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Case Report

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The Emergency Medical Team Operating System: design, implementation, and evaluation of a field hospital information management system

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ABSTRACT

In case of sudden-onset disasters (SODs), the World Health Organization deploys specialized emergency medical teams (EMTs); yet, the coordination and operation of such teams pose significant challenges. One issue is the lack of digital information systems and standards. We developed a highly customizable and scalable electronic medical record (EMR) system, tailored to EMT requirements, called the "Emergency Medical Team Operating System" (EOS). EOS was successfully tested through 9 realistic clinical tasks during a full-scale EU Module Exercise. During the initial evaluation, 21 team members from 9 countries evaluated the system positively, stressing the urgent need for an EMR for EMTs. EMTs face unique challenges during disaster relief missions. To provide an effective and coordinated delivery of care, there is a great need for an EMR tailored to the specific needs of EMTs. EOS may serve as an effective EMR during SOD missions.

Key words: emergency medical team, electronic medical record, emergency medicine, disaster preparedness, hospital information system

Lay Summary

In case of sudden disasters like earthquakes or tsunamis, specialized emergency medical teams (EMTs) are deployed by the World Health Organization to support the affected local healthcare systems. Although electronic medical records (EMRs) are well established in standard care, most EMTs still rely on paper-based patient records despite the benefits of a digital system. This is because it is difficult to accommodate the different needs of different EMTs from different countries, and because the system needs to be effective under the difficult conditions of a disaster. In this article, we present an EMR that is specifically tailored to the needs of EMTs, taking the special conditions of disaster relief missions into account. The article describes design approaches and presents a small evaluation study during a field test, where 21 participants had to perform specific tasks with the system and were able to provide feedback. The results demonstrate the successful use of the system and strong approval among all user types.

INTRODUCTION AND BACKGROUND

As the coronavirus disease 2019 pandemic has demonstrated on a global scale, disasters/healthcare crises wreak havoc on existing care systems that must cope with an unexpected and large influx of patients. With projections of an increasing frequency and severity of sudden-onset disasters (SODs) due to climate change,[1–10] healthcare systems worldwide will face such challenges more frequently. Fast response to help cope with large volumes of patients is crucial.[11]

Many developed countries have specific emergency medical teams (EMTs)/foreign medical teams trained to provide aid during complex humanitarian crises, defined by the World Health Organization (WHO) as "[...] groups of health professionals (doctors, nurses, paramedics, etc.) that treat patients affected by an emergency or disaster."[12] However, coordination between such teams, their capacity to address specific scenarios and constraints, and their ability to integrate into existing systems in the target country have proven to be fraught with difficulties, as was demonstrated during the 2010 Haiti earthquake.[11,13] Therefore, the WHO has proposed standards and criteria,[11] resulting in WHO-certified projects and EMTs. This has resulted in a clear classification system designating the capacities of employed field hospitals, ranging from triage and initial emergency care (EMT level 1) to complex inpatient referral and surgical care (EMT level 3). Disaster-struck countries may request the deployment of these teams and field hospitals, a process coordinated and overseen by the WHO.

One major challenge remaining is the information infrastructure used by EMTs during missions, potentially complicating coordination and care delivery.[14] While record-keeping is a core standard,[11] currently there is no standard documentation system employed by the WHO in place: Documentation by EMTs varies greatly[14] and is still almost entirely paper based.[15–17] Electronic medical record (EMR) systems can improve the delivery of healthcare on multiple levels: from public health, through the organizational level, to patient outcomes.[18–21] Particular benefits include structured digital documentation that impacts the quality of care,[22] patient tracking capabilities,[23] and post-evacuation continuity of care.[21,24] Finally, an EMR can aid in analyzing and evaluating mission data, both during and after disasters, which is essential for better coordination and improving future disaster responses.[13]

