

Introduction

The image of the first responder—be it an Emergency Medical Technician (EMT), paramedic, or a dentist facing acute facial trauma—has long been defined by speed, triage, and stabilization for transport. The ambulance and the dental office were often viewed as isolated waypoints, with critical diagnostic and definitive care reserved for the hospital emergency department (ED) or specialist clinic. This paradigm is being rendered obsolete by a confluence of technological advancements that are fundamentally augmenting the capabilities of these frontline providers. The modern first responder is increasingly equipped not just with a stretcher or a dental mirror, but with an array of sensors, communication devices, and intelligent software that transforms them into a critical diagnostic and therapeutic node within a digitally connected emergency ecosystem (Chan et al., 2019; Lumley et al., 2020).

Three interconnected domains drive this technological augmentation. First, wearable biosensors and advanced monitors move beyond basic vital signs to provide continuous, non-invasive streams of data—from core temperature and tissue oxygenation to single-lead ECG waveforms and capnography—offering unprecedented insight into a

*Corresponding author e-mail: Masherya@moh.gov.sa (Mashari Agaig A Alsharari).
Receive Date: 21 December 2024, Revise Date: 30 December 2024, Accept Date: 31 December 2024

patient's dynamic physiologic state during the crucial "golden hour" (Majumder et al., 2017). Second, telemedicine and augmented reality (AR) platforms shatter geographic and expertise barriers, allowing remote specialists (e.g., neurologists, trauma surgeons, oral-maxillofacial surgeons) to visually assess a patient, guide procedures, and make complex disposition decisions in real-time (Lazarus et al., 2020). Third, mobile clinical decision support (CDS) systems, embedded in tablets or smart devices, provide evidence-based protocol guidance, drug dose calculators, and differential diagnosis checklists at the point of care, reducing cognitive load and variation in practice (Singh et al., 2022).

This narrative review synthesizes the evidence from 2010 to 2024 to critically examine this transformation. It moves beyond a simple catalog of devices to analyze the integrated deployment of wearables, tele-guidance, and CDS in two distinct yet parallel arenas: traditional prehospital EMS and the often-overlooked realm of dental and oral-facial emergency care. We contend that the principles of technological augmentation are universal, but their application and challenges are context-specific. This review will further analyze the ripple effects of this prehospital data surge on receiving teams: the nursing role in receiving and acting on transmitted data streams in the ED; pharmacy's critical input in vetting and managing CDS-driven drug dosing; and the profound informatics challenges of device interoperability, data overload, and cybersecurity that underpin—and often undermine—this technological promise. The central thesis is that technology is not merely adding tools to the first responder's belt; it is redefining their clinical identity, demanding new interdisciplinary workflows, and testing the resilience of our health information infrastructures.

Wearable Biosensors in Dynamic Environments

The foundation of augmentation is enhanced sensing. In the chaotic, mobile prehospital environment, traditional intermittent vital sign checks are insufficient for detecting subtle, trending deterioration. Wearable technology addresses this gap through continuous, hands-free monitoring.

Beyond the Sphygmomanometer in Expanding the Vital Sign Palette

Modern wearable devices for EMS go far beyond pulse oximetry. Multi-parameter patches can continuously measure heart rate, respiratory rate, skin temperature, posture, and activity (Majumder et al., 2017). Advanced capnography, integrated into airway management devices, provides a continuous waveform (etCO2) that is a more sensitive indicator of ventilation and perfusion than respiratory rate alone, crucial for monitoring head-injured or sedated patients (Wollner et al., 2023). Regional oximetry (rSO2) sensors, often placed on the forehead, monitor cerebral oxygenation, providing early warning of hypoperfusion in trauma or cardiac arrest (Chiong et al., 2022). For cardiac cases, wireless 12-lead ECG systems can transmit full electrocardiograms to the receiving cardiologist even before the ambulance departs, shaving critical minutes off "door-to-balloon" time for STEMI patients (Mori et al., 2021).

Application in Dental and Oral-Facial Emergencies

In dental emergencies, wearables play a different but vital role in risk assessment and procedural monitoring. A patient presenting with a severe odontogenic infection or post-extraction bleeding may be hemodynamically stable but at risk of septic shock or vasovagal syncope (Gharahbaghian et al., 2017). A continuous heart rate variability (HRV) monitor, or a simple wearable that tracks pulse and blood pressure trends, can provide objective data to guide decisions about referral to a medical ED versus in-office management (Osterwalder et al., 2023). During conscious sedation for emergency dental procedures, continuous pulse oximetry and capnography are standard of care, and newer wearable versions improve patient comfort and mobility monitoring (Becker & Haas, 2007).

