Pre-hospital Application of Telemedicine in Acute-Onset Disaster Situations

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1. Introduction

There have been several examples of devastating and large scale disasters over the last few decades with multiple etiologies, from the anthropogenic (e.g. terrorist attacks and bioterrorism) to the natural (e.g., Earthquake in Bam Iran, Indonesian tsunami, hurricane Katrina, famine in Africa). These disaster events have had a significant acute and long-term impact on human health and healthcare delivery systems.

Disasters generate human need at a time when services, infrastructure, and resources may be least available. Disasters that cause structural damage to buildings often result in traumatic injury, exposure to high-voltage electricity, inhalation lung injuries resulting from fire or explosions, or secondary illnesses or injuries resulting from serious health threats from contaminated air, water and sewage, animal bites, and human threats such as rape and theft. Disasters can also cause mental health consequences, including depression, anxiety, agitation, and post-traumatic stress. Dealing with these health effects is further complicated in a disaster-compromised healthcare system and public infrastructure that is overwhelmed by the surge in demand, damaged, or destroyed.[1]

Medical disaster response supplements local emergency medical response systems with resources from federal government, neighboring communities, humanitarian assistance organizations, medical personnel, hazardous materials teams, and volunteers from external sources. Managing an effective response requires effective collaboration, facilitated by telecommunication technologies, and up-to-date information about conditions at the scene. Unfortunately, existing telephone networks become disabled during many disaster events, because of either physical damage to the communication infrastructure or an inability to handle increased demand.[2] Without question, there is a critical need for effective information management and communication in generating coordinated actions to prevent and treat serious health problems resulting from acute-onset disasters.[3]

2. Telemedicine

The term *'telemedicine'* derives from the Greek *'tele',* which means *'at a distance'* , and *'medicine'* which derives from the Latin *'mederi',* meaning *'healing'.* Thomas Bird used this phrase for the first time in the 1970s when referring to health care delivery where physicians examine distant patients through the use of telecommunications technologies.[4]

There are several definitions of telemedicine, but the World Health Organization defines telemedicine as[5]:

> *"The delivery of healthcare services, where distance is a critical factor, by all healthcare professionals using information and communication technologies for the exchange of valid information for diagnosis, treatment and prevention of disease and injuries, research and evaluation, and for continuing education of healthcare providers, all in the interests of advancing the health of individuals and their communities".*

There are two methods of telemedicine delivery, real-time (synchronous) and store-and-forward (asynchronous):[6]

Real-time telemedicine (synchronous) requires the presence of both parties at the same time and a communications link between them that allows a real-time interaction to take place. Video-conferencing equipment is one of the most common forms of technologies used in synchronous telemedicine. Some devises like ECG monitoring, glucometers, stethoscopes and even ophtalmoscopes and otoscopes can be attached to videoconferencing equipment which can help simultaneous examination and monitoring of a telepatient. Teleconsultation is another example of real time telemedicine, during which a family physician can easily consult with specialist at the time of patient's visit, or consultation of various specialists in different countries about a complicated patient through video-conferencing.

Store-and-forward (asynchronous) technologies are those that store clinical data (images, video, and audio) on the client's computer, and transmit them to another location at a later time. The user may also have the ability to log onto the client's computer at access the clinical data from a remote location. The advantage of store-and-forward technology is that it does not require both parties to simultaneously be present, allowing each to transmit their opinions/reports at a more convenient time. Store-and-forward technologies are used in specialties where response time is not critical such as teleradiology, teledermatology, and telepathology.

2.1. Disaster Applications

Telemedicine has potential applications in every step of an effective disaster management, from prevention to preparedness/preparation, response, and recovery. There are three response phases to manage a disaster situation:[1]

1. **Acute phase response (immediate post disaster period)**

   Telemedicine would play a support role in this acute phase, including assistance with triage, transportation, and medical logistics coordination along with present on-scene skilled medical personnel for managing emergent needs. As national assets take at least 2 days to arrive in disaster affected areas, local telemedicine solutions are crucial in this phase.

   For example, special needs patients, such as the ventilator-dependent and cardiac arrest patients could be remotely monitored if reliable communications systems were in place, via e–intensive care unit systems.

2. **Subacute disaster response (days to weeks):**

Primary care and specialty consultation services could be provided by telemedicine, which will offload the less urgent patients from emergency medical facilities. This system can also be used for medication checks and other routine care, which enable patients to stay in the shelter and avoid transport to the emergency department. In addition, telemedicine may also play a significant role in the event of an epidemic or bioterrorism. Telemedicine systems may enable the identification of outbreaks within these affected populations.

3. **Chronic disaster recovery phase (months to years):**

Telemedicine would continue to supplement primary and specialty care services as well as address disaster-unique healthcare needs, such as mental health, infectious disease, and environmental or bioterrorism agent exposure in extended period which depends on the scope and nature of a disaster.