An EMR for EMTs during SOD scenarios faces unique challenges: It needs to be implementable almost immediately, be lightweight, scalable, highly customizable, flexible, and offer fast localization to accommodate both the many different foreign teams involved and the efforts that may already be underway in the target country. Furthermore, potential barriers to implementation—such as cost and fear of workflow disruption,[17] local computer literacy, and stable access to electricity and internet[15,16]—exist. Due to potential limitations in resources and infrastructure, the EMR must also be centered around standardized operating procedures or protocols (such as START for triage[25]) and facilitate large-scale evacuations. Many of these requirements cannot be accommodated by existing EMR systems, as they require greater flexibility and simplicity[26] that the existing (commercial) EMRs tend to lack.[27,28]

To address this issue, this article introduces and evaluates an EMR addressing EMTs' specific needs during disaster relief missions, providing a standardized platform that can aid in coordinating and delivering care after SODs. The Emergency Medical Team Operating System (EOS) was developed during the European Modular Field Hospital (EUMFH) project [Project of the European Directorate General for European Civil Protection and Humanitarian Aid Operations (DG ECHO) 2017–2018, ECHO/SUB/2016/739964/PREP14],[29] an initiative supported by the General Directorate for Civil Protection and Humanitarian Aid Operations of the European Commission to conceptualize a Pan-European EMT3.

MATERIALS AND METHODS

EMTs need to provide quality care under serious constraints, facing potential shortages of any conceivable resource: from diagnostics, medications, and personnel to electricity, connectivity, and patient information. This makes triage a key feature of care during a SOD scenario. Furthermore, tremendous time pressure complicates the gathering, communication, and documentation of patient data, as does the lack of a standardized framework among EMTs hailing from many different countries and backgrounds. An EMR for EMTs needs to be able to address all these challenges while being lightweight, scalable, and highly customizable. Key features to address these requirements are outlined in the following sections.

Modularity and adaptability

Due to the modular character of field hospitals, department composition may change between or even during missions to adapt to new situations. Thus, departments (eg, triage, ward, radiology, etc.) can be configured in EOS for the deployment scenario. Subsequently, the EMR will adjust itself around this department composition, such as transferring patients, monitoring department workload, or calculating total bed capacity for reports.

Since many EMTs are used to working with paper-based forms, a card-based approach (see Figure 1) was chosen to improve information overview, lower the entry barrier and combine the advantages of paper based and electronic records in 1 system. Each information category (eg, findings, diagnoses, etc.) has a dedicated information card. Appropriate cards can be added to the patient's overview when needed and will show the most recent related data. This serves as a patient summary since users get a quick overview of the available data, the patient's journey, and recent conditions. Cards that are not relevant to a mission can be deactivated completely.

A click on a card will open a menu with complete information about that information category (see Figure 2). Furthermore, various features that are only required for specific disaster scenarios (eg, mass burn casualty incidents) can be activated or deactivated according to the scenario.

Standard triage systems (eg, WHO-ICRC, Manchester, or NATO according to START algorithm) are supported by default, but also custom ones can be created, if an EMT prefers to adjust the triage system for themselves. Additionally, 2 modes—ordinary triage and mass casualty incident triage—can be toggled depending on the current patient flow.

Different EMTs may apply different terminologies, and different disaster scenarios entail different medical conditions and interventions. To ensure prompt and adequate delivery of care with minimal misunderstanding between teams, highly configurable lists for medications, diagnoses, tests, and nursing are provided, that can be prepopulated at the onset of a disaster and updated during missions to accommodate changing conditions and requirements. These lists ensure that all teams adhere to the same terminologies while simultaneously providing information on available medical resources, preventing EMTs from ordering unavailable tests or medications. Lists can be exported/imported to allow reuse in future missions.

Monitoring and reporting

The built-in "command view" (see Figure 3) allows an assessment of the field hospital's current situation by providing live statistics about patient flow, triage results, department workload, etc. Additionally,

Figure 1. EOS uses a card-based approach to visualize patient-specific information. The card colors indicate if the card was changed since the last visit of the user.