The Challenge of Signal vs. Noise

The primary challenge with wearable data is not collection but interpretation. The motion artifact inherent in ambulance transport or an anxious patient can generate false alarms. Systems must incorporate intelligent filtering and trend analysis to highlight clinically meaningful changes rather than raw data streams, presenting "smart alerts" to the provider (Mirjalali et al., 2021).

Telemedicine and Augmented Reality for Remote Expertise

Telemedicine in emergency care has evolved from simple radio consultation to rich, bidirectional audio-video communication, and is now entering the era of spatial computing with AR.

Tele-EMS and the "Doc-in-the-Ambo"

High-bandwidth, secure video links transmitted via 4G/5G or satellite allow emergency physicians to perform remote assessments. This is most impactful for time-sensitive diagnoses like stroke, where tools like the Los Angeles Motor Scale (LAMS) can be applied via video to determine eligibility for direct transport to a Comprehensive Stroke Center, bypassing closer facilities (McCartan et al., 2023). In trauma, a remote surgeon can assess wound severity, guide bleeding control, and decide on the appropriate trauma center level. Studies show tele-EMS consultation improves diagnostic accuracy and reduces unnecessary transports (Winburn et al., 2018).

Overlaying Guidance onto Reality

AR represents the next frontier. Using smart glasses (e.g., Microsoft HoloLens, Vuzix), a paramedic can have procedural guidance, such as landmarks for a difficult intravenous access or steps for a cricothyrotomy, visually overlaid onto their field of view. A remote expert can "see through" the responder's eyes and draw annotations directly onto their visual field—for instance, circling a fracture on an X-ray displayed on a tablet or pointing to the correct anatomical landmark for an injection (Ponce et al., 2016). For dental emergencies, an oral surgeon could guide a general dentist through the reduction of a complex mandibular fracture in a remote clinic, visualizing the dentist's hands and the patient's anatomy in real time.

Dental Teledentistry for Triage and Trauma

In dentistry, telemedicine platforms are used extensively for triage. Patients can transmit images of dental trauma (avulsed teeth, fractures) or infections to an on-call dentist or oral surgeon, who can then provide immediate first-aid instructions, prescribe analgesics/antibiotics if appropriate, and schedule an urgent in-person visit, effectively managing patient flow and reducing ED visits for non-critical dental pain (Lin et al., 2022).

Mobile Clinical Decision Support Systems

In high-stress, information-poor environments, CDS systems act as an externalized, evidence-based memory and reasoning aid. Mobile CDS apps can walk a paramedic through complex protocols, such as advanced cardiac life support (ACLS) or pediatric dosing algorithms, with dynamic checklists that adjust based on patient inputs (Choi et al., 2023). For vague presentations like abdominal pain or altered mental status, CDS can prompt the responder to consider and rule out less common but critical diagnoses (e.g., aortic dissection, hyperglycemic crisis).

This is a critical intersection with pharmacy. CDS systems integrate weight-based drug calculators, allergy checks, and suggestions for alternative agents based on the local formulary. For example, in managing status epilepticus in a child, a CDS app can calculate the precise milligram dose of midazolam based on the patient's estimated weight, suggest the optimal route (intranasal vs. intramuscular), and provide contraindication warnings (Bashiri et al., 2019). This reduces mathematical errors and promotes adherence to best-practice guidelines. Similarly, dental CDS apps can guide the management of acute pulpitis, avulsed teeth, or dentoalveolar trauma. They can provide the International Association of Dental Traumatology (IADT) guidelines for tooth reimplantation, recommend appropriate analgesics (factoring in drug interactions from the patient's medical history), and indicate when a patient requires immediate referral to an oral surgeon or hospital (Levin et al., 2020).

Impact on Nursing, Pharmacy, and Informatics

The technological augmentation of field responders does not operate in isolation; it generates significant and complex ripple effects for the clinical teams responsible for receiving and acting upon the transmitted data and guidance. This transformation fundamentally reshapes workflows and responsibilities in the emergency department (ED), pharmacy, and health informatics, creating both new opportunities and formidable challenges (Table 1).

