A mHealth System for Patient Handover in Emergency Medical Services

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ABSTRACT

This research uses multiple methods to investigate the use of an enterprise mobile multimedia information system aimed at improving handover of patient and emergency incident information from pre-hospital Emergency Medical Services (EMS) to hospital emergency department providers. A field study was conducted across EMS and hospital organizations in the Boise, Idaho region of the United States for three months to examine use of the system and to assess practitioner perspectives. Findings include perceived benefits and challenges to using digital audio recordings and digital pictures, captured using a smartphone application, for improving the timeliness, completeness, accuracy, convenience, and security of patient information for handover in EMS; limitations on how much data can be collected in the field due to a wide variety of contextual constraints; and a need to better understand the value of video within the EMS handover context.

Keywords

mHealth, emergency medical services, mobile computing, multimedia, information systems design theory.

INTRODUCTION

Emergency Medical Services (EMS) is an organized and collaborative effort between several organizations providing different levels or tiers of care designed to transport sick or injured patients to the hospital. Handover of patient information in EMS poses significant challenges. During an emergency medical incident, communication occurs between pre-hospital responders (paramedics) and emergency department (ED) staff prior to and/or during patient transport and arrival to the medical facility. This information exchange is essential to the decision making process for healthcare practitioners and for achieving positive health outcomes for patients (Aase, Soyland, and Hansen, 2011). Prior research has identified significant challenges to efficient, accurate, and complete information handover for communicating pre-hospital patient information to EDs for the purposes of point of care decision making including: 1) limited time for paramedics to collect and transmit data on-scene or en-route using electronic patient care record (ePCR) systems, 2) a limited number of tools in the field for paramedics to collect value-added multi-media information (Schooley et al., 2010), 3) often fragmented communications or lack of information exchange standards and practices (Aase et al. 2011), 4) significant reliance on the use of synchronous two-way voice radio communication technologies (Chu and Ganz, 2004), and 5) frequently missed, unreported, or incorrectly reported verbal or written information to the ED especially for more severe medical incidents.

With the rapid advancement high-capability smartphones and mobile devices, many in industry and research are motivated to explore new approaches to collect and transmit voice, data, pictures, and video information to improve healthcare processes. The goal of this research was to explore the potential impact of an enterprise mobile multimedia information system to aid in EMS communications. This paper describes an application developed by the authors that enables pre-hospital emergency responders to capture and transmit digital images, video and digital audio about patients and related emergency incident information to the hospital prior to patient

arrival. In this paper, we discuss: 1) system overview, 2) system design processes, 3) field study design, 4) pilot study evaluation, and 5) evaluation findings.

INFORMATION HANDOVER IN MEDICAL EMERGENCIES

The transfer of care from one care provider to the next is referred to as patient handover, or handoff (Riesenberg, 2009). Transfer of accurate and timely information during patient handover is a critical clinical and organizational process to ensure continuity of care (Ghandhi, 2005; Abraham et al., 2011) and to secure patient safety (Horwitz et al., 2009). Communication failures in patient handover have been cited as a major cause for a range of medical errors (nearly 70%) in healthcare (Sutcliffe, 2004). The communication challenges are further magnified in fast-paced, short-stay, and critical care environments such as the ambulance or emergency department (ED) (Wiler et al., 2010; Benner et al., 2007; Abraham et al., 2011). The nature of the communication process in EMS settings is complex and cognitively taxing for clinicians, further increasing information handoverchallenges (Laxmisan, 2007). This paper specifically addresses an information handoff gap between pre-hospital emergency medical services (EMS) and hospital emergency department settings (Schooley et al., 2011).

For EMS, information processes frequently occur as verbal and written information exchanges. In a typical scenario, one or several first responders (e.g., fire department or ambulance) will collect patient and incident information from the patient, family members, or bystanders. These personnel may then write the collected information in various places such as a paper form, any available piece of scratch paper, a mobile device, a latex glove, or other convenient location (Orthner, 2005; Schooley and Horan, 2007; Institute of Medicine, 2006). These information collection points act as a 'staging location' until electronic records can be completed – one by each responding organization. A two-way radio call or wireless phone call is then made to the receiving ED to report patient status and an expected arrival time. Frequently the patient will arrive at the ED in advance of a comprehensive electronic record. Hence, a verbal information handoff to providers at the receiving ED is provided, many times in an environment that is not conducive to hearing and understanding important details (Trzeciak and Rivers, 2003).