Table 1 – Incorporation of telemedicine in ongoing activities required for effective medical response to MCIs (adapted from Balch[7])

1. Planning and preparedness	2. Early detection and surveillance	3. Crisis response	4. Treatment	5. Recovery and mitigation
• Risk assessment & implementation of risk avoidance measures	• Real-time health monitoring to achieve early detection and areas of vulnerability	• Coordinated response for rapid assessment and identification of medical need	• Timely consultations from a wide range of specialists	• Clinical needs of the affected populations remain significant even after the cameras, volunteers, and Disaster Medical Assistance Teams go home
• Continuous education of healthcare workers, hospitals, and other organizations involved in disaster management	• Local, state, regional, and national data assessment	• Epidemiology planning for diagnostic, therapeutic, contamination, and containment	• Supervision of treatment at regional, state, and local levels	• Mental health needs are most pressing and local mental health resources are often very limited
• Telemedicine skills training for providers, Exercises & drills that simulate MCIs* likely to occur in the region serviced by a telemedicine installation	• Education of public safety officers, public health personnel, and healthcare and telemedicine providers	• Medical resource and supply tracking	• Management of patient transfers and referrals to special needs shelters and alternative care centers	• Rebuild areas to prevent similar situations in the future (evacuation planning, stored medical capacity)
• Integration of telemedicine technologies into readiness and response planning	• Timely communication regarding emerging threats	• Access to existing telemedicine network resources	• Patient tracking patient care & addressing medical issues, hygiene, immunization, water, shelter, and clothing	

*Mass casualty incident (MCI)

One of the first telemedicine applications in a disaster situation occurred 18 years ago in response to the earthquake in Armenia, Russia. The Spacebridge Program is a joint program between the NASA's Division of Aerospace Medicine and the Russian Space agency. It is an internet-based application that links clinicians through videoconferencing to assist with teleconsultation efforts. It was used as a tool to address 240 medical cases caused by the earthquake. Furthermore, efforts have been made towards establishing a global emergency network.[8]

Several studies support the cost effectiveness[7] and clinical feasibility and diagnostic accuracy of application of telemedicine in acute phase response in disaster situations. For example, Huffer[9] demonstrated the feasibility and diagnostic accuracy of a portable satellite transmission system in the assessment of cardiac emergencies for the real-time support of mass casualty and humanitarian relief efforts.

Balch[7] states that "successful implementation of telemedicine into mass casualty incident (MCI) response requires an integrated approach that utilizes existing telemedicine resources working in conjunction with first responders, medical and public health communities, and state and federal agencies." High-speed telemedicine networks can improve communications reliability for medical response to disaster and coordination between local and external parties as well as keeping all parties informed about any changes occurring at the scene of the disaster. These networks can either use existing telemedicine infrastructure, or temporary infrastructures, including rapidly deployable satellite links, local wireless networking, and mobile clinical and environmental monitoring technologies.[2]

2.2. Pre-hospital Care

The unique conditions and stresses on the traditional healthcare system imposed by an acute-onset disaster scenario require the efficient use of healthcare resources outside of the hospital setting. Schwartz et al.[10] remark that "the restructuring of the pre-hospital healthcare system was crucial for optimal management of the healthcare needs of Tsunami victims and for the reduction of the patient loads on secondary medical facilities." Maximizing the effectiveness of pre-hospital management of medical emergencies could diffuse the burden of care among first responders and medical personnel at the disaster site, and healthcare providers in secondary and tertiary healthcare institutions, resulting in a direct impact on patient outcomes.[11]

Telemedicine, in particular, has been shown to be effective in improving the management of emergencies in pre-hospital care. While telemedicine can be utilized in the hospital setting, these implementations are similar to traditional telemedicine systems. We have identified pre-hospital telemedicine as a current area of weakness that holds the greatest promise for medical care improvement. The value and scarcity of medical resources in disaster situations dramatically magnifies the potential for pre-hospital telemedicine to: 1) facilitate the avoidance of unnecessary emergency transport, 2) improve patient care in the hospital, and 3) enhance the capabilities of first responder and medical personnel.

The large volume of injured and displaced patients in a disaster situation requires frugal triage techniques to identify and prioritize the most critical patients, and prevent excessive overload of hospital emergency departments. A retrospective chart review of ambulance transports to four hospitals by three certified emergency physicians revealed that 15% of them could have been avoided by utilizing telemedicine consultation by emergency medical service (EMS) personnel to assess and evaluate potential patients.[12] Furthermore, a study by Saffle et al.[13] found that referring physicians overestimated burn areas a mean value of 75% from burn centre estimates. They suggest that visual estimate of burn area by burn centres using telemedicine could potentially reduce unnecessary transport of burn victims. Finally, using teleradiology to connect a remote military training site to the nearest hospital avoided transport of 29 out of 32 patients in whom diagnosis was uncertain or the urgency of the case could not be established.[14]

The destruction of critical transportation infrastructure often results in aeromedical evacuation of patients, which is both costly and time consuming. Two studies that used video telemedicine to pre-screen patients for whom emergency or commercial air medical transport was requested from Taiwan's surrounding islands, and from Palm Island in Australia, found that it reduced the number of transports by 36.2% and 14% respectively.[15,16]