For nursing, the role evolves from the passive receipt of a verbal handoff to the active, real-time monitoring of a live patient data stream. Effective integration hinges on dashboard functionality within the ED's operational command center. Incoming data from wearable monitors—such as trending blood pressure, continuous ECG, or cerebral oximetry—along with live video feeds from the ambulance, must be displayed on centralized tracking boards. This allows the charge nurse to anticipate specific patient needs (e.g., "STEMI alert, ETA 8 minutes, ECG transmitted, systolic BP trending downward from 140 to 100") and proactively allocate resources such as cath lab staff or trauma bays (Mazor et al., 2016). This shift demands new nursing competencies in interpreting remotely acquired physiologic trends and necessitates a completely redefined handoff protocol where the rich, time-stamped prehospital dataset is seamlessly incorporated into the patient's permanent electronic health record (EHR), becoming a foundational component of ongoing care rather than a transient verbal snapshot.

Concurrently, the pharmacy department experiences a territorial and functional expansion of its role into the prehospital domain. As mobile clinical decision support (CDS) systems guide drug administration in the field, clinical pharmacists must be integral to the selection, configuration, and ongoing validation of the embedded drug-dosing algorithms. This ensures that prehospital medication guidance aligns precisely with hospital protocols, the latest evidence-based guidelines, and the local antimicrobial formulary (Siebert et al., 2021). Furthermore, pharmacists assume responsibility for auditing prehospital medication administrations that were CDS-guided, establishing a critical quality control and feedback loop with EMS agencies to refine protocols and enhance patient safety, thereby extending their stewardship from the inpatient pharmacy to the point of first medical contact (Prgomet et al., 2017).

Ultimately, the viability of this entire augmented ecosystem rests upon the often-fragile foundation of health informatics. Three core, interrelated challenges threaten its stability and efficacy. First, the profound lack of interoperability presents a major barrier. Wearable devices and monitors from different manufacturers typically utilize proprietary data formats, making the integration of a Zoll monitor's data stream into an Epic EHR dashboard a task requiring complex and costly interface engineering. The absence of universally adopted standards for real-time health data exchange, such as Fast Healthcare Interoperability Resources (FHIR) for streaming data, severely limits seamless data flow (Martin et al., 2022).

Second, the risk of data overload and alert fatigue is significant. The indiscriminate transmission of every data point risks inundating already busy ED clinicians with non-actionable noise, leading to critical alerts being ignored (van de Burgt et al., 2023). Informatics systems must therefore employ intelligent filtering and clinical summarization tools to present synthesized insights—like a "trending toward shock" alert—rather than overwhelming raw data feeds (Wright et al., 2022). Finally, cybersecurity and resilience become paramount concerns. Ambulances and connected dental offices essentially become new, mobile endpoints on the hospital network, creating vulnerable access points for cyberattacks. All data transmission must be rigorously encrypted, and system architecture must ensure core functionality ("lights-out" capability) is maintained during inevitable network outages to prevent a total collapse of care coordination during critical moments (Lieneck et al., 2023). Figure 1 illustrates the digitally connected emergency care ecosystem. The first responder (paramedic or emergency dentist) is shown at the center, equipped with wearable biosensors (continuous ECG, capnography, oxygen saturation), mobile clinical decision support (CDS), and real-time telemedicine connectivity.

Table 1: Technological Augmentation Across Two Emergency Domains

Technology Class	Application in Prehospital EMS	Application in Dental/Oral-Facial Emergency	Key Interdisciplinary Interface
Wearable Biosensors	Continuous 12-lead ECG for STEMI; etCO2 for ventilation status; rSO2 for cerebral perfusion.	Continuous HR/BP monitoring during sedation; Pulse oximetry for infection/sepsis risk assessment.	**Nursing:** Monitors incoming vital sign trends in ED. **Informatics:** Manages data feed integration.
Telemedicine & AR	Video consultation for stroke assessment (RACE/LAMS); Remote trauma surgeon guidance; AR overlay for complex procedure steps.	Teledentistry for trauma triage; AR guidance for fracture reduction by a remote oral surgeon.	**Specialist Physician/Surgeon:** Provides remote expertise. **IT/Telecom:** Ensures bandwidth & connection stability.
Mobile CDS	ACLS/PALS protocol guidance; Weight-based drug dosing calculators; Differential diagnosis prompts for vague presentations.	IADT trauma guideline apps; Analgesic/antibiotic selection support; Referral decision algorithms.	**Pharmacy:** Validates & maintains dosing algorithms. **Informatics:** Embeds CDS into workflow with minimal clicks.