E-PCR Systems and Handover in EMS

An electronic tool that is used in EMS to help facilitate incident and patient data collection is the electronic patient care record (ePCR) (Spaite, 1990; Meislin et al., 1999). E-PCR systems were conceptualized and have been designed to improve EMS record availability and legibility for ED clinicians, as well as to improve quality assurance, outcomes research, and billing for EMS agencies (Landman et al., 2012). E-PCR systems aggregate data across 9-1-1 call centers, first responders, and transport organizations; capture over 400+ standardized data elements (Dawson, 2006); and record health care procedures, patient assessments, medications, protocols, patient history, demographics, and situational context information for each incident. E-PCR systems are comprehensive and standards based.

However, the purpose for which ePCR systems were designed often stands in contrast to efficient handover of essential information to the ED (Schooley et al., 2010; Orthner, 2007). For example, an analysis of over 22,000 EMS transports across one California County showed completion of an ePCR took an average of 39 minutes 42 seconds (median 33 minutes 59 seconds) *after* EMS arrival and patient handoff to an ED (Schooley, 2007). A larger study showed that only 49% of EMS Agencies report collecting some electronic data at the patient's side prior to arriving to an ED (Williams, 2008). Of the 48 States providing information for a National survey, 23 (48%) reported a requirement exists to leave a formal copy of the PCR (paper or electronic) with the patient's receiving healthcare provider at the time of transfer (Mears et al., 2011). A statewide California survey of EMS Administrators and Medical Directors found that 70% of the respondents did not know how long it usually takes to complete the ePCR and that there exists no standard reports, metrics, or methods for evaluating the timeliness of ePCR completion (Schooley et al., 2010). Case studies conducted across Idaho, Utah, California, and Minnesota confirm this finding, as do EMS industry surveys and educational materials (Marich et al., 2007; Schooley et al., 2011; Ragone, 2010; Tintinalli et al., 2010). The true extent to which delays in ePCR handover occurs is unclear. Available research on the topic, and our past findings illustrate that 1) ePCRs are commonly completed well after patient arrival to the ED, especially for the most critical incidents, and 2) there are very few studies that demonstrate the efficacy or effectiveness of ePCR systems for facilitating handover and clinical decision making at the point of care.

The system being described hereafter is not an ePCR. Rather, the system design was motivated by: 1) inefficiencies found in EMS information handoff through prior research efforts, including the ePCR tools being used, and 2) the potential benefits of using multimedia information to supplement EMS reports to the ED.

Multi-media Systems and Handover in EMS

Multi-media mHealth applications have also been developed for the EMS context. One study by Chu and Ganz (2004) used an off-the-shelf mobile hardware platform and utilized commercially available 3G wireless networks to create a mobile teletrauma system that simultaneously transmits patient videos, medical images, and electrocardiogram signals to ED physicians. Their work was limited to the design of the system by stakeholders other than end-users and the research did not include field testing by practitioners. Furthermore, the impact of the system on EMS care practices and the perceived value of the system from medical provider perspectives were not investigated. The study discussed herein is aimed at extending mHealth research for EMS in these three regards.

In terms of using multimedia for EMS more generally, (Dickinson, O'Connor, and Krett, 1997) examined the impact of instant photography for decision making in motor vehicle crash (MVC) incidents. In their study, paramedics were provided instant cameras and were given detailed instructions to 1) take two images for each MVC they responded to, and 2) place the images inside the ambulance for later collection and viewing. While the 1997 study reported important findings on the impact of MVC images on physician perceptions, the impact of these images for time-critical decision making (e.g. before or at patient arrival to ED) was not studied, nor was the use of a Smartphone for collecting and transmitting such information in a real world, time-critical environment. The study described herein is positioned to address these research gaps and extend the work of these authors within the context of multi-media mHealth for improving the effectiveness of handover in EMS.