Telemedicine can be a very powerful tool when a reduction in the number of patient transports is combined with improved patient care of those patients who are transported. Transmitting electrocardiogram (ECG) recordings to a receiving physician prior to arrival at a hospital can reduce the time-to-treatment.[17] In one case, rerouting an ambulance to the nearest cardiology department for a suspected pulmonary embolism resulted in a confirmed diagnosis and successful treatment.[18] This example demonstrates that triaging patients to the most appropriate centre of care can improve the effectiveness of medical treatment. In another study, redirecting acute myocardial infarction (MI) patients to a primary percutaneous coronary intervention (PCI) centre reduced door-to-PCI time by 63 minutes.[19] By automating the ambulance telemedicine system data synchronization between dispatch, ambulance, and hospital EMR, pre-hospital treatment can begin in consultation with a physician, which eliminates task redundancy once the patient arrives at the hospital.[20] Plischke et al.[21] suggest that simply using telemedicine to reduce documentation requirements during a mass casualty incident, by managing patient records electronically, can improve patient care.

The ability to capitalize on the expertise of physicians and specialists for decision support through teleconsultation is invaluable in disasters areas, where access to these medical resources is usually impossible. In at least 60% of the examined cases, both referring and consulting physicians also felt that the use of telemedicine to assess patients prior to transport, and during remote trauma resuscitation, improved patient care, and that referring physicians felt they were better able to manage the patients in 59% of the cases.[15,22] After an emergency simulation, first responders reported that their confidence was enhanced by having a medical professional work with them through a telemedicine video link[23]

In a previously mentioned study by Sejersten et al.[19], 911-to-door transport time for redirected acute MI patients increased by 8 minutes, however, this was offset by reduced treatment time and no adverse effects were noted for the increased duration of ambulance transport. When implementing and using a telemedicine system in the pre-hospital context, care must be given to minimize the potential health impact caused by additional treatment delay in critically ill patients.

The potential for telemedicine to improve pre-hospital management of medical emergencies during a disaster is significant when these factors are all taken into consideration. Reducing unnecessary transports, proper triaging of patients, and improving the capabilities of *in situ* medical personnel can all ultimately improve care of affected patients when the limited medical resources of a disaster site must be used effectively and efficiently.

2.3. Rapidly Deployable Telemedicine Technology

Telemedicine encompasses a broad range of mobile technologies used to deliver health care, and are a critical clinical aid when performing medical duties outside of a hospital-based environment. Without the advent of these devices and wireless communication infrastructure to support them, telemedicine would be virtually impossible in hostile environments such as disaster areas.

It has only been in the last few years that telemedicine has been able to truly take shape. Mobile computing and medical devices have recently become powerful and versatile enough to support the stress of a health care environment, along with reaching a level of standardization needed to be used in a rapidly deployable setting while maintaining reliability. The technology used in telemedicine falls into three distinct categories: portable medical imaging devices, PDAs/smartphones and the wireless communication infrastructure.

Portable medical imaging devices consist of the same features that traditional imaging devices have, but are scaled down in size to allow easy transport. These devices allow a physician to perform medical imaging in a remote setting without sacrificing any features of a full-scale device. The use of portable ultrasound for sonography has increased due to its relatively inexpensive cost, which has precipitated its role as the primary imaging device in remote and extreme environments. Still, the widespread use of portable ultrasound devices are laden due to their complex and expensive training procedures. It is very easy to perform the ultrasound, but very costly and logistically complex to always have a radiologist on-site to read the image.[24] Organizations, such as Medical Imaging Resources, Inc. *(Ann Arbor, MI)*[25], provide a wide variety of other rental medical equipment including: mobile MRIs, CTs, Cath Labs, Angio Labs and mobile nuclear medicine labs. Their goal is to provide the consumer with a full range of rapidly deployable medical devices through the use of their mobile transport vehicle for rough terrain. Their turn-key operations provide licensed contractors to set up and dismantle the equipment, all heating, ventilation, plumbing, hydraulics and electrical services.[25]

PDAs are an example of mobile computing that have been used for telemedicine. The main difference between these devices and laptops is that they run scaled down versions of full operating systems because they utilize a less powerful processor. Other then the lack of a few ports (e.g. USB and DVD-ROM) that can be found on a laptop, a PDA can handle basic tasks such as: opening text-based documents, collecting vital signs, connecting to the internet, performing limited video conferencing, and emailing. These devices are designed to be small enough to fit into the clinician’s pocket for easy access. The eventual goal in mobile computing is to consolidate all daily portable devices into one device, and the smartphone, an amalgamation of a PDA and a cellular phone, is the next step in that process. The added advantage of a smartphone is the ability to connect to the cell phone carrier's wireless data service, allowing the user to log onto the internet by using the cellular network instead of conventional means, such as Wi-Fi. An example of a smartphone in use for telemedicine is given in Figure 1.