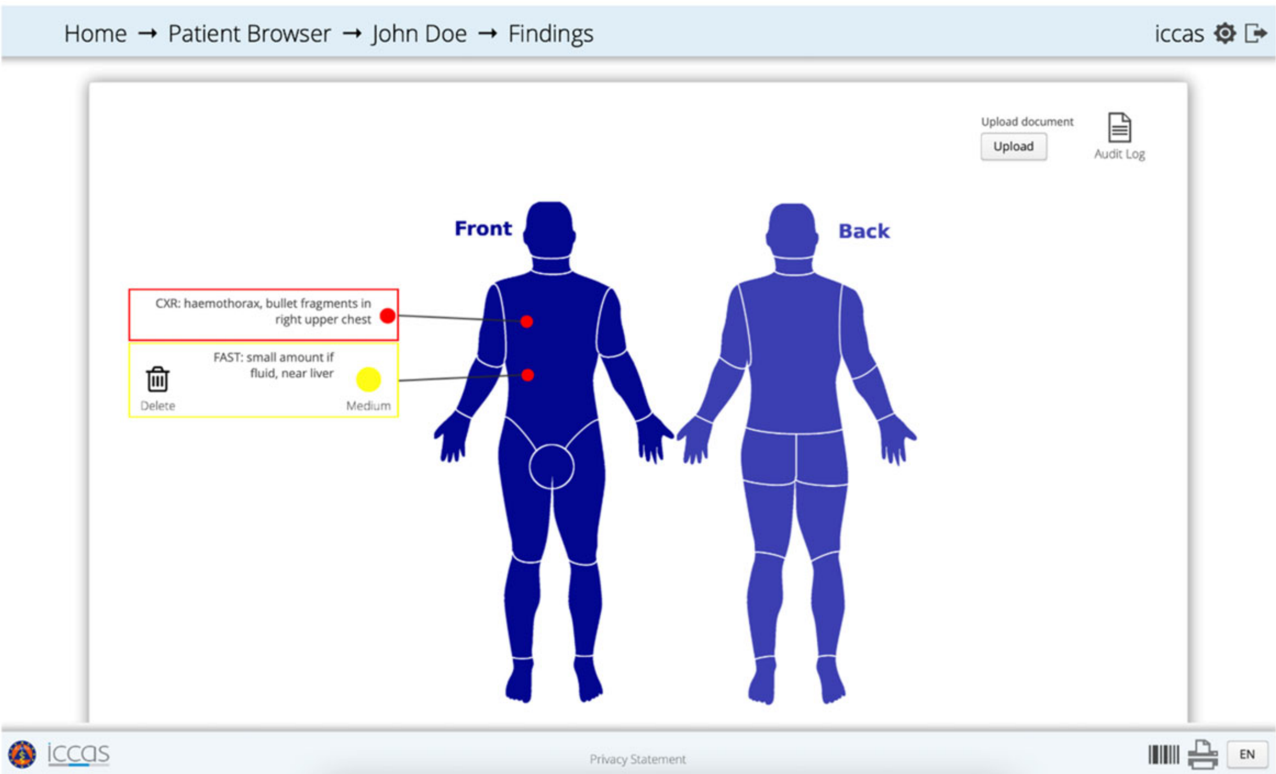

Figure 2. Depiction of clinical findings on the schematic patient in EOS.