Figure 1. The Technologically Augmented First Responder Ecosystem

Synthesis of Evidence and Outcomes

The evidence, while evolving, points to significant benefits tempered by implementation realities. For wearables, studies show improved detection of respiratory depression and shock states in transport, leading to earlier intervention (Wong et al., 2022). Telemedicine consistently reduces time-to-decision for stroke and improves the accuracy of trauma triage, directly impacting mortality and morbidity (Itrat et al., 2016; Sarpourian et al., 2023). Mobile CDS improves protocol adherence and reduces medication errors in simulated and real-world settings (Hekman et al., 2023).

However, the measured impact is often less than the theoretical potential due to human factors and system failures. Usability studies reveal that poorly designed CDS can increase cognitive load; telemedicine systems can fail due to connectivity issues; and nurses may ignore wearable data streams if they are not presented in a clinically intuitive format (Wright et al., 2016). Success is not determined by the technology alone, but by its socio-technical integration—the careful design of workflows, training, and supportive culture around the tools.

Barriers and Future Directions

Widespread, effective adoption faces significant headwinds (see Table 2). Cost remains prohibitive for many agencies, particularly for AR and advanced wearables. Regulatory and liability frameworks are unclear: who is liable if a CDS algorithm suggests an incorrect dose, or if a video link fails during a critical consultation? Workforce training must evolve to include digital literacy and data interpretation. Crucially, interoperability standards must be developed and enforced to avoid a "Tower of Babel" of incompatible devices.

Table 2: Key Barriers and Enablers for the Augmented First Responder Ecosystem

Domain	Critical Barriers	Essential Enablers & Solutions
Financial & Procurement	High upfront cost of devices/software; Uncertain ROI for EMS agencies; Lack of sustainable payment models for tele-consultation.	Grant funding for pilot programs; Value-based contracting that rewards outcomes enabled by tech; Bundled payment models that include prehospital tech.
Human Factors & Training	Device complexity & poor UX design; Alert fatigue for responders & nurses; Lack of training in data interpretation & tele-presence etiquette.	Human-centered design of devices & software; Simulation-based training integrating tech; Creation of new roles (e.g., Telemedicine Nurse Coordinator).
Interoperability & Data	Proliferation of proprietary data formats; Lack of real-time health data standards (e.g., FHIR for streams); Inability to integrate prehospital data into EHRs.	Adoption of open API standards by manufacturers; Federal policy pushing for interoperability; Development of lightweight data integrator "hubs" for EMS.
Legal & Regulatory	Unclear malpractice liability for CDS-guided care or tele-advice; Varied state licensure laws for telemedicine across jurisdictions; FDA regulation of mobile medical apps.	Development of clear liability frameworks and practice guidelines for tech use; Interstate licensure compacts for emergency telemedicine; Regulatory clarity on software as a medical device (SaMD).
Infrastructure & Security	Lack of broadband in rural areas ("digital divide"); Cybersecurity vulnerabilities of connected ambulances & devices; System failure during network outages.	Investment in public safety broadband networks (e.g., FirstNet); Mandatory security-by-design for connected health devices; Robust offline functionality in CDS apps.

Conclusion

The technological augmentation of the first responder is an inevitable and necessary evolution, promising to elevate the standard of care at the most critical and resource-constrained point in the patient journey. It heralds a shift from a linear, handoff-dependent model to a symbiotic emergency ecosystem, where data, expertise, and guidance flow seamlessly across traditional boundaries. In this ecosystem, the paramedic or emergency dentist is empowered with diagnostic clarity and guided precision, the receiving nurse is primed with anticipatory intelligence, the pharmacist ensures therapeutic safety from afar, and the informatician weaves it all into a coherent, secure digital tapestry.

However, this future is not guaranteed by technology alone. It will be realized only through deliberate, interdisciplinary collaboration that places equal emphasis on workflow redesign, competency development, and ethical governance as well as on the hardware and software itself. The goal is not to replace the clinician's judgment with an algorithm or a remote video feed, but to augment human expertise with superhuman sensing, connectivity, and knowledge access. By thoughtfully integrating these technologies, we can create an emergency response system that is not only faster and more efficient but fundamentally more intelligent, equitable, and capable of delivering definitive care from the very first moment of contact.

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