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The Digital Chain of Survival: A Review of Informatics-Enabled Resuscitation from Field to ICU

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Abstract

Background: The resuscitation of critically ill or injured patients involves a critical continuum from pre-hospital care to ICU management, often disrupted by information loss during transitions and fragmented data capture. Although technologies such as point-of-care ultrasound and lab testing have advanced, their integration into a cohesive patient record poses significant challenges, affecting the overall chain of survival.

Aim: This narrative review aims to critically analyze the current state and potential of health informatics to create a seamless "Digital Chain of Survival."

Methods: A comprehensive literature search was conducted across PubMed, IEEE Xplore, CINAHL, and Scopus databases for English-language articles published between 2010 and 2024.

Results: The review highlights a critical translational gap between data-generation technologies and their informatics integration, citing issues such as data silos, transcription errors, and cognitive overload. It presents a three-phase informatics framework: 1) Seamless Data Capture & Transmission in the field, 2) Intelligent Data Synthesis & Display through real-time dashboards in the ED/trauma bay, and 3) Post-Hoc Data Aggregation & Mining for feedback and protocol improvement. Implementation relies on interoperability standards, user-centered design, and a cultural shift towards data-driven resuscitation.

Conclusion: A fully realized Digital Chain of Survival is vital for modern resuscitation science, enabling healthcare systems to leverage informatics for structuring, transmitting, and visualizing critical data. This approach minimizes information degradation, empowers clinical teams with shared situational awareness, and establishes a continuous learning loop to improve resuscitation protocols, signifying a shift from episodic, memory-based care to a continuous, data-enriched ecosystem.

Keywords: Resuscitation Informatics, Prehospital Care, Data Integration, Clinical Dashboard, Telemedicine.

Introduction

The paradigm of the "Chain of Survival" for critical events like cardiac arrest, major trauma, and septic shock powerfully illustrates that patient outcomes depend on a sequence of interdependent, time-sensitive interventions. However, a critical but often overlooked weak link in this chain is information flow (Dai et al., 2022). The journey of a critically ill patient—from the 911 call and paramedic intervention, through the chaotic reception of the emergency department (ED) or trauma bay, to the controlled intensity of the intensive care unit (ICU)—generates a torrent of vital data (Montisci et al., 2022). This includes discrete metrics like vital signs, point-of-care lab values, and drug administration times, as well as rich contextual information from paramedic assessments, ultrasound findings, and evolving physical exams (Krefting et al., 2023).

Yet, the systems designed to capture and convey this information are frequently brittle, relying on radio patches, handwritten run sheets, and frantic verbal handoffs that are prone to omission, distortion, and loss (Knutsen & Fredriksen, 2013; Zhang et al., 2021). This information degradation forces each

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receiving team to effectively "start over," wasting precious minutes, leading to redundant or conflicting interventions, and obscuring the patient's physiological trajectory. In an era where point-of-care testing (POCT) and ultrasound have moved into the ambulance, and where resuscitation science emphasizes precise, physiology-guided care, this analog information pipeline is fundamentally inadequate (Alghamdi et al., 2020; El Samad et al., 2022).

This narrative review posits that the next evolutionary leap in resuscitation outcomes will be driven not by a new drug or device alone, but by the sophisticated application of health informatics. The concept of a "Digital Chain of Survival" envisions a seamless, intelligent, and bidirectional flow of structured data that binds the pre-hospital and in-hospital phases into a coherent continuum. This review will critically analyze the current landscape of data capture, transmission, and use across this continuum; evaluate the role of informatics in real-time team coordination and post-event learning; and propose an integrated framework for building a resilient, data-enriched ecosystem that supports precision resuscitation from field to ICU.

The Field Data Frontier – Capture and Transmission from Point of Care

The informatics chain begins at the moment of first medical contact. Modern EMS systems are increasingly equipped with advanced monitoring capabilities that generate dense, high-frequency data streams. Beyond standard vital signs, paramedics now utilize waveform capnography, 12-lead ECG with computer interpretation, continuous non-invasive blood pressure, and, in advanced systems, point-of-care ultrasound (POCUS) and laboratory testing (e.g., lactate, blood gas, troponin) (Serra et al., 2023). This represents a paradigm shift from qualitative assessment to quantitative, physiologic data acquisition in the field. However, the primary output of this technological investment is often still a static, narrative-style electronic patient care report (ePCR) completed after the call, with critical real-time data remaining trapped on the device or in the paramedic's short-term memory (Kowalczyk et al., 2023).

The first informatics challenge is real-time, structured data capture. This requires ePCR systems that move beyond digital notepads to become interactive clinical documentation platforms. These platforms should integrate directly with monitor/defibrillators and other devices via Bluetooth or other standards (e.g., IEEE 11073), auto-populating vital sign trends, drug logs, and procedure timestamps (Porter et al., 2020). For complex findings like POCUS, structured templates with dropdown menus for common findings (e.g., "cardiac activity: present/absent," "IVC collapsibility: >50%") can capture discrete data far more useful for downstream decision support than a free-text note stating "FAST exam positive." The second, more complex challenge is secure, reliable data transmission to the receiving facility. While simple text-based alerts or "12-lead faxes" are common, true continuity requires the transmission of a rich, structured data object (O'Connor et al., 2023).