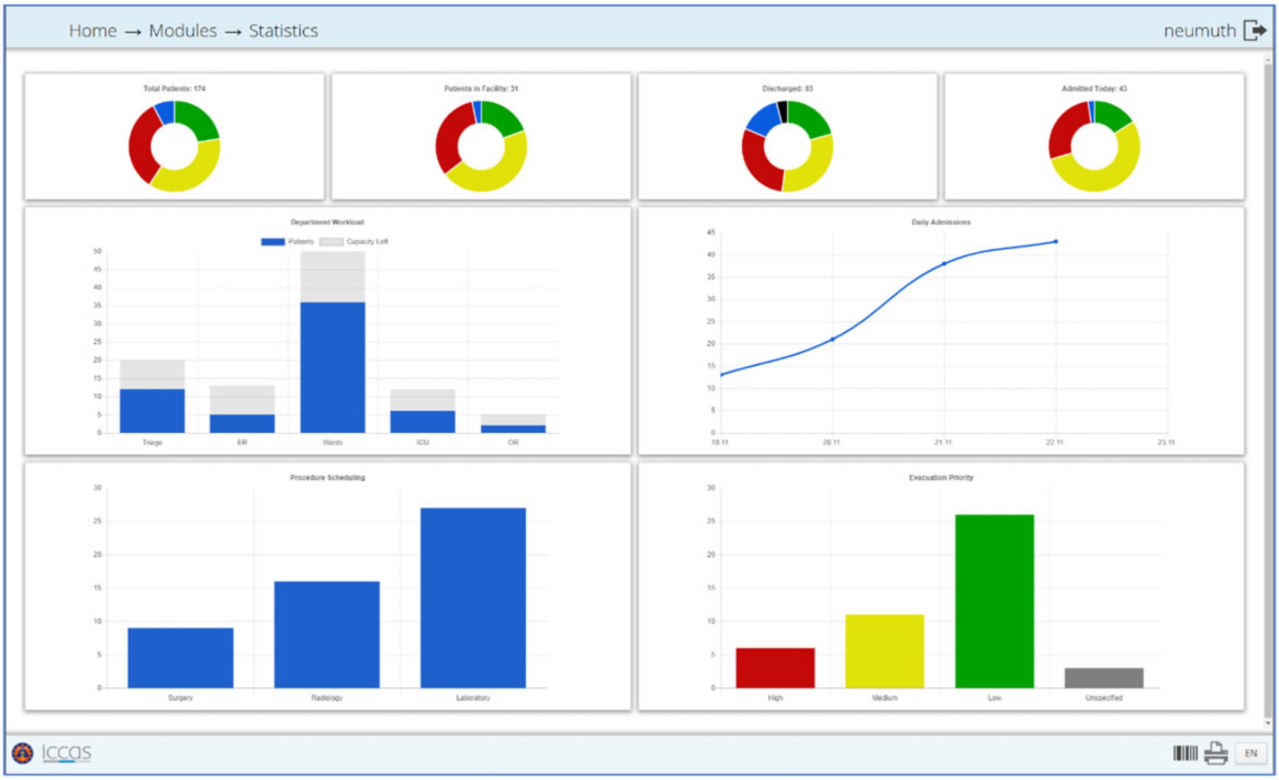

Figure 3. The EOS command view provides a quick overview of the current status of the facility by providing information about admitted patients, their triage categories, department workload, etc.

various lists for newborns, deceased patients, and an ordered evacuation list are automatically generated.

Reporting is essential during EMT missions, requiring standardized daily reports to the local ministry of health and the WHO. For this purpose, a standardized data sheet was developed by the "Emergency Medical Team Minimum Data Set Working Group" called EMT Minimum Data Set (MDS).[30–32] EOS generates a prefilled MDS conformant report for a specified time range, containing patient statistics, critical health events, general needs and risks, etc.

Since an EMT might be operating in tandem with first responders and local hospitals, data exchange with other systems is crucial. For this, an HL7 FHIR interface was implemented to facilitate standardized information exchange and ease its integration into a bigger information processing chain. Additionally, scanned or downloaded documents can be attached to any information card to integrate external information and complement EOS data forms, ensuring continuity of care. In case of a prolonged power cut, this feature would also allow to use preprinted EOS forms during the blackout and add scans of filled forms to their according cards, when the power supply is restored.

Usability

Usability directly affects user acceptance, user performance, and patient safety.[33] Users must be able to familiarize themselves quickly with the EMR since there is often no time for intensive training during missions. Depending on the deployment country, computer literacy might be limited as well.[15]

To make the usage of the EMR as easy and intuitive as possible, EOS is accessed via a web browser supporting any device from phone to PC. The UI for patient treatment is optimized for tablet PCs allowing personnel to move through the field hospital as needed. The EMR language can be toggled at any time to accommodate the typically multinational teams.