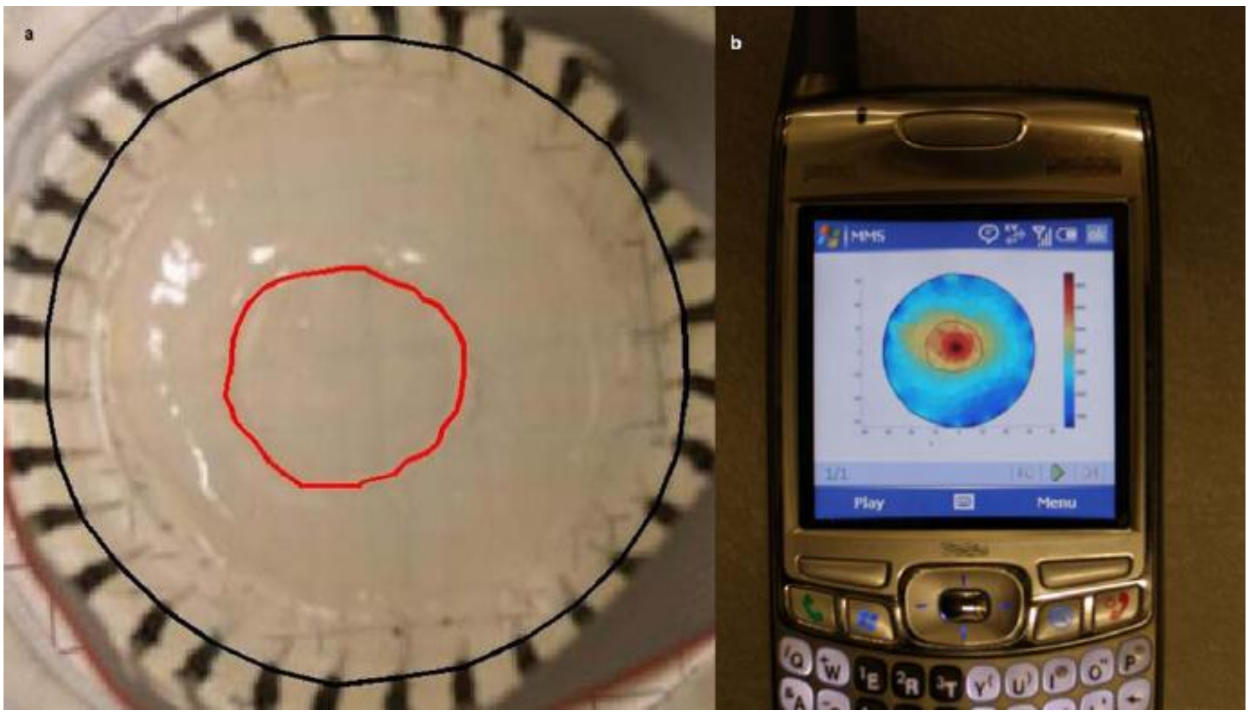

Figure 1 – Minimally invasive surgery example. A) The data acquisition device of the system with two types of gel representing an area treated with irreversible electroporation, marked in red, surrounded by normal tissue. B) Reconstructed result as it was displayed on the screen of a commercial cell phone. Warm colors represent higher conductivity regions that denote an electroporated area.[26]

Participants in a telemedicine setting need to communicate with each other on a constant basis. Whether that be transferring data, video conferencing, using voice communication, instant messaging, emailing, or having access to a network, the method of connectivity needs to be stable, secure and easily deployable. In a disaster or remote area, the lack of infrastructure creates a barrier when trying to set up a network. Due to the geographic makeup of most areas which would utilize telemedicine services, wireless networking is the option of choice.[27]

There are many forms of wireless connectivity, some for short-range data exchange and others for long-range networking. Bluetooth is a great form of a short-range wireless technology that helps with the transfer of data by replacing the cables that were once needed in connecting medical devices to computers. It is not meant for networking multiple workstations, but rather connecting peripheral/medical devices that are in close proximity. Bluetooth has evolved to provide greater range and lower power consumption by introducing its new series, ultra-wideband (UWB). UWB can now easily penetrate through walls to ranges of 10m.[27]

Wireless local area network (WLAN) is the concept behind networking all laptops and workstations together through means of a wireless infrastructure. A WLAN is based on the Institute of Electrical and Electronics Engineers (IEEE) standards for wireless communication, 802.11x (where x denotes the speed/spectrum). A popular WLAN product is Wi-Fi networking, which is based on the 802.11a/b/g/n standard. Wi-Fi is the most common form of a WLAN, where it is utilizes by most homes and institutions. In a telemedicine setting, Wi-Fi would be the choice of connectivity as it provides the easiest and most affordable means of being creating an ad-hoc network.[27] One downfall of a Wi-Fi network is its difficulty in penetrating through walls; in an outdoor setting this is not a problem, but when multiple stories and rooms are involved, the range and bandwidth are substantially limited. Another issue of a Wi-Fi network is its need for a pre-existent internet connection. The internet connection plugs into the Wi-Fi router (the central hub for the network). Even though a Wi-Fi connection can create an internal network without an internet connection, the infrastructure needs to be in place to provide the network with internet access.

Zigabee[27] is a standard that acts as an additional layer onto the Wi-Fi network by utilizing the IEEE 802.15.4 standard. Zigabee throws out data packets on a continuous basis to warn other mobile units of its presence, and automatically connects them to the network. In a rapid deployment setting, when new clinicians are added to teams, they can be instantly connected to the network, and have access to every patient's medical data. This saves time and eliminates the need to manually connect each client to the network.