Technologies such as cellular-based telemedicine platforms enable streaming of video, ultrasound clips, and real-time vital sign trends to a hospital dashboard (Latifi, 2020). The emerging integration of the HL7® FHIR® standard in EMS holds promise for creating interoperable data packets that can be electronically pushed ahead of the patient, populating the hospital's EHR in a structured format before arrival (Bae et al., 2022). This "digital patient arrival" ensures the trauma team sees not just a note, but a graphical trend of the patient's prehospital systolic blood pressure, the capnography waveform during intubation, and images from a prehospital FAST exam (Chatterjee et al., 2022).

The Hospital Receiver – Synthesis, Visualization, and Situational Awareness

The arrival of a critically ill patient triggers a well-rehearsed but informationally chaotic scene in the ED or trauma bay. The receiving team is typically bombarded with a simultaneous verbal report from paramedics while simultaneously initiating their own primary survey and interventions (Patel et al., 2021). Critical data from the field is often lost in this noise. Informatics plays a transformative role here by synthesizing incoming pre-hospital data with newly generated in-hospital data and presenting it through an intelligently designed clinical dashboard (Miao et al., 2023).

An effective resuscitation dashboard is more than a data aggregator; it is a cognitive aid designed for high-stress, high-noise environments. It must provide shared situational awareness for all team members—physicians, nurses, respiratory therapists, and anesthesiologists (Whitehouse et al., 2023). Key principles include Timeline Visualization: A central, graphical timeline that plots key events from the field (time of arrest, first shock, drug administration) and continues in real-time with hospital events (intubation, chest tube insertion, blood product administration). This allows the team to instantly grasp the patient's history and trajectory (Mirani et al., 2023). Goal-Directed Alerting: Integrating clinical decision support (CDS) rules that compare real-time data (e.g., lactate, blood pressure) against evidence-based resuscitation bundles (e.g., sepsis, trauma) and visually alert the team to next steps or protocol deviations (Downing et al., 2019; Thorkildsen et al., 2023). Multimodal Data Integration: Displaying POCUS video clips or still images alongside the vital signs from the time they were acquired, or showing the prehospital ECG next to the first in-hospital ECG. Furthermore, informatics enables tele-resuscitation, where remote specialists (e.g., a trauma surgeon, cardiologist, or toxicologist) can view the same live dashboard, see procedural videos (e.g., of an

ultrasound), and communicate with the frontline team, effectively extending expertise to the point of need (Guinemer et al., 2020).

This phase also encompasses automated code documentation. Traditional "scribing" during a code blue is difficult and often inaccurate. Voice recognition, automated data pulls from defibrillators and ventilators, and templated documentation tools can generate a precise, time-stamped record of the entire event, freeing a nurse or provider to focus on patient care and ensuring an accurate record for debriefing and quality improvement (QI) (Sood et al., 2023).

The Learning Loop – Data Aggregation, Mining, and Protocol Refinement

The conclusion of the acute resuscitation marks the beginning of a critical third phase: learning from the data. The aggregated digital record of the resuscitation continuum—from dispatch log to final ICU admission note—creates a rich dataset for continuous system improvement. This is where informatics transitions from supporting individual patient care to enabling population health management for critical care.

Post-hoc data aggregation involves combining data from the ePCR, hospital EHR, monitor outputs, and device logs into a searchable data warehouse. Data mining and analytic techniques can then be applied to answer previously unanswerable questions (Rumsfeld et al., 2016; Wagle et al., 2021). For instance, analysts can examine whether shorter on-scene intervals for trauma patients are associated with specific patterns of prehospital vitals or interventions. They can identify common deviations from sepsis bundles and correlate them with outcomes. For cardiac arrest, every time-stamped event (compression depth/fraction, shock timing, drug administration, ETCO2 values) can be analyzed to identify patterns associated with return of spontaneous circulation (ROSC) (Askar et al., 2020).

This analytics engine directly feeds quality improvement (QI) and protocol refinement. Instead of reviewing a handful of cases monthly, QI teams can run automated reports on every resuscitation meeting certain criteria. Informatics can enable automated debriefing tools that generate a chronological summary of the event for the team to review (Coulter et al., 2022). More powerfully, data from many cases can inform predictive analytics. Could prehospital lactate and ETCO2 trends predict which trauma patients will require massive transfusion? Could specific patterns in the pre-arrival data stream help the ED better anticipate and allocate resources? By closing this learning loop, the digital chain transforms resuscitation from a series of discrete, isolated events into a learning health system where every case informs and improves the system's future performance, directly impacting both pre-hospital medical transportation protocols and in-hospital nursing and physician resuscitation guidelines (Couper et al., 2015).

Overcoming Barriers

Implementing a robust Digital Chain of Survival faces significant, interrelated barriers. The foremost is interoperability. The ecosystem involves devices and software from dozens of vendors across EMS and hospital settings, often using proprietary data formats. Widespread adoption of standards like FHIR and IEEE 11073 for device communication is essential but progressing slowly (Mandel et al., 2020). Technical and security infrastructure, including reliable cellular/wifi coverage for ambulances and secure health information exchange (HIE) networks, is a foundational requirement (Vorisek et al., 2022).

A barrier as critical as technology is usability. Field and hospital interfaces must be designed for high-stress, low-literacy, and low-attention conditions. Complex login processes, slow data entry screens, or cluttered dashboards will be rejected by frontline users. This requires deep clinician engagement in a user-centered design process (Park et al., 2021). Furthermore, the implementation must not increase cognitive load or task burden for paramedics or nurses; automation should be the goal (Plaisance et al., 2016).

Finally, cultural and workflow resistance can be formidable. Shifting from familiar verbal handoffs to trusting a dashboard requires change management. Concerns about liability related to transmitted data (e.g., an unclear ultrasound image) or about technology replacing clinical judgment must be addressed. Success depends on framing informatics as a tool that augments expertise, reduces cognitive burden, and ultimately delivers better care, thereby fostering buy-in from all levels of the clinical team.

The Three-Tier Digital Resuscitation Platform

To synthesize the concepts, a three-tier architectural framework for a Digital Resuscitation Platform is proposed (Table 1).

Table 1: Three-Tier Architecture of the Digital Resuscitation Platform

Tier	Name & Scope	Core Functions	Key Technologies & Standards
Tier 1: Capture & Transport (Pre-hospital & Point-of-Care)	Secure, real-time acquisition of structured data from the scene/ambulance and its transmission to the hospital.	- Bi-directional device integration (monitor, US, lab) - Structured ePCR documentation - Low-latency,	Bluetooth/Wi-Fi/5G, IEEE 11073 (PoCD), HL7 FHIR, TLS encryption

		secure data push to ED	
Tier 2: Synthesis & Action (Hospital Reception & Resuscitation)	Aggregation, visualization, and analysis of multi-source data to support real-time team situational awareness and decision-making.	- Clinical resuscitation dashboard - Telemedicine consultation interface - Automated code documentation - Real-time CDS & protocol guidance	Data visualization engines, Video conferencing APIs, CDS rules engines, EHR APIs
Tier 3: Aggregation & Learning (System-Wide QI)	Storage, aggregation, and analysis of data across all resuscitation events to drive protocol refinement and performance improvement.	- Centralized data warehouse - Automated performance reports - Predictive analytics models - Feedback tools for EMS/hospital	Cloud data warehouses, Machine learning pipelines, BI tools (Tableau, Power BI)

This platform is not a single application but a connected ecosystem. Its effectiveness relies on the disciplined roles of various stakeholders (Table 2)

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Table 2: Key Stakeholder Roles in the Digital Chain of Survival

Stakeholder Group	Primary Role in the Digital Chain	Critical Contributions & Needs
Paramedics & Field Personnel	**Primary Data Capturers & Initiators**	Must use and trust ePCR/device interfaces; need simple, rapid data entry; require feedback on how their data was used.
ED/Trauma Bay Clinical Team	**Primary Data Consumers & Actuators**	Need intuitive, glance-able dashboards; require reliable data to trust and act upon; must integrate dashboard use into team dynamics.
Informatics/IT Teams	**Architects & Integrators**	Must ensure interoperability, security, and reliability; engage in user-centered design; maintain and evolve the platform.
EMS & Hospital Leadership	**Champions & Governors**	Must fund and prioritize the platform; align policies and protocols with data capabilities; foster a data-driven QI culture.
QI & Data Analytics Teams	**Learning Engine Operators**	Must define key metrics; build reports and analyses; translate data insights into actionable protocol changes.
Remote Specialists (e.g., Trauma Surgeon, Cardiologist)	**Tele-Consultants**	Need secure, reliable access to live data and video; require clear communication protocols with receiving teams.

Conclusion

The resuscitation continuum is a complex, adaptive system where information is as vital as any pharmaceutical or procedural intervention. The current state, reliant on fallible human memory and fractured communication channels, imposes an unacceptable tax on patient safety and outcomes. This review has articulated the vision and framework for a Digital Chain of Survival—an informatics-enabled ecosystem that seamlessly connects care from field to ICU. By implementing robust systems for structured data capture and transmission, intelligent clinical dashboards for synthesis and situational awareness, and data analytics engines for continuous learning,

healthcare systems can forge an unbreakable informational link. This transformation will minimize the degradation of critical information during handoffs, empower teams with a shared, data-rich understanding of the patient, and unlock the potential for truly physiology-guided, precision resuscitation.

Ultimately, it represents a necessary evolution from viewing resuscitation as a heroic, artisanal effort to managing it as a reliable, data-driven, and continuously improving process. The technology to build significant components of this chain exists today; the imperative is to integrate it with purpose, design it with clinicians, and deploy it with a commitment to closing the learning loop. In doing so, we can strengthen the most fragile link in the Chain of Survival and ensure that every patient benefits from the full, informed expertise of the entire care continuum.

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