In general, the system is designed to be as unrestrictive as possible and as restrictive as needed with a minimal click depth since too many restrictions may prevent personnel from acting and adapting fast, especially in emergencies.

Patient identification and tracking

Besides the patient's ID, EOS facilitates adding pictures of the patient and audio recordings for manual patient identification. EMT staff might be unfamiliar with local pronunciation and spelling, thus both could be used as alternative identification to enable a quick patient admission. Missing information can be added later by, for example, local staff members. Additionally, patients receive a wristband with a unique patient ID coded as bar- or QR-code. This ID can be scanned (eg, with the built-in camera of a tablet PC) to open the corresponding patient in EOS to save time and prevent errors.

Safety, security, and legal considerations

EOS implements a full audit log, tracking any added or modified data by any user to ensure traceability, quality, and safety requirements. Also, it allows for a customizable role allocation (eg, physician, nurse, technician, etc.) with configurable system rights per role. Roles and privileges can be prepopulated and updated to accommodate changing conditions while also ensuring safe and legal medical conduct. New user accounts have to be created by an

Table 1. Test cases for technical verification of the EMR

Test case	Procedure
Test case 1: EMR login and browsing	• Open the browser and navigate to EMR address • Login to the EMR with the provided login data • Optional: set personal preferences • Browse patient list
Test case 2: Perform a visit and capture vital data	• Pick an existing example patient from the list • Start a visit • Enter vital data: weight, pulse, blood pressure, respiration rate, etc.
Test case 3: Diagnosis	• Add a primary diagnosis: start typing and use suggestions from the ICD-10 diagnosis list • Add a secondary diagnosis • End the visit
Test case 4: Open patient record and review charts	• Open the patient record of the previous patient • Explore the record, view demographic and vital data • Open and view charts (temperature, weight, etc.)
Test case 5: Merge an unidentified patient with an existing one	• Create a new unidentified patient • Merge this patient with an existing record (eg, by barcode scan)
Test case 6: Admission, transfer, and discharge	• Admit a new patient • Transfer the patient to a ward • Discharge a different patient and create a discharge report
Test case 7: FHIR data exchange interface	• Use the FHIR interface to import predisaster data for a specific patient (medication list, previous surgeries, etc.) electronically as well as paper based • Use the FHIR interface to export data for a specific patient (Discharge Report) electronically as well as paper based
Test case 8: Hospital command view	• Open the command view of a ward and hospital command views • Explore statistics and possible warnings
Test case 9: Patient Search Station	• Start the Patient Search Station • View presented patients

administrator. At initial login, new users must set a custom password that matches the configured security policy.

The EMR can be deployed online or locally, for example, on a laptop that acts as a server for other client devices in the same network. In the latter case, an internet connection is not required. Also, there are no specific hardware requirements for devices or routers. Any current low-end product from the consumer market will be suitable, which contributes to affordability, especially for developing countries. However, local climate conditions may require the use of outdoor devices.

Development process and current features

We followed a user-centric design, including users from the very first day of development. Users took part in structured interviews but also provided product requirement documents and their currently used paper-based patient record forms. The development process used an adapted agile system (scrum) and adheres to the regulatory requirements of ISO 13485. Online test versions were provided to the users in short release cycles for direct feedback on newly finished features and reality checks.

Currently, EOS supports the following management features: configuration of mission details, clinical departments, user and role management, triage system configuration and specifics for consumable materials or present appliances (eg, laboratory tests and medicines), and also the command view for monitoring the current hospital state and the MDS report generation. Regarding patient treatment, the currently implemented features are the support of ADT (admission, discharge, transfer) operations and evacuation, automated registers (patients, births, and deaths), card-based data management, medical documentation, including delivery and surgical documentation as well as order management for laboratory tests.