Wireless broadband (WiBro) is an internet connection purely based on the use of cellular data networks by allowing users to access the internet through their cell/smartphone.[27] If a user does not have a cell/smartphone, they also have the choice of access the cellular network through a USB model that plugs into their laptop/desktop. This is a great tool when all the clinician has access to is their cell/smartphone. In a remote setting where the infrastructure is already in place, this is easily deployable and ready to use for telemedicine. One downfall is that the cellular infrastructure needs to be in place, and another is that using these cellular data networks are very costly because a third party carrier is involved.

Satellites are the last form of wireless communication, where they provide the most expansive form of coverage, a broadband global area network (BGAN). There are three types of satellites in orbit, low earth orbit (LEO), mid earth orbit (MEO) and geostationary earth orbit (GEO).[27] LEO satellites provide low latency times but also low bandwidth. MEO satellites provide low latency times but only provide enough bandwidth if it has been dedicated to the communication link.[27] GEO does not have the low latency requirements for telesurgery but enough for communication, but it does have the bandwidth requirements for both. Satellites are a great resource when no infrastructure is in place, because it is able to provide a greater coverage then most WLANs. They are capable of providing enough bandwidth for data transfer, EHR transfer, low bandwidth tele-consultation and health administration, but not for performing telesurgical procedures. Until additional resources are devoted to the improvement of satellites technologies, it can only be used as a backup to when alternate communication infrastructure is not present or available. Figure 2 shows a summary of wireless networks and the mobile technologies that exist at each successive level.

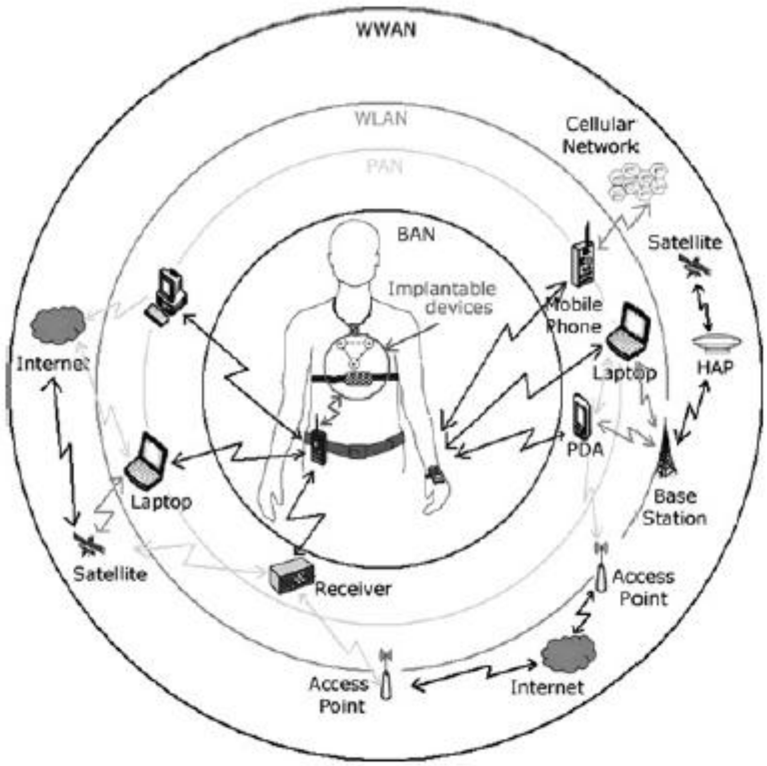

Figure 2 – Wireless device technology map.[27]

Despite the large number of appropriate telemedicine technologies, a single solution cannot be applied in all emergency contexts. It is imperative that disaster response plans that incorporate telemedicine maintain a degree of technical flexibility and recognize the need to adapting their system to the needs of the specific emergency.

3. Gap Analysis

3.1. Technological Barriers

As the services offered by telemedicine evolves, the need to quickly overcome its barriers become greater and greater. Telemedicine is a great tool and can be used in many more settings, but it is being held back by multiple gaps within its foundation. Before telemedicine can evolve by adding to its roster of services, its core competencies need to be strengthened. A framework of gaps within telemedicine has been developed by Arisoylu et al.[28] to address the growing foundational problems that face telemedicine. This framework below lays out seven rules that telemedicine services must follow in order to comply with rapid deployment situations:

4. A rapidly deployable, portable, yet rugged system, that can reach into hazard zones and buildings;
5. A self-repairing system that heals itself automatically in the event of loss of portions of infrastructure;
6. A system that supports wireless communications for off-the-shelf systems and devices;
7. A system that supports both high bandwidth (digital video) communications for a small number of devices and low bandwidth communications for many (hundreds to thousands) of devices;
8. A system that provides robust (but not necessarily high data rate) Internet communications to access critical off site data;
9. A system that maintains quality of service for transmission of critical information; and
10. A system that provides adequate data security.