RESEARCH APPROACH AND METHODOLOGY

This study employed a multi-method research approach. First, prior work by the research team: 1) identified practitioner challenges to exchanging information across pre-hospital and hospital settings (Horan and Schooley, 2007), 2) examined existing and alternative methods and tools, including ePCR systems, for addressing data exchange solutions (Schooley et al., 2009; Schooley and Horan, 2007), 3) assessed practitioner requirements for an mHealth solution within the EMS context (Schooley et al., 2011), 4) constructed a prototype system in multiple iterations and feedback cycles with practitioners (Schooley et al., 2011), and reported perceived benefits of multi-media information from pilot study findings (Abed et al., 2012). Through these research phases, both qualitative and quantitative data were collected and analyzed including interviews and observations with over 150 EMS practitioners across 4 states (regions) within the United States (U.S.) (including California, Idaho, Utah, Minnesota), on the use and adoption of data systems in EMS (including ePCR systems). Details on the methodologies, findings, and design artifacts from these prior phases can be found in the references noted above. The results of this prior research were utilized to inform and guide an inquiry in the Boise, Idaho field study location (live field test discussed below) on how the artifact impacts patient handover processes. A design evaluation was conducted and preliminary data was reported in Abed et al., (2012).

This paper focuses in greater detail on the handover element of the process, with particular reference to the value of multi-media information as part of that handover. Researchers examined the quantity and timeliness of handovers that took place, where in the patient care process these handovers occurred, where the perceived value was reported, and the differential role and value of multi-media information in that hand over.

SYSTEM DESCRIPTION

The mHealth system described below is aimed at assisting with handover for patient care decision making at the hospital emergency department (ED) and Trauma Center. The system combines mobile Smartphone, multimedia, web server, and location-based technologies to enable more timely and rich communications. The system requirements are described below.

System requirements

Findings from prior research were synthesized and generalized into guiding principles, informed by specified kernel theories, to meet the requirements. First, the system shall allow paramedics to capture multimedia information through a user friendly interface similar to what can be experienced on the latest hand held device,

multi-media, social networking, and location based applications. It must not take long to enter information. Prior research that motivated this design feature came from participant responses including, "I'll take a picture of an [automobile] accident with my own personal cell phone and show it when I get there [to the ED] (Paramedic)." Comments from trauma physicians and ED physicians included: "A picture can sometimes tell you a lot. You know the saying, 'a picture is worth a thousand words.'"

Second, the system must transmit information in a timely manner at or before the patient arrives to the ED. Past findings that motivated this design feature included: "We have to find a way to get it [information] to the ED on time. There has to be some way to resolve this (ED Physician);" "This is a challenge everywhere. It's not just here. We just don't get the [ePCR] report [from the medic] for a lot of these [ambulance] runs (charge nurse)."

Third, the system must have a visual capability to display the information that was sent by paramedics to ED personnel. Past responses included: "I want to have some way to see a picture and then, you know, let the medics in the field know what I think. Like, move in closer [with the camera] or ask a question [to a patient] (Trauma Surgeon)," and "It's nice to see on a screen, like a lot of the new systems we are getting nowadays, that shows who is coming, when they're coming, what things to expect. It makes a difference to see it (charge nurse)."

Several other support features were identified by participants to embed within the software application. First, the system must be capable of capturing and sending basic patient information including: age, date of birth, gender, name, incident location (GPS), patient indicators (e.g., chief complaint of the patient or primary impression of the paramedic), and critical interventions (e.g., immobilized patient, cardiac pacing). Second, the system must allow ED users to visually drill-down on an incident record through a graphical user interface to display multi-media details including a gallery of images, video, and digital audio files pertaining to a specific patient and incident. Third, the system must immediately notify the ED users when a new incident is sent by a paramedic unit (text message, email). Fourth, data, device, storage, and network transmission security; as well as application availability are essential requirements.

Implementation

An enterprise software artifact was developed through multiple iterations to achieve the above requirements utilizing a range of current and emerging concepts and technologies including web services, encryption, and multimedia mobile applications. The system has three primary components: 1) a mobile Smartphone application for paramedics and emergency medical technicians (EMTs) to collect basic patient and incident information, 2) enterprise middleware component, and 3) an ED web application for hospital practitioners to be notified of and view emergency patient and incident information.

The mobile application for paramedics, unlike an ePCR, does not require any certain types of data to be collected prior to notifying a receiving ED. There are no mandatory data fields. Only basic demographic data (i.e., gender, age, date of birth), a short checklist showing the chief complaint (i.e., Cardiac Arrest, Brain Attack/Stroke, Chest Pain, General Medical, Level 1 Trauma, Level 2 Trauma, Level 3 Trauma, Respiratory Arrest, Seizure, STEMI), and interventions that matter to the ED (i.e., Cardiac Pacing, CPAP/BiPAP, Immobilized, Intubated/Artificial Ventilation, Psych/Combative) are captured and sent. Pictures and audio recordings can also be captured and sent.

Upon sending the data, notifications are automatically sent via text message and automated phone call to pre-selected providers in the ED. Pictures and audio recordings and patient data can be accessed through a web interface. ED practitioners can then send acknowledgements and other communications to paramedics via text message. Mobile app and device security, geo-location and mapping services, and administration features are also built in. While much more extensive data collection features, and similar messaging features have been marketed by ePCR vendors, they have not been evaluated for their efficacy or effectiveness in the research literature.

PILOT TEST DESIGN

To evaluate the artifact and to understand the use of multimedia in emergency medical decisions, the research team conducted a three month pilot test in the Boise, Idaho region inclusive of the following participating organizations: Ada County Paramedics, Canyon County Paramedics, St. Alphonsus Boise hospital, St. Alphonsus Nampa hospital, St. Alphonsus Eagle hospital, St. Luke's Boise hospital, St. Luke's Meridian hospital, and West Valley Medical Center. The pilot test began on July 17 and 18 with visits by researchers to

each of the Boise hospitals. The test ended on October 31, 2011. For the pilot test, each medic unit at each ambulance agency was equipped with one Motorola Droid Smartphone activated on the Verizon 3G network. User names and passwords were created and distributed to each paramedic and to emergency department managers/directors to provide access to the web application in each Emergency Department. A 1 hour training session occurred via video conference and in-person at each ambulance agency and hospital. Phone and email support were offered to end users throughout the duration of the pilot. General system administration, security monitoring, and some technical assistance occurred throughout the pilot by the research team in order to keep the system operational.

Paramedics and nurses alike were not required nor provided with incentives to use the system at any time. The system was to be used voluntarily. Each of the features within the mHealth application were optional. For example, there were no mandatory data fields, nor were there requirements that a multimedia file be captured or transmitted for an incident. The only mandatory aspect of the system was that medics enter a unique identification number prior to sending an incident record. This was required for security and user identification purposes. Paramedics continued with their standard protocols and policies to use radios and cell phones to make a verbal report to an incoming hospital for each incident. E-PCR systems continued to be used normally, that is, typically after patient arrival to the ED. Practitioners were invited to participate in the test and provide feedback to the research team. All users were asked to stop using the system at any time they felt that the system interfered with patient care.

Pilot Evaluation Data Collection

System utilization data was collected throughout the duration of the pilot test. In addition, at the conclusion of the pilot test, field visits were made to each participating organization. Qualitative data were collected through a series of individual and group interviews with practitioners whom used the system at least once during the pilot. Participants included 22 paramedics, 17 nurses, 2 physicians, 3 hospital and 2 EMS administrators. Participants were asked a series of questions in order to understand their perceptions about the utilization, usability, perceived value and challenges of the system and use of multimedia information in EMS communication processes and decision-making. Example questions included: How did you use the Smartphone application? What benefits and/or challenges were experienced from using the system? How did using the system, and information that was transmitted, affect communications processes? All interviews were recorded, transcribed, and uploaded into a qualitative data analysis tool (Atlas.ti). Data was aggregated, categorized in terms of media type used, clinical uses, efficiencies experienced, and challenges using the system.

FINDINGS

Paramedics and ED staff actively used the mobile, multimedia, and web-based features of the application. In terms of system use, a total of 72 paramedics transmitted 801 records, 437 digital images, 446 digital voice recordings, and 25 digital video files to emergency departments during the three-month pilot test. The design goal at the outset of the project was to explore whether the system would be used and how it might be used. The research team did not estimate how many users would utilize the system or how often it would be utilized for patient handover. Participation was voluntary. Nonetheless, results showed that over half of all paramedic participants used the mobile application at least once, with approximately 30% of paramedic participants using the system at least 10 times (see Table 1). Findings indicated that paramedics attached a proportionately large number of images (pictures) and audio files to incident records. For the pilot study, the majority of incidents were sent to hospitals that receive a very significant number of patients from Canyon County Paramedics. These include St. Alphonsus Nampa, West Valley, St. Lukes Meridian, and St. Alphonsus Boise.

Table 1. Paramedics Usage Tiers

Number of paramedics that sent incident reports per usage tier (% of users)	# Incident records sent
15 (20.8%)	21 or more
8 (11.1%)	11-20
34 (47.2%)	2-10
15 (20.8%)	1 (one)

Total Medic Participants: 72

- Below, findings are discussed in terms of the perceived value that was experienced, categorized by the following system qualities: timeliness, security, convenience, completeness, and accuracy.
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Timeliness

Participants noted various ways that the mHealth system augmented handover. The mobile app was perceived to be user-friendly and to not interfere with time spent on pre-hospital patient care any more than current radio and phone communication activities. As a baseline measure for timeliness, EMTs and Paramedics are typically trained to provide a radio report to a receiving hospital in less than 30 seconds. The actual time it takes can be longer, however, if the radio channel is being used by other EMS personnel, or if ED staff are unavailable for a radio call. In comparison, system log file data from the pilot test showed that the average amount of time it took paramedics to create a digital audio report was 26.347 seconds (median= 25 seconds). Picture recording times, or the time it took to open the camera, take pictures and exit the camera application was 66.818 seconds (median= 23 seconds). The median time it took paramedics to enter patient information was 38 seconds, and median time it took paramedics to complete an entire record (from clicking "start" until clicking "send") was 103 seconds.

While the time spent on the application was longer than the typical 30 second benchmark for an audio report, medics described how using the Smartphone application did not seem to interfere with current on-scene medical care practices, and in some cases assisted current EMS workflow and communication processes more efficiently. Several paramedics and charge nurses compared the use of the system with current 2-way radio usage. One explained:

> "…when we first got 'em [the phones]… I felt a lot of people's attitude was 'I don't have time to, you know, work with technology and take away from the patient.' And so I was a little bit skeptical at first too until I started using it. And actually found that you can do that a lot quicker than you tend to call [radio] to the hospital. Cause you have another ambulance on that channel already and you're gonna have to sit and wait and then no one is at the nurses station to take the call--- so I actually found it to be faster and more user-friendly than actually calling in to the hospital."

Participants described several other examples where handover was more efficient. For example, one nurse described how text messaging was used to provide room assignments or to ask additional questions to paramedics, which aided the ambulance crew and ED to know where to go what tasks to perform sooner than otherwise. Another nurse described a severe motor vehicle crash where patient demographic data had been sent by the paramedic.

"I was able to register the patient before she got here. That was good."

Charge nurses in the smaller, less busy hospitals also appreciated receiving automated notifications of an incoming patient, and the ability to text medics a room assignment or ask about their estimated time of arrival.

Use of the system may have provided the most value for EMS incidents exibiting higher severity levels and longer transport times, and provided less value for incidents exibiting short transport times. Several participants explained that the sending and receiving of incident records was less valuable and useful for incidents in which transport times were short. For example, transport times that were 3 or 4 minutes long often did not allow the nurse enough time to gain meaningful information from the sent record prior to patient arrival. One charge nurse explained:

> "sometimes I would look at the report, or you know the pager would go off and then I look up and they're coming through the doors [Medic & patient]" (Charge Nurse)

On the other hand, participants thought that the system provided significant value for those incidents where transport times were long, for example, from rural and remote regions. Such long transports enabled adequate time to review information by ED practitioners and allowed for time to make pre-arrival preparation. One charge nurse explained:

> "I think it is best for the guys [Medic & patient] who are coming from further out, well, it's really helpful to have this information." (Charge Nurse)

Security

A significant security challenge in EMS communications is the unsecured nature of 2-way radio. Sending information over a secure channel enabled communicating personal health information that otherwise could not have been sent (i.e., patient name, gender, age). For example, the system encrypts all files to the device, sends the encrypted files over an encrypted channel, stores the data in a secure database, and deletes the encrypted

files off the smartphone once the files have been sent. Participants noted a comfort level knowing that information could be sent securely. One nurse stated,

> "You know, we can't get the name of the patient over radio because its open [an open channel]. But seeing it on the screen was good."

Convenience

Several medic participants explained that the system allows them to record audio at their own convenience and not have to wait for the ED to respond before talking. On the receiving end, charge nurses explained how they can access the record when convenient, as many times as needed, and allow physicians to listen to the context if they feel the information is important enough. One charge nurse explained:

> "I can look at it [the record] when it suits me. Cause that's what I hate, when we're talking to patients or I'm in the middle talking with a patient or trying to do something or I'll have an upset patient I'm trying to calm them down and then, 'Oh, I'm sorry, I have to take this call.'"

Medic participants also explained how the mobile app design enabled data entry and multi-tasking on scene. For example, one participant explained:

> "I take pictures or do the audio while I'm walking to the rig. Maybe it's a generational thing, but I use it while I'm doing other things so you know it doesn't really get in the way more than what we already do."

In addition, many medics already use Smartphones for taking pictures using their own personal phones. Some of the medics are already "used to texting" and using other Smartphone "apps" for augmenting their work. As such, using the mHealth system did not represent significant changes to the work they already perform. Rather, the Smartphone application provided a platform to conduct communications that otherwise could not be accomplished.

Completeness

The patient data, pictures, and audio recordings stored in a database and retrievable via a web browser enabled a sense of completeness to the handover. Nurses described situations where the physician was called over to look at pictures or listen to a report. A nurse explained,

> "For a few of them [reports], I just told the doctor to come and listen to it [the recording]. It was better than coming from me."

Listening to the recording and reading the patient information on the screen augmented current practices by enabling permanence to the information. That is, the recording could be accessed by downstream medical practitioners in the hospital as a more robust and complete report than might otherwise be provided by busy ED staff.

Accuracy

Using the system helped practitioners rely less on individual memory and to deliver/retrieve information when required. A physician explained the benefits of hearing the medic report "from the horses mouth," as being more accurate and reliable than if the message were described from a "second hand" reporting. Several medics described their use of images to better understand patient injury and/or health status progression. They discussed how taking pictures or audio recordings at various points in time allowed for an understanding, in the hospital emergency room, that a patient may (or may not) require attention. For example, one medic explained:

> "We had a burn patient whose face, and arm, upper chest is burned. So we took pictures of and you can see the progression certainly from the time we sent the pictures to the time we left the hospital how the burn has progressed."

Similarly, another medic described the use of the system for a brain attack (stroke) incident and its impact on describing the situation to the attending physician:

> "They took a picture of him [stroke patient] sitting up and you could definitely see the whole side [of his face] was down and he was looking bad. Then you saw the next picture…he's sitting up smiling, everything has resolved and…when you come in and tell the doctor what you saw…it's not the same as seeing it as a picture."

Viewing well-taken and effective pictures enabled emergency practitioner decision making, a key component of an effective patient handover. Paramedics took the following types of pictures: trauma injuries, immobilized patients, severe wounds, and blood pools (blood loss), crash intrusion into the vehicle, damaged windshields, damages as seen from inside of the vehicle, unused seat-belt restraints and motorcycle helmets, the surrounding

crash site (e.g., vehicle at a distance, vehicle close up, depth of ditches, and existence and length of skid marks). These pictures were used to augment decision-making due to their ability to help reveal the severity of a trauma situation. For example, one nurse explained:

> "Seeing the picture, I'd be able to judge before I get there how severe the trauma is." (Nurse)

Several participants saw significant value in the use of effective pictures to better allocate needed resources at the hospital. For example, one charge nurse explained:

> "If we saw a picture of a two feet intrusion onto the driver's side or the front end [of the car] is completely in like this, then they're going to get more scans and they're going to get more – you see everybody, but if you've got a background to go by you can say oh my gosh, this person really took it in the door or wherever and we need to be very cautious here." (Nurse)

Another nurse explained,

> "…the steering wheel's bent or there's a star on the windshield. Those are classic things. That makes a big difference even if I'm not seeing anything [on the patient] when they come in."

Other pictures taken included: EKG reports, paper run reports, and medication bottle descriptions. Participants working for ambulance providers that are not able to afford expensive devices for capturing patient vital signs (e.g., EKG) used the camera to take pictures of the EKG readouts and send them to the ED. Medics also took pictures of paper run reports written by first responders whom collected information prior to their arrival. This enabled medics to send previously collected information rather than collect it themselves.

In sum, most participants agreed that multi-media information can provide for more complete, accurate, and timely understanding about a patient's condition if captured and delivered effectively. Many images for example did not provide value as per participant responses, and furthermore discussed a need to define protocols for effective picture taking. Participants also agreed that using a Smartphone application to capture and send pictures and audio provided a more secure, timely, and permanent way to communicate those incidents than using a standalone digital camera or personal Smartphone owned by a medic. Overall, use of the mHealth system in the ED was perceived to provide actionable value as described above.

Other Potential Benefits

Organizational administrators at the regional level, across multiple hospitals, ambulance providers, and agencies, discussed potential large-scale implications of the system for improving handoff. First, a method for capturing data about the timeliness and completeness of a handoff could provide a means to evaluate patient handoff processes more effectively. Second, participants described how the system may provide a richer means to evaluate quality control in patient information collection and handover due to the richness and permanence of the information collected. That is, multi-media incident information can be reviewed in a retrospective manner. Third, the system may enable better handover, including resource utilization at a regional level. In this regard, the system may facilitate sending patients to the right hospital with the most appropriate resources (i.e., stroke, STEMI, trauma, burn, available resources, other specialties)). In this sense, participants suggested the need to develop a stronger capability to enable hospital to hospital referrals in the case a patient needs to be transferred to a higher level of care (i.e., Trauma level 2 to Trauma level 1) or more appropriate care (i.e., stroke center).

Challenges and future directions

The pilot evaluation found significant challenges to improve handover in the future. First, it was suggested that one improvement could be to utilize the "wireline" telecommunications network to send EMS notifications more reliably inside of hospitals. Second, the amount of time required to encrypt and send large multimedia files (i.e., a video file) on the mobile device through a 3G network was far too extensive. As such, users did not use the video feature. The use of a 4G network may reduce some of these issues, as well as implementing a more "real-time" video stream directly to the ED. Third, in some cases, pictures may have been a handover distraction to ED practitioners as they viewed and tried to determine how to interpret the value of some photos. For example, a picture of a broken arm, photo of a wound taken from a non-descriptive angle, or images of a minor medical condition were described by participants to be of little or no value to the handover process. The pilot test revealed a need to develop protocols on the types and quantity of pictures to capture and send to the ED. Fourth, a significant challenge was the need to address varying work flows across hospitals. Not all hospitals communicate with paramedics in same manner. Future studies should focus on understanding the range of methods whereby multi-media Smartphone information could "fit" within an existing ED work flow, and/or how a work flow might be improved through incorporating functionality. Finally, many users were enthusiastic about using the application and the potential for many new features for improving handover including: automated notifications (e.g., text messages), automated transcription of voice recorded files to text, iPhone and

iPad apps to view data in the ED, integration of data into the electronic patient chart, and new web-based "views" of the data for other users (e.g., for traffic crash clearance operations), etc.

CONCLUSION

In this paper, we described the field testing and exploratory evaluation of a mobile health information system focusing on the patient handoff. Findings indicated that the digital audio provides advantages over radio reports, the main advantages being that the recording 1) can be replayed for downstream providers, and 2) provides a much more secure medium for communicating patient information. Second, pictures represent a significant advancement for providing details that supplement the audio report, but the best usage is yet to be found. Third, the use and value of video is not yet well understood. Fourth, patient and incident data can be very useful for handover, but there are limitations on how much can be collected in the field due to a wide variety of contextual constraints. More generally, mobile smartphone use by paramedics, automated notifications to the ED, and asynchronous communications using multimedia information may be useful for improving handover in EMS.

There are several limitations of this research that would encourage future work in this area. First, the field study was conducted in one U.S. City. Future studies should examine and compare the use of mobile and multimedia for handover in other locations in the U.S. and globally. Second, the study participants included only two ED physicians. Physicians are traditionally a difficult participant group to access in health information technology studies. However, these participants represent a critical user group and thus should be included in larger numbers in future studies. Third, due to the exploratory nature of this study, the manner in which the mobile devices were used lacked protocols and processes. As per some participant responses, the images may provide much greater value if paramedics follow picture taking protocols that are tied to specific types of incidents (i.e., stroke, trauma, burn, motor vehicle crashes, etc.). Such protocol development could also apply to the use of video, digital audio recordings, and the capture of data in the field. Finally, this research applied a qualitative evaluation methodology, which fit well with the exploratory focus of the study. However, future studies should examine a much wider audience and utilize a range of other evaluation methods including surveys, experiments, and a larger sample of qualitative participants.

While this study has its limitations and future research directions, it also provides significant contributions. The study developed and applied a specific ISDT for a new generation of enterprise multimedia mHealth systems for EMS. From a practical perspective, this research provides a robust mHealth system for EMS to utilize in the future and demonstrates potential handover benefits to EMS practitioners.

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