Evaluation

To evaluate EOS, the EMR was reviewed by the staff of the EUMFH project[29] during the European Modular Exercise (EU MODEX) in Bucharest, Romania. A survey plan was prepared that included details of the study objectives, design, data collected, and test cases. This survey plan was reviewed and approved by the exercise organizing committee prior to the exercise. During the general briefing on the first day of the exercise, exercise participants were informed about the general characteristics of the survey, its details, and that participants might be approached by us. Survey participation was voluntary and could be declined without giving a reason. The predefined test cases that the staff had to perform during the evaluation are listed in Table 1.

After performing the test cases, EUMFH staff were asked to answer a custom questionnaire and provide feedback about supportive, missing, or bothersome functions. A convenience sample of exercise participants was selected quasirandomly for interviews during exercises.

RESULTS

Twenty-one team members from 9 different countries (NL: 1, GB: 1, EE: 4, FR: 2, DE: 2, IT: 4, RO: 2, BE: 2, and DK: 3) were interviewed, 14 of them with medical roles (physicians and nurses), and 7 of them with supportive roles (management, logistics, or training) with 3 of these being medical team leaders. Participants' medical

Table 2. Results of the interviews (5—strongly agree, 4—agree, 3—neutral, 2—disagree, and 1—strongly disagree)

	All participants		Medical staff		Management/Logistics/Training staff	
	Mean ± SD	Median	Mean ± SD	Median	Mean ± SD	Median
Useful-Useless	4.7 ± 0.6	5	4.7 ± 0.5	5	4.7 ± 0.7	5
Comfortable-Uncomfortable	4.4 ± 0.9	5	4.2 ± 0.9	4	4.7 ± 0.7	5
Necessary-Unnecessary	5.0 ± 0.0	5	5.0 ± 0.0	5	5.0 ± 0.0	5
Facilitating-Disturbing	4.6 ± 0.6	5	4.5 ± 0.6	5	4.7 ± 0.5	5
Effective-Ineffective	4.4 ± 0.7	4	4.2 ± 0.6	4	4.7 ± 0.7	5
Supportive-Confusing	4.5 ± 0.7	5	4.5 ± 0.6	5	4.7 ± 0.7	5
Advantageous-Disadvantageous	4.8 ± 0.4	5	4.8 ± 0.4	5	4.8 ± 0.4	5
Desirable-Undesirable	4.8 ± 0.4	5	4.7 ± 0.5	5	4.9 ± 0.3	5
Motivating-Exhausting	4.5 ± 0.6	5	4.4 ± 0.6	4.5	4.7 ± 0.5	5
Subchallenging-Overcharging	2.9 ± 0.4	3	2.9 ± 0.5	3	3.0 ± 0.0	3

roles comprised nurses and medical doctors (with and without PhD) including emergency physicians, surgeons, and a psychologist. Supportive roles comprised logisticians, lab assistants, and engineers. Their years of professional experience ranged from 0 to 42 (*M* 13.1, Mdn 9) and their age from 26 to 70 (*M* 39.7, Mdn 39.5). All test cases were performed successfully without significant shortcomings. The results of the interviews conducted after the test cases were completed are shown in Table 2.

Free text answers contained mainly suggestions for minimizing the click depth for entering values and the option to link patients, for example, mother/child.

DISCUSSION

Our initial results demonstrate a strong approval of the system among all user types. All interviewees assessed the necessity for an EMR tailored to EMT needs with the highest score possible (5.0/5.0), emphasizing the urgent need for it. The overall ratings for the general concept (6.8/7.0) and realization (6.1/7.0) indicate that the design decisions and implementation have the desired effects.

Despite these results, there are some limitations. The study was conducted in a controlled environment. On a real mission, with users being under stress, issues might arise that users can easily cope with when not under pressure. Also, only basic functionalities were included in the test cases. More advanced features and adaption features were not part of the study. So, participants had only the chance to see and assess a part of the system and had a limited amount of time. Also, including more participants might have brought up additional points and worse results.