The above framework lists seven “to be” rules that must be followed in order to make telemedicine’s “as is” foundation strong. The research reveals three common problems that plague telemedicine from furthering its adoption.

The communication infrastructure behind telemedicine operations needs to be further enhanced, particularly in a WLAN setting. In a disaster scenario, it is imperative that the teams of medical professionals have access to the network at all times. The network is what houses all medical records, up-to-date medical information, vital statistics of all patients, connects users to many of the medical technologies, and gives the teams the ability to communicate with each other through means of voice, video or instant messaging.[28] If the WLAN keeps on disconnecting or has insufficient dedication of bandwidth, the reliability of the network will come into question, creating more disadvantages then advantages.

The research shows that in most situations where rapid-deployment is necessary, the proper infrastructure does not exist to accommodate a WLAN, and therefore the mobile team has the responsibility for creating their own network. Many disaster zones have no fiber optics or cellular towers in place to facilitate wireless communication, or that the current infrastructure is too unstable to support a large number of users. Satellite technology is another solution, but it does not provide the necessary latency time or the bandwidth needed for more advanced telemedicine services, such as telesurgery. Also, acquiring a satellite channel is a difficult task, especially when dealing with a project that requires the use of multiple uplinks.[27] Wi-Fi is the choice of most studies, where an ad-hoc Wi-Fi installation has been created. The problems with these Wi-Fi networks lie in the range of coverage, and the lack of bandwidth.

The network range is crucial when the disaster zones are extensive; most 802.11n Wi-Fi connections can output an operating range of 91m while transmitting at 70mpbs.[27] For consumer usage, this range is sufficient, but for an emergency situation, 91m might not be sufficient. If the Wi-Fi connection is stretched beyond 91m, it starts to lose its speed and increases its latency time. A study was connected by the United States (U.S.) Army Telemedicine in conjunction with the Advanced Technology Research Center (TATRC).[29] They used mobile robotic telesurgery (MRT) to perform unmanned surgeries in disaster zones. To perform its surgical duties, the MRT needed a low latency to reduce the response time between the remote surgeons actions and the MRT's movements. It also required a high bandwidth to stream the high definition (HD) encoded video feed to ensure the remote surgeon can see a crisp representation of the patient. Even though a 802.11n Wi-Fi connection meets both requirements, the terrain was too scattered and a larger operating range was needed. The research team used repeater access nodes to increase the range of the Wi-Fi signal as a relatively cheap way to fix the problem. These access nodes increase the range by having the Wi-Fi signal piggy back off its repeater antennae to extend the output of the signal. These nodes were placed on unmanned drone aircrafts which were positioned in key points in the sky. This "network in the sky" increased the range and allowed the Wi-Fi network to have an unobstructed extension, providing the MRT with the necessary latency time and bandwidth to conduct its intended duties.

The second problem with a WLAN infrastructure is the amount of dedicated bandwidth required to perform the required tasks. In 2001, an internet-based telemedicine network was set up in Mali, West Africa by Pyke et al.[24] to initiate teleconsultantions and teleducation. They used a 802.11b Wi-Fi network to communicate with regional health care institutions by setting up basic services such as e-mails and web portals. Due to the large area the network needed to cover, the dedicated bandwidth was not sufficient enough in providing the WLAN the speeds it needed to perform many of the advanced services of the project. Realizing that implementing a high-bandwidth connection was not an option, low-bandwidth alternatives were used as opposed to hardware fixes. Low-bandwidth medical education course were shown on a bi-monthly basis in a large auditorium for all the clinicians. These courses were then saved on internal servers and allowed to be re-played via an internal web portal, which did not use the external bandwidth. Instant messaging was used to communicate with speakers during international conferences. A telephony network (using the phone to transmit data) was used for simple communication to hospitals instead of the WLAN. The bandwidth was saved for cases where teleconsultation and image transfer was utilized in remote areas where the expertise did not exist in regards to neurosurgery and oncology. The study also showed that there was a significant need to focus on setting up installations locally instead of using international bandwidth. If email communication used a local host instead of international, bandwidth drain would be mitigated.[24]

In a fast paced environment in which the operational parameters constantly change, the technology needs to adapt and keep up. Unfortunately, it is not always possible to have dispatched medical teams consist of technical personnel responsible for repairs. One way to combat this issue is to have technology that has the ability to "self heal" itself, in that it can automatically repair itself without any or minimal human intervention.[28] In some network installations, software is being built into the infrastructure which automatically adjusts the parameters to accommodate any changes. If the topology is changed/disrupted the network is smart enough to switch to an alternate access node. By using the data stored in its buffer, the network will continue working without any disruption to the distribution of its data flow.[28] Another method is using the idea of "components off the shelf" (COTS) in the construction of these medical devices. [28] COTS components are non-proprietary, not vendor unique and can be found through most distribution outlets, making them easily replaceable. By having the medical technology (ie. Medical scanners) constructed using components that are readily found, replacing broken parts can be done by medical staff that have a basic understanding of technology. This will not only reduce downtime, but alleviate the need to learn multiple vendor-specific material.

Medical imaging requires a great deal of raw computing power, in a telemedicine situation, making that power mobile is a huge challenge. Even though the mobile devices of today are powerful, they still do not house the necessary hardware and software requirements needed for medical imaging processing. Medical imaging devices are constructed by using three types of components:[26]

1. Data acquisition hardware, which is the component that is in direct contact with the patient to acquire the medical data
2. An image display, which is responsible for allowing the clinician to view the medical image on a screen
3. The image processing hardware, which analyzes the patient's medical data and processes the image

Current medical imaging devices combine all three components into one self-contained unit. The scanning interface is integrated with the display module, which is housed with the hardware meant for processing the image. This consolidation creates duplication in hardware, a complicated design format which leads to a device that is easier to fail due its tightly coupled architecture. Aside from the obvious drawbacks of being less cost effective, harder to maintain and train, this amalgamation also puts a drain on the hardware capabilities. If one medical device take care of all three components, the hardware will now have its focus taken away from processing the image, and will need to equally distribute its resources to scanning the patient and outputting the image. This slows down the speed at which the raw data is processed.[26]

Granot et al.[26] conducted a study where they suggested breaking the imaging device into three physical components:

1. A data acquisition device (DAD), responsible for scanning the patient and acquiring the medical data

2. An off-site processing facility which is fed the raw data from the DAD; composed of computers equipped with software for image reconstruction
3. A smartphone which acts as a transmission conduit between the DAD and central site; doubles as an image display to view the processed medical image

After the DAD captures the patient's medical data, it uses the smartphone's EVDO network to transmit the raw data to the central site. The central site uses its software to reconstruct the image and sends the file in the format of a multimedia message (MMS) back to the smartphone. The smartphone is then able to view the image through its HTML based web browser. Unlike the conventional method, the smartphone transmits only the raw data to the central site, whereas before the entire processed image was transmitted. Since the hardware is now only responsible for one activity, the processing time was dramatically increased.[26]

This concept has many advantages, four of which are of particular interest. First, splitting the medical imaging hardware into three separate components mitigates the expense when equipment fails. Before, if the medical device were to fail, then all three components would need to be repaired due to the tightly coupled architecture. Now, if the DAD or the smartphone fails, only the DAD or smartphone will need to go in for repair. Since this system is built using COTS components, repair time is minimal, and temporarily replacing these failed units with working ones is a feasible task. Secondly, the duplication in hardware has dropped significantly. Prior to this new system, the medical stations were fitted with several displays to view the image. Now since the smartphones are equipped with high-resolution images, there is no need for its duplication; the need for multiple displays is reduced. Thirdly, by allowing the hardware component to act independently, processing power has increased allowing more images to be processed at a faster rate. There is no need to bring large equipment on-site, freeing up space. Also, since it is one central site, the updates can be performed all at one once, instead of having to individually install the update on multiple sites. Lastly, this idea of having a central site taking care of the hardware processing has given birth to a new type of concept, the “economical concept”. This economical concept utilizes the idea of having multiple DADs, which are standardized in their data formats, each being responsible for the different types of scans. The various DADs can plug into the smartphone, transmit their data accordingly, and allow the central site to process their data. Since the process would be standardized, the central site could handle processing the images for different types of scans. The economical concept idea also explores the ability of having multiple sites being able to log into the central site to process their imaging needs. This sharing of resources provides an economical way of conducting scans while not having to sacrifice computing power.[26]

Fortunately, technology development is constantly changing and improvement to overcome these limitations. Inherently, telemedicine is the combination and integration of technologies from other fields to accomplish a specific task. The market drivers of these other fields will help accelerate the evolution of these technologies, and thus will indirectly enhance the ability to provide medical care through telemedicine.

3.2. Deficiencies in Clinical Research

Unfortunately, studies of the effectiveness of pre-hospital disaster telemedicine in the literature are sparse. A structured review of PubMed, The Cochrane Library, ISI Web of Knowledge, EMBASE, and Inspec was conducted using combinations of the following search terms: *telemedicine, telehealth, teleradiology, telepathology, teleconsultation, remote, mass casualty, disaster, disaster recovery, disaster response, and disaster management*. In addition, hand searches of the identified articles' references were conducted to improve comprehensiveness. Papers were not included if they involved homecare, if they dealt exclusively with the technological aspects of telemedicine, or if they were in a language other than English or Persian. Thirty-four (n=34) papers were identified, of which only five (n=5, 15%) directly dealt with telemedicine in pre-hospital mass casualty care.[21,2,30-32] Of these 34 papers, only one[31] (n=1, 3%) discussed the use of pre-hospital telemedicine in two actual disasters, the 2005 Hurricane Katrina disaster and the 2004 tsunami in Thailand, while the other four (n=4, 12%) studied simulated mass casualty disaster scenarios. The remaining papers assess telemedicine capabilities between hospitals and the technological feasibility of telemedicine infrastructure and instruments during acute-onset disasters.

As expected, none of the 34 papers were able to quantitatively analyze the efficacy of telemedicine systems in improving medical care or patient outcomes. Although there are some examples of clinical studies of telemedicine, the inconsistency in current system standards and the wide range of clinical applications negatively impacts their generalizability.[33,34] The nature of acute-onset disasters is such that their rarity and unpredictability, in conjunction with the need to pre-emptively establish medical response protocols, that include a telemedicine system for rapid deployment, pose significant barriers to research in this area. The difficulties of designing adequate study methodologies arising from disaster research may explain why the vast majority (80%) of identified studies conducted simulations. That is, the variability inherent between and during disasters, in terms of severity, affected geographic area, and management ability of local authorities, likely mask the effects of any telemedicine intervention by preventing the use of control comparisons and severely limiting the transferability and external validity of any results.

Performing simulated disasters may allow for greater control of study variables, however, the high cost and resource commitment of various partners restricts their scale and frequency. For instance, a disaster preparedness scenario in North Carolina included local, county, state, and military emergency medical services (EMS), emergency management, specialized response units, and local fire and police units.[2] These other partners' interests and goals may represent potential confounding factors.

For now, future studies may be limited to highly subjective retrospective chart analyses of previous or future disaster patients by medical experts, in an attempt to determine transport or treatment decisions that may have been affected by telemedicine, similar to Haskins et al.[12] A time-series design, using the patients as their own controls, may also elucidate the effect of telemedicine on transport or treatment decisions, by tracking any changes resulting from medical assessments prior to and following teleconsultation. Finally, as in most new areas of research, the most effective approach might simply involve qualitative analysis of focus groups, interviews, and surveys of medical providers in the field and in referral hospitals on the efficacy of telemedicine interventions in future disasters [see 35].

The most difficult aspect of these studies will be measures the impact on patient outcomes, especially considering the diversity of medical emergencies that may occur. This does not preclude, however, the measure of other outcomes of interest, such as the number of admitted patients in hospital EDs, emergency transports, or quality of patient care in the field.

In conclusion, uncertainties regarding the cost effectiveness and ability to improve patient outcomes will remain for some time given the difficulty in developing rigorous research methodologies to address these issues. The experiences thus far are promising, and each new disaster provides the opportunity for further learning, which must be capitalized by the telemedicine community to fully reveal the benefit of telemedicine in disaster situations.

4. Legal and Ethical Issues

There are several barriers that need to be addressed before telemedicine is widely integrated into disaster response, specifically issues of patient consent, doctor-patient relationships, malpractice, and technological reliability issues need to be addressed.

The first transatlantic operation performed by Marescaux et al.[36] was approved by both the ethical committee in France and the U.S. FDA. In this case, France took full responsibility for the performance and outcome of the surgery. On the other hand, in the remote surgical practice set up by Anvari et al.[37] both surgeons (mentor and mentee) share responsibility for the outcome of the procedure, and both names are placed on two patient consent forms, one for the actual surgery, and one for telesurgical intervention.[38] In disaster situations, however, an injured patient is in a desperate and urgent need for help and he might be unconscious at the time of resuscitation or transportation. This would preclude the ability to obtain consent, and as such would allow unrestricted access and use of teleconsultation.

Stanberry[39] has expressed concern over the degradation of the doctor-patient relationship, and the care and compassion provided to patients, resulting from an increasing reliance on medical decision-support software, and in the case of telemedicine the loss of patient contact. However, an increase in "medical tourism" has shown that some patients no longer care about extended doctor-patient interaction, or even if their physician is appropriately licensed to practice in their home nation. Following the globalization of telemedicine, local patients who have to pay for their own health care may seek foreign telemedical providers who can provide the same medical care at a reduced cost by bypassing local licensing and insurance regulations. However, medical malpractice becomes more complicated in an international context. Although there are methods of compensation in the event of an undesirable surgical outcome, such as arbitration, early consideration of a legal framework to regulate the provision of surgical services by foreign health care professionals can help protect patients and facilitate remediation. [40]

Finally, some healthcare professionals doubt about the quality of images transmitted for teleconsultation and telediagnosis. An international standard for image quality (i.e. colour, resolution, field of view) should be established for teleradiology, telepathology, and teledermatology, to avoid misinterpretation and misdiagnosis.[7] Furthermore, difficulty distinguishing the cause of misdiagnosis of a telepatient, between a physician or technical failure, is a prime concern when using telemedical systems and must be considered during its implementation.[39]

5. Conclusion

There has been a greater emphasis in recent years to develop a global, coordinated, comprehensive strategy to improve medical response to catastrophic events. In a disaster situation, communication from affected sites between first responders and with external medical personnel is a critical problem. Telemedicine technologies and methods can be used to remotely assist with medical triage and transportation decision-making in the pre-hospital setting by providing access to primary and specialty medical care expertise. This remote support has the potential to decrease the logistic strain on damaged medical infrastructure by maximizing the efficiency of available medical resources. However, the limited experience with telemedicine utilization in disasters has raised some unresolved medical–legal and technical issues that must be addressed before telemedicine can be routinely used globally in disaster medical response. Furthermore, a lack of strong methodological research poses a significant barrier against alleviating resistance to the adoption of telemedicine technologies. Until the uncertainty of telemedicine in disasters regarding its cost-effectiveness and contribution to improved patient outcomes has been addressed, its potential will continue to remain untapped.

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