An EMR has great potential to improve documentation quality, accessibility, security, and especially interoperability with other systems and teams. However, digital systems can be vulnerable to externally induced failures and tend to fail their intended benefits when not adopted by the users. The chosen user-centric design approach with short release cycles may minimize the risk of failed user adoption. However, to make the EMR resilient to failures (eg, power surges or blackouts), local IT staff and engineers are required that can provide general support, manage backups and security, and prepare countermeasures to potential failures. Although some of these measures are already partly implemented depending on the EMT, this nevertheless leads to an additional expense.

Other projects with comparable goals to EOS are WIISARD (Wireless Internet Information System for Medical Response in Disasters)[34] and OpenMRS.[35] WIISARD is a system specifically designed for the coordination and enhancement of care during mass casualty events and tracks the conditions of victims on large scale. WIISARD also includes hardware, a network architecture and is, therefore, best suited for mobile field teams that deliver care onsite of a disaster. Hence, it is targeted for use during the first hours to days of a disaster. However, WIISARD focuses on providing a broader view of the victims and, therefore, lacks support for more specialist care like lab tests and surgeries.

In contrast, OpenMRS is a freely available, open-source EMR that was specially designed for developing countries. Due to the collaborative character, there is a great number of plugins. However, OpenMRS requires adopters to be self-sufficient, from setting up a hosting server to customizing/adapting the record to local processes and fixing potential bugs. The many different plugins from different authors are partly incompatible with each other; therefore, intense expert knowledge and adoption effort are required. Also, OpenMRS is intended for hospitals and not EMTs. Hence, EOS is located between WIISARD and OpenMRS in the treatment chain.

Beyond these systems, our team encountered several DIY EMR solutions at various SOD exercises, which address parts of a full EMR like patient admission and department assignment for a better overview. Although these solutions are isolated solutions for specific problems, they also strongly emphasize the urgent demand for digital EMR solutions during disaster relief missions originating from the users.

There are also military applications like the EMR from the Israeli Defence Force. Because of its use in the military, however, such systems are unavailable to the public. Hence, there is no EMR for EMTs known to the authors that follows a general approach by being adaptable to the specific needs and workflows of different EMTs.

Although testing of EOS during this initial multinational EMT field exercise was successful, further evaluation through different and prolonged (training) scenarios is required. Future efforts will focus on developing additional features based on current findings and gathering more extensive data on system merit and usability. Currently, we are closely supporting the adoption of EOS at our EMT partners and are preparing for requests for quality-of-life features and customization options. Subsequently, we will focus on alternative authentication options (eg, by PIN, RFID, biometric, or user device), enhanced patient tracking, and also improving interoperability by integrating the International Patient Summary or adding support for various PACS systems. Also, we plan further studies on the adaptability to changing situations and a comparative study versus a paper-based record.

CONCLUSION

EOS provides a highly adaptable EMR tailored to EMT needs. It addresses the thus far unmet need for a cheap and lightweight digital tool for structured and transparent documentation, which is vital for monitoring, coordinating, and evaluating disaster relief missions. Initial testing during a multinational field exercise demonstrated successful implementation and user approval of the system. Future research will focus on expanding system functionalities and evaluating system performance during additional (training) scenarios, as well as assessing system performance against existing paper-based solutions. After release, EOS will be free of charge for civil healthcare providers.

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AUTHOR CONTRIBUTIONS

TN designed the original idea and directed the project. ES and JG designed and implemented the EMR and coordinated the development process. TH and JG provided domain knowledge and critically reviewed the work. ES and JG conducted interviews and feedback sessions with the respecting EMTs and derived work items. ES and TN planned the study design, conducted the study, performed the analytical calculations and evaluation of the results, and contributed to the interpretation of the data and evaluation of the results. ES and TH wrote the manuscript with support from all other authors. All authors discussed the results and contributed to the final manuscript. The authors read and approved the final manuscript.

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CONFLICT OF INTEREST STATEMENT

None declared.

DATA AVAILABILITY

The survey data will be shared on reasonable request to the corresponding author